Exhibit M

WRAP Fugitive Dust Handbook

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TABLE OF CONTENTS

PREFACE

In 2004 the Western Regional Air Partnership's (WRAP) Dust Emissions Joint Forum (DEJF) selected Countess Environmental to prepare a fugitive dust handbook and an associated website (www.wrapair.org/forums/dejf/fdh) for accessing the information contained in the handbook. The material presented in the original handbook released on November 15, 2004 addressed the estimation of uncontrolled fugitive dust emissions and emission reductions achieved by demonstrated control techniques for eight major fugitive dust source categories. In 2006 WRAP hired Countess Environmental to update the handbook. The updates included revising each chapter in the handbook to reflect the new PM2.5/PM10 ratios developed for WRAP by the Midwest Research Institute (MRI) in 2005, addressing four additional major fugitive dust source categories as well as several minor source categories, and updating the existing chapters.

The material in this handbook focuses on fugitive dust emissions "at the source" and does not evaluate factors related to the transport and impact of emissions on downwind locations where ambient air monitoring occurs. The methods for estimation of dust emissions rely primarily on AP-42 with additional references to alternative methods adopted by state and local control agencies in the WRAP region. With regard to emission factor correction parameters, source extent/activity levels, control efficiencies for demonstrated control techniques, and emission reductions by natural mitigation and add-on control measures, sources of data are identified and default values are provided in tables throughout the handbook. Graphs, charts, and tables are provided throughout the handbook to assist the end user.

The handbook:

(a) compiles technical and policy evaluations for the benefit of WRAP members, stakeholders, and other interested parties when addressing specific air quality issues and when developing regional haze implementation plans;

(b) incorporates available information from both the public (federal, state and local air quality agencies) and private sectors (e.g., reports addressing options to reduce fugitive dust emissions in areas of the country classified as nonattainment for PM10); and

(c) serves as a comprehensive reference resource tool of currently available technical information on emission estimation methodologies and control measures for the following twelve fugitive dust source categories: agricultural tilling, agricultural harvesting, construction and demolition, materials handling, paved roads, unpaved roads, mineral products industry, abrasive blasting, livestock husbandry, and windblown dust emissions from agricultural fields, material storage piles, and exposed open areas.

This handbook is not intended to suggest any preferred method to be used by stakeholders in preparation of SIPs and/or Conformity analyses but rather to outline the most commonly adopted methodologies currently used in the US. The information contained in this handbook has been derived from a variety of sources each with its own accuracy and use limitations. Because many formulae and factors incorporate default values that have been derived for average US conditions, area specific factors should be used whenever they are available. Additionally, the input terms (commonly referred to as "correction factors") used in any given emission factor equation presented in this handbook were obtained using a specific test methodology and are designed to give an estimate of the emission from a specific activity or source under specific conditions. As a result the emission estimate must be used appropriately in any downstream application such as dispersion modeling of primary PM emissions.

It is important to note that EPA's criteria for exceedances, violations, and model calibration and validation are based on ambient data from the National Ambient Air Monitoring Sites. It should be further noted that estimates of the relative contribution of fugitive dust to ambient PM concentrations based on chemical analysis of exposed filters are usually much lower than that based on emission inventory estimates, in some cases by a factor of 4. Part of this discrepancy between ambient measurements and emission estimates is due to the near source deposition losses of freshly generated fugitive dust emissions. It is not an objective of this handbook to resolve this modeling discrepancy issue. It is the role of modelers to incorporate deposition losses into their dispersion models and to account for the formation of secondary PM, which in many areas of the country are responsible for an overwhelming contribution to exceedances of the federal PM NAAQS.

Applicability to Tribes

The Regional Haze Rule explicitly recognizes the authority of tribes to implement the provisions of the Rule, in accordance with principles of Federal Indian law, and as provided by the Clean Air Act §301(d) and the Tribal Authority Rule (TAR) (40 CFR §§49.1– .11). Those provisions create the following framework:

1. Absent special circumstances, reservation lands are not subject to state jurisdiction.

2. Federally recognized tribes may apply for and receive delegation of federal authority to implement CAA programs, including visibility regulation, or "reasonably severable" elements of such programs (40 CFR §§49.3, 49.7). The mechanism for this delegation is a Tribal Implementation Plan (TIP). A reasonably severable element is one that is not integrally related to program elements that are not included in the plan submittal, and is consistent with applicable statutory and regulatory requirements.

3. The Regional Haze Rule expressly provides that tribal visibility programs are "not dependent on the strategies selected by the state or states in which the tribe is located" (64. Fed. Reg. 35756), and that the authority to implement §309 TIPs extends to all tribes within the GCVTC region (40 CFR §51.309(d)(12).

4. The EPA has indicated that under the TAR tribes are not required to submit §309 TIPs by the end of 2003; rather they may choose to opt-in to §309 programs at a later date (67 Fed. Reg. 30439).

5. Where a tribe does not seek delegation through a TIP, EPA, as necessary and appropriate, will promulgate a Federal Implementation Plan (FIP) within reasonable timeframes to protect air quality in Indian country (40 CFR §49.11). EPA is committed to consulting with tribes on a

government-to-government basis in developing tribe-specific or generally applicable TIPs where necessary (see, e.g., 63 Fed. Reg.7263-64).

It is our hope that the findings and recommendations of this handbook will prove useful to tribes, whether they choose to submit full or partial 308 or 309 TIPs, or work with EPA to develop FIPs. We realize that the amount of modification necessary will vary considerably from tribe to tribe and we have striven to ensure that all references to tribes in the document are consistent with principles of tribal sovereignty and autonomy as reflected in the above framework. Any inconsistency with this framework is strictly inadvertent and not an attempt to impose requirements on tribes which are not present under existing law.

Tribes, along with states and federal agencies, are full partners in the WRAP, having equal representation on the WRAP Board as states. Whether Board members or not, it must be remembered that all tribes are governments, as distinguished from the "stakeholders" (private interest) which participate on Forums and Committees but are not eligible for the Board. Despite this equality of representation on the Board, tribes are very differently situated than states. There are over four hundred federally recognized tribes in the WRAP region, including Alaska. The sheer number of tribes makes full participation impossible. Moreover, many tribes are faced with pressing environmental, economic, and social issues, and do not have the resources to participate in an effort such as the WRAP, however important its goals may be. These factors necessarily limit the level of tribal input into and endorsement of WRAP products.

The tribal participants in the WRAP, including Board members, Forum and Committee members and co-chairs, make their best effort to ensure that WRAP products are in the best interest of the tribes, the environment, and the public. One interest is to ensure that WRAP policies, as implemented by states and tribes, will not constrain the future options of tribes who are not involved in the WRAP. With these considerations and limitations in mind, the tribal participants have joined the state, federal, and private stakeholder interests in approving this handbook as a consensus document.

EXECUTIVE SUMMARY

This fugitive dust handbook addresses the estimation of uncontrolled fugitive dust emissions and emission reductions achieved by demonstrated control techniques for twelve major and several minor fugitive dust source categories. The handbook focuses on fugitive dust emissions “at the source” and does not evaluate factors related to the transport and impact of emissions on downwind locations where ambient air monitoring occurs. The methods for estimating emissions draw (a) from established methods published by the USEPA, specifically AP-42: Compilation of Air Pollutant Emission Factors that are available from the Internet (www.epa.gov/ttn/chief/ap42), and (b) from alternate methods adopted by state and local air control agencies in the WRAP region such as the California Air Resources Board (www.arb.ca.gov/ei/areasrc/areameth.htm), Clark County, Nevada (www.co.clark.nv.us/air_quality), and Maricopa County, Arizona (www.maricopa.gov/envsvc/air). Sources of data are identified and default values for emission factor correction parameters, source extent/activity levels, control efficiencies, and emission reductions by natural mitigation and add-on control measures are provided in tables throughout the handbook.

The handbook has several distinct features that give it a major advantage over the use of AP-42 or other resource documents. The handbook is a comprehensive document that contains all the necessary information to develop control strategies for major sources of fugitive dust. These features include:

(a) extensive documentation of emission estimation methods adopted by both federal and state agencies as well as methods in the “developmental” stage;
(b) detailed discussion of demonstrated control measures;
(c) lists of published control efficiencies for a large number of fugitive dust control measures;
(d) example regulatory formats adopted by state and local agencies in the WRAP region;
(e) compliance tools to assure that the regulations are being followed; and
(f) a detailed methodology for calculating the cost-effectiveness of different fugitive dust control measures, plus sample calculations for control measure cost-effectiveness for each fugitive dust source category.

The handbook and associated website (www.wrapair.org/forums/dejf/fdh) are intended to:

(a) support technical and policy evaluations by WRAP members, stakeholders, and other interested parties when addressing specific air quality issues and when developing regional haze implementation plans;

(b) incorporate available information from both the public and private sectors that address options to reduce fugitive dust emissions in areas of the country classified as nonattainment for PM10; and

(c) provide a comprehensive resource on emission estimation methodologies and control measures for the following twelve fugitive dust source categories: agricultural tilling, agricultural harvesting, construction and demolition, materials handling, paved roads, unpaved roads, minerals products industry, abrasive blasting, livestock husbandry, and windblown dust emissions from agricultural fields, material storage piles, and exposed open areas.

The handbook contains separate, stand-alone chapters for each of the twelve major fugitive dust source categories identified above. Because the chapters are meant to stand alone, there is some redundancy between chapters. Each chapter contains a discussion of characterization of the source emissions, established emissions estimation methodologies, demonstrated control techniques, regulatory formats, compliance tools, a sample control measure cost-effectiveness calculation, and references. A separate chapter addressing several minor fugitive dust source categories and several appendices are also included in the handbook. Appendix A contains a discussion of test methods used to quantify fugitive dust emission rates. Appendix B contains cost information for demonstrated control measures. Appendix C contains a step-wise method to calculate the cost-effectiveness of different fugitive dust control measures. Appendix D contains a brief discussion of fugitive PM10 management plans and record keeping requirements mandated by one of the air quality districts within the WRAP region.

A list of fugitive dust control measures that have been implemented by jurisdictions designated by the USEPA as nonattainment for federal PM10 standards is presented in the table below. The published PM10 control efficiencies for different fugitive dust control measures vary over relatively large ranges as reflected in the table. The user of the handbook is cautioned to review the assumptions included in the original publications (i.e., references identified in each chapter of the handbook) before selecting a specific PM10 control efficiency for a given control measure. It should be noted that Midwest Research Institute (MRI) found no significant differences in the measured control efficiencies for the PM2.5 and PM10 size fractions of unpaved road emissions based on repeated field measurements of uncontrolled and controlled emissions. Thus, without actual published PM2.5 control efficiencies, the user may wish to utilize the published PM10 values for both size fractions.

Many control cost-effectiveness estimates were reviewed in preparation of this handbook. Some of these estimates contain assumptions that are difficult to substantiate and often appear unrealistic. Depending on which assumptions are used, the control cost-effectiveness estimates can vary by one to two orders of magnitude. Thus, rather than presenting existing cost-effectiveness estimates, the handbook presents a detailed methodology to calculate the cost-effectiveness of different fugitive dust control measures. This methodology is presented in Appendix C. The handbook user is advised to calculate the cost-effectiveness values for different fugitive dust control options based on current cost data and caveats that are applicable to the particular situation.

Fugitive Dust Control Measures Applicable for the WRAP Region

Source Category	Control Measure	Published PM10 Control Efficiency
Agricultural Tilling	Reduce tilling during high winds	1 – 5%
	Roughen surface	15 – 64%
	Modify equipment	50%
	Employ sequential cropping	50%
	Increase soil moisture	90%
	Use other conservation management practices	25 - 100%
Agricultural Harvesting	Limited activity during high winds	5 – 70%
	Modify equipment	50%
	Night farming	10%
	New techniques for drying fruit	25 –60%
Construction/Demolition	Water unpaved surfaces	10 – 74%
	Limit on-site vehicle speed to 15 mph	57%
	Apply dust suppressant to unpaved areas	84%
	Prohibit activities during high winds	98%
Materials Handling	Implement wet suppression	50 – 90%
	Erect 3-sided enclosure around storage piles	75%
	Cover storage pile with a tarp during high winds	90%
Paved Roads	Sweep streets	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%
Mineral Products Industry	Cyclone or muliclone	68 –79%
	Wet scrubber	78 –98%
	Fabric filter	99 – 99.8%
	Electrostatic precipitator	90 – 99.5%
Abrasive Blasting	Water spray	50 – 93%
	Fabric filter	> 95%
Livestock Husbandry	Daily watering of corrals and pens	> 10%
	Add wood chips or mulch to working pens	> 10%
Wind Erosion (agricultural, open area, and storage piles)	Plant trees or shrubs as a windbreak	25%
	Create cross-wind ridges	24 – 93%
	Erect artificial wind barriers	4 – 88%
	Apply dust suppressant or gravel	84%
	Revegetate; apply cover crop	90%
	Water exposed area before high winds	90%

Chapter 1. Introduction

This chapter describes the purpose for the preparation of this fugitive dust handbook; presents a summary of WRAP's fugitive dust definition and dust emissions categorization scheme; provides a brief overview/primer on fugitive dust that includes a summary of factors affecting dust emissions, an overview of emission calculation procedures (including a discussion of emission factors), and a discussion of options for controlling emissions; and summarizes the organizational structure of the handbook.

This handbook does not address particulate emissions from wildfires or prescribed fires that are discussed in Section 13.1 of EPA's Compilation of Air Pollutant Emission Factors (AP-42). For more information on particulate emissions from fires, the reader is directed to the WRAP's Fire Emissions Joint Forum at www.wrapair.org/forums/fejf.

1.1 Background

Most of the more than 70 areas of the United States that have been unable to attain the national ambient-air quality standards (NAAQS) for PM10 (particles smaller than 10 µm in aerodynamic diameter) are in western states with significant emission contributions from fugitive dust sources. Fugitive dust sources may be separated into two broad categories: process sources and 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 of solid particles by the forces of wind or machinery acting on exposed material. Open dust sources include industrial sources of particulate emissions associated with the open transport, storage, and transfer of raw, intermediate, and waste aggregate materials, and nonindustrial sources such as unpaved roads and parking lots, paved streets and highways, heavy construction activities, and agricultural tilling.

On a nationwide basis, fugitive dust consists mostly of soil and other crustal materials. However, fugitive dust may also be emitted from powdered or aggregate materials that have been placed in open storage piles or deposited on the ground or roadway surfaces by spillage or vehicle trackout. Dust emissions from paved roadways contain tire and break wear particles in addition to resuspended road surface dust composed mostly of crustal geological material.

Generic categories of open dust sources include:

Agricultural Tilling and Harvesting
Construction and Demolition (Buildings, Roads)
Materials Handling
Paved Travel Surfaces
Unpaved Travel Surfaces
Minerals Products Industry (Metallic Ores, Non-metallic Ores, Coal)
Abrasive Blasting
Livestock Husbandry (Dairies, Cattle Feedlots)
Wind Erosion of Exposed Areas (Agricultural Fields, Open Areas, Storage Piles)

1.2 Purpose of the Handbook

In early 2004 the Western Regional Air Partnership's (WRAP) Dust Emissions Joint Forum (DEJF) selected the Countess Environmental project team composed of senior scientists/consultants from Countess Environmental and Midwest Research Institute to prepare a fugitive dust handbook and a website (www.wrapair.org/forums/dejf/fdh) for accessing the information contained in the handbook. The handbook and website are intended to:

(a) be used for technical and policy evaluations by WRAP members, stakeholders, and other interested parties when addressing specific air quality issues and when developing regional haze implementation plans;
(b) incorporate available information from both the public and private sectors that address options to reduce fugitive dust emissions in areas of the country classified as nonattainment for PM10; and
(c) serve as a comprehensive reference resource tool that will provide technical information on emission estimation methodologies and control measures for all of the major and several minor fugitive dust source categories.

The material presented in the original handbook released on November 15, 2004 addressed the estimation of uncontrolled fugitive dust emissions and emission reductions achieved by demonstrated control techniques for eight major fugitive dust source categories. In 2006 WRAP hired Countess Environmental to update the handbook. The updates included revising each chapter in the handbook to reflect the new PM2.5/PM10 ratios developed for WRAP by the Midwest Research Institute (MRI) in 2005, addressing four additional major fugitive dust source categories as well as several minor source categories, and updating the existing chapters.

1.3 Dust Definition and Categorization Scheme

The WRAP Dust Emissions Joint Forum (DEJF) adopted a definition of dust and fugitive dust on October 21, 2004 that included developing criteria for separating anthropogenic dust from dust of natural origin.[1] Dust was defined as particulate matter which is or can be suspended into the atmosphere as a result of mechanical, explosive, or windblown suspension of geologic, organic, synthetic, or dissolved solids, and does not include non-geologic particulate matter emitted directly by internal and external combustion processes. Fugitive dust was defined as dust that could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening. The purpose of these definitions is to provide consistency when using the terms dust, fugitive dust, anthropogenic dust, and natural dust in the context of the federal regional haze rule. The distinction between anthropogenic dust and natural dust is made to: (a) clarify how the WRAP defines dust, its sources, and causes; (b) provide an operational definition for use in receptor- and emissions-based source apportionment techniques; and (c) identify and prioritize sources of dust which are most appropriate to control for purposes of improving visibility in Class I areas.

Natural and anthropogenic dust will often be indistinguishable and may occur simultaneously. For example, natural, barren areas will emit some dust during high wind events, but will emit more when the surface is disturbed by human activities. Hence, the dust from a disturbed, naturally barren area on a given day could be part natural and part anthropogenic. Any mitigation of dust for regional haze control would likely be focused on those anthropogenic sources which are most likely to contribute to visibility impairment in Class I areas and which are technically feasible and cost-effective to control. Sources that are already controlled or partially controlled may be technically infeasible or not cost-effective to control further. According to the WRAP's definition of dust, anthropogenic emissions do not include any emissions that would occur if the surface were not disturbed or altered beyond a natural range. Such emissions should be subtracted, if practicable, from the total dust emissions to determine the precise anthropogenic emission quantity.

Examples of anthropogenic and natural dust categories in accordance with the WRAP's dust definition are provided in Tables 1-1 and 1-2. All mechanically suspended dust from human activities is classified as anthropogenic emissions, and windblown dust from lands not disturbed or altered by humans beyond a natural range is classified as natural emissions. For emissions from other sources, the emissions may be categorized as either anthropogenic or natural, depending on whether the mechanically-suspended emissions are due to indigenous or non-indigenous animals, and whether the windblown emissions are from surfaces disturbed by humans beyond a natural range or from surfaces which have not been disturbed by humans beyond a natural range.

Table 1-1. WRAP Fugitive Dust Categorization Scheme for Mechanically Generated Dust

Anthropogenic Dust	Natural Dust
Mechanically- and explosively-suspended solids and dissolved solids from activities including but not limited to: • Agriculture • Construction, mining, and demolition • Material handling, processing, and transport • Vehicular movement on paved and unpaved surfaces • Animal movement on surfaces which have been disturbed or altered by humans beyond a natural range • Animal movement on undisturbed or unaltered surfaces by a number of animals which is greater than native populations • Cooling towers	• Movement of a number of indigenous animals on surfaces which have not been disturbed or altered by humans beyond a natural range • Natural landslides, rockslides, and avalanches • Solids and dissolved solids emitted by volcanoes, geysers, waterfalls, rapids, and other types of splashing • Extraterrestrial material and impacts

Table 1-2. WRAP Fugitive Dust Categorization Scheme for Windblown Dust

<table>
<tr><th>Anthropogenic Dust</th><th>Natural Dust</th></tr>
<tr><td>Solids and dissolved solids entrained by wind passing over surfaces that have been disturbed or altered by humans beyond a natural range. Such surfaces may include, but are not limited to:
• Undeveloped lands
• Construction and mining sites
• Material storage piles, landfills, and vacant lots
• Agricultural crop, range, and forest lands
• Roadways and parking lots
• Artificially-exposed beds of natural lakes and rivers
• Exposed beds of artificial water bodies
• Areas burned by anthropogenic fires (as defined by the WRAP Policy for Categorizing Fire Emissions) which have yet to be revegetated or stabilized</td><td rowspan="2">Solids and dissolved solids entrained by wind passing over surfaces that have not been disturbed or altered by humans beyond a natural range. Such surfaces may include, but are not limited to:
• Naturally-dry river and lake beds
• Barren lands, sand dunes, and exposed rock
• Natural water bodies (e.g., sea spray)
• Non-agricultural grass, range, and forest lands
• Areas burned by natural fires (as defined by the WRAP Policy for Categorizing Fire Emissions) which have yet to be revegetated or stabilized</td></tr>
<tr><td>Wind-blown particulate matter from sources created by natural events over 12 months ago, similar to EPA's natural events policy</td></tr>
</table>

The WRAP's original dust characterization scheme broke down fugitive dust emissions into five categories ranging from 100% anthropogenic emissions (i.e., all mechanically-suspended dust from human activities except animal movement) to 100% natural emissions (i.e., windblown dust from lands not disturbed or altered by humans beyond a natural range), with three categories between these two extremes representing a mixture of anthropogenic and natural emissions. Environ developed an alternative dust characterization scheme for WRAP in 2005 that broke down fugitive dust emissions into three categories based on activity rather than a description of spatial location since very different dust sources may spatially co-exist at the same site.[2] Environ's three categories are:

Category 1: Purely anthropogenic sources (e.g., construction, mining, wind erosion and vehicle traffic on paved and unpaved roads, agricultural tilling and harvesting, wind erosion of agricultural fields, particle emissions from cooling towers).

Category 2: Purely natural sources (e.g., volcanic ash emissions, wind erosion of unstable soil following landslides, mineral particle emissions from wave action/sea spray).

Category 3: Natural sources that may be anthropogenically influenced (e.g., wind erosion and mechanical suspension of soil due to animal movement [both native and non-native], wind erosion of bare areas on natural lands [undisturbed versus previously disturbed], wind erosion of sediment from dried ephemeral water bodies [natural or anthropogenic]).

1.4 Factors Affecting Dust Emissions

1.3.1 Mechanically Generated Dust

Mechanically generated emissions from open dust sources exhibit a high degree of variability from one site to another, and emissions at any one site tend to fluctuate widely. The site characteristics that cause these variations may be grouped into (a) properties of the exposed surface material from which the dust originates, and (b) measures of energy expended by machinery interacting with the surface. These site characteristics are discussed below.

Surface Material Texture and Moisture. The dry-particle size distribution of the exposed soil or surface material determines its susceptibility to mechanical entrainment. The upper size limit for particles that can become suspended has been estimated at ~ 75 µm in aerodynamic diameter.[3] Conveniently, 75 µm in physical diameter is also the smallest particle size for which size analysis by dry sieving is practical.[4] Particles passing a 200-mesh screen on dry sieving are termed "silt". Note that for fugitive dust particles, the physical diameter and aerodynamic diameter are roughly equivalent because of the offsetting effects of higher density and irregular shape. Dust emissions are known to be strongly dependent on the moisture level of the mechanically disturbed material.[3] Water acts as a dust suppressant by forming cohesive moisture films among the discrete grains of surface material. In turn, the moisture level depends on the moisture added by natural precipitation, the moisture removed by evaporation, and moisture movement beneath the surface. The evaporation rate depends on the degree of air movement over the surface, material texture and mineralogy, and the degree of compaction or crusting. The moisture-holding capacity of the air is also important, and it correlates strongly with the surface temperature. Vehicle traffic intensifies the drying process primarily by increasing air movement over the surface.

Mechanical Equipment Characteristics. In addition to the material properties discussed above, it is clear that the physical and mechanical characteristics of materials handling and transport equipment also affect dust emission levels. For example, visual observation suggests (and field studies have confirmed) that vehicle emissions per unit of unpaved road length increase with increasing vehicle speed.[3] For traffic on unpaved roads, studies have also shown positive correlations between emissions and (a) vehicle weight and (b) number of wheels per vehicle.[5] Similarly, dust emissions from materials-handling operations have been found to increase with increasing wind speed and drop distance.

1.3.2 Wind Generated Dust

Wind-generated emissions from open dust sources also exhibit a high degree of variability from one site to another, and emissions at any one site tend to fluctuate widely. The site characteristics that cause these variations may be grouped into (a) properties of the exposed surface material from which the dust originates, and

(b) measures of energy expended by wind interacting with the erodible surface. These site characteristics are discussed below.

Surface Material Texture and Moisture. As in the case of mechanical entrainment, the dry-particle size distribution of the exposed soil or surface material determines its susceptibility to wind erosion. Wind forces move soil particles by three transport modes: saltation, surface creep, and suspension. Saltation describes particles, ranging in diameter from about 75 to 500 µm, that are readily lifted from the surface and jump or bounce within a layer close to the air-surface interface. Particles transported by surface creep range in diameter from about 500 to 1,000 µm. These large particles move very close to the ground, propelled by wind stress and by the impact of small particles transported by saltation. Particles smaller than about 75 µm in diameter move by suspension and tend to follow air currents. As stated above, the upper size limit of silt particles (75 µm in physical diameter) is roughly the smallest particle size for which size analysis by dry sieving is practical. The threshold wind speed for the onset of saltation, which drives the wind erosion process, is also dependent on soil texture, with 100-150 µm particles having the lowest threshold speed. Saltation provides energy for the release of particles in the PM10 size range that typically are bound by surface forces to larger clusters. Dust emissions from wind erosion are known to be strongly dependent on the moisture level of the erodible material.[6] The mechanism of moisture mitigation is the same as that described above for mechanical entrainment.

Nonerodible Elements. Nonerodible elements, such as clumps of grass or stones (larger than about 1 cm in diameter) on the surface, consume part of the shear stress of the wind which otherwise would be transferred to erodible soil. Surfaces impregnated with a large density of nonerodible elements behave as having a "limited reservoir" of erodible particles, even if the material protected by nonerodible elements is itself highly erodible. Wind-generated emissions from such surfaces decay sharply with time, as the particle reservoir is depleted. Surfaces covered by unbroken grass are virtually nonerodible.

Crust Formation. Following the wetting of a soil or other surface material, fine particles will move to form a surface crust. The surface crust acts to hold in soil moisture and resist erosion. The degree of protection that is afforded by a soil crust to the underlying soil may be measured by the modulus of rupture (roughly a measure of the hardness of the crust) and thickness of the crust.[7] Exposed soil that lacks a surface crust (e.g., a disturbed soil or a very sandy soil) is much more susceptible to wind erosion.

Frequency of Mechanical Disturbance. Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface. A disturbance is defined as an action that results in the exposure of fresh surface material. This would occur whenever a layer of aggregate material is either added to or removed from the surface. The disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest material present. Each time that a surface is disturbed, its erosion potential is increased by destroying the mitigative effects of crusts, vegetation, and friable nonerodible elements, and by exposing new surface fines.

Wind Speed. Under high wind conditions that trigger wind erosion by exceeding the threshold velocity, the wind speed profile near the erodible surface is found to follow a logarithmic distribution:[6]

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \tag{1}$$

where: u = wind speed (cm/s)
u^* = friction velocity (cm/s)
z = height above test surface (cm)
z_0 = roughness height (cm)
0.4 = von Karman's constant (dimensionless)

The friction velocity *(u^*)* is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the *y*-intercept of the velocity profile (i.e., the height at which the wind speed is zero) on a logarithmic-linear graph. Agricultural scientists have established that total soil loss by continuous wind erosion of highly erodible fields is dependent roughly on the cube of wind speed above the threshold velocity.[6] More recent work has shown that the loss of particles in suspension mode follows a similar dependence. Soils protected by nonerodible elements or crusts exhibit a weaker dependence of suspended particulate emissions on wind speed.[9]

Wind Gusts. Although mean atmospheric wind speeds may not be sufficient to initiate wind erosion from a particular "limited-reservoir" surface, wind gusts may quickly deplete a substantial portion of its erosion potential. In addition, because the erosion potential (mass of particles constituting the "limited reservoir") increases with increasing wind speed above the threshold velocity, estimated emissions should be related to the gusts of highest magnitude. The current meteorological variable which appropriately reflects the magnitude of wind gusts is the fastest 2-minute wind speed from the "First Order Summary of the Day," published by the U.S. Weather Service for first order meteorological stations.[10] The quantity represents the wind speed corresponding to the largest linear passage of wind movement during a 2-minute period. Two minutes is approximately the same duration as the half-life of the erosion process (i.e., the time required to remove one-half the erodible particles on the surface). It should be noted that instantaneous peak wind speeds can significantly exceed the fastest 2-minute wind speed. Because the threshold wind speed must be exceeded to trigger the possibility of substantial wind erosion, the dependence of erosion potential on wind speed cannot be represented by any simple linear function. For this reason, the use of an average wind speed to calculate an average emission rate is inappropriate.

Wind Accessibility. If the erodible material lies on an exposed area with little penetration into the surface wind layer, then the material is uniformly accessible to the wind. If this is not the case, it is necessary to divide the erodible area into subareas representing different degrees of exposure to wind. For example, the results of physical modeling show that the frontal face of an elevated materials storage pile is exposed to surface wind speeds of the same order as the approach wind speed upwind of the pile at a height matching the top of the pile;[11] on the other hand, the leeward face of the pile is exposed to much lower wind speeds.

1.5 Use of Satellite Imagery to Inventory Erodible Vacant Land

Windblown dust from arid soils in the West contributes to exceedances of national air quality standards for inhalable particulate matter. This problem is intensifying because of increasing land disturbance associated with rapid population growth in areas such as the Las Vegas Valley. The rates of fine particle emissions from open areas are strongly dependent on the type and frequency of land disturbance that destroys the mitigative stabilization effects of natural crusting and vegetation. Satellite imagery has been shown to be a useful tool in tracking land disturbances (source activity levels) and the resultant degree of soil vulnerability to high wind events. This method has recently been used to develop an inventory of native desert, disturbed vacant land, stabilized vacant land and private unpaved roads in the Las Vegas Valley.[12] Wind tunnel studies have shown that each of these land categories have distinctly different potentials for wind-generated dust emissions. For example, native desert is essentially non-erodible because of the high stability of the undisturbed soil surface. Conversely, disturbed vacant land such as active grading areas at construction sites has the highest erodibility among the inventoried land categories.

In this study funded by Clark County, Nevada, multi-spectral satellite imagery was used to inventory vacant land and private unpaved roads throughout the Las Vegas Valley. Landsat TM imagery was found to be appropriate for classifying surface areas as a measure of activity level. Although Landsat TM imagery has much lower spatial resolution (30 meter pixel size) than commercial satellite imagery (10 times smaller pixel size), it has higher spectral resolution (an additional two IR wavelength bands) and costs only about 1 percent of the cost of commercial satellite imagery. In the surface classification process, it was found useful to define additional land categories that could be profiled with the satellite imagery, as follows: barren/shadow (areas with steep slopes); concrete; urban vegetation (golf courses and irrigated parks); natural drainage (rocky surfaces); and urban structures (rooftops, asphalt surfaces, etc.). Ground-truthing test sites were used to develop and verify the applicability of distinctive multi-spectral reflectance patterns for each land category. A classification error matrix showed that the method has an 89 percent reliability for this application. This method can be applied at regular intervals to track the effect of land development on emissions from open areas.

1.6 Emission Calculation Procedure

A calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is given as follows:

$$R = \mathrm{SE}\ e\ (1 - c) \qquad (2)$$

where: R = estimated mass emission rate in the specified particle size range
SE = source extent
e = uncontrolled emission factor in the specified particle size range (i.e., mass of uncontrolled emissions per unit of source extent)
c = fractional efficiency of control

The source extent (activity level) is the appropriate measure of source size or the level of activity that is used to scale the uncontrolled emission factor to the particular source in question. For process sources of fugitive particulate emissions, the source extent is usually the production rate (i.e., the mass of product per unit time). Similarly, the source extent of an open dust source entailing a batch or continuous drop operation is the rate of mass throughput. For other categories of open dust sources, the source extent is related to the area of the exposed surface that is disturbed by either wind or mechanical forces. In the case of wind erosion, the source extent is simply the area of erodible surface. For emissions generated by mechanical disturbance, the source extent is also the surface area (or volume) of the material from which the emissions emanate. For vehicle travel, the disturbed surface area is the travel length times the average daily traffic (ADT) count, with each vehicle having a disturbance width equal to the width of a travel lane.

If an anthropogenic control measure (e.g., treating the surface with a chemical binder which forms an artificial crust) is applied to the source, the uncontrolled emission factor in Equation 2 must be multiplied by an additional term to reflect the resulting fractional control. In broad terms, anthropogenic control measures can be considered as either continuous or periodic, as the following examples illustrate:

Continuous controls	Periodic controls
Wet suppression at conveyor transfer points	Watering or chemical treatment of unpaved roads
Enclosures/wind fences around storage piles	Sweeping of paved travel surfaces
Continuous vegetation of exposed areas	Chemical stabilization of exposed areas

The major difference between the two types of controls is related to the time dependency of performance. For continuous controls, the efficiency of the control measure is essentially constant with respect to time. On the other hand, the efficiency associated with periodic controls tends to decrease (decay) with time after application until the next application, at which time the cycle repeats but often with some residual effects from the previous application.

In order to quantify the performance of a specific periodic control, two measures of control efficiency are required. The first is "instantaneous" control efficiency and is defined by:

$$c(t) = \left(1 - \frac{e_c(t)}{e_u}\right) \times 100 \qquad (3)$$

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

The other important measure of periodic control performance is average efficiency, defined as:

$$C(T) = \frac{1}{T}\int_0^T c(t)dt \tag{4}$$

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

The average control efficiency is needed to estimate the emission reductions due to periodic applications.

1.7 Emission Factors

Early in the USEPA field testing program to develop emission factors for fugitive dust sources, it became evident that uncontrolled emissions within a single generic source category may vary over two or more orders of magnitude as a result of variations in source conditions (equipment characteristics, material properties, and climatic parameters). Therefore, it would not be feasible to represent an entire generic source category in terms of a single-valued emission factor, as traditionally used by the USEPA to describe average emissions from a narrowly defined ducted source operation. In other words, it would take a large matrix of single-valued factors to adequately represent an entire generic fugitive dust source category. In order to account for emissions variability, therefore, the approach was taken that fugitive dust emission factors be constructed as mathematical equations for sources grouped by the dust generation mechanisms. The emission factor equation for each source category would contain multiplicative correction parameter terms that explain much of the variance in observed emission factor values on the basis of variances in specific source parameters. Such factors would be applicable to a wide range of source conditions, limited only by the extent of experimental verification. For example, the use of the silt content as a measure of the dust generation potential of a material acted on by the forces of wind or machinery proved to be an important step in extending the applicability of the emission factor equations to a wide variety of aggregate materials of industrial importance.

A compendium of predictive emission factor equations for fugitive dust sources is maintained on a CD-ROM by the U.S. EPA.[13] These emission factor equations are also published in Volume I of the U.S. EPA's Compilation of Air Pollutant Emission Factors commonly referred to as AP-42.[14] A set of particle size multipliers for adjusting the calculated emission factors to specific particle size fractions is provided with each equation. The ratios of PM2.5 to PM10 for fugitive dust sources published in Section 13 of AP-42 typically range from 0.10 to 0.20.

Example: Vehicle Traffic on Unpaved Roads. For the purpose of estimating uncontrolled emissions, the U.S. EPA emission factor equation applicable to vehicle traffic on publicly accessible unpaved roads takes source characteristics into consideration:

$$E = [1.8\ (s/12)^{1.8}\ (S/30)^{0.5}\ /\ (M/0.5)^{0.2}] - C \qquad (5)$$

where: E = PM10 emission factor (lb/VMT)
s = surface material silt content (%)
S = mean vehicle speed (mph)
M = surface material moisture content (%)
C = emission factor for 1980's vehicle fleet exhaust, plus break/tire wear

The denominators in each of the multiplicative terms of the equation constitute normalizing default values, in case no site-specific correction parameter data are available. The default moisture content represents dry (worst-case) road conditions. Extrapolation to annual average uncontrolled emission estimates (including natural mitigation) is accomplished by assuming that emissions are occurring at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable precipitation.

1.8 Emission Control Options

Typically, there are several options for the control of fugitive particulate emissions from any given source. This is clear from Equation 2 used to calculate the emission rate. Because the uncontrolled emission rate is the product of the source extent and the uncontrolled emission factor, a reduction in either of these two variables produces a proportional reduction in the uncontrolled emission rate. In the case of open sources, the reduction in the uncontrolled emission factor may be achieved by adjusted "work practices". The degree of the reduction of the uncontrolled emission factor can be estimated from the known dependence of the factor on source conditions that are subject to alteration. For open dust sources, this information is embodied in the predictive emission factor equations for fugitive dust sources as presented in Section 13 of AP-42. The reduction of source extent and the incorporation of adjusted work practices that reduce the amount of exposed dust-producing material are preventive measures for the control of fugitive dust emissions.

Add-on controls can also be applied to reduce emissions by reducing the amount (areal extent) of dust-producing material, other than by cleanup operations. For example, the elimination of mud/dirt carryout onto paved roads at construction and demolition sites is a cost-effective preventive measure. On the other hand, mitigative measures involve the periodic removal of dust-producing material. Examples of mitigative measures include: cleanup of spillage on travel surfaces (paved and unpaved) and cleanup of material spillage at conveyor transfer points. Mitigative measures tend to be less favorable from a cost-effectiveness standpoint.

Periodically applied control techniques for open dust sources begin to decay in efficiency almost immediately after implementation. The most extreme example of this is the watering of unpaved roads, where the efficiency decays from nearly 100% to 0% in a matter of hours. On the other hand, the effects of chemical dust suppressants applied to unpaved roads may last for several months. Consequently, to describe the performance of most intermittent control techniques for open dust sources, the "time-weighted average" control efficiency must be reported along with the time period over which the value applies. For continuous control systems (e.g., wet suppression for continuous drop materials transfer), a single control efficiency is usually appropriate.

Table 1-3 lists fugitive dust control measures that have been judged to be generally cost-effective for application to metropolitan areas unable to meet PM10 standards. The most highly developed performance models available apply to application of chemical suppressants on unpaved roads. These models relate the expected instantaneous control efficiency to the application parameters (application intensity and dilution ratio) and to the number of vehicle passes (rather than time) following the application. More details on available dust control measure performance and cost are presented in two MRI documents.[15, 16]

Table 1-3. Controls for Fugitive Dust Sources

Source category	Control action
Agricultural Tilling and Harvesting, Livestock Husbandry	Conservation management practices
Construction/Demolition	Paving permanent roads early in project Covering haul trucks Access apron construction and cleaning Watering of graveled travel surfaces
Abrasive Blasting, Materials Handling, Mineral Products Industry	Wet suppression
Paved Roads	Water flushing/sweeping Improvements in sanding/salting applications and materials Covering haul trucks Prevention of trackout Curb installation Shoulder stabilization
Unpaved Roads	Paving Chemical stabilization Surface improvement (e.g., gravel) Vehicle speed reduction
Wind Erosion (agricultural, open area, and storage pile)	Revegetation Limitation of off-road vehicle traffic

1.9 Document Organization

The handbook contains separate, stand-alone chapters for each fugitive dust source category with chapters arranged in the following order:

Chapter 2: Agricultural Tilling
Chapter 3: Construction and Demolition
Chapter 4: Materials Handling
Chapter 5: Paved Roads
Chapter 6: Unpaved Roads
Chapter 7: Agricultural Wind Erosion
Chapter 8: Open Area Wind Erosion
Chapter 9: Storage Pile Wind Erosion
Chapter 10: Agricultural Harvesting
Chapter 11: Mineral Products Industry
Chapter 12: Abrasive Blasting
Chapter 13: Livestock Husbandry
Chapter 14: Miscellaneous Minor Fugitive Dust Sources

Each chapter contains the following subsections:

(a) Characterization of Source Emissions
(b) Emissions Estimation: Primary Methodology (generally from AP-42)
(c) Emissions Estimation: Alternate Methodology (if available; e.g., CARB)
(d) Demonstrated Control Techniques
(e) Regulatory Formats
(f) Compliance Tools
(g) Sample Cost-Effectiveness Calculation
(h) References

A glossary and a series of Appendices are included in the handbook. Appendix A contains a discussion of two basic test methods used to quantify fugitive dust emission rates, namely:

(a) The upwind-downwind method that involves the measurement of upwind and downwind particulate concentrations, utilizing ground-based samplers under known meteorological conditions, followed by a calculation of the source strength (mass emission rate) with atmospheric dispersion equations; and
(b) The exposure-profiling method that involves simultaneous, multipoint measurements of particulate concentration and wind speed over the effective cross section of the plume, followed by a calculation of the net particulate mass flux through integration of the plume profiles.

Appendix B contains cost information for demonstrated control measures. Appendix C contains a step-wise methodology to calculate the cost-effectiveness of different fugitive dust control measures. Appendix D contains a brief discussion of fugitive PM10 management plans and record keeping requirements mandated by one of the air quality districts within the WRAP region.

In compiling information regarding control cost-effectiveness estimates (i.e., $ per ton of PM10 reduction) of different control options 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 what assumptions are used, the control cost-effectiveness estimates can range over one to two orders of magnitude. Consequently, the end user of the handbook would get a distorted view if we published these estimates. Rather than presenting these published cost-effectiveness estimates, we have prepared a detailed methodology containing the steps to calculate cost-effectiveness that is included in Appendix C. 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 for their particular situation.

1.10 References

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Chapter 2. Agricultural Tilling

2.1 Characterization of Source Emissions

The agricultural tilling source category includes estimates of the airborne soil particulate emissions produced during the preparation of agricultural lands for planting and after harvest activities. Operations included in this methodology are discing, shaping, chiseling, leveling, and other mechanical operations used to prepare the soil. Dust emissions are produced by the mechanical disturbance of the soil by the implement used and the tractor pulling it. Soil preparation activities tend to be performed in the early spring and fall months. Particulate emissions from land preparation are computed by multiplying a crop specific emission factor by an activity factor. The crop specific emission factors are calculated using operation specific (i.e., discing or chiseling) emission factors which are combined with the number of operations provided in the crop calendars. The activity factor is based on the harvested acreage of each crop for each county in the state. In addition, acre-passes are computed, which are the number of passes per acre that are typically needed to prepare a field for planting a particular crop. The particulate dust emissions produced by agricultural land preparation operations are estimated by combining the crop acreage and the operation specific emission factor.

The current version of AP-42 (i.e., the 5^{th} edition) does not address agricultural tilling even though an earlier edition (i.e., the 4^{th} edition) included a PM10 emission factor equation for this fugitive dust source category expressed as follows:

$$EF = 1.01\ s^{0.6}$$

where, EF is the PM10 emission factor (lb/acre-pass) and s is the silt content of surface soil (%). Thus, the methodology adopted by the California Air Resources Board (CARB) is presented below as the primary emissions estimation methodology in lieu of an official EPA methodology for this fugitive dust source category.

2.2 Emission Estimation: Primary Methodology[1-5]

This section was adapted from Section 7.4 of CARB's Emission Inventory Methodology. Section 7.4 was last updated in January 2003.

The particulate dust emissions from agricultural land preparation are estimated for each crop in each county using the following equation.

$$Emissions_{crop} = Emission\ Factor_{crop} \times Acres_{crop}$$

Then the crop emissions for each county are summed to produce the county and statewide PM10 and PM2.5 emission estimates. The remainder of this section discusses each component of the above equation.

Acres. The acreage data used for estimating land preparation emissions are based on the state summary of crop acreage harvested. The acreage data are subdivided by county and crop type for the entire state, and are compiled from individual county agricultural commissioner reports.

Crop Calendars and Acre-Passes. Acre-passes (the total number of passes typically performed to prepare land for planting during a year) are used in computing crop specific emission factors for land preparation. These land preparation operations may occur following harvest or closer to planting, and can include discing, tilling, land leveling, and other operations. Each crop is different in the type of soil operations performed and when they occur. For the crops that are not explicitly updated, an updated crop profile from a similar crop can be used. For updating acre-pass data, it is also useful to collect specific information on when agricultural operations occur. Using these data, it is possible to create detailed temporal profiles that help to indicate when PM emissions from land preparations may be highest.

Emission Factor. The operation specific PM10 emission factors used to estimate the crop specific emission factor for agricultural land preparations were initially extracted from a University of California Davis report.[4] After discussions with regulators, researchers, and industry representatives, the emission factors were adjusted based on a combination of scientific applicability, general experience, and observations. Five emission factors were developed by UC Davis using 1995 to 1998 test data measured in cotton and wheat fields in California. The operations tested included root cutting, discing, ripping and subsoiling, land planing and floating, and weeding, which produced emission factors that are summarized in Table 2-1 below. CARB has recently proposed adopting a PM2.5/PM10 ratio for fugitive dust from agricultural tilling and related land preparation activities of 0.15 based on the analysis conducted by MRI on behalf of WRAP.[5, 6]

Table 2-1. Land Preparation Emission Factors

Land preparation operations	Emission factor (lbs PM10/acre-pass)
Root cutting	0.3
Discing, Tilling, Chiseling	1.2
Ripping, Subsoiling	4.6
Land Planing & Floating	12.5
Weeding	0.8

There are more than thirty different land preparation operations commonly used. With five emission factors available, the other operations can be assigned "best-fit" factors based on similar potential emission levels. The assignment of emission factors for operations are based on the expertise and experience of regulators, researchers, and industry representatives. For each crop, the emission factor is the sum of the acre-pass weighted emission factors for each land preparation operation.

Assumptions and Limitations. The CARB methodology is subject to the following assumptions and limitations:

1. The land preparation emission factors for discing, tilling, etc., are assumed to produce the same level of emissions, regardless of the crop type.
2. The land preparation emission factors do not change geographically for counties.

3. A limited number of emission factors are assigned to all land preparation activities.
4. Crop calendar data collected for test area (i.e., San Joaquin) crops and practices were extrapolated to the same crops in the remainder of the state. Existing crop profiles were used for the small percentage of crops in which update information was not collected.
5. In addition to the activities provided in the crop calendars, it is also assumed that field and row crop acreage receive a land-planing pass once every five years.

Temporal Activity. Temporal activity for agricultural tilling (and other land preparation activities) is derived by summing, for each county, the monthly emissions from all crops. For each crop, the monthly emissions are calculated based on its monthly crop calendar profile, which reflects the percentage of activities that occurs in that month. An example of the monthly activity profile for almonds, cotton, and wine grapes is shown below in Table 2-2. Because the mix of crops varies by county, composite temporal profiles combining all of the other county crops vary by county. An example of a composite land preparation profile by month for Fresno County, showing the combined temporal profile for all of the land preparation activities in the county, is shown in Table 2-3.

Table 2-2. Monthly Activity Profile of Selected Crops

Crops	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
Almonds	0	0	0	0	0	0	0	0	0	0	50	50
Cotton	0	9	9	0	0	0	0	0	0	0	41	41
Grapes-wine	0	0	0	4	16	16	12	12	12	28	0	0

Table 2-3. County Land Preparation Profile Composite

County	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
Fresno	3	6	6	2	2	1	3	4	2	12	30	29

2.3 Demonstrated Control Techniques

The emission potential of agricultural land preparation operations, including soil tilling, is affected by the soil management and cropping systems that are in place. Table 2-4 presents a summary of demonstrated control measures and the associated PM10 control efficiencies. It is readily observed that reported control efficiencies for many of the control measures are highly variable. This may reflect differences in the operations as well as the test methods used to determine control efficiencies. A list of control measures for agricultural tilling operations is available from the California Air Pollution Control Officers' Association's (CAPCOA) agricultural clearinghouse website (http://capcoa.org/ag_clearinghouse.htm). The list of control measures for land preparation activities for field and orchard crops include: ceasing activities under very windy conditions, combining operations to reduce the number of passes, application of chemicals through an irrigation system, fallowing land, use cover crops and/or mulch/crop residue to reduce wind erosion of soil, operating at night when moisture levels are higher and winds tend to be lighter, precision farming with a GPS system to reduce overlap of passes, roughening the soil or establishing ridges perpendicular to the prevailing wind direction, and using wind barriers.

Table 2-4. Control Efficiencies for Control Measures for Agricultural Tilling[7-11]

Control measure	PM10 control efficiency	References/Comments
Equipment modification	50%	MRI, 1981. Control efficiency is for electrostatically charged fine-mist water spray.
Limited activity during a high-wind event	1 - 5%	SCAQMD, 1997. Control efficiency assumes no tilling when wind speed exceeds 25 mph.
Reduced tillage system (Conservation Tilling)	35 - 50%	Coates, 1994. This study identified total PM10 emissions generated for five different cotton tillage systems, including conventional tilling. Four of the systems combine several tillage operations (e.g., shredding, discing, mulching).
	60%	MRI, 1981. Control efficiency is for a minimum tillage technique that confines farm equipment and vehicle traffic to specific areas (for cotton and tomatoes).
	25 - 100%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for application of herbicide that reduces need for cultivation (i.e., 25% for barley, alfalfa, and wheat; 100% for cotton, corn, tomatoes, and lettuce).
	30%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for laser-directed land plane that reduces the amount of land planing.
	50%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for using "punch" planter instead of harrowing (for cotton, corn, and lettuce).
	50%	MRI, 1981. Control efficiency is for using "plug" planting that places plants more exactly and eliminates the need for thinning (for tomatoes, only).
	50%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for aerial seeding which produces less dust than ground planting (for alfalfa and wheat).
	91 - 99%	Grantz, et al. 1998. Control efficiency is for revegetation of fallow agricultural lands by direct seeding.
Tillage based on soil moisture	90%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for sprinkler irrigation as a fugitive dust control measure. Also, sprinkler irrigation could reduce the need for extensive land planing associated with surface irrigation.
Sequential cropping	50%	MRI, 1981. Control efficiency is for double cropping corn.
Surface roughening	15 - 64%	Grantz et al, 1998. Control efficiency is for increasing surface roughness using rocks and soil aggregates.

2.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. However, most air quality districts currently exempt agricultural operations from controlling fugitive dust. Air quality districts that regulate fugitive dust emissions from agricultural operations include Clark County, NV and several districts in California such as the Imperial County APCD, the San Joaquin Valley APCD and the South Coast AQMD. Imperial County APCD’s Rule 806 prohibits fugitive dust emissions from farming activities for farms over 40 acres. The San Joaquin Valley APCD and the South Coast AQMD prohibit fugitive dust emissions for the larger farms defined as farms with areas where the combined disturbed surface area within one continuous property line and not separated by a paved public road is greater than 10 acres. The San Joaquin Valley APCD’s Rule 4550 (Conservation Management Practices, CMPs) requires farmers with 100 acres or more of contiguous or adjacent farmland to implement and document a biennial CMP plan to reduce fugitive dust emissions from on-farm sources, such as unpaved roads and equipment yards, during land preparation and harvesting activities. The District’s rule requires farmers to implement a separate CMP for each crop for the following source categories: land preparation and cultivation, harvesting, unpaved roads, unpaved equipment yards, and other cultural practices. Example regulatory formats downloaded from the Internet are presented in Table 2-5. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- San Joaquin Valley APCD, CA: valleyair.org/SJV_main.asp
- South Coast AQMD, CA: aqmd.gov/rules
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/aq

CAPCOA’s agricultural clearinghouse website (capcoa.org/ag_clearinghouse.htm) provides links to rules of different air quality agencies within California that regulate fugitive dust emissions from agricultural operations.

Table 2-5. Example Regulatory Format for Agricultural Tilling

Control measure	Agency
Any person engaged in agricultural operations shall take all reasonable precautions to abate fugitive dust from becoming airborne from such activities.	Clark County Reg. 41 7/10/04
Limit visible dust emissions to 20% opacity by pre-watering, phasing of work, applying water during active operations	SJVAPCD Rule 8021 11/15/2001
Implement one of following during inactivity: restricting vehicle access or applying water or chemical stabilizers	SJVAPCD Rule 8021 11/15/2001
Use mowing or cutting instead discing and maintain at least 3" stubble above soil (Also requires pre-application of watering if discing for weed abatement)	SCAQMD Rule 403 12/11/1998
Cease activities when wind speeds are greater than 25 mph	SCAQMD Rule 403.1 4/02/04

2.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations (e.g., observation of visible dust plume). An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Compliance tools applicable to agricultural tilling are summarized in Table 2-6.

Table 2-6. Compliance Tools for Agricultural Tilling

Record keeping	Site inspection/monitoring
Maintain daily records to document the specific dust control options taken; maintain such records for a period of not less than three years; and make such records available to the Executive Officer upon request.	Observation of dust plumes during periods of agricultural tilling; observation of dust plume opacity (visible emissions) exceeding a standard; observation of high winds (e.g., >25 mph).

2.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for agricultural tilling. A sample cost-effectiveness calculation is presented below for a specific control measure (conservation tilling) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for agricultural tilling, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Agricultural Tilling

Step 1. Determine source activity and control application parameters.

Field size (acres)	320
Frequency of operations per year	4
Control Measure	Conservation tilling
Control application/frequency	Reduce 4 passes to 3 passes
Control Efficiency	25%

The field size and frequency of operations are assumed values, for illustrative purposes. Conservation tilling has been chosen as the applied control measure. The control application/frequency and control efficiency are values determined from the proportional reduction in tilling frequency.

Step 2. Obtain PM10 Emission Factor.
The PM10 emission factor for agricultural tilling dust is 1.2 (lb/acre-pass).[12]

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor, EF, (given in Step 2) is multiplied by the field size and the frequency of operations (both under activity data) and then divided by 2,000 lbs to compute the annual PM10 emissions in tons per year, as follows:

Annual PM10 emissions = (EF x Field Size x Frequency of Ops) / 2,000
Annual PM10 emissions = (1.2 x 320 x 4) / 2,000 = 0.768 tons

Annual PM2.5 emissions = (PM2.5/PM10) x PM10 emissions
CARB proposed PM2.5/PM10 ratio for agricultural operations[5] = 0.15
Annual PM2.5 emissions = (0.15 x 0.768 tons) = 0.115 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 conservation tilling as our control measure. Based on a control efficiency estimate of 25%, the annual controlled PM emissions are calculated to be:

Annual Controlled PM10 emissions = (0.768 tons) x (1 – 0.25) = 0.576 tons
Annual Controlled PM2.5 emissions = (0.115 tons) x (1 – 0.25) = 0.086 tons

Step 5. Determine Annual Cost to Control PM Emissions.

In this example, eliminating one tilling pass actually reduces the annual tilling costs. The annual cost savings of this control measure is calculated by multiplying the number of acres by the tilling cost per acre. The cost of tilling is assigned a value of $10 per acre (WSU, 1998[13]). Thus, the annual cost savings from eliminating one tilling pass is estimated to be: 320 x 10 = $3,200.

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annual cost (in this case annual cost savings) by the emissions reduction (i.e., uncontrolled emissions minus uncontrolled emissions), as follows:

Cost-effectiveness = Annual Costs Savings / (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = -$3,200 / (0.687 – 0.576) = -$16,667/ton
Cost-effectiveness for PM2.5 emissions = –$3,200 / (0.115 – 0.086) = –$111,111/ton

[Note: The negative cost-effectiveness values indicate a net cost savings for this control measure.]

2.7 References

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Chapter 3. Construction and Demolition

3.1 Characterization of Source Emissions

Heavy construction is a source of dust emissions that may have a substantial temporary impact on local air quality. Building and road construction are two examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a particular building or road. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from construction vehicle traffic over temporary roads at the construction site.

The temporary nature of construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected (1) to have a definable beginning and an end, and (2) to vary substantially over different phases of the construction process. This is in contrast to most other fugitive dust sources where emissions are either relatively steady or follow a discernable annual cycle. Furthermore, there is often a need to estimate areawide construction emissions without regard to the actual plans of any individual construction project. For these reasons, methods by which either areawide or site-specific emissions may be estimated are presented below.

The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources, one can expect emissions from construction operations to be positively correlated with the silt content of the soil (i.e., particles smaller than 75 micrometers [μm] in diameter), as well as with the speed and weight of the construction vehicle, and to be negatively correlated with the soil moisture content.

Table 3-1 displays the dust sources involved with construction. In addition to the on-site activities shown in Table 3-1, substantial emissions are possible because of material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (i.e., not just that associated with the construction) can resuspend the deposited material, this "secondary" source of emissions may be far more important than all the dust sources located within the construction site. Furthermore, this secondary source will be present during all construction operations. Persons developing construction site emission estimates must consider the potential for increased adjacent emissions from off-site paved roadways (see Chapter 5). High wind events also can lead to emissions from cleared land and material stockpiles. Chapters 8 and 9 present estimation methodologies that can be used for such sources at construction sites.

Table 3-1. Emission Sources for Construction Operations

Construction phase	Dust-generating activities
I. Demolition and debris removal	1. Demolition of buildings or other (natural) obstacles such as trees, boulders, etc. a. Mechanical dismemberment ("headache ball") of existing structures b. Implosion of existing structures c. Drilling and blasting of soil d. General land clearing 2. Loading of debris into trucks 3. Truck transport of debris 4. Truck unloading of debris
II. Site Preparation (earth moving)	1. Bulldozing 2. Scrapers unloading topsoil 3. Scrapers in travel 4. Scrapers removing topsoil 5. Loading of excavated material into trucks 6. Truck dumping of fill material, road base, or other materials 7. Compacting 8. Motor grading
III. General Construction	1. Vehicular Traffic 2. Portable plants a. Crushing b. Screening c. Material transfers 3. Other operations

3.2 Emissions Estimation: Primary Methodology[1-6]

This section was adapted from: Estimating Particulate Matter Emissions from Construction Operations, report prepared for USEPA by Midwest Research Institute dated September 15, 1999.[1]

Note that AP-42 Section 13.2.3, "Heavy Construction Operations," was not adopted for the primary emission estimation methodology because it relies on a single-valued emission factor for TSP of 1.2 tons/acre-month based on only one set of field tests.[2]

3.2.1 PM Emissions from Construction

Construction emissions can be estimated when two basic construction parameters are known: the acres of land disturbed by the construction activity, and the duration of the activity. A general emission factor for all types of construction activity is 0.11 tons PM10/acre-month and is based on a 1996 BACM study conducted by Midwest Research (MRI) Institute for the California South Coast Air Quality Management District (SCAQMD).[3] The single composite factor of 0.11 tons PM10/acre-month assumes that all construction activity produces the same amount of dust on a per acre basis. In other words, the amount of dust produced is not dependent on the type of construction but merely on the area of land being disturbed by the construction activity. A second assumption is that land affected by construction activity does not involve large-scale cut and fill operations. Factors for the conversion of dollars spent on construction to acreage disturbed, along with the estimates for the duration of construction activity, were originally developed by MRI in 1974.[4]

Separate emission factors segregated by type of construction activity provide better estimates of PM10 emissions that are more accurate estimate than are obtained using a general emission factor. The factors from the 1996 MRI BACM study[3] are summarized in Table 3-2. Specific emission factors and activity levels for residential, nonresidential, and road construction activities are described below.

Table 3-2. Recommended PM10 Emission Factors for Construction Operations[1]

Basis for emission factor	Recommended PM10 emission factor
Level 1 Only area and duration known	0.11 ton/acre-month (average conditions) 0.42 ton/acre-month (worst-case conditions)[a]
Level 2 Amount of earth moving known, in addition to total project area and duration	0.011 ton/acre-month for general construction (for each month of construction activity) <u>plus</u> 0.059 ton/1,000 cubic yards for on-site cut/fill[b] 0.22 ton/1,000 cubic yards for off-site cut/fill[b]
Level 3 More detailed information available on duration of earth moving and other material movement	0.13 lb/acre-work hr for general construction <u>plus</u> 49 lb/scraper-hr for on-site haulage[c] 94 lb/hr for off-site haulage[d]
Level 4 Detailed information on number of units and travel distances available	0.13 lb/acre-work hr for general construction <u>plus</u> 0.21 lb/ton-mile for on-site haulage 0.62 lb/ton-mile for off-site haulage[c]

[a] Worst-case refers to construction sites with active large-scale earth moving operations.
[b] These values are based on assumptions that one scraper can move 70,000 cubic yards of earth in one month and one truck can move 35,000 cubic yards of material in one month. If the on-site/off-site fraction is not known, assume 100% on-site.
[c] If the number of scrapers in use is not knows, MRI recommends that a default value of 4 be used. In addition, if the actual capacity of earth moving units is known, the user is directed to use the following emission rates in units of lb/scraper-hour for different capacity scrapers: 19 for 10 yd^3 scraper, 45 for 20 yd^3 scraper, 49 for 30 yd^3 scraper, and 84 for 45 yd^3 scraper.
[d] Factor for use with over-the-road trucks. If "off-highway" or "haul" trucks are used, haulage should be considered "on-site."

3.2.2 Residential Construction

Residential construction emissions can be calculated for three basic types of residential construction:

- Single-family houses
- Two-family houses
- Apartment buildings

Housing construction emissions are calculated using an emission factor of 0.032 tons PM10/acre-month. Also required are: the number of housing units created, a units-to-acres conversion factor, and the duration of construction activity. The formula for calculating emissions from residential construction is:

$$\text{Emissions} = (0.032 \text{ tons PM10/acre-month}) \; B \times f \times m$$

where, B = the number of houses constructed
f = building to acres conversion factor
m = the duration of construction activity in months

Following the California methodology, residential construction acreage is based on the number of housing units constructed rather than the dollar value of construction.

An alternative methodology is recommended for residential construction in areas in which basements are constructed or the amount of dirt moved at a residential construction site is known. The F.W. Dodge reports (www. fwdodge.com/newdodgenews.asp) give the total square footage of homes for both single-family and two-family homes. These values can be used to estimate the volume in cubic yards of dirt moved. Multiplying the total square footage of the homes by an average basement depth of 8 ft, and adding 10% additional volume to account for peripheral dirt removed for footings, space around the footings, and other backfilled areas adjacent to the basement, produces an estimate of the total volume in cubic yards of earth moved during residential construction.

The information needed to determine activity levels of residential construction may be based either on the dollar value of construction or the number of housing units constructed. Construction costs vary throughout the United States. The average home cost can vary from the low to upper $100,000s depending on where the home is located in the United States. Because residential construction characteristics do not show as much variance as the cost does, the number of units constructed is a better indicator of activity level. The amount of land impacted by residential construction is determined to be about the same on a per house basis. The number of housing units for the three types of residential construction (single family, two-family, and apartments) for a county or state are available from the F.W. Dodge's "Dodge Local Construction Potentials Bulletin."

A single-family house is estimated to occupy 1/4 acre. The "building to acres" conversion factor for a single-family house was determined by finding the area of the base of a home and estimating the area of land affected by grading and other construction activities beyond the "footprint" of the house. The average home is around 2,000 sq. ft. Using a conversion factor of 1/4 acre/house indicates that five times the base of the house is affected by the construction of the home. The "building to acres" conversion factor for two-family housing was found to be 1/3 acre per building. The 1/3 acre was derived from the average square footage of a two-family home (approximately 3,500 sq. ft.) and the land affected beyond the base of the house, about 4 times the base for two-family residences.

For comparison purposes, residential construction emission factor calculations are calculated below for BACM Level 1 and Level 2 scenarios. The PM10 construction emission factor for one single-family home is based on typical parameters for a single-family home:

- area of land disturbed 1/4 acre
- area of home 2,000 sq. ft.
- duration 6 months
- basement depth 8 ft.
- moisture level 6%
- silt content 8%

The BACM Level 1 emission calculation is estimated as follows:

0.032 tons PM10/acre-month x 1/4 acre x 6 months = 0.048 tons PM10 = 96 lb PM10

The BACM Level 2 emission calculation is estimated as follows:

Cubic yards of dirt moved = 2,000 ft^2 x 8 ft. x 110% = 17,600 ft^3 = 652 yd^3
PM10 = (0.011 tons/acre-month x 1/4 acre x 6 months) + (0.059 tons/1000 yd^3 dirt x 652 yd^3 dirt)
= 0.016 tons + 0.038 tons = 0.0545 tons PM10 = 109 lb PM10

The emission factor recommended for the construction of apartment buildings is 0.11 tons PM10/acre-month because apartment construction does not normally involve a large amount of cut-and-fill operations. Apartment buildings vary in size, number of units, square footage per unit, floors, and many other characteristics. Because of these variations and the fact that most apartment buildings occupy a variable amount of space, a "dollars-to-acres" conversion is recommended for apartment building construction rather than a "building-to-acres" conversion factor. An estimate of 1.5 acres/$\$10^6$ (in 2004 dollar value) is recommended to determine the acres of land disturbed by the construction of apartments. This "dollars-to-acres" conversion factor is based on updating previous conversion factors developed by MRI[4, 5] using cost of living adjustment factors.

3.2.3 Nonresidential Construction

Nonresidential construction includes building construction (commercial, industrial, institutional, governmental) and also public works. The emissions produced from the construction of nonresidential buildings are calculated using the dollar value of the construction. The formula for calculating the emissions from nonresidential construction is:

$$\text{PM10 Emissions} = (0.19 \text{ tons PM10/acre-month}) \times \$ \times f \times m$$

where, \$ = dollars spent on nonresidential construction in millions
f = dollars to acres conversion factor
m = duration of construction activity in months

The emission factor of 0.19 tons PM10/acre-month was developed by MRI in 1999 using a method similar to a procedure originated by Clark County, Nevada and the emission factors recommended in the 1996 MRI BACM Report.[3] A quarter of all nonresidential construction is assumed to involve active earthmoving in which the recommended emission factor is 0.42 tons PM10/acre-month. The 0.19 tons PM10/acre-month was calculated by taking 1/4 of the heavy emission factor, (0.42 tons PM10/acre-month) plus 3/4 of the general emission factor (0.11 tons/acre-month). The 1/4:3/4 apportionment is based on a detailed analysis of a Phoenix airport construction where specific unit operations had been investigated for PM10 emissions.[6] The proposed emission factor of 0.19 tons/acre-month for nonresidential building construction resulted in a total uncontrolled PM10 emissions estimate that was within 25% of that based on a detailed unit operation emissions inventory using detailed engineering plans and "unit-operation" emission factors.

Extensive earthmoving activities will produce higher amounts of PM10 emissions than the average construction project. Thus, a worst-case BACM "heavy construction emission factor" of 0.42 tons PM10/acre-month should provide a better emissions estimate for areas in which a significant amount of earth is disturbed.

The dollar amount spent on nonresidential construction is available from the U.S. Census Bureau (www.census.gov/prod/www/abs/cons-hou), and the Dodge Construction Potentials Bulletin (www. fwdodge.com/newdodgenews.asp). Census data are delineated by SIC Code, whereas the Potentials Bulletin divides activity by the types of building being constructed rather than by SIC Code. It is estimated that for every million dollars spent on construction (in 2004 dollars), 1.5 acres of land are impacted. The "dollars to acres" conversion factor reflects the current dollar value using the Price and Cost Indices for Construction that are available from the Statistical Abstract of the United States, published yearly. The estimate for the duration of nonresidential construction is 11 months.

3.2.4 Road Construction

Road construction emissions are highly correlated with the amount of earthmoving that occurs at a site. Almost all roadway construction involves extensive earthmoving and heavy construction vehicle travel, causing emissions to be higher than found for other construction projects. The PM10 emissions produced by road construction are calculated using the BACM recommended emission factor for heavy construction[1] and the miles of new roadway constructed. The formula used for calculating roadway construction emissions is:

$$\text{PM10 Emissions} = (0.42 \text{ tons PM10/acre-month}) \times M \times f \times d$$

where, M = miles of new roadway constructed
f = miles to acres conversion factors
d = duration of roadway construction activity in months

The BACM worst case scenario emission factor of 0.42 tons/acre-month is used to account for the large amount of dirt moved during the construction of roadways. Since most road construction consists of grading and leveling the land, the higher emission factor more accurately reflects the high level of cut and fill activity that occurs at road construction sites.

The miles of new roadway constructed are available at the state level from the *Highway Statistics* book published yearly by the Federal Highway Administration (FHWA; www.fhwa.dot.gov/ohim/hs97/hm50.pdf) and the Bureau of Census Statistical Abstract of the United States. The miles of new roadway constructed can be found by determining the change in the miles of roadway from the previous year to the current year. The amount of roadway constructed is apportioned from the state to the county level using housing start data that is a good indicator of the need for new roads.

The conversion of miles of roadway constructed to the acres of land disturbed is based on a method developed by the California Air Resources Board. This calculation is performed by estimating the overall width of the roadway, then multiplying the width by a mile to determine the acres affected by one mile of roadway construction. The California "miles to acres disturbed" conversion factors are available for freeway, highway and city/county roads. In the Highway Statistics book, roadways are divided into separate functional classes. MRI developed a "miles-to-acres" conversion factor in 1999[1] according to the roadway types found in the "Public Road Length, Miles by Functional System" table of the annual *Highway Statistics*. The functional classes are divided into four groups. Group 1 includes Interstates and Other Principal Arterial roads and is estimated to occupy 15.2 acres/mile. Group 2 includes Other Freeways and Expressways (Urban) and Minor Arterial Roads and is estimated at 12.7 acres/mile. Group 3 has Major Collectors (Rural) and Collectors (Urban) and a conversion factor of 9.8 acres/mile. Minor Collectors (Rural) and Local roads are included in Group 4 and converted at 7.9 acres/mile. Table 3-3 shows the data used to calculate the acres per mile of road constructed.

Table 3-3. Conversion of Road Miles to Acres Disturbed

	Group 1	Group 2	Group 3	Group 4
Lane Width (feet)	12	12	12	12
Number of Lanes	5	5	3	2
Average Shoulder Width (feet)	10	10	10	8
Number of Shoulders	4	2	2	2
Roadway Width* (feet)	100	80	56	40
Area affected beyond road width	25	25	25	25
Width Affected (feet)	125	105	81	65
Acres Affected per Mile of New Roadway	15.2	12.7	9.8	7.9

* Roadway Width= (Lane Width x # of Lanes) + (Shoulder Width x # of Shoulders).

The amount of new roadway constructed is available on a yearly basis and the duration of the construction activity is determined to be 12 months. The duration accounts for the amount of land affected during that time period and also reflects the fact that construction of roads normally lasts longer than a year. The duration of construction of a new roadway is estimated at 12 to 18 months.

3.3 Emission Estimation: Alternate Methodology for Building Construction

This section was adapted from Section 7.7 of CARB's Emission Inventory Methodology. Section 7.7 was last updated in September 2002.

The building construction dust source category provides estimates of the fugitive dust particulate matter caused by construction activities associated with building residential, commercial, industrial, institutional, or governmental structures. The emissions result predominantly from site preparation work, which may include scraping, grading, loading, digging, compacting, light-duty vehicle travel, and other operations. Dust emissions from construction operations are computed by using a PM10 emission factor developed by MRI during 1996.[3] The emission factor is based on observations of construction operations in California and Las Vegas. Activity data for construction is expressed in terms of acre-months of construction. Acre-months are based on estimates of the acres disturbed for residential construction, and project valuation for other non-residential construction.

3.3.1 Emission Estimation Methodology

Emission Factor. The PM10 emission factor used for estimating geologic dust emissions from building construction activities is based on work performed by MRI[3] under contract to the PM10 Best Available Control Measure (BACM) working group. For most parts of the state, the emission factor used is 0.11 tons PM10/acre-month of activity. This emission factor is based on MRI's observation of the types, quantity, and duration of operations at eight construction sites (three in Las Vegas and five in California). The bulk of the operations observed were site preparation-related activities. The observed activity data were then combined with operation-specific emission factors provided in AP-42[2] to produce site emissions estimates. These site estimates were then combined to produce the overall average emission factor of 0.11 tons PM10/acre-month. The PM2.5/PM10 ratio for fugitive dust from construction and demolition activities is 0.1 based on the analysis conducted by MRI on behalf of WRAP.[7]

The construction emission factor is assumed to include the effects of typical control measures such as routine watering. A dust control effectiveness of 50% is assumed from these measures, which is based on the estimated control effectiveness of watering.[8] Therefore, if this emission factor is used for construction activities where watering is not used, it should be doubled to more accurately reflect the actual emissions. The MRI document[3] lists their average emission factor values as uncontrolled. However, it can be argued that the activities observed and the emission estimates do include the residual effects of control. All of the test sites observed were actual operations that used watering controls as part of their standard industry practice in California and Las Vegas. So, even if in some cases watering was not performed during MRI's actual site visits, the residual decreases in emissions from the watering controls and raising the soil moisture are included in the MRI estimates.

The 1996 MRI report[3] also includes an emission factor for worst-case emissions of 0.42 tons PM10/acre-month. This emission factor is appropriate for large-scale construction operations, which involve substantial earthmoving operations. The South Coast Air Quality Management District (SCAQMD) estimated that 25% of their construction projects involve these types of operations. For the remainder of the state, such detailed information is not readily available, so the average emission factor of 0.11 tons PM10/acre-month is used by CARB for these other areas of California..

Activity Data. For the purpose of estimating emissions, it is assumed that the fugitive dust emissions are related to the acreage affected by construction. Because regionwide estimates of the acreage under construction may not be directly available, other construction activity data can be used to derive acreage estimates. Activity data are estimated separately for residential construction and the other types of construction (commercial, industrial, institutional, and governmental).

For residential construction, the number of new housing units estimated by the California Department of Finance[9] are used to estimate acreage disturbed. It is estimated that single family houses are built on 1/7 of an acre in heavily populated counties, and 1/5 of an acre in less populated counties.[10-12] It is also estimated that multiple living units such as apartments occupy 1/20 of an acre per living unit. For all of these residential construction activities, a project duration of 6 months is assumed.[10] Applying these factors to the reported number of new units in each county results in an estimate of acre-months of construction. This estimate of acre-months of construction combined with the construction emission factor is used to estimate residential construction particulate emissions.

For commercial, industrial, and institutional building construction, construction acreage is based on project valuations. Project valuations for additions and alterations are not included. According to the Construction Industry Research Board,[13] most additions and alterations would be modifications within the existing structure and normally would not include the use of large earthmoving equipment. Most horizontal additions would usually be issued a new building permit. The valuations are 3.7, 4.0 and 4.4 acres per million dollars of valuation for the respective construction types listed.[12] Valuations were corrected from 1999 values to 1977 values using the Annual Average Consumer Price Index (CPI-U-RS) provided by the U.S. Census Bureau.[14] The Census Bureau uses the Bureau of Labor Statistics' experimental Consumer Price Index (CPI-U-RS) for 1977 through 2000.[15] Valuations were corrected from 1999 values to 1977 values because the acres per dollar valuation values are based on 1977 valuations. For example, the CPI-U-RS for 1999 is 244.1 and the CPI-U-RS for 1977 is 100.0. The ratio of 1977 to 1999 dollars is 100.0/244.1 or 0.41. Inflation from 1999 to 2004 is estimated to be 12%. Thus, updating the 1977 valuation results to 2004 dollars produces a ratio of 1977 to 2004 dollars of 0.41/1.12 or 0.37. CARB assumes that each acre is under construction for 11 months for each project type.[10]

3.3.2 Assumptions and Limitations

1. The current methodology assumes that all construction operations in all parts of the state emit the same levels of PM10 on a per acre basis.
2. It is assumed that watering techniques are used statewide, reducing emissions by 50% and making it valid to apply the MRI emission factor without correction.
3. The methodology assumes that valuation is proportional to acreage disturbed, even for high-rise type building construction.
4. The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction.
5. The estimates of acreage disturbed are limited in their accuracy. New housing units and project valuations do not provide direct estimates of actual acreage disturbed by construction operations in each county.
6. The methodology assumes that the Consumer Price Index (CPI-U-RS) provides an accurate estimate of 1977 and current values.

3.3.3 Temporal Activity

The temporal activity is assumed to occur five days a week between the hours of 8:00 AM and 4:00 PM. The table below shows the percentage of construction activity that is estimated to occur during each month. The monthly activity increases during the spring and summer months. Some districts may use a different profile that has a larger peak during the summer months.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
6.4	6.4	8.3	9.2	9.2	9.2	9.2	9.2	9.2	8.3	8.3	7.3

3.4 Emission Estimation: Alternate Methodology for Road Construction

This section was adapted from Section 7.8 of CARB's Emission Inventory Methodology. Section 7.8 was last updated in August 1997.

The road construction dust source category provides estimates of the fugitive dust particulate matter due to construction activities while building roads. The emissions result from site preparation work that may include scraping, grading, loading, digging, compacting, light-duty vehicle travel, and other operations. Dust emissions from road construction operations are computed by using a PM10 emission factor developed by MRI.[3] The emission factor is based on observations of construction operations in California and Las Vegas. Activity data for road construction is expressed in terms of acre-months of construction. Acre-months are based on estimates of the acres disturbed for road construction. The acres disturbed are computed based on: estimates of the annual difference in road mileage; estimates of road width (to compute acres disturbed); and an assumption of 18 months as the typical project duration.

3.4.1 Emissions Estimation Methodology

Emission Factor. The PM10 emission factor used for estimating geologic dust emissions from road construction activities is based on work performed by MRI under contract to the PM10 Best Available Control Measure working group.[3] For most parts of the State, the emission factor used is 0.11 tons PM10/acre-month of activity. This emission factor is based on MRI's observation of the types, quantity, and duration of operations at eight construction sites (three in Las Vegas, and five in California). The bulk of the operations observed were site preparation related activities. The observed activity data were then combined with operation specific emission factors provided in U.S. EPA's AP-42 (5th Edition)[2] document to produce site emissions estimates. These site estimates were then combined to produce the overall average emission factor of 0.11 tons PM10/acre-month. The PM2.5/PM10 ratio for fugitive dust from construction and demolition activities is 0.1 based on the analysis conducted by MRI on behalf of WRAP.[7]

The construction emission factor is assumed to include the effects of routine dust suppression measures such as watering. A dust control effectiveness of 50% is assumed from these measures, which is based on the estimated control effectiveness of watering.[8] Therefore, if this emission factor is used for road construction activities where watering is not used, it should be doubled to more accurately reflect the actual emissions. The MRI document[3] lists their average emission factor values as uncontrolled. However, it can be argued that the activities do include the effects of controls. All of the test sites were actual operations that used watering controls, even if in some cases they were not used during the actual site visits. It is believed that the residual effects of controls are reflected in the MRI emission estimates.

The MRI report[3] also includes an emission factor for worst-case construction emissions of 0.42 tons of PM10/acre-month. This emission factor is appropriate for large scale construction operations that involve substantial earthmoving operations. The South Coast Air Quality Management District (SCAQMD) estimated that a percentage of their construction projects involve these types of operations, and applied the larger emission factor to these activities. For the remainder of the state, such detailed information is not readily available, so the average emission factor of 0.11 tons PM10 per acre-month is used by CARB.

Activity Data. For the purpose of estimating emissions, it is assumed that the fugitive dust emissions are related to the acreage affected by construction. Regionwide estimates of the acreage disturbed by roadway construction may not be directly available. Therefore, the miles of road built and the acreage disturbed per mile of construction can be used to estimate the overall acreage disturbed.

The miles of road built are based on the annual difference in the road mileage. These data, from the California Department of Finance[9] and Caltrans[16], are split for each county into freeways, state highways, and city and county road. The acreage of land disturbed per mile of road construction is based on the number of lanes, lane width, and shoulder width for each listed road type. The assumptions used are provided in Table 3-4. Because most projects will probably also disturb land outside of the immediate roadway corridor, these acreage estimates are somewhat conservative.

The final parameter needed is project duration, which is assumed to be an average of 18 months.[10] Multiplying the road mileage built by the acres per mile and the months of construction provides the acre-months of activity for road building construction. This, multiplied by the emission factor, provides the emissions estimate.

Table 3-4. Roadway Acres per Mile of Construction Estimates

Road Type	Freeway	Highway	City & County
Number of Lanes	5	5	2
Width per Lane (feet)	12	12	12
Shoulder Width (feet)	10'x4 = 40'	20'x2 = 40'	20'x2 = 40'
Roadway Width* (feet)	100	76	64
Roadway Width* (miles)	0.019	0.014	0.012
Area per Mile** (acres)	12.1	9.2	7.8

*Roadway Width (miles) = [(Lanes x Width per Lane) + Shoulder Width] x (1 mile/5,280 feet)
**Area per Mile (acres) = Length x Width = 1 Mile x Width x 640 acres/mile^2

3.4.2 Temporal Activity

Temporal activity is assumed to occur five days a week between the hours of 8 AM and 4 PM. The table below shows the percentage of construction activity that is estimated to occur during each month. The monthly activity increases during the spring and summer months as shown below. Some districts use a slightly different profile that has a larger peak during the summer months.

ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
100	7.7	7.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	7.7

3.4.3 Assumptions and Limitations

1. The current methodology assumes that all construction operations in all parts of the state emit the same levels of PM10 on a per acre basis.
2. It is assumed that watering techniques are used statewide, reducing emissions by 50% and making it valid to apply the MRI emission factor without correction.
3. The methodology assumes that the acreage disturbed per mile for road building is similar statewide, and the overall disturbed acreage is approximately the same as the finished roadway's footprint.
4. The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction.

3.5 Supplemental Emission Factors

AP-42 lists uncontrolled TSP emission factors for specific activities at construction sites.[2] These TSP emission factors as well as references to the relevant chapters of this handbook that provide PM10 and/or TSP emission factors for similar activities are presented in Table 3-5.

Table 3-5. TSP Emission Factors for Specific Construction Site Activities

Construction Phase	Activity	TSP Emission Factor*
Demolition and Debris Removal	Drilling soil	1.3 lb/hole
	Land clearing with bulldozer	5.7 $(s)^{1.2}$ / $M^{1.3}$ lb/hr
	Loading debris into trucks and subsequent unloading	See Chapter 4
	Truck transport of debris on paved or unpaved roads	See Chapters 5 and 6
Site Preparation (earth moving)	Bulldozing and compacting	5.7 $(s)^{1.2}$ / $M^{1.3}$ lb/hr
	Scrapers unloading topsoil	0.04 lb/ton
	Scrapers in travel mode	See Chapter 6
	Scrapers removing topsoil	20.2 lb/mile
	Grading	0.040 $(S)^{2.5}$ lb/mile
	Loading excavated material into trucks and subsequent unloading	See Chapter 4
General Construction	Vehicular traffic	See Chapters 5 and 6
	Crushing and screening aggregate	See Chapter 11
	Material transfer	See Chapter 4

* Symbols for equations: M = material moisture content (%), s = material silt content (%), S = mean vehicle speed (mph).

3.6 Demonstrated Control Techniques

Because of the relatively short-term nature of construction activities, some control measures are more cost-effective than others. Frank Elswick of Midwest Industrial Supply Inc. presented an extensive summary of control measures for construction activities and their associated costs at a WRAP sponsored fugitive dust workshop in Palm Springs, CA in May 2005.[17] Elswick concluded that dust suppressant methods fall into the following six categories:

1. **Watering**

* Watering works by agglomerating surface particles together.
* No negative environmental impacts from using water.
* Normally readily available.
* Evaporates quickly, therefore typically only effective for short periods of time.
* Frequency of application depends on temperature and humidity.
* Generally labor intensive due to frequent application.
* Costs associated with pre-watering and as needed watering are $55 to $80/hour.

2. **Chemical Stabilizers**

(a) Water absorbing products (e.g., calcium chloride brine or flakes, magnesium chloride brine, sodium chloride)

* These products work by significantly increasing surface tension of water between dust particles, helping to slow evaporation and further tighten compacted soil.
* Products ability to absorb water from the air is a function of temperature and humidity.
* These products work best in low humidity environments.
* Frequent re-application in dry climates.
* Must be watered to activate during dry months.
* Potential costly environmental impacts to fresh water aquatic life, plants and water quality
* Corrosive to metal and steel.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are \$.03 - \$.05 per square foot.

(b) Organic Petroleum Products (e.g. asphalt emulsions, cut/liquid asphalt, dust oils, petroleum resins)

* These products work by binding and/or agglomerating surface particles together because of asphalt adhesive properties.
* Potentially costly environmental due to presence of polycyclic aromatic hydrocarbons that are "hazardous air and water pollutants" that may be subject to reporting requirements.
* Can fragment under traffic conditions.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are \$.05 - \$.075 per square foot.

(c) Organic Non-Petroleum Products (e.g., ligninsulfonates, tall oil emulsions, vegetable oils)

* These products work by binding and/or agglomerating surface particles together.
* Surface binding for these product may be reduced or destroyed by rains.
* Generally limited availability of non-petroleum products.
* Ligninsulfonates can impact freshwater aquatic life due to high B.O.D. and C.O.D.
* Not suitable for non-traffic areas.
* Costs associated with traffic area program are \$.04 - \$.08 square foot.

(d) Polymer Products (e.g., polyvinyl acetates, vinyl acrylics)

* These products work by binding soil particles together because of the polymer's adhesive properties.
* Polymers also increase the load-bearing strength of all types of soils.
* Polymers are non-toxic, non-corrosive, and do not pollute ground water.
* Polymers dry virtually clear to create an aesthetically pleasing result.
* Polymers create a tough yet flexible crust to prevent wind and water erosion.
* Costs associated with traffic areas are \$.05 - \$.08 per square foot.
* Costs associated with disturbed non-traffic areas are \$300 - \$800 per acre depending on longevity desired.

* Costs associated with slopes and inactive stockpiles are $500 to $1,000 per acre.

(e) Synthetic Products (e.g., iso-alkane compounds)
* Synthetic fluids work as a dust suppressing ballasting mechanism, while also acting as a durable re-workable binder.
* Formulated with safe and environmentally friendly synthetic fluids; non-hazardous per OSHA, EPA and US DOT; contains no asphalt, oil or PAH's.
* Easy application; no water required.
* Costs associated with traffic area program are $.05 - $.10 per square foot.

3. **Sand Fences**
* Fabric on chain link fence.
* Redwood slat fence.
* Mylar sand fence.
* Most effective when used in conjunction with chemical stabilizers.

4. **Perimeter Sprinklers**
* Most effective when used in conjunction with other methods.

5. **Tire Cleaning Systems at Site Exit**
* Rumble strips to prevent track-out from site onto pavement.
* Washed rock 100' prior to exit onto pavement.

6. **On- Site Speed Control**
* Limiting on-site vehicle speed to 15mph.

Wet suppression and wind speed reduction are the two most common methods used to control open dust sources at construction sites because a source of water and material for wind barriers tend to be readily available on a construction site. However, several other forms of dust control are available. Table 3-6 displays each of the preferred control measures by dust source.[18, 19]

Table 3-6. Control Options for General Construction Sources of PM10

Emission source	Recommended control methods(s)
Debris handling	Wind speed reduction; wet suppression[a]
Truck transport[b]	Wet suppression; paving; chemical stabilization[c]
Bulldozers	Wet suppression[d]
Pan scrapers	Wet suppression of travel routes
Cut/fill material handling	Wind speed reduction; wet suppression
Cut/fill haulage	Wet suppression; paving; chemical stabilization
General construction	Wind speed reduction; wet suppression; early paving of permanent roads

[a] Dust control plans should contain precautions against watering programs that confound trackout problems.
[b] Loads could be covered to avoid loss of material in transport, especially if material is transported offsite.
[c] Chemical stabilization is usually cost-effective for relatively long-term or semipermanent unpaved roads.
[d] Excavated materials may already be moist and not require additional wetting. Furthermore, most soils are associated with an "optimum moisture" for compaction.

One of the dustiest construction operations is cutting and filling using scrapers, with the highest emissions occurring during scraper transit. In a 1999 MRI field study,[5] it was found that watering can provide a high level of PM10 control efficiency for scraper transit emissions. Average control efficiency remained above 75% approximately 2 hours after watering. The average PM10 efficiency decay rate for water was found to vary from approximately 3% to 14% hour. The decay rate depended upon relative humidity in a manner consistent with the effect of humidity on the rate of evaporation. Test results for watered scraper transit routes showed a steep increase in control efficiency with a doubling of surface moisture and little additional control efficiency at higher moisture levels. This is in keeping with past studies that found that control efficiency data can be successfully fitted by a bilinear function. In another recent MRI field study (MRI, 2001),[20] tests of mud and dirt trackout indicated that a 10% soil moisture content represents a reasonable first estimate of the point at which watering becomes counter productive. The control efficiencies afforded by graveling or paving of a 7.6 m (25 ft) access apron were in the range of 40% to 50%.

Table 3-7 summarizes tested control measures and reported control efficiencies for dust control measures applied to construction and demolition operation.

Table 3-7. Control Efficiencies for Control Measures for Construction/Demolition[20, 21]

Control measure	Source component	PM10 control efficiency	References/Comments
Apply water every 4 hrs within 100 feet of a structure being demolished	Active demolition and debris removal	36%	MRI, April 2001, test series 701. 4-hour watering interval (Scenario: lot remains vacant 6 mo after demolition)
Gravel apron, 25” long by road width	Trackout	46%	MRI, April 2001
Apply dust suppressants (e.g., polymer emulsion)	Post-demolition stabilization	84%	CARB April 2002; for actively disturbed areas
Apply water to disturbed soils after demolition is completed or at the end of each day of cleanup	Demolition Activities	10%	MRI, April 2001, test series 701. 14-hour watering interval.
Prohibit demolition activities when wind speeds exceed 25 mph	Demolition Activities	98%	Estimated for high wind days in absence of soil disturbance activities
Apply water at various intervals to disturbed areas within construction site	Construction Activities	61%	MRI, April 2001, test series 701. 3.2-hour watering interval
		74%	MRI, April 2001, test series 701. 2.1-hour watering interval
Require minimum soil moisture of 12% for earthmoving	Scraper loading and unloading	69%	AP-42 emission factor equation for materials handling due to increasing soil moisture from 1.4% to 12%
Limit on-site vehicle speeds to 15 mph (Scenario: radar enforcement)	Construction traffic	57%	Assume linear relationship between PM10 emissions and uncontrolled vehicle speed of 35 mph

3.7 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats downloaded from the Internet for several local air quality agencies in the WRAP region are presented in Table 3-8. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledsc.asp

3.8 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations (e.g., whether an unpaved road has been paved, graveled, or treated; whether haul truck beds are covered ; whether water trucks are being used during construction activities). An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 3-9 summarizes the compliance tools that are applicable to construction and demolition.

Table 3-8. Example Regulatory Formats for Construction and Demolition

Source	Control measure	Goal	Threshold	Agency
Paved Roads-Public and Private Track-out and Carryout	Install track-out ctrl device	Prevent/remove track-out from haul trucks and tires	Paved roads within construction sites, where haul trucks traverse; with disturbed surface area >2 acres, with 100 cubic yards of bulk material hauled	Maricopa County Rule 310 04/07/2004
	Either immediately cleanup track-out (>50ft) and nightly clean-up of rest; install grizzly/wheel wash system; install gravel pad--30ftx50ft, 6" deep; pave intersection--100ftx20ft; route traffic over track-out ctrl devices; limit access to unprotected routes; pave construction roadways ASAP	Control track-out on paved construction roads	Immediate track-out clean-up after 50ft, at end of workday for less; gravel pad standards are min; paved intersection also min and must be accessible to public; limit access to unprotected routes with barriers	Maricopa County Rule 310 04/07/2004
	Track-out control device must be installed at all access points to public roads and there must be mud/dirt removal from interior paved roads with sufficient frequency	Allow mud/dirt to drop off before leaving site and prevent track-out	For sites greater than 5 acres or those with more than 100 yd3 of daily import/export	SJVAPCD Rule 8041 11/15/2001
	Removal of track-out within one hour or selecting a track-out prevention option and removing track-out at the end of the day		For sites greater than 5 acres or those with more than 100 yd3 of daily import/export and track-out is less than 50ft	SCAQMD Rule 403 12/11/1998
	Removing track-out ASAP		Track-out greater than 50 ft	SCAQMD Rule 403 12/11/1998
	Require road surface paved or chemically stabilized from point of intersection with a public paved road to distance of at least 100 ft by 20 ft or installation of track-out control device from point of intersection with a public paved road to a distance of at least 25 ft by 20 ft	Prohibits material from extending more than 25 ft from a site entrance	For sites greater than 5 acres or those with more than 100 yd3 of daily import/export	SCAQMD Rule 403 12/11/1998
Bulk Materials Transport	Establishes speed limits. Requires at least 6" freeboard when crossing paved public road, water applied to top of load. Haul trucks need tarp or suitable cover and truck interior must be cleaned before leaving site	Limit visible dust emissions to 20% opacity and prevent spillage from holes	Trucks entering paved public roads (6" freeboard); leaving work site; specific haul trucks need covering	SJVAPCD Rule 8031 11/15/2001
	Requires covering haul trucks or to use bottom-dumping if possible and maintain minimum 6" freeboard (in high winds)			SCAQMD Rule 403 12/11/1998
	Freeboard at least 3"; prevent spillage from holes; install track-out ctrl devices	Prevent/remove track-out onto paved roads	Within the work site; removes possible track-out from tires, exterior of trucks that traverse work site	Maricopa County Rule 310 04/07/2004
Construction and Demolition Earthmoving	Require water and chemical stabilizers (dust suppressants) be applied, in conjunction with optional wind barrier	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Specifies Dust Control Plan must be submitted	Limit visible dust emissions to 20% opacity	For areas 40 acres or larger where earth movement of 2500 yd3 or more on at least 3 days is intended	SJVAPCD Rule 8021 11/15/2001

Table 3-8. Example Regulatory Formats for Construction and Demolition (Continued)

Source	Control measure	Goal	Threshold	Agency
	Requires implementation of Best Available Control Measures (BACM)	Prohibit visible dust emissions beyond property line and limit an upwind/downwind PM10 differential to 50 ug/m3. Limit visible dust emissions to 100 ft from origin		SCAQMD Rule 403 12/11/1998
Construction and Demolition Demolition	Application of dust suppressants	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Application of best available control measures (BACM)	Prohibits visible dust emissions beyond property line. Limits downwind PM10 levels to 50 ug/m3	For projects greater than 5 acres or 100 yd3 of daily import/export	SCAQMD Rule 403 12/11/1998
Construction and Demolition Grading Operations	Requires pre-watering and phasing of work	Limit VDE to 20% opacity		SJVAPCD Rule 8021 11/15/2001
	Requires water application and chemical stabilizers	Increase moisture content to proposed cut	For graded areas where construction will not begin for more than 60 days after grading	SCAQMD Rule 403 12/11/1998
	Preapplication of water to depth of proposed cuts and reapplication of water as necessary. Also stabilization of soils once earth-moving is complete	Ensure visible emissions do not extend more than 100 ft from sources		SCAQMD Rule 403 12/11/1998

Table 3-9. Compliance Tools for Construction and Demolition

Record keeping	Site inspection/monitoring
Site map; description of work practices; duration of project activities; locations and methods for demolition activities; locations and amounts of all earthmoving and material (types) handling operations; dust suppression equipment (types) and maintenance; frequencies, amounts, times, and rates of watering or dust suppressant application; mud/dirt carryout prevention and remediation requirements; wind shelters; meteorological log.	Observation of earthmoving and demolition activities, considering timeframe of project; observation of operation of dust suppression systems, vehicle/ equipment operation and disturbance areas; surface material sampling and analysis for silt and moisture contents; observation of truck spillage onto adjacent paved roads; mud/dirt carryout prevention and remediation; inspection of wind sheltering; real-time portable monitoring of PM; observation of dust plume opacity exceeding a standard.

3.9 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for construction and demolition. A sample cost-effectiveness calculation is presented below for a specific control measure (gravel apron at trackout egress points) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for construction and demolition, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Construction and Demolition (Mud/Dirt Egress Points)

Step 1. Determine source activity and control application parameters.

Egress traffic rate (veh/day)	100
Number of egress points	2
Duration of construction activity (month)	24
Wet days/year	10
Number of workdays/year	260
Number of emission days/yr (workdays without rain)	250

Control Measure	Gravel apron 25 ft long by road width
Economic Life of Control System (yr)	2
Control Efficiency	46%
Reference	MRI, 2001[20]

The number of vehicles per day, wet days per year, workdays per year, and the economic life of the control are determined from climatic and industrial records. The number of emission days per year are calculated by subtracting the number of annual wet days from the number of annual workdays as follows:

Number of workdays/year – Wet days/year = 260 – 10 = 250

Gravel aprons at the two construction site egress points have been chosen as the applied control measure. The control efficiency was obtained from MRI, 2001.[19]

Step 2. Obtain PM10 Emission Factor. The PM10 emission factor for construction and demolition dust is 6 g/vehicle.[22]

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor, EF, (given in Step 2) is multiplied by the number of vehicles per day and by the number of emission days per year (both under activity data) and divided by 454 grams/lb and 2000 lb/ton to compute the annual PM10 emissions, as follows:

Annual PM10 emissions = (EF x Veh/day x Emission days/year)/(454 x 2,000)
Annual PM10 emissions = (6 x 100 x 250) / (454 x 2,000) = 0.165 tons/year

Annual PM2.5 emissions = 0.1 x PM10 emissions[7]
Annual PM2.5 emissions = (0.1 x 0.165 tons/year) = 0.0165 tons/year

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 gravel aprons at egress points as our control measure. Based on a control efficiency estimate of 46% for a gravel apron, the annual PM emissions are calculated to be:

Annual Controlled PM10 emissions = (0.165 tons/yr) x (1 – 0.46) = 0.089 tons/yr
Annual Controlled PM2.5 emissions = (0.0165 tons/yr) x (1 – 0.46) = 0.0089 tons/yr

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	500
Annual Operating/Maintenance costs ($)	3,150
Annual Interest Rate	5%
Capital Recovery Factor	0.54
Annualized Cost ($/year)	3,419

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 as follows:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$
$$\text{Capital Recovery Factor} = 5\% \times (1+5\%)^{2} / (1+5\%)^{2} - 1 = 0.54$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the annual Operating and Maintenance costs:

Annualized Cost = (CRF x Capital costs) + Annual Operating and Maintenance costs
Annualized Cost = (0.54 x $500) + $3,150 = $3,419

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 = $3,420 / (0.165 - 0.089) = $44,991/ton
Cost effectiveness for PM2.5 emissions = $3,420 / (0.0165 - 0.0089) = $449,908/ton

3.10 References

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Chapter 4. Materials Handling

4.1 Characterization of Source Emissions

Inherent in operations that use minerals in aggregate form is the handling and transfer of materials from one process to another (e.g., to and from storage). Outdoor storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage. Dust emissions occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust. Dust emissions also occur at transfer points between conveyors or in association with vehicles used to haul aggregate materials

4.2 Emissions Estimation: Primary Methodology[1-14]

This section was adapted from Section 13.2.4 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.4 was last updated in January 1995.

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Emissions also depend on the age of the pile, moisture content, and proportion of aggregate fines. When freshly processed aggregate is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. However, as the aggregate pile weathers the potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and then the drying process is very slow.

Table 4-1 summarizes measured moisture and silt content values for industrial aggregate materials. Silt (particles equal to or less than 75 micrometers [μm] in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200-mesh screen, using ASTM-C-136 method.[1]

Total dust emissions from aggregate storage piles result from several distinct source activities within the storage cycle:

1. Loading of aggregate onto storage piles (batch or continuous drop operations).
2. Equipment traffic in storage area.
3. Wind erosion of pile surfaces and ground areas around storage piles (see Chapter 9).
4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Either adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

Table 4-1. Typical Silt and Moisture Contents of Materials at Various Industries[a]

Industry	No. of facilities	Material	Silt content (%)			Moisture content (%)		
			No. of samples	Range	Mean	No. of samples	Range	Mean
Iron and steel production	9	Pellet ore	13	1.3-13	4.3	11	0.64-4.0	2.2
		Lump ore	9	2.8-19	9.5	6	1.6-8.0	5.4
		Coal	12	2.0-7.7	4.6	11	2.8-11	4.8
		Slag	3	3.0-7.3	5.3	3	0.25-2.0	0.92
		Flue dust	3	2.7-23	13	1	–	7
		Coke breeze	2	4.4-5.4	4.9	2	6.4-9.2	7.8
		Blended ore	1	–	15	1	–	6.6
		Sinter	1	–	0.7	0	–	–
		Limestone	3	0.4-2.3	1.0	2	ND	0.2
Stone quarrying and processing	2	Crusted limestone	2	1.3-1.9	1.6	2	0.3-1.1	0.7
		Various limestone products	8	0.8-14	3.9	8	0.46-5.0	2.1
Taconite mining and processing	1	Pellets	9	2.2-5.4	3.4	7	0.05-2.0	0.9
		Tailings	2	ND	11	1	–	0.4
Western surface coal mining	4	Coal	15	3.4-16	6.2	7	2.8-20	6.9
		Overburden	15	3.8-15	7.5	0	–	–
		Exposed ground	3	5.1-21	15	3	0.8-6.4	3.4
Coal-fired power plant	1	Coal (as received)	60	0.6-4.8	2.2	59	2.7-7.4	4.5
Municipal solid waste landfills	4	Sand	1	–	2.6	1	–	7.4
		Slag	2	3.0-4.7	3.8	2	2.3-4.9	3.6
		Cover	5	5.0-16	9.0	5	8.9-16	12
		Clay/dirt mix	1	–	9.2	1	–	14
		Clay	2	4.5-7.4	6.0	2	8.9-11	10
		Fly ash	4	78-81	80	4	26-29	27
		Misc. fill materials	1	–	12	1	–	11

[a] References 1-10. ND = no data.

The quantity of particulate emissions generated by either type of drop operation, expressed as a function of the amount of material transferred, may be estimated using the following empirical expression:[11]

Metric Units

$$E = k(0.0016)\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (kg/megagram [Mg])} \qquad (1)$$

English Units

$$E = k(0.0032)\frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (pound [lb]/ton)}$$

where:

E = emission factor
k = particle size multiplier (dimensionless)
U = mean wind speed (meters per second, m/s, or miles per hour, mph)
M = material moisture content (%)

The particle size multiplier in the equation, k, varies with aerodynamic particle size range. For PM10, k is 0.35.[11] There are two sources of fugitive dust associated with materials handling activities, namely particulate emissions from aggregate handling and storage piles, which typically consists of loader and truck traffic around the storage piles, and fugitive dust associated with the transfer of aggregate by buckets or conveyors. The PM2.5/PM10 ratios for these two sources of fugitive dust are 0.1 and 0.15, respectively.[12] In general, particulate emissions from loader and truck traffic around the storage piles predominates over particulate emissions from transfer of aggregate by buckets or conveyors. Equation 1 retains the assigned quality rating of A if applied within the ranges of source conditions that were tested in developing the equation; see table below. Note that silt content is included, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the two was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from Equation 1 be reduced one quality rating level if the silt content used in a particular application falls outside the following range:

Ranges of Source Conditions for Equation 1			
Silt content (%)	Moisture content (%)	Wind speed	
		m/s	mph
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15

For Equation 1 to retain the quality rating of A when applied to a specific facility, reliable correction parameters must be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 4-1 may be used, but the quality rating of the equation is reduced by one letter.

For emissions from trucks, front-end loaders, dozers, and other vehicles traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Chapter 6). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst-case emissions from storage pile areas occur under dry, windy conditions. Worst-case emissions from materials-handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst-case averaging period, usually 24 hours. A separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity also may be justified for the worst-case averaging period.

4.3 Demonstrated Control Techniques

Watering and the use of chemical wetting agents are the principal means for control of emissions from materials handling operations involving transfer of bulk minerals in aggregate form. The handling operations associated with the transfer of materials to and from open storage piles (including the traffic around piles) represent a particular challenge for emission control. Dust control can be achieved by: (a) source extent reduction (e.g., mass transfer reduction), (b) source improvement related to work practices and transfer equipment such as load-in and load-out operations (e.g., drop height reduction, wind sheltering, moisture retention)), and (c) surface treatment (e.g., wet suppression).

In most cases, good work practices that confine freshly exposed material provide substantial opportunities for emission reduction without the need for investment in a control application program. For example, loading and unloading can be confined to leeward (downwind) side of the pile. This statement also applies to areas around the pile as well as the pile itself. In particular, spillage of material caused by pile load-out and maintenance equipment can add a large source component associated with traffic-entrained dust. Emission inventory calculations show, in fact, that the traffic dust component may easily dominate over emissions from transfer of material and wind erosion. The prevention of spillage and subsequent spreading of material by vehicles traversing the area is essential to cost-effective emission control. If spillage cannot be prevented because of the need for intense use of mobile equipment in the storage pile area, then regular cleanup should be employed as a necessary mitigative measure.

Fugitive emissions from aggregate materials handling systems are frequently controlled by wet suppression systems. These systems use liquid sprays or foam to suppress the formation of airborne dust. The primary control mechanisms are those that prevent emissions through agglomerate formation by combining small dust particles with larger aggregate or with liquid droplets. The key factors that affect the degree of agglomeration and, hence, the performance of the system are the coverage of the material by the liquid and the ability of the liquid to "wet" small particles. There are two types of wet suppression systems—liquid sprays which use water or water/surfactant mixtures as the wetting agent and systems that supply foams as the wetting agent.

Liquid spray wet suppression systems can be used to control dust emissions from materials handling at conveyor transfer points. The wetting agent can be water or a combination of water and a chemical surfactant. This surfactant, or surface-active agent, reduces the surface tension of the water. As a result, the quantity of liquid needed to achieve good control is reduced.

Watering is also useful to reduce emissions from vehicle traffic in the storage pile area. Continuous chemical treating of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90%.[13, 14]

Table 4-2 presents a summary of control measures and reported control efficiencies for materials handling that includes the application of a continuous water spray at a conveyor transfer point and two control measures for storage piles.

Table 4-2. Control Efficiencies for Control Measures for Materials Handling

Control measure	PM10 control efficiency	References/comments
Continuous water spray at conveyor transfer point	62%	The control efficiency achieved by increasing the moisture content of the material from 1% to 2% is calculated utilizing the AP-42 emission factor equation for materials handling which contains a correction term for moisture content.
Require construction of 3-sided enclosures with 50% porosity for storage pile	75%	Sierra Research, 2003.[15] Determined through modeling of open area windblown emissions with 50% reduction in wind speed and assuming no emission reduction when winds approach open side.
Water the storage pile by hand or apply cover when wind events are declared	90%	Fitz et al., April 2000.[16]

4.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 4-3. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: http://www.maricopa.gov/envsvc/air/ruledesc.asp

Table 4-3. Example Regulatory Formats for Materials Handling

Control Measure	Goal	Threshold	Agency
Establishes wind barrier and watering or stabilization requirements and bulk materials must be stored according to stabilization definition and outdoor materials covered	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8031 11/15/2001
Best available control measures: wind sheltering, watering, chemical stabilizers, altering load-in/load-out procedures, or coverings	Prohibits visible dust emissions beyond property line and limits upwind/downwind PM10 differential to 50 μg/m3		SCAQMD Rule 403 12/11/1998
Watering, dust suppressant (when loading, stacking, etc.); cover with tarp, watering (when not loading, etc.); wind barriers, silos, enclosures, etc.	Limit VDE to 20% opacity; stabilize soil	For storage piles with >5% silt content, 3ft high, >/=150 sq ft; work practices for stacking, loading, unloading, and when inactive; soil moisture content min 12%; or at least 70% min for optimum soil moisture content; 3 sided enclosures, at least equal to pile in length, same for ht, porosity </=50%	Maricopa County Rule 310 04/07/2004
Watering, clean debris from paved roads and other surface after demolition	Stabilize demolition debris and surrounding area; establish crust and prevent wind erosion	Immediately water and clean-up after demolition	Maricopa County Rule 310 04/07/2004
Utilization of dust suppressants other than water when necessary; prewater; empty loader bucket slowly	Prevent wind erosion from piles; stabilize condition where equip and vehicles op	Bulk material handling for stacking, loading, and unloading; for haul trucks and areas where equipment op	Maricopa County Rule 310 04/07/2004

4.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 4-4 summarizes the compliance tools that are applicable to materials handling.

Table 4-4. Compliance Tools for Materials Handling

Record keeping	Site inspection/monitoring
Site map; work practices and locations; material throughputs; type of material and size characterization; typical moisture content when fresh; vehicle/equipment disturbance areas; material transfer points and drop heights; spillage and cleanup occurrences; wind fence/enclosure installation and maintenance; dust suppression equipment and maintenance records; frequencies, amounts, times, and rates for watering and dust suppressants; meteorological log.	Observation of material transfer operations and storage areas (including spills), operation of wet suppression systems, vehicle/ equipment operation and disturbance areas; surface material sampling and analysis for silt and moisture contents; inspection of wind sheltering including enclosures; real-time portable monitoring of PM; observation of dust plume opacities exceeding a standard.

4.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for materials handling. A sample cost-effectiveness calculation is presented below for a specific control measure (continuous water spray at conveyor transfer point) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for materials handling, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Materials Handling (Conveyor Transfer Point)

Step 1. Determine source activity and control application parameters.

Material throughput (tons/hr)	25
Operating cycle (hours/day)	12
Number of workdays/year	312
Number of transfer points	1
Moisture content of material, M (%)	1
Mean wind speed, U (mph)	6
Control Measure	Water spray located at conveyor transfer point
Control application/frequency	Continuous
Economic Life of Control System (yr)	10

The material throughput, operating cycle, number of workdays per year, number of transfer points, material moisture content, wind speed, and economic life of the control system are assumed values for illustrative purposes. A continuous water spray located at a conveyor transfer point has been chosen as the applied control measure to increase the moisture content of the material from 1% to 2%.

Step 2. Calculate Uncontrolled PM10 Emission Factor. The PM10 emission factor, EF, is calculated from the AP-42 equation utilizing the appropriate correction parameters (mean wind speed U = 6 mph and moisture content M = 1%), as follows:

$$EF=(0.35) \times (0.0032) \times (6/5)^{1.3} / (1/2)^{1.4} = 0.00377 \text{ lb/ton}$$

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor (calculated in Step 2) is multiplied by the material throughput, operating cycle, and workdays per year (all under activity data) and then divided by 2,000 lbs to compute the annual PM10 emissions in tons per year, as follows:

Annual PM10 emissions = (EF x Material Throughput x Operating Cycle x Workdays/yr) / 2,000
Annual PM10 emissions = (0.00377 x 25 x 12 x 312) / 2000 = 0.175 tons

Annual PM2.5 emissions = 0.15 x PM10 emissions[12]
Annual PM2.5 emissions = (0.15 x 0.175 tons) = 0.0263 tons

Step 4. Calculate Controlled PM Emission Factor. The PM emission factor for controlled emissions, EF, is calculated from the AP-42 equation utilizing the appropriate correction parameters (mean wind speed U = 6 mph and moisture content M = 2%), as follows:

$$EF=(0.35) \times (0.0032) \times (6/5)^{1.3} / (2/2)^{1.4} = 0.00142 \text{ lb/ton}$$

Step 5. Calculate Controlled PM Emissions. The controlled PM emissions (i.e., the PM emissions remaining after control) is calculated by multiplying the PM10 emission factor (calculated in Step 4) by the material throughput, operating cycle, and workdays per year (all under activity data) and then divided by 2,000 lbs to compute the annual emissions in tons per year, as follows:

Annual emissions = (EF x Material Throughput x Operating Cycle x Workdays/yr) / 2,000
Annual PM10 Emissions = (0.00142 x 25 x 12 x 312) / 2000 = 0.0664 tons

Annual PM2.5 emissions for material transfer = 0.15 x PM10 emissions[12]
Annual PM2.5 Emissions = (0.15 x 0.0665 tons) = 0.00100 tons

Note: The control efficiency of using a water spray to increase the material moisture content from 1% to 2% is 62% (100 x (0.175 – 0.0664) / 0.175)

Step 6. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	16,000
Annual Operating/Maintenance costs ($)	12,200
Annual Interest Rate	3%
Capital Recovery Factor	0.1172
Annualized Cost ($/yr)	14,076

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:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factory} = 3\% \times (1+3\%)^{10} / (1+3\%)^{10} - 1 = 0.1172$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor by the Capital costs with the annual Operating/Maintenance costs as follows:

Annualized Cost = (CRF x Capital costs) + Operating/Maintenance costs
Annualized Cost = (0.1172 x 16,000) + 12,200 = $14,076

Step 7. 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 = $14,076/ (0.175– 0.0664) = $129,267/ton
Cost-effectiveness for PM2.5 emissions = $14,076/ (0.0263– 0.0100) = $861,779/ton

4.7 References

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Chapter 5. Paved Roads

5.1 Characterization of Source Emissions

Particulate emissions occur whenever vehicles travel over a paved surface such as a road or parking lot. Particulate emissions from paved surfaces are due to direct emissions from vehicles in the form of exhaust, brake wear and tire wear emissions, and resuspension of loose material on the road surface. In general terms, resuspended particulate emissions from paved surfaces originate from, and result in the depletion of the loose material present on the surface (i.e., the surface loading). In turn, that surface loading is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas.

Various field studies have found that public streets and highways as well as roadways at industrial facilities can be major sources of the atmospheric particulate matter within an area.[1-9] Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of granular materials for snow and ice control, mud/dirt carryout from construction activities in the area, and deposition from wind and/or water erosion of surrounding unstabilized areas. In the absence of continuous addition of fresh material (through localized trackout or application of antiskid material), paved road surface loading should reach an equilibrium value in which the amount of material resuspended matches the amount replenished. The equilibrium surface loading value depends upon numerous factors. It is believed that the most important factors are: the mean speed of vehicles traveling the road, the average daily traffic (ADT), the number of lanes and ADT per lane, the fraction of heavy vehicles (buses and trucks), and the presence or absence of curbs, storm sewers and parking lanes.[10]

5.2 Emissions Estimation: Primary Methodology[1-29]

This section was adapted from Section 13.2.1 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.1 was last updated in December 2003.

Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers [µm] in physical diameter) per unit area of the travel surface. The total road surface dust loading consists of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL." Additional details on the sampling and analysis of such material are provided in Appendices C.1 and C.2 of AP-42.

The surface silt loading (sL) provides a reasonable means of characterizing seasonal variability in a paved road emission inventory. In many areas of the country, road surface silt loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest.[11-21] As noted earlier, once replenishment of fresh material is eliminated, the road surface silt loading can be expected to reach an equilibrium value, which is substantially lower than the late winter/early spring values.

The quantity of particulate emissions from resuspension of loose material on the road surface due to vehicle travel on a dry paved road may be estimated using the following empirical expression:

$$E = k\left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{W}{3}\right)^{1.5} - C \qquad (1)$$

where,

E = particulate emission factor (having units matching the units of k),
k = particle size multiplier for particle size range,
sL = road surface silt loading (grams per square meter, g/m^2),
W = average weight (tons) of the vehicles traveling the road, and
C = emission factor for 1980’s vehicle fleet exhaust, brake wear and tire wear.[27]

It is important to note that Equation 1 calls for the average weight of all vehicles traveling the road. For example, if 99% of traffic on the road are 2-ton cars/trucks while the remaining 1% consists of 20-ton trucks, then the mean weight “W” is 2.2 tons. More specifically, Equation 1 is not intended to be used to calculate a separate emission factor for each vehicle weight class. Instead, only one emission factor should be calculated to represent the “fleet” average weight of all vehicles traveling the road. The particle size multiplier (*k*) varies with aerodynamic size range. For PM10, k equals 0.016 lb/VMT (i.e., 7.3 g/VMT or 4.6 g/VKT). The PM2.5/PM10 ratio for fugitive dust from travel on paved roads is 0.15.[28]

The PM2.5 and PM10 emission factors for the exhaust, brake wear and tire wear of a 1980’s vehicle fleet (*C*) were obtained from EPA’s MOBILE6.2 model.[29] The emission factor also varies with aerodynamic size range as shown in Table 5-1. Equation 1 is based on a regression analysis of numerous emission tests, including 65 tests for PM10.[10] Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. All sources tested were of freely flowing vehicles traveling at constant speed on relatively level roads. No tests of “stop-and-go” traffic or vehicles under load were available for inclusion in the database. The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation, as follows:

Silt loading:	0.03 - 400 g/m^2; 0.04 - 570 grains/square foot
Mean vehicle weight:	1.8 - 38 megagrams; 2.0 - 42 tons
Mean vehicle speed:	16 - 88 kilometers per hour; 10 - 55 miles per hour

Table 5-1. Emission Factors for 1980's Vehicle Fleet Exhaust, Brake Wear, and Tire Wear

Particle size	*C*, Emission factor for exhaust, brake wear, and tire wear[a]		
	g/VMT	g/VKT	lb/VMT
PM2.5	0.1617	0.1005	0.00036
PM10	0.2119	0.1317	0.00047

[a] Units shown are grams per vehicle mile traveled (g/VMT), grams per vehicle kilometer traveled (g/VKT), and pounds per vehicle mile traveled (lb/VMT).

NOTE: There may be situations where low silt loading and/or low average weight will yield calculated negative emissions from Equation 1. If this occurs, the emissions calculated from Equation 1 should be set to zero.

Users are cautioned that application of Equation 1 outside of the range of variables and operating conditions specified above (e.g., application to roadways or road networks with speeds below 10 mph and with stop-and-go traffic) will result in emission estimates with a higher level of uncertainty. To retain the quality rating of A for PM10 for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific silt loading (sL) data for public paved road emission inventories are strongly recommended. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendices C.1 and C.2 of AP-42. In the event that site-specific silt loading values cannot be obtained, an appropriate value for a paved public road may be selected from the default values given in Table 5-2, but the quality rating of the equation should be reduced by two levels. Also, recall that Equation 1 refers to emissions due to freely flowing (not stop-and-go) traffic at constant speed on level roads.

Equation 1 may be extrapolated to average uncontrolled conditions (but including natural mitigation) under the simplifying assumption that annual (or other long-term) average emissions are inversely proportional to the frequency of measurable (at least 0.254 mm [0.01 inch]) precipitation by application of a precipitation correction term. The precipitation correction term can be applied on a daily or an hourly basis.[26]

For the daily basis, Equation 1 becomes:

$$E_{ext} = \left[k \left(\frac{sL}{2} \right)^{0.65} \left(\frac{W}{3} \right)^{1.5} - C \right] \left(1 - \frac{P}{4N} \right) \qquad (2)$$

where *k*, *sL*, *W*, *and C* are as defined in Equation 1 and

E_{ext} = annual or other long-term average emission factor in the same units as *k*,
P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period, and
N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)

Note that the assumption leading to Equation 2 is based by analogy with the approach used to develop long-term average unpaved road emission factors in Chapter 6. However, Equation 2 above incorporates an additional factor of "4" in the denominator to account for the fact that paved roads dry more quickly than unpaved roads and that the precipitation may not occur over the complete 24-hour day.

Table 5-2. Ubiquitous Silt Loading Default Values with Hot Spot Contributions from Anti-Skid Abrasives for Public Paved Roads (g/m^2)

Average Daily Traffic (ADT) Category	< 500	500-5,000	5,000-10,000	> 10,000
Ubiquitous baseline (g/m^2)	0.6	0.2	0.06	0.03 0.015 limited access
Ubiquitous winter baseline multiplier during months with frozen precipitation	X4	X3	X2	X1
Initial peak additive contribution from application of antiskid abrasive (g/m^2)	2	2	2	2
Days to return to baseline conditions (assume linear decay)	7	3	1	0.5

For the hourly basis, Equation 1 becomes:

$$E_{ext} = \left[k \left(\frac{sL}{2} \right)^{0.65} \left(\frac{W}{3} \right)^{1.5} - C \right] \left(1 - \frac{1.2P}{N} \right) \tag{3}$$

where k, sL, and W, and C are as defined in Equation 1 and

E_{ext} = annual or other long-term average emission factor in the same units as *k*,
P = number of hours with at least 0.254 mm (0.01 in) of precipitation during the averaging period, and
N = number of hours in the averaging period (e.g., 8,760 for annual; 2,124 for season; 720 for monthly).

Note that the assumption leading to Equation 3 is based by analogy with the approach used to develop long-term average unpaved road emission factors in Chapter 6. Also note that in the hourly moisture correction term (1-1.2P/N) for Equation 3, the 1.2 multiplier is applied to account for the residual mitigative effect of moisture. For most applications, this equation will produce satisfactory results. However, if the time interval for which the equation is applied is short (e.g., 1 hour or 1 day), the application of this multiplier makes it possible for the moisture correction term to become negative. This will result in calculated negative emissions which is not realistic. Users should expand the time interval to include sufficient "dry" hours such that negative emissions are not calculated. For the special case where this equation is used to calculate emissions on an hour by hour basis, such as would be done in some emissions modeling situations, the moisture correction term should be modified so that the moisture correction "credit" is applied to the first hours following cessation of precipitation. In this special case, it is suggested that this 20% “credit” be applied on a basis of one hour credit for each hour of precipitation up to a maximum of 12 hours.

Maps showing the geographical distribution of “wet” days on an annual basis for the United States based on meteorological records on a monthly basis are available in the *Climatic Atlas of the United States*.[23] Alternative sources include other Department of Commerce publications such as local climatological data summaries. The National Climatic Data Center (NCDC) offers several products that provide hourly precipitation data. In particular, NCDC offers a *Solar and Meteorological Surface Observation Network 1961-1990* (SAMSON) CD-ROM, which contains 30 years worth of hourly meteorological data for first-order National Weather Service locations. Whatever meteorological data are used, the source of that data and the averaging period should be clearly specified. It is emphasized that the simple assumption underlying Equations 2 and 3 has not been verified in any rigorous manner. For that reason, the quality ratings for Equations 2 and 3 should be downgraded one letter from the rating that would be applied to Equation 1.

Table 5-2 presents recommended default silt loadings for normal baseline conditions and for wintertime baseline conditions for public paved roads in areas that experience frozen precipitation with periodic application of antiskid material.[24] The winter baseline is represented as a multiple of the nonwinter baseline, depending on the average daily vehicle traffic count (ADT) value for the road in question. As shown, a multiplier of 4 is applied for low volume roads (< 500 ADT) to obtain a wintertime baseline silt loading of $4 \times 0.6 = 2.4$ g/m^2.

It is suggested that an additional (but temporary) silt loading contribution of 2 g/m^2 occurs with each application of antiskid abrasive for snow/ice control. This was determined based on a typical application rate of 500 lb per lane mile and an initial silt content of 1%. Ordinary rock salt and other chemical deicers add little to the silt loading because most of the chemical dissolves during the snow/ice melting process.

To adjust the baseline silt loadings for mud/dirt trackout, the number of trackout points is required. It is recommended that in calculating PM10 emissions, six additional miles of road be added for each active trackout point from an active construction site, to the paved road mileage of the specified category within the county. In calculating PM2.5 emissions, it is recommended that three additional miles of road be added for each trackout point from an active construction site. It is suggested the number of trackout points for activities other than road and building construction areas be related to land use. For example, in rural farming areas, each mile of paved road would have a specified number of trackout points at intersections with unpaved roads. This value could be estimated from the unpaved road density (miles per square mile).

The use of a default value from Table 5-2 should be expected to yield only an order-of-magnitude estimate of the emission factor. Public paved road silt loadings are dependent upon: traffic characteristics (speed, ADT, and fraction of heavy vehicles); road characteristics (curbs, number of lanes, parking lanes); local land use (agriculture, new residential construction) and regional/seasonal factors (snow/ice controls, wind blown dust). As a result, the collection and use of site-specific silt loading data is highly recommended. In the event that default silt loading values are used, the quality ratings for the equation should be downgraded two levels.

Limited access roadways (high speed freeways) pose severe logistical difficulties in terms of surface sampling, and few silt loading data are available for such roads. Nevertheless, the available data do not suggest great variation in silt loading for limited access roadways from one part of the country to another. For annual conditions, a default value of 0.015 g/m^2 is recommended for limited access roadways.[9, 22] Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high traffic speeds and high ADT rates. A default value of 0.2 g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads.[22]

The limited data on silt loading values for industrial roads have shown as much variability as public roads. Because of the variations of traffic conditions and the use of preventive mitigative controls, the data probably do not reflect the full extent of the potential variation in silt loading on industrial roads. However, the collection of site specific silt loading data from industrial roads is easier and safer than for public roads. Therefore, the collection and use of site-specific silt loading data is preferred and is highly recommended. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 5-3, but the quality rating of the equation should be reduced by two levels.

AP-42 measurements of silt loading for paved roads involve periodic sampling from representative roads that are then used to calculate emissions. These silt loadings have been shown to be highly variable in time and space, and the labor required for their acquisition mitigates against frequent sampling that covers a wide spatial extent. Several groups – Desert Research Institute (DRI) and UC Riverside (CE-CERT) - have developed vehicle-based mobile sampling systems for PM10 emissions of re-entrained paved road dust over the past several years.[30] Both systems (DRI's system is called TRAKER and CE-CERT's system is called SCAMPER) have been calibrated in Las Vegas against actual AP-42 silt loadings determined for samples taken in the study area for a complete range of paved roadway classifications and a large range of visible paved road surface loadings. The study results showed a reasonable relationship between the continuous vehicle-based PM10 emission measurements and actual silt loadings.

Table 5-3 Typical Silt Content and Loading Values for Paved Roads at Industrial Facilities[a] (Metric And English Units).

Industry	No. of sites	No. of samples	Silt content (%)		No. of travel lanes	Total loading x 10^{-3}			Silt loading (g/m^2)	
			Range	Mean		Range	Mean	Units[b]	Range	Mean
Copper smelting	1	3	15.4-21.7	19.0	2	12.9-19.5 45.8-69.2	15.9 55.4	kg/km lb/mi	188-400	292
Iron and steel production	9	48	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	0.09-79	9.7
Asphalt batching	1	3	2.6-4.6	3.3	1	12.1-18.0 43.0-64.0	14.9 52.8	kg/km lb/mi	76-193	120
Concrete batching	1	3	5.2-6.0	5.5	2	1.4-1.8 5.0-6.4	1.7 5.9	kg/km lb/mi	11-12	12
Sand and gravel processing	1	3	6.4-7.9	7.1	1	2.8-5.5 9.9-19.4	3.8 13.3	kg/km lb/mi	53-95	70
Municipal solid waste landfill	2	7	—	—	2	—	—	—	1.1-32.0	7.4
Quarry	1	6	—	—	2	—	—		2.4-14	8.2

[a] References 1-2, 5-6, 11-13; dashes indicate information not available.
[b] Multiply entries by 1,000 to obtain stated units: kilograms per kilometer (kg/km) and pounds per mile (lb/mi).

5.3 Emission Estimation: Alternate Methodology

This section was adapted from Section 7.9 of CARB's Emission Inventory Methodology. Section 7.9 was last updated in July 1997.

The paved road dust category includes emissions of fugitive dust particulate matter entrained by vehicular travel on paved roads. The California Air Resources Board (CARB) estimates road dust emissions for the following four classes of roads: (1) freeways/expressways, (2) major streets/highways, (3) collector streets, and (4) local streets. Dust emissions from vehicle travel on paved roads are computed using the emission factor equation provided in AP-42 (see Section 5.2 of this document). Inputs to the paved road dust equation were developed from area-specific roadway silt loading and average vehicle weight data measured by Midwest Research Institute (MRI, 1996).[31]

Data from states and air districts are used to estimate county specific VMT (vehicle miles traveled) data.[32, 33] State highway[34] data are used to estimate the fraction of travel on each of the four road types in each county.

The statewide average vehicle weight for California is assumed to be 2.4 tons. This estimate is based on an informal traffic count estimated by MRI while they were performing California silt loading measurements.[31] CARB assumes the following silt loadings for the four road categories: 0.02 g/m^2 for freeways, 0.035 g/m^2 for major roads, and 0.32 g/m^2 for collector and local roads.[35]

Temporal activity is assumed to be the same as on-road vehicle travel: uniform in spring and fall, increasing slightly in summer, and decreasing slightly in winter. The monthly temporal profile shown below in Table 5-4 shows this trend. The weekly and daily activities are estimated to have higher activities on weekdays and during daylight hours.

Table 5-4. Monthly Temporal Profile for On-road Vehicle Travel

ALL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
100	7.7	7.7	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	7.7

This alternative methodology utilized by CARB is subject to the following assumptions and limitations:

1. The current AP-42 emission factor assumes that road dust emissions are proportional to VMT, roadway silt loading, and average vehicle weight.
2. It may be necessary to assume that virtually the same silt loading values apply throughout the state because of lack of measured silt loadings.
3. The methodology assumes that roadway silt loading, and therefore the emission factor, varies by the type of road.
4. It is assumed that the EPA particle size multiplier (i.e., the 'k' factor in the AP-42 equation) reasonably represents the size distribution of paved road dust.

5. The average vehicle fleet weight is assumed to be 2.4 tons in California (except for the SCAQMD that assumes 3 tons).
6. For freeway and major roads, emissions growth is assumed to be proportional to changes in roadway centerline mileage. For collector and local roads, emissions growth is assumed proportional to changes in VMT.

5.4 Demonstrated Control Techniques

Because of the importance of road surface silt loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Covering of loads in trucks and the paving of access areas to unpaved lots or construction sites are examples of preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing. Actual control efficiencies for any of these techniques can be highly variable. Locally measured silt loadings before and after the application of controls is the preferred method to evaluate controls. It is particularly important to note that street sweeping of gutters and curb areas may actually increase the silt loading on the traveled portion of the road. Redistribution of loose material onto the travel lanes will actually produce a short-term increase in the emissions.

In general, preventive controls are usually more cost effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. The cost-effectiveness of mitigative measures is also unfavorable if only a short period of time is required for the road to return to equilibrium silt loading condition. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note, however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the silt loading, controlled emission factors may be obtained by substituting controlled silt loading values into the appropriate equation. (Note that emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated) roads provides a means to track effectiveness of the controls over time.

Table 5-5 summarizes tested control measures and reported control efficiencies for measures that reduce the generation of fugitive dust from paved roads.

Table 5-5. Control Efficiencies for Control Measures for Paved Roads[36-38]

Control measure	Source component	PM10 control efficiency	References/Comments
Implement street sweeping program with non-efficient vacuum units (14-day frequency)	Local streets	7%	MRI, September 1992. For non-PM10 efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	11%	
Implement street sweeping program with PM10 efficient vacuum units (14-day frequency)	Local streets	16%	MRI, September 1992. For PM10 efficient sweepers, based on 86% efficient sweeping, 8.6 day return time, and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	26%	
Require streets to be swept by non-efficient vacuum units (once per month frequency)	Local, arterial and collector streets	4%	MRI, September 1992. For non-PM10 efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
Require streets to be swept by PM10 efficient vacuum units (once per month frequency)	Local, arterial and collector streets	9%	MRI, September 1992. For PM10 efficient sweepers, based on 86% efficient sweeping, 8.6 day return time, and CA-VMT weighted sweeping frequency (7 to 30 days)
Require wind- or water-borne deposition to be cleaned up within 24 hours after discovery	All Streets	100%	Assumes total cleanup of spill on roadway before traffic resumes
Install pipe-grid trackout-control device	Mud/dirt carryout	80%	Sierra Research, 2003.
Install gravel bed trackout apron (3 in deep, 25 ft long and full road width)	Mud/dirt carryout	46%	MRI, April 2001
Require paved interior roads to be 100 foot long and full road width, or add 4 foot shoulder for paved roads	Mud/dirt carryout	42%	MRI, April 2001

5.5 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 5-6. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

Table 5-6. Example Regulatory Formats for Paved Roads

Control Measure	Goal	Threshold	Agency
Limit speed limit to 15 mph or less	Limit track-out from bulk material transport; reduce particulate matter emissions from paved roads	Work site roads, crossing paved roads transporting bulk materials; during disking and blading ops	Maricopa County Rule 310 04/07/2004
Requires paved travel section, and 4 ft of paved or stabilized shoulder on each side of travel section. Shoulders shall be paved with dust palliative or gravel (2"). Medians shall be constructed as follows: with curbing, solid paving; apply dust palliatives, or with material that prevent track-0ut such as landscaping or decorative rock.	Comply with stabilization standard: limit shoulder visible dust emissions to 20% opacity; limit silt loading to 0.33 oz/ft2	Newly constructed or modified paved roads	Clark County Hydrographic Basins 212, 216, 217 Sect. 93 Air Quality Reg. 07/01/04
Requires paved shoulders. As an option to paving or vegetation requirements, oils or chemical dust suppressants can be used and must be maintained	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) of 500 or more	SJVAPCD Rule 8061 11/15/2001
Require average shoulder width to be 4 ft. Curbing adjacent to and contiguous with a paved lane or shoulder can be used in lieu of shoulder width requirements. Intersections, auxiliary entry and exit lanes may be constructed adjacent to and contiguous with a paved roadway in lieu of shoulder requirements	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) 500-3000	SJVAPCD Rule 8061 11/15/2001
Require average shoulder width to be 8 ft. Curbing adjacent to and contiguous with a paved lane or shoulder can be used in lieu of shoulder width requirements. Intersections, auxiliary entry and exit lanes may be constructed adjacent to and contiguous with a paved roadway in lieu of shoulder requirements	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) greater than 3000	SJVAPCD Rule 8061 11/15/2001
Medians constructed with minimum 4 ft shoulder widths adjacent to traffic lanes, and landscaped. Medians constructed with curbing id speed limit < 45 mph.	Meet stabilized surface requirements and limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) of 500 or more and medians part of roadway	SJVAPCD Rule 8061 11/15/2001
Curbing and shoulder width requirements in event of contingency notification	Maintain stabilized surface; limit paved road dust	Roads with average daily vehicle trips (ADVT) of 500 or more	SCAQMD Rule 1186 9/10/1999
Require average shoulder width to be 4 ft.	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) 500-3000	SCAQMD Rule 1186 9/10/1999
Require average shoulder width to be 8 ft.	Limit visible dust emissions to 20% opacity	Roads with average daily vehicle trips (ADVT) > 3000	SCAQMD Rule 1186 9/10/1999
For speed limit >45 mph: pave median area with typical roadway materials. For speed limit <45 mph: medians must be landscaped or treated with chemical stabilizers.	Maintain stabilized surface	Roads with average daily vehicle trips (ADVT) of 500 or more	SCAQMD Rule 1186 9/10/1999

5.6 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 5-7 summarizes the compliance tools that are applicable to paved roads.

Table 5-7. Compliance Tools for Paved Roads

Record keeping	Site inspection/monitoring
Road map; traffic volumes, speeds, and patterns; vacuum sweeping, mud/dirt trackout precautions, spill cleanup, erosion control, tarping of haul trucks; curbing of roads; application of sand/salt for anti-skid operations; dust suppression equipment and maintenance records.	Sampling of silt loading on paved road surfaces; counting of traffic volumes; observations of vacuum sweeping, high dust emission areas (including track-on and wash-on points), road curbing/shoulders; observation of dust plume opacity (visible emissions) exceeding a standard; real-time portable monitoring of PM.

5.7 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from paved roads. A sample cost-effectiveness calculation is presented below for a specific control measure (PM10 efficient street sweeper) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for paved roads, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Paved Roads
(Arterial Road Through Industrial Area)

Step 1. Determine source activity and control application parameters.

Vehicles/day	200
Average vehicle speed (mph)	40
Length of road (miles)	10
Control Measure	Use of PM10 efficient street sweepers
Control application/frequency	Once per month
Economic Life of Control System (yr)	10
Control Efficiency	9.2%

The number of vehicles per day, the average vehicle speed, road length, and economic life are assumed values for illustrative purposes. Street sweeping, using PM10 efficient sweepers has been chosen as the applied control measure. The control application/frequency and control efficiency are default values provided by MRI.[37]

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

$$\mathbf{E\ (lb/VMT) = 0.016\ (sL/2)^{0.65}\ (W/3)^{1.5} - C)\ x\ (1-(P/1460))}$$

sL—silt loading (g/m^2)	12
W—average vehicle weight (tons)	5
C—exhaust plus break and tire wear (lb/VMT)	0.00047
P—wet days/yr (number/yr)	50

E = 0.106 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 and the road length (both under activity data) and then multiplied by 365/2,000 to compute the annual PM10 emissions, as follows:

Annual PM10 emissions = (Emission Factor x Vehicles/day x Road length x 365 / 2,000
Annual PM10 emissions = (0.106 x 200 x 10) x 365 /2,000 = 39 tons

Annual PM2.5 emissions = 0.15 x PM10 emissions[28]
Annual PM2.5 emissions = (0.15 x 39) = 5.8 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, a PM10 efficient street sweeper with a control efficiency of 9.2% has been selected as the control measure. Thus, the annual controlled PM10 and PM2.5 emissions estimates are calculated to be:

Annual Controlled PM10 emissions = (39 tons) x (1 – 0.092) = 35 tons
Annual Controlled PM2.5 emissions = (5.8 tons) x (1 – 0.092) = 5.3 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	152,000
Annual Operating/Maintenance costs ($)	16,000
Annual Interest Rate	3%
Capital Recovery Factor	0.1172
Annualized Cost ($/yr)	33,819

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:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factory} = 3\% \times (1+3\%)^{10} / (1+3\%)^{10} - 1 = 0.1172$$

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 152,000) + 16,000 = $33,819

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 = $33,819 / (39 - 35) = $9,492/ton
Cost effectiveness for PM2.5 emissions = $33,819 / (5.8 - 5.3) = $63,283/ton

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

Chapter 6. Unpaved Roads

6.1 Characterization of Source Emissions

When a vehicle travels on an unpaved surface such as an unpaved road or unpaved parking lot, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on source parameters that characterize the condition of a particular road and the associated vehicle traffic. Characterization of these source parameters allow for "correction" of emission estimates to specific road and traffic conditions present on public and industrial roadways.

6.2 Emission Estimation: Primary Methodology[1-26]

> This section was adapted from Section 13.2.2 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.2 was last updated in December 2003.

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt (particles smaller than 75 micrometers [μm] in physical diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen using the ASTM-C-136 method. A summary of this method is contained in Appendix C of AP-42. Table 6-1 summarizes measured silt values for industrial unpaved roads. Table 6-2 summarizes measured silt values for public unpaved roads. It should be noted that the ranges of silt content for public unpaved roads vary over two orders of magnitude. Therefore, the use of data from this table can potentially introduce considerable error. Use of this data is strongly discouraged when it is feasible to obtain locally gathered data.

Since the silt content of a rural dirt road will vary with geographic location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles. Other variables are important in addition to the silt content of the road surface material. For example, at industrial sites, where haul trucks and other heavy equipment are common, emissions are highly correlated with vehicle weight. On the other hand, there is far less variability in the weights of cars and pickup trucks that commonly travel publicly accessible unpaved roads throughout the United States. For those roads, the moisture content of the road surface material may be more dominant in determining differences in emission levels between a hot desert environment and a cool moist location.

Table 6-1. Typical Silt Content Values of Surface Material on Industrial Unpaved Roads[a]

Industry	Road use or surface material	Plant sites	No. of samples	Silt content (%) Range	Silt content (%) Mean
Copper smelting	Plant road	1	3	16-19	17
Iron and steel production	Plant road	19	135	0.2-19	6.0
Sand and gravel processing	Plant road	1	3	4.1-6.0	4.8
	Material storage area	1	1	–	7.1
Stone quarry and processing	Plant road	2	10	2.4-16	10
	Haul road to/from pit	4	20	5.0-15	8.3
Taconite mining and processing	Service road	1	8	2.4-7.1	4.3
	Haul road to/from pit	1	12	3.9-9.7	5.8
Western surface coal mining	Haul road to/from pit	3	21	2.8-18	8.4
	Plant road	2	2	4.9-5.3	5.1
	Scraper route	3	10	7.2-25	17
	Haul road (freshly graded)	2	5	18-29	24
Construction sites	Scraper routes	7	20	0.56-23	8.5
Lumber sawmills	Log yards	2	2	4.8-12	8.4
Municipal solid waste landfills	Disposal routes	4	20	2.2-21	6.4

[a] References 1, 5-15.

Table 6-2. Typical Silt Content Values of Surface Material on Public Unpaved Roads[a]

Industry	Road use or surface material	Plant sites	No. of samples	Silt content (%) Range	Silt content (%) Mean
Publicly accessible roads	Gravel/crushed limestone	9	46	0.1-15	6.4
	Dirt (i.e., local material compacted, bladed, and crowned)	8	24	0.83-68	11

[a] References 1, 5-16.

6.2.1 Emission Factors

The PM10 emission factors presented below are the outcomes from stepwise linear regressions of field emission test results of vehicles traveling over unpaved surfaces. For vehicles traveling on unpaved surfaces at industrial sites, PM10 emissions are estimated from the following empirical equation:

$$E = 1.5\ (s/12)^{0.9}\ (W/3)^{0.45} \qquad (1a)$$

and, for vehicles traveling on publicly accessible roads, dominated by light duty vehicles, PM10 emissions may be estimated from the following equation:

$$E = \frac{1.8\ (s/12)^{1.8}\ (S/30)^{0.5}}{(M/0.5)^{0.2}} - C \qquad (1b)$$

where

E = PM10 emission factor (lb/VMT)
s = surface material silt content (%)
W = mean vehicle weight (tons)
M = surface material moisture content (%)
S = mean vehicle speed (mph)
C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

The source characteristics s, W and M are referred to as correction parameters for adjusting the emission estimates to local conditions. The metric conversion from lb/VMT to grams (g) per vehicle kilometer traveled (VKT) is 1 lb/VMT = 281.9 g/VKT. Equations 1a and 1b have a quality rating of B if applied within the ranges of source conditions that were tested in developing the equations shown in Table 6-3.

Table 6-3. Range of Source Conditions Used in Developing Equations 1a and 1b

Emission factor	Surface silt content, %	Mean vehicle weight		Mean vehicle speed		Mean No. of wheels	Surface moisture content, %
		Mg	ton	km/hr	mph		
Industrial roads (Equation 1a)	1.8-25.2	1.8-260	2-290	8-69	5-43	4-17[a]	0.03-13
Public roads (Equation 1b)	1.8-35	1.4-2.7	1.5-3	16-88	10-55	4-4.8	0.03-13

As noted earlier, the models presented as Equations 1a and 1b were developed from tests of traffic on unpaved surfaces, mostly performed in the 1980s. Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall or watering, because of traffic-enhanced natural evaporation. Factors influencing how fast a road dries are discussed in Section 6.5 below. A higher mean vehicle weight and a higher than normal traffic rate may be justified when performing a worst-case analysis of emissions from unpaved roads.

The PM2.5/PM10 ratio for fugitive dust from vehicles traveling on unpaved roads is 0.1.[23] The PM2.5 and PM10 emission factors for the exhaust, brake wear, and tire wear of a 1980's vehicle fleet (*C*) are shown in Table 6-4. They were obtained from EPA's MOBILE6.2 model.[24]

Table 6-4. Emission Factors for 1980's Vehicle Fleet Exhaust, Brake Wear, and Tire Wear

Particle size	*C*, Emission factor for exhaust, brake wear, and tire wear (lb/VMT)
PM2.5	0.00036
PM10	0.00047

A PM10 emission factor for the resuspension of fugitive dust from unpaved shoulders created by the wake of high-profile vehicles such as tractor-trailers traveling on paved roads at high speed has been developed by Desert Research Institute (DRI). A discussion of the emissions estimation methodology for fugitive dust originating from unpaved shoulders is presented in Chapter 14.

6.2.2 Source Extent

It is important to note that the vehicle-related source conditions refer to the average weight, speed, and number of wheels for all vehicles traveling the road. For example, if 98% of the traffic on the road are 2-ton cars and trucks while the remaining 2% consists of 20-ton trucks, then the mean weight is 2.4 tons. More specifically, Equations 1a and 1b are not intended to be used to calculate a separate emission factor for each vehicle class within a mix of traffic on a given unpaved road. That is, in the example, one should not determine one factor for the 2-ton vehicles and a second factor for the 20-ton trucks. Instead, only one emission factor should be calculated that represents the “fleet” average of 2.4 tons for all vehicles traveling the road. Moreover, to retain the quality ratings when addressing a group of unpaved roads, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt and moisture contents are given in Appendices C.1 and C.2 of AP-42. Vehicle-related parameters should be developed by recording visual observations of traffic. In some cases, vehicle parameters for industrial unpaved roads can be determined by reviewing maintenance records or other information sources at the facility.

In the event that site-specific values for correction parameters cannot be obtained, then default values may be used. In the absence of site-specific silt content information, an appropriate mean value from Tables 6-1 and 6-2 may be used as a default value, but the quality rating of the equation is reduced by two letters. Because of significant differences found between different types of road surfaces and between different areas of the country, use of the default moisture content value of 0.5 percent in Equation 1b is discouraged. The quality rating should be downgraded two letters when the default moisture content value is used. It is assumed that readers addressing industrial roads have access to the information needed to develop average vehicle information for their facility.

6.2.3 Natural Mitigation

The effect of routine watering to control emissions from unpaved roads is discussed below in Section 6.5. However, all roads are subject to some natural mitigation because of rainfall and other precipitation. The Equation 1a and 1b emission factors can be extrapolated to annual average uncontrolled conditions (but including natural mitigation) under the simplifying assumption that annual average emissions are inversely proportional to the number of days with measurable (more than 0.254 mm [0.01 inch]) precipitation:

$$E_{ext} = E[(365 - P)/365] \quad (2)$$

where,

E_{ext} = annual size-specific emission factor extrapolated for natural mitigation (lb/VMT)

E = emission factor from Equation 1a or 1b

P = number of days in a year with at least 0.254 mm (0.01 in) of precipitation

Maps showing the geographical distribution of "wet" days on an annual basis for the United States based on meteorological records on a monthly basis are available in the *Climatic Atlas of the United States*.[16] Alternative sources include other Department of Commerce publications such as local climatological data summaries. The National Climatic Data Center (NCDC) offers several products that provide hourly precipitation data. In particular, NCDC offers a *Solar and Meteorological Surface Observation Network 1961-1990* (SAMSON) CD-ROM, which contains 30 years worth of hourly meteorological data for first-order National Weather Service locations. Whatever meteorological data are used, the source of that data and the averaging period should be clearly specified.

Equation 2 provides an estimate that accounts for precipitation on an annual average basis for the purpose of inventorying emissions. It should be noted that Equation 2 does not account for differences in the temporal distributions of the rain events, the quantity of rain during any event, or the potential for the rain to evaporate from the road surface. In the event that a finer temporal and spatial resolution is desired for inventories of public unpaved roads, estimates can be based on a more complex set of assumptions. These assumptions include:

1. The moisture content of the road surface material is increased in proportion to the quantity of water added;
2. The moisture content of the road surface material is reduced in proportion to the Class A pan evaporation rate;
3. The moisture content of the road surface material is reduced in proportion to the traffic volume; and
4. The moisture content of the road surface material varies between the extremes observed in the area.

The CHIEF Web site (www.epa.gov/ttn/chief/ap42/ch13/related/c13s02-2) has a file that contains a spreadsheet program for calculating emission factors that are temporally and spatially resolved. Information required for use of the spreadsheet program includes monthly Class A pan evaporation values, hourly meteorological data for precipitation, humidity and snow cover, vehicle traffic information, and road surface material information.

It is emphasized that the simple assumption underlying Equation 2 and the more complex set of assumptions underlying the use of the procedure which produces a finer temporal and spatial resolution have not been verified in any rigorous manner. For this reason, the quality ratings for either approach should be downgraded one letter from the rating that would be applied to Equation 1.

6.3 Emission Estimation: Alternate Methodology for Non-Farm Roads

This section was adapted from Section 7.10 of CARB's Emission Inventory Methodology. Section 7.10 was last updated in August 1997.

This source category provides estimates of the entrained geologic particulate matter emissions that result from vehicular travel over non-agricultural unpaved roads. The emissions are estimated separately for three major unpaved road categories: city and county roads, U.S. forests and park roads, and Bureau of Land Management (BLM) and Bureau of Indian Affairs (BIA) roads. The emissions result from the mechanical disturbance of the roadway and the vehicle generated air turbulence effects. Agricultural unpaved road estimates are computed in a separate methodology; see Section 6.4.

6.3.1 Emission Factor

The PM10 emission factor used for estimates of geologic dust emissions from vehicular travel on unpaved roads is based on work performed by UC Davis[28] and the Desert Research Institute.[29] The emission factor used for all unpaved roads statewide is 2.27 lbs PM10/VMT.[30] Because the emission measurements were performed in California, this emission factor was used by CARB to replace the previous generic emission factor provided in EPA's AP-42 document.[31] The new emission factor is slightly smaller than the factors derived with the AP-42 methodology. The PM2.5/PM10 ratio for unpaved road dust is 0.1.[23]

6.3.2 Source Extent (Activity Level)

For the purpose of estimating emissions, it is assumed that the unpaved road dust emissions are primarily related to the vehicle miles traveled (VMT) on the roads. State highway data are used to estimate unpaved road miles for each roadway category in each county. It is assumed that 10 daily VMT (DVMT) are traveled on unpaved city and county roads as well as U.S. forest and parks roads and BLM and BIA roads. Road mileage, if needed, can be simply computed by dividing the annual VMT values by 3650 (which is 10 DVMT x 365 days).

Daily activity on unpaved roads occurs primarily during daylight hours. Activity is assumed to be the same each day of the week. Monthly activity varies by county and is based on estimates of monthly rainfall in each county. This is to reflect that during wet months there is less unpaved road traffic, and there are also lower emissions per mile of road when the road soils have a higher moisture content. Unpaved road growth is tied to on-road VMT growth for many counties. For other counties, growth is set to zero and VMT is not used.

6.3.3 Assumptions and Limitations

CARB's methodology is subject to the following assumptions and limitations:

1. This methodology assumes that all unpaved roads emit the same levels of PM10 per VMT during all times of the year for all vehicles and conditions.
2. It is assumed that all unpaved roads receive 10 VMT per day.
3. This methodology assumes that no controls are used on the roads.
4. It is assumed that the emission factors derived in a test county are applicable to the rest of California.

6.4 Emission Estimation: Alternative Methodology for Farm Roads

This section was adapted from Section 7.11 of CARB's Emission Inventory Methodology. Section 7.11 was last updated in August 1997.

This source category provides estimates of the entrained geologic particulate matter emissions that result from vehicular travel over unpaved roads on agricultural lands. The emissions result from the mechanical disturbance of the roadway and the vehicle generated air turbulence effects. This emission factor used is oriented towards dust emissions from light duty vehicle use, but the activity data implicitly include some larger vehicle use for harvest and other operations.

6.4.1 Emission Factor

The PM10 emission factor used for estimates of geologic dust emissions from vehicular travel on unpaved roads is based on work performed by UC Davis[28] and the Desert Research Institute.[29] The emission factor used for all unpaved roads statewide is 2.27 lbs PM10/VMT.[30] Because the emission measurements were performed in California, this emission factor was used by CARB to replace the previous generic emission factor provided in EPA's AP-42 document.[31] CARB's emission factor is slightly smaller than the factors derived with the AP-42 methodology. The PM2.5/PM10 ratio for unpaved road dust is 0.1.[23]

6.4.2 Source Extent (Activity Level)

For the purpose of estimating emissions, it is assumed that the unpaved road dust emissions are primarily related to the vehicle miles traveled (VMT) on the roads. In 1976 an informal survey was made of several county agricultural commissioners in the San Joaquin Valley, who estimated that each 40 acres of cultivated land receives approximately 175 vehicle passes per year on the unpaved farm roads.[32] This value of 4.28 VMT/acre-year has been used in the past by CARB to calculate emissions from unpaved farm roads. CARB is now proposing the following estimates of source extent for unpaved farm roads for different crops: 0.38 VMT/acre-year for grapes, 0.40 VMT/acre-year for cotton, and 1.23 VMT/acre-year for citrus.[33]

The crop acreage data used to estimate the road dust emissions are from the state agency summary of crop acreage harvested.[34, 35] The acreage estimates do not include pasture lands because it is thought that the quantity of vehicular travel on these lands is minimal. Daily activity on unpaved roads occurs primarily during daylight hours. Activity is assumed to be the same each day of the week. Monthly activity varies by county and is based on estimates of monthly rainfall in each county. This is to reflect that during wet months there is less unpaved road traffic, and there are also lower emissions per mile of road when the road soils have a higher moisture content. Unpaved road growth for farm roads is based on agricultural crop acreage or agricultural production. This value is set to zero for many counties.

6.4.3 Assumptions and Limitations

CARB's methodology is subject to the following assumptions and limitations:

1. This methodology assumes that all unpaved farm roads emit the same levels of PM10 per VMT during all times of the year for all vehicles and conditions.
2. It is assumed that all unpaved farm roads receive 175 VMT per 40 acres per year for all crops and cultivation practices.
3. This methodology assumes that no controls are used on the roads.
4. It is assumed that the emission factors derived in the test area are applicable to the rest of California.
5. This methodology assumes that unpaved road travel associated with pasture lands is negligible.

6.5 Demonstrated Control Techniques

A wide variety of options exist to control emissions from unpaved roads. Options fall into the following three groupings:

1. Vehicle restrictions that limit the speed, weight or number of vehicles on the road
2. Surface improvement by measures such as (a) paving or (b) adding gravel or slag to a dirt road
3. Surface treatment such as watering or treatment with chemical dust suppressants

Available control options span broad ranges in terms of cost, efficiency, and applicability. For example, traffic controls provide moderate emission reductions (often at little cost) but are difficult to enforce. Although paving is highly effective, its high initial cost is often prohibitive. Furthermore, paving is not feasible for industrial roads subject to very heavy vehicles and/or spillage of material in transport. Watering and chemical suppressants, on the other hand, are potentially applicable to most industrial roads at moderate to low costs. However, these require frequent reapplication to maintain an acceptable level of control. Chemical suppressants are generally more cost-effective than water but not in cases of temporary roads (which are common at mines, landfills, and construction sites). In summary, then, one needs to consider not only the type and volume of traffic on the road but also how long the road will be in service when developing control plans.

Vehicle restrictions. These measures seek to limit the amount and type of traffic present on the road, or to lower the mean vehicle speed. For example, many industrial plants have restricted employees from driving on plant property and have instead instituted bussing programs. This eliminates emissions due to employees traveling to/from their worksites. Although the heavier average vehicle weight of the busses increases the base emission factor, the decrease in vehicle-miles-traveled results in a lower overall emission rate.

Surface improvements. Control options in this category alter the road surface. As opposed to "surface treatments" discussed below, improvements are relatively "permanent" and do not require periodic retreatment. The most obvious surface improvement is paving an unpaved road. This option is quite expensive and is probably most applicable to relatively short stretches of unpaved road with at least several hundred vehicle passes per day. Furthermore, if the newly paved road is located near unpaved areas or is used to transport material, it is essential that the control plan address routine cleaning of the newly paved road surface. The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions. The predictive emission factor equation for paved roads, given in Chapter 5, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto unpaved shoulders (berms) also must be taken into account in estimating the control efficiency of paving.

Other surface improvement methods involve covering the road surface with another material that has a lower silt content. Examples include placing gravel or slag on a dirt road. The control efficiency can be estimated by comparing the emission factors obtained using the silt contents before and after improvement. The silt content of the road surface should be determined after 3 to 6 months rather than immediately following placement. Control plans should address regular maintenance practices, such as grading, to retain larger aggregate on the traveled portion of the road.

Surface treatments. These measures refer to control options that require periodic reapplication. Treatments fall into the two main categories of:

(a) wet suppression (i.e., watering, possibly with surfactants or other additives), which keeps the road surface wet to control emissions, and
(b) chemical stabilization that attempts to change the physical characteristics of the surface.

The necessary reapplication frequency varies from minutes or hours for plain water under summertime conditions to several weeks or months for chemical dust suppressants.

Wet Suppression. Watering increases the moisture content, which in turn causes particles to conglomerate and reduces their likelihood of becoming suspended when vehicles pass over the surface. The control efficiency depends on how fast the road dries after water is added. This in turn depends on: (a) the amount (per unit road surface area) of water added during each application; (b) the period of time between applications; (c) the weight, speed and number of vehicles traveling over the watered road during the period between applications; and (d) meteorological conditions (temperature, wind speed, cloud cover, etc.) that affect evaporation during the period. Figure 6-1 presents a simple bilinear relationship between the instantaneous control efficiency due to watering and the resulting increase in surface moisture. The moisture ratio “M” (i.e., the x-axis in Figure 6-1) is found by dividing the surface moisture content of the watered road by the surface moisture content of the uncontrolled road. As the watered road surface dries, both the ratio M and the predicted instantaneous control efficiency (i.e., the y-axis in the figure) decrease. The figure shows that between the uncontrolled moisture content (M = 1) and a value twice as large (M = 2), a small increase in moisture content results in a large increase in control efficiency. Beyond that, control efficiency grows slowly with increased moisture content.

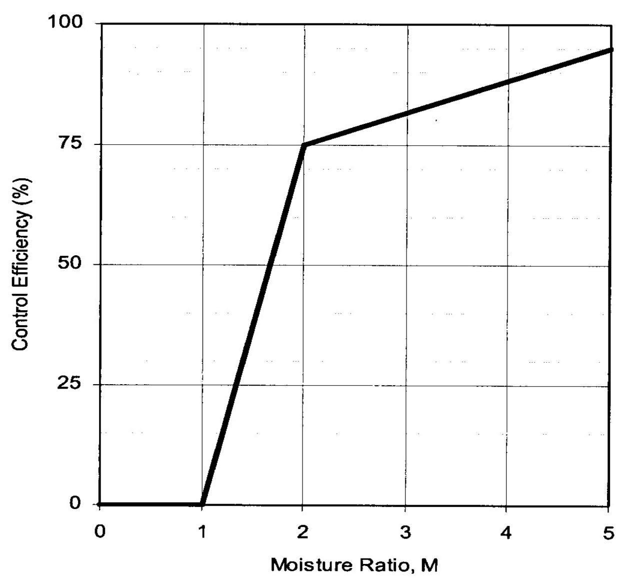

Figure 6-1. Watering Control Effectiveness for Unpaved Travel Surfaces

Given the complicated nature of how the road dries, characterization of emissions from watered roadways is best done by collecting road surface material samples at various times between water truck passes. AP-42 Appendices C.1 and C.2 present the recommended sampling and analysis procedures, respectively, for determining the surface/bulk dust loading. The moisture content measured can then be associated with a control efficiency by use of Figure 6-1. Samples that reflect average conditions during the watering cycle can take the form of either a series of samples between water applications or a single sample at the midpoint. It is essential that samples be collected during periods with active traffic on the road. Finally, because of different evaporation rates, it is recommended that samples be collected at various times during the year. If only one set of samples is to be collected, these must be collected during hot, summertime conditions.

When developing watering control plans for roads that do not yet exist, it is strongly recommended that the moisture cycle be established by sampling similar roads in the same geographic area. If the moisture cycle cannot be established by similar roads using established watering control plans, the more complex methodology used to estimate the mitigation of rainfall and other precipitation can be used to estimate the control provided by routine watering. An estimate of the maximum daytime Class A pan evaporation (based upon daily evaporation data published in the monthly Climatological Data for the state by the National Climatic Data Center) should be used to insure that adequate watering capability is available during periods of highest evaporation. Hourly precipitation values are replaced by the equivalent inches of precipitation resulting fro watering. One inch of precipitation is equivalent to an application of 5.6 gallons of water per square yard of road. Information on the long term average annual evaporation and on the percentage that occurs between May and October is available in the Climatic Atlas.[16] This methodology should be used only for prospective analyses and for designing watering programs for existing roadways. The quality rating of an emission factor for a watered road that is based on this methodology should be downgraded two letters. Periodic road surface samples should be collected and analyzed to verify the efficiency of the watering program.

Chemical Dust Suppressants. As opposed to wet suppression (i.e., watering), chemical dust suppressants have much less frequent reapplication requirements. These materials suppress emissions by changing the physical characteristics of the existing road surface material. Many chemical dust suppressants applied to unpaved roads form a hardened surface that binds particles together. After several applications, a treated unpaved road often resembles a paved road except that the surface is not uniformly flat. Because the improved surface results in more grinding of small particles, the silt content of loose material on a highly controlled surface may be substantially higher than when the surface was uncontrolled. For this reason, the models presented as Equations 1a and 1b cannot be used to estimate emissions from chemically stabilized roads. Should the road be allowed to return to an uncontrolled state with no visible signs of large-scale cementing of material, the Equation 1a and 1b emission factors could then be used to obtain conservatively high emission estimates.

The control effectiveness of chemical dust suppressants appears to depend on: (a) the dilution rate used in the mixture; (b) the application rate (volume of solution per unit road surface area); (c) the time between applications; (d) the size, speed and amount of traffic during the period between applications; and (e) meteorological conditions (rainfall, freeze/thaw cycles, etc.) during the period. Other factors that affect the performance of chemical dust suppressants include other traffic characteristics (e.g., cornering, track-out from unpaved areas) and road characteristics (e.g., bearing strength, grade). The variability in these factors and differences between individual dust control products make the control efficiencies of chemical dust suppressants difficult to estimate. Past field testing of emissions from controlled unpaved roads has shown that chemical dust suppressants provide a PM10 control efficiency of about 80% when applied at regular intervals of 2 weeks to 1 month.

Petroleum resin products historically have been the dust suppressants (besides water) most widely used on industrial unpaved roads. Figure 6-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.[20] The following items should be noted:

1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (not solution) applied since the start of the dust control season.
2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 6-2 presents control efficiency values averaged over two common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.
3. Note that zero efficiency is assigned until the ground inventory reaches 0.05 gallon per square yard (gal/yd^2). Requiring a minimum ground inventory ensures that one must apply a reasonable amount of chemical dust suppressant to a road before claiming credit for emission control. Recall that the ground inventory refers to the amount of petroleum resin concentrate rather than the total solution.

As an example of the application of Figure 6-2, suppose that Equation 1a was used to estimate a PM10 emission factor of 7.1 lb/VMT from a particular road. Also, suppose that, starting on May 1, the road is treated with 0.221 gal/yd^2 of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. The average controlled PM10 emission factors calculated from Figure 6-2 are shown in Table 6-5.

Besides petroleum resins, other newer dust suppressants have also been successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins and watering, are provided in References 18 through 21.

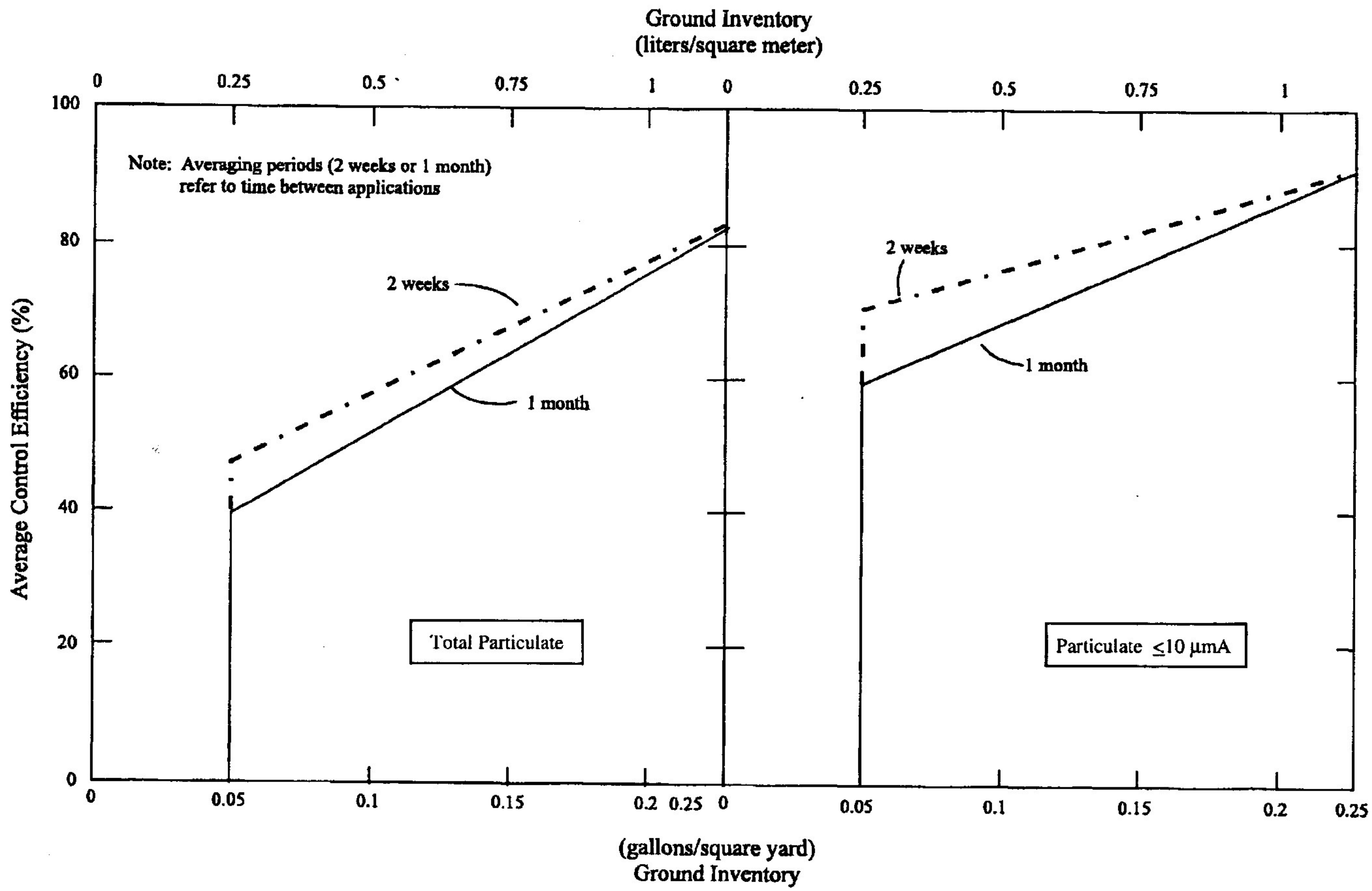

Figure 6-2. Average TSP and PM10 Control Efficiencies for Two Common Application Intervals

Table 6-5. Average Controlled PM10 Emission Factors for Specific Conditions

Period	Ground inventory, gal/yd^2	Average control efficiency, %[a]	Average controlled PM10 emission factor, lb/VMT
May	0.037	0	7.1
June	0.073	62	2.7
July	0.11	68	2.3
August	0.15	74	1.8
September	0.18	80	1.4

[a] From Figure 6-2. Zero efficiency assigned if ground inventory is less than 0.05 gal/yd^2.
1 lb/VMT = 281.9 g/VKT. 1 gal/yd^2 = 4.531 L/m^2.

Table 6-6 summarizes tested control measures and reported control efficiencies for measures that reduce the generation of fugitive dust from unpaved roads.

Table 6-6. Control Efficiencies for Control Measures for Unpaved Roads[36, 37]

Control measure	PM10 control efficiency	References/Comments
Limit maximum speed on unpaved roads to 25 miles per hour	44%	Assumes linear relationship between PM10 emissions and vehicle speed and an uncontrolled speed of 45 mph.
Pave unpaved roads and unpaved parking areas	99%	Based on comparison of paved road and unpaved road PM10 emission factors.
Implement watering twice a day for industrial unpaved road	55%	MRI, April 2001
Apply dust suppressant annually to unpaved parking areas	84%	CARB April 2002

6.6 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats downloaded from the Internet for several local air quality agencies in the WRAP region are presented in Table 6-7. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

Table 6-7. Example Regulatory Formats for Unpaved Roads

Control Measure	Goal	Threshold	Agency
Requires annual treatment of unpaved public roads beginning in 1998 and continuing for each of 8 years thereafter by implementing one of the following: paving at least one mile with typical roadway material, applying chemical stabilizers to at least two miles to maintain stabilized surface, implementing at least one of the following on at least three miles of road surface: installing signage at 1/4 mile intervals limiting speed to 15 mph, installing speed control devices every 500 ft, or maintaining roadway to limit speed to 15 mph		Set applicability standard: unpaved road must be more than 50 ft wide at all points or must not be within 25 ft of property line, or have more than 20 vehicle trips per day. All roads with average daily traffic greater than average of all unpaved roads within its jurisdiction must be treated	SCAQMD Rule 1186 9/10/1999
Control measures implemented by June 1, 2003: pave, apply dust palliative, or other	Complies with stabilization standard: limit visible dust emissions to 20% opacity, limit silt loading to 0.33 oz/ft2, and limit silt content to 6%	All unpaved roads with vehicular traffic 150 vehicles or more per day	Clark County Hydrographic Basins 212, 216, 217 Sect. 91 Air Quality Reg. 06/22/2000
Limit vehicle speed </=15mph and </=20 trips/day; BACM: watering, paving, apply/maintain gravel, asphalt, or dust suppressant; Dust control plan for construction site roads	Limit VDE to 20% opacity; limit silt loading to 0.33oz/ft^2, limit silt content to 6%	Construction site roads, inactive/active; limiting vehicle speed and trips is alternative to stabilization requirement and max number of trips each day in control plan (also number of vehicles, earthmoving equip, etc.); for roads with >/=150 vehicles/day implement BACM by 06/10/2004; same for >/=250 vehicles day (existing roads by 06/10/2000)	Maricopa County Rules 310 and 310.01 04/07/2004 and 02/16/2000

6.7 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 6-8 summarizes the compliance tools that are applicable for unpaved roads.

Table 6-8. Compliance Tools for Unpaved Roads

Record keeping	Site inspection/monitoring
Road map; traffic volumes, speeds, and patterns; dust suppression equipment and maintenance records; frequencies, amounts, times, and rates for watering and dust suppressants (type); use of water surfactants; calculated control efficiencies; regrading, graveling, or paving of unpaved road segments; control equipment downtime and maintenance records; meteorological log.	Observation of water truck operation and inspection of sources of water; observation of dust plume opacity exceeding a standard; counting of traffic volumes; surface material sampling and analysis for silt and moisture contents; real-time portable monitoring of PM.

6.8 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from unpaved roads. A sample cost-effectiveness calculation is presented below for a specific control measure (watering) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for unpaved roads, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for 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*
Economic Life of Control System (year)	10
Control Efficiency	55%

* No nighttime traffic.

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.

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

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 Emissions[23]
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

<u>Step 5. Determine Annual Cost to Control PM Emissions.</u>

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:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1 + \text{AIR})^{\text{Economic life}} / (1 + \text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factor} = 3\% \times (1 + 3\%)^{10} / (1 + 3\%)^{10} - 1 = 0.1172$$

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

<u>Step 6. Calculate Cost Effectiveness.</u> 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

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Chapter 7. Agricultural Wind Erosion

7.1 Characterization of Source Emissions

Wind blowing across exposed nonpasture agricultural land results in particulate matter (PM) emissions. Windblown dust emissions from agricultural lands are calculated by multiplying the process rate (acres of crop in cultivation) by an emission factor (tons of PM per acre per year).

7.2 Emission Estimation Methodology [1-13]

This section was adapted from Section 7.12 of CARB's Emission Inventory Methodology. Section 7.12 was last updated in July 1997.

MRI developed a PM10 emission factor for agricultural wind blown dust of 86.6 lb/acre on behalf of the EPA in 1992.[1] However this emission factor is not included in AP-42. Thus, the methodology adopted by the California Air Resources Board[2,3] (CARB) is presented as the emissions estimation methodology in lieu of an official EPA methodology for this fugitive dust source category. The methodology for estimating fugitive dust emissions from open area wind erosion is presented in Chapter 8 of this handbook.

The standard methodology for estimating the emission factor for windblown emissions from agricultural lands is the wind erosion equation (WEQ). Although the WEQ is well established, it is controversial. The WEQ was developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) during the 1960s, for the estimation of wind erosion on agricultural land.[4, 5] The U.S. EPA adapted the USDA-ARS methodology for use in estimating windblown TSP emissions from agricultural lands in 1974[5], and the California Air Resources Board (CARB) adopted the U.S. EPA methodology in 1989. The PM10/TSP ratio for wind erosion is 0.5.[6] The PM2.5/PM10 ratio for windblown fugitive dust posted on EPA's CHIEF website is 0.15 based on the analysis conducted by MRI on behalf of WRAP.[7]

The USDA-ARS has undertaken ambitious programs over the past decade to replace the WEQ with improved wind erosion prediction models such as the Revised Wind Erosion Equation (RWEQ)[8] and the Wind Erosion Prediction System (WEPS)[9] models. CARB does not consider these models feasible for use, although certain portions of the RWEQ were incorporated into the CARB methodology in 1997. According to CARB, the WEQ (with modifications) continues to be the best available, feasible method for estimating windblown agricultural emissions.

7.2.1 Summary of CARB's Wind Erosion Equation (ARBWEQ)

Much of the controversy surrounding the WEQ has related to its tendency to produce inflated emission estimates. Some of the reasons for the inflated emissions relate to the fact that it was developed in the Midwestern United States, and that it does not take into account many of the environmental conditions and farm practices specific to the West. In the revised methodology developed by CARB (referred to as the ARBWEQ), CARB staff added adjustments to the WEQ to improve its ability to estimate windblown emissions from western agricultural lands.

The U.S. EPA-modified version of the USDA-ARS derived wind erosion equation (WEQ) reads as follows:[6]

$$E_S = A\ I\ K\ C\ L'\ V' \qquad (1)$$

where,
- E_S = total suspended particulate fraction of wind erosion losses of tilled fields (tons TSP/acre/year)
- A = portion of total wind erosion losses that would be measured as total suspended particulate, estimated to be 0.025
- I = soil erodibility (tons/acre/year)
- K = surface roughness factor (dimensionless)
- C = climatic factor (dimensionless)
- L' = unsheltered field width factor (dimensionless)
- V' = vegetative cover factor (dimensionless)

As an aid in understanding the mechanics of this equation, the soil erodibility factor I may be thought of as the basic erodibility of a flat, very large, bare field in a climate highly conducive to wind erosion (i.e., high wind speeds and high temperature with little precipitation). This factor was initially established for the WEQ for a large, flat, bare field in Kansas that has relatively high winds along with hot summers and low precipitation. The parameters K, C, L' and V' may be thought of as reduction factors for a ridged surface, a climate less conducive to wind erosion, smaller-sized fields, and vegetative cover, respectively, to adjust the equation for applicability to field conditions that differ from the original Kansas field. The A factor in Equation 1 has been used in the ARBWEQ without modification. There has been concern that this factor doesn't take into account finite dust loading. The RWEQ[8] and WEPS[9] models are attempting to address that concern.

Soil Erodibility, I. Soil erodibility by the wind is a function of the amount of erodible fines in the soil. The largest soil aggregate size normally considered to be erodible is approximately 0.84 mm equivalent diameter. The soil erodibility factor, I, is related to the percentage of dry aggregates greater than 0.84 mm as shown in Figure 7-1.[6] The percentage of nonerodible aggregates (and by difference the amount of fines) in a soil sample can be determined experimentally by a standard dry sieving procedure, using a No. 20 U.S. Bureau of Standards sieve with 0.84 mm square openings. For areas larger than can be field sampled for soil aggregate size (e.g., a county) or in cases where soil particle size distributions are not available, a representative value of I can be obtained from the predominant soil type(s) for farmland in the area. Measured erodibilities, I (in units of tons/acre-year), of various soil textural classes are presented in Table 7-1 as a function of percent of dry soil aggregates greater than 0.84 mm in diameter.[6] For California, the soil textural classes were determined by CARB staff from University of California soil maps.[10] An additional level of detail was included in the ARBWEQ by using the United States Department of Agriculture-Natural Resources Conservation Service's (NRCS) State Geographic Data Base (STATSGO) of soil data.[11] In addition, the USDA-ARS recommended an adjustment for changes to long term erodibility due to irrigation.[12] This affects a property known as cloddiness, and refers to the increased tendency for a soil to form stable agglomerations after being exposed to irrigation water.

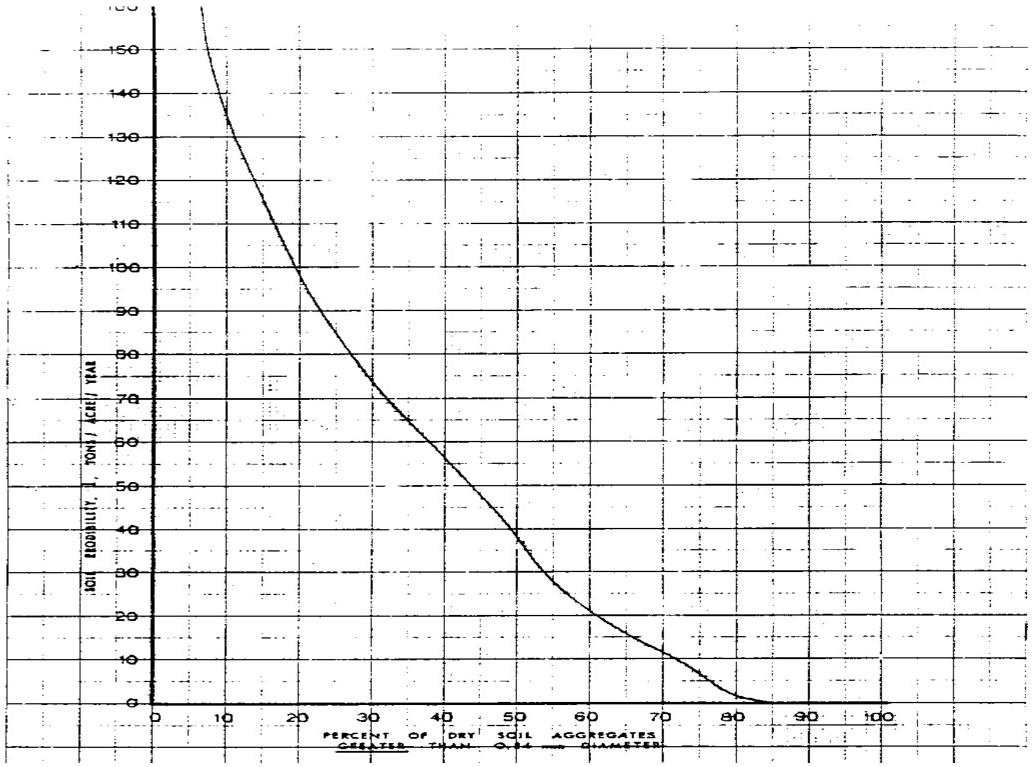

Figure 7-1. Soil Erodibility as a Function of Particle Size[6]

Table 7-1. Soil Erodibility, I, for Various Soil Textural Classes[6]

Predominant Soil Textural Class	Erodibility (tons/acre-year)
Sand	220
Loamy sand	134
Sandy loam, clay, silty clay	86
Loam, sandy clay loam, sandy clay	56
Silty loam, clay loam	47
Silty clay loam, silt	38

Surface Roughness Factor, K. The surface roughness factor, K, accounts for the resistance to wind erosion provided by ridges and furrows or large clods in the field and is crop specific. The surface roughness factor, K, is a function of the height and spacing of the ridges, and varies from 1.0 (no reduction) for a field with a smooth surface to a minimum of 0.5 for a field with the optimum ratio of ridge height (h) to ridge spacing (w). The relationship between K and h^2/w is shown in Figure 7-2.[6] Average K values of common field crops are shown in Table 7-2. Similar crops are assigned similar surface roughness values.

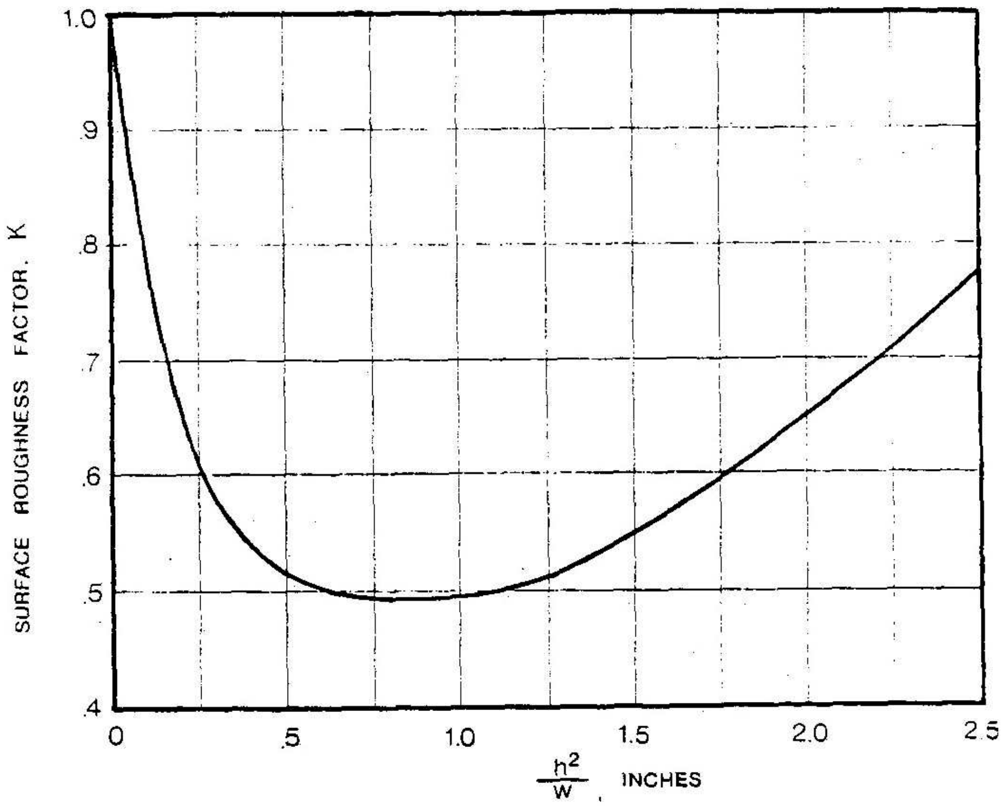

Figure 7-2. Determination of Surface Roughness Factor, K[6]

Table 7-2. Surface Roughness Factor, K, for Common Field Crops[6]

Crop	K
Alfalfa, safflower	1.0
Grain hays, oats, potatoes, rice	0.8
Barley, corn, peanuts, rye, soybeans, sugar beets, vegetables, wheat	0.6
Beans, cotton, sorghum	0.5

Climatic Factor, C. The annual climatic factor, C, is based on data that show that erosion varies directly with the wind speed cubed, and as the inverse of the square of surface soil moisture. The C factor can be calculated from the following equation:

$$C = 0.345\ W^3 / (PE)^2 \qquad (2)$$

where, W = mean annual wind speed (mph), corrected to a standard height of 10 meters
PE = Thornthwaite's precipitation-evaporation index (i.e., ratio of precipitation to evapotranspiration)

Monthly or seasonal climatic factors can be estimated from Equation 2 by substituting the mean wind speed of the period of interest for the mean annual wind speed. Climatic factors have been computed from National Weather Bureau data for many locations throughout the country. The annual climatic factors for many areas of the US are shown in Figure 7-3. The monthly precipitation/evaporation ratio varies from <16 for arid deserts to >127 for rain forests. For the ARBWEQ, CARB staff improved the input data for calculating the factor C, as well as the methods associated with developing the county wide averaged annual climatic factor. Monthly climatic factors were obtained by modifying the annual climatic factor calculation method. Annual climatic factors for different counties within California range from 0.019 to 1.274.[14] The reader is directed to CARB's website to obtain the list of climatic factors for counties within California (www.arb.ca.gov/emisinv/areasrc/fullpdf).

Unsheltered Field Width Factor, L'. Soil erosion across a field is directly related to the unsheltered width along the prevailing wind direction. The rate of erosion is zero at the windward edge of the field and increases approximately proportionately with distance downwind until, if the field is large enough, a maximum rate of soil movement is reached. Correlation between the width of a field and its rate of erosion is also affected by the soil erodibility of its surface: the more erodible the surface, the shorter the distance in which maximum soil movement is reached. This relationship between the unsheltered width of a field (L), its surface erodibility (IK), and its relative rate of soil erosion (L') is shown graphically for different values of IK (ranging from IK = 20 to IK = 134) in Figure 7-4.[6] If the curves of Figure 7-4 are used to obtain the L' factor for the windblown dust equation, values for the variables I and K must already be known and an appropriate value for L most be determined.

L is calculated as the distance across the field in the prevailing wind direction minus the distance from the windward edge of the field that is protected from wind erosion by a barrier. The distance protected by a barrier is equal to 10 times the height of the barrier, or 10H. For example, a row of 30-foot high trees along the windward side of a field reduces the effective width of the field by 300 feet. If the prevailing wind direction differs significantly (>25 degrees) from perpendicularity with the field. L should be increased to account for this additional distance of exposure to the wind. The distance across the field, L, is equal to the field width divided by the cosine of the angle between the prevailing wind direction and the perpendicularity to the field.

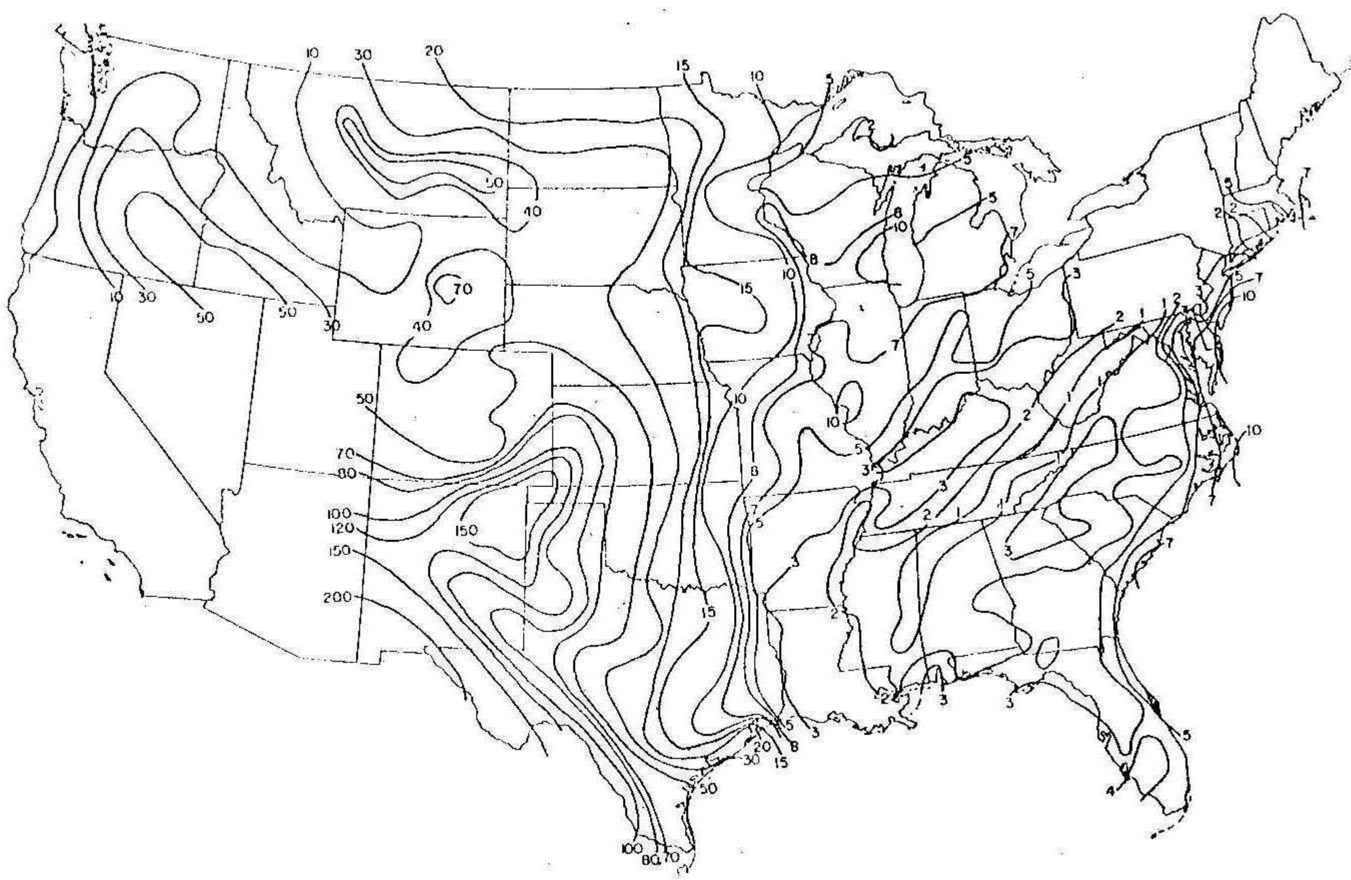

Figure 7-3. Annual Climatic Factor Used in Wind Erosion Equation[6]

[Note: Isopleths for several western and northeastern states were not available at the time this figure was prepared.]

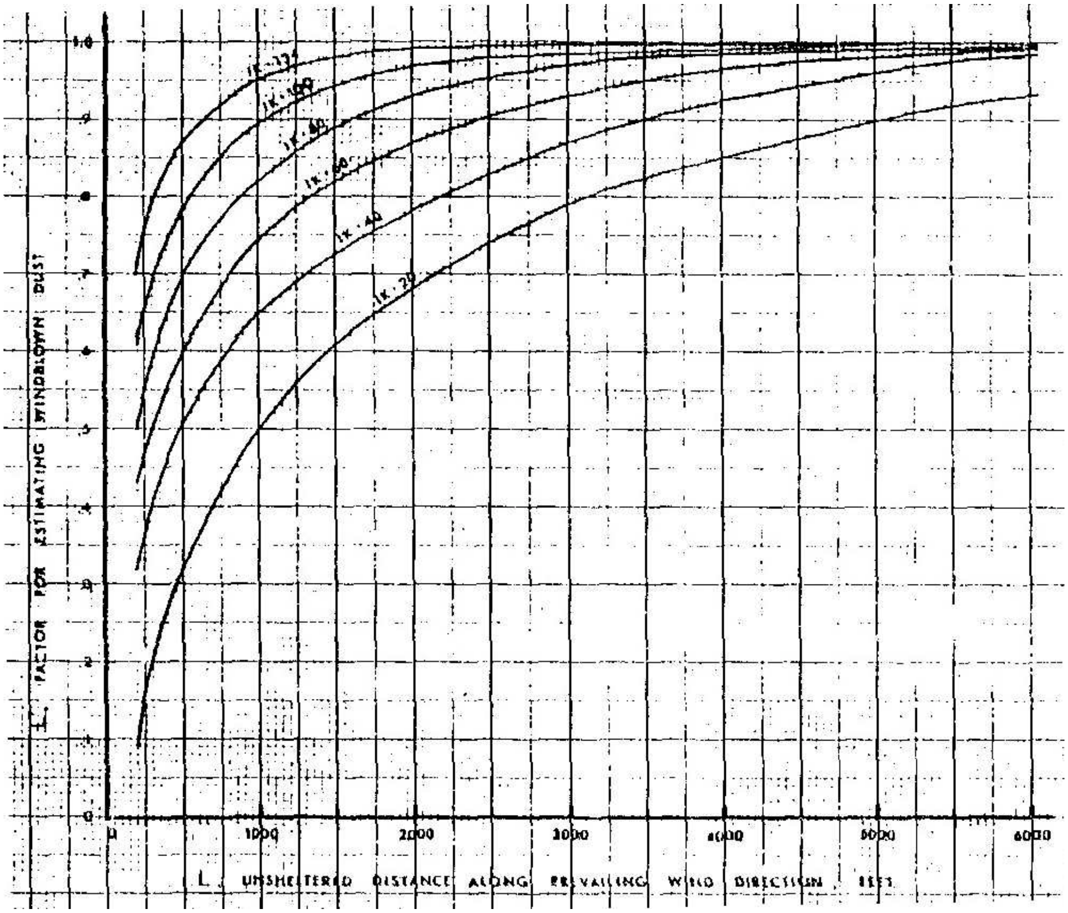

Figure 7-4. Effect of Field Length on Relative Soil Erosion Rate[6]

Vegetative Cover Factor, V'. Vegetative cover on agricultural fields during periods other than the primary crop season greatly reduces wind erosion of the soil. This cover most commonly is crop residue, either standing stubble or mulched into the soil. The effect of various amounts of residue, V, in reducing erosion is shown qualitatively in Figure 7-5, where IKCL' is the potential annual soil loss (in tons/acre-year) from a bare field, and V' is the fractional amount of this potential loss which results when the field has a vegetative cover of V (in lb of air-dried residue/acre). The amount of vegetative cover on a single field can be ascertained by collecting and weighing clean residue from a representative plot or by visual comparison with calibrated photographs. The vegetative soil cover factor, V', is especially problematic for California, and was completely replaced by a series of factors in the ARBWEQ (see analysis below). This factor assumes a certain degree of cover year round based upon post harvest soil cover, and does not account for barren fields from land preparation, growing canopy cover, or replanting of crops during a single annual cycle. All of these factors are very important in the estimation of windblown agricultural dust emissions. Therefore, CARB staff replaced the vegetative soil cover factor, V', with separate crop canopy cover, post harvest soil cover, and post harvest replant factors.

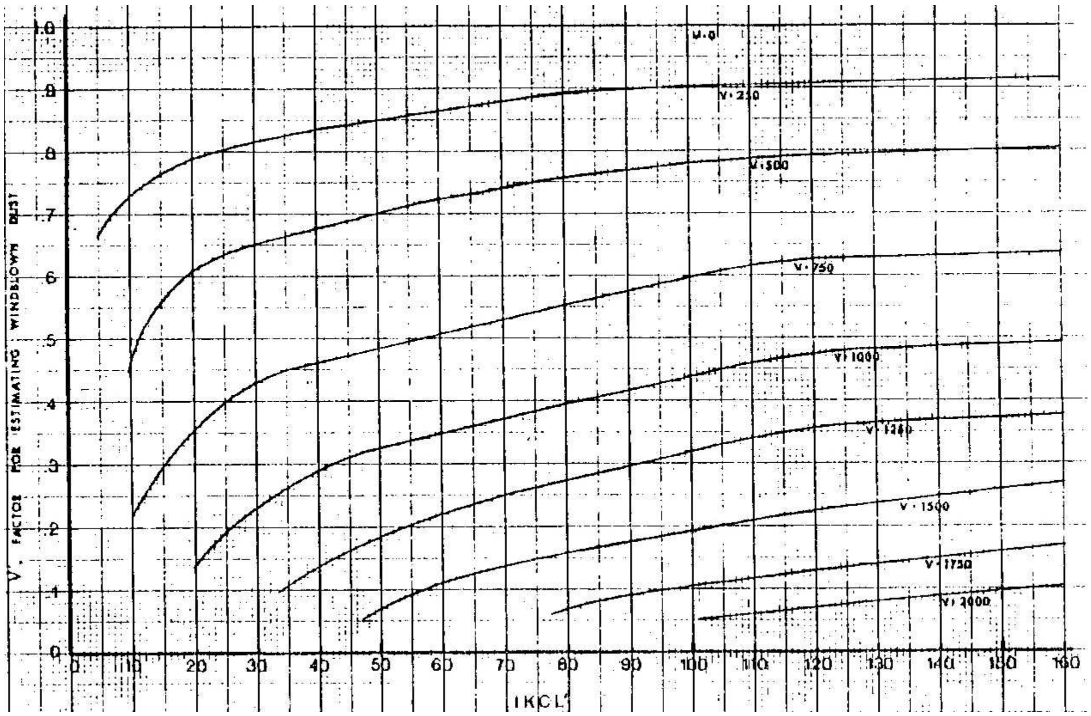

Figure 7-5. Effect of Vegetative Cover on Relative Emission Rate[6]

7.2.2 Climate-Based Improvements in the ARBWEQ

The calculation of the climatic factor C requires mean monthly temperature, monthly rainfall, and mean annual wind speed for a given location as data inputs. This factor is used to estimate climatic effects on an annual basis. In order to make estimates of emissions using the ARBWEQ that are specific to different seasons, it is necessary to estimate the climatic factor that would apply to each season. The changes to the agricultural windblown emissions inventory discussed here, include modifications to both the annual and the monthly climatic factor profile determination methodology included in the ARBWEQ.

The Annual Climatic Factor for the ARBWEQ. Reference 6 includes a definition of the climatic factor that agrees with the method utilized by the NRCS.[13] It incorporates the monthly precipitation effectiveness derived from precipitation and temperature, along with monthly average wind speeds. Garden City, Kansas is assigned a factor of 1.0 and the climatic factors for all other sites are adjusted from this value.

The Monthly Climatic Factor for the ARBWEQ. There are several ways to create a climate-based monthly profile for the ARBWEQ. Because the ARBWEQ is an annual emission estimation model, CARB staff did not directly estimate monthly emissions using the monthly climatic factor. Instead, the annual climatic factor was used to determine annual emissions, and then the monthly-normalized climatic factors were multiplied by the annual emissions. This helped to limit the effect of extreme monthly values on the annual emissions estimate. CARB staff devised a method termed the "month-as-a-year" method which produced climatic factors that would apply if the climate for a given month were instead the year round climate. These monthly numbers, once normalized, provided the climate-based temporal profile. The improvements arising from the use of the month-as-a-year method are due to the fact that it relies on temperature, and precipitation inputs, in addition to wind. The ARBWEQ further modified the temporal profile calculation, by also adding nonclimate-based temporal factors. The month-as-a-year method in the ARBWEQ produces pronounced curves with small climatic factors (resulting in lower emissions) in the cool, wet and more stagnant periods, and large climatic factors (and higher emissions) in the hot, dry, and windy periods. The U.S. EPA method yields gentler profiles, which are shifted into the cooler and wetter months from the ARBWEQ profiles. The 1989 CARB methodology established one erosive wind energy distribution statewide. This resulted in an unrealistic, nearly flat distribution, with very little seasonality. Therefore, the ARBWEQ month-as-a-year method provides a more realistic picture of the windblown dust temporal profile (see Reference 3 for comparison curves and supporting references).

7.2.3 Nonclimate-Based Improvements in the ARBWEQ

Among the nonclimate-based factors that influence windblown agricultural emissions are soil type, soil structure, field geometry, proximity to wind obstacles, crop, soil cover by crop canopy or post harvest vegetative material, irrigation, and replanting of the post harvest fallow land with a different crop. CARB has attempted to correct many of these limitations in the ARBWEQ. Many of the corrections are temporally based and rely upon the establishment of accurate crop calendars to reflect field conditions throughout the year. The long-term irrigation-based adjustment to erodibility, due to soil cloddiness, is not temporally based, and is therefore applied for the entire year.[12] The change in erodibility varies based on soil type, but often results in a reduction in the tons per acre value for irrigated crops of about one-third.

Crop Calendars: Quantifying Temporal Effects. Factors such as crop canopy cover, post harvest soil cover, irrigation, and replanting to another crop have a major effect on windblown emissions. Estimating the effects of these factors requires establishing accurate crop calendars. The planting and harvesting dates are principal components of the crop calendar. The list of references consulted to establish the planting and harvesting dates is included in Reference 3.

Each planting month for a given crop was viewed by CARB staff as a separate cohort (maturation class). Since a single planting cohort may be harvested in several months, each cohort was split into cohort-plant/harvest date pairs. The cohort-plant/harvest date pairs were then assigned based upon a first-in-first-out ordering. The fraction of the total annual crop assigned to a given cohort-plant/harvest date pair was derived by multiplying the fraction of the total annual crop planted in a given month (cohort) by the fraction of the cohort harvested in a given month. The fraction of a cohort-plant/harvest date pair that has been planted, but not harvested at any given time, is termed the growing canopy fraction, or GCF (although the canopy may or may not actually be increasing at any given time). The growing canopy fraction determines the fraction of the acreage that will have the crop canopy factor applied to its emission calculations. The acreage that is not assigned to the growing canopy fraction is the postharvest/preplant (PHPP) acreage. The PHPP acreage will have the post harvest soil cover, and replanting to a different crop factors applied when calculating its emissions. The effect of using cohort-plant/harvest date pairs is to blend the crop canopy, soil cover, replanting, and irrigation effects over both the planting and harvesting periods. This approach provides a more realistic estimate of the temporal windblown emissions profile during these periods. All of the monthly factor profile adjustments described below are calculated for each month of the year, for each cohort-harvest/plant date pair, for each crop, for each county.

Adding a Short-Term Irrigation Factor for Wetness. This adjustment takes into account the overall soil texture, number of irrigation events, and fraction of wet days during the time period[12] (one month for the purposes of the CARB inventory). The list of references consulted to establish the irrigation profiles is included in Reference 3. The irrigation factor for months in which irrigations take place will typically be greater than 0.80. In other words, the irrigations will result in a reduction in erodibility of less than 20%. This is only an estimate for a typical case during the growing season. When averaged over the year, the overall reduction in erodibility is lower.

Replacement Factors to Address Problems with the Vegetative Soil Cover Factor in the WEQ. According to CARB, there are many problems with the vegetative soil cover factor, V. For example, this factor is applied to the acreage year round, even during the growing season, and ignores the effect of disk-down and other land preparation operations on post harvest vegetative soil cover. The factor also does not account for canopy cover during the growing season. In addition, the WEQ was derived based on agricultural practices typical of the Midwestern United States. Crops such as alfalfa have full canopy cover for nearly the entire year. There is also a large amount of acreage that is used for more than one crop per year, and there was no provision in the vegetative soil cover factor for estimating the effects on emissions of this replanting. Whether the land is to be immediately replanted to a different crop, or is going to remain fallow until the next planting of the same crop, it is common practice to disk under the harvested crop within a month or two of harvest. The vegetative soil cover factor for the most part assumes that the post harvest debris remains undisturbed. References to support this agricultural practice are included in Reference 3. CARB staff replaced the vegetative soil cover factor in the ARBWEQ with the three adjustments discussed below to approximate the effects on windblown agricultural PM emissions of: (a) crop canopy cover during the growing season; (b) changes to post harvest soil cover; and (c) post harvest planting of a different crop on the harvested acreage.

<u>Crop Canopy Factor.</u> Crop canopy cover is the fraction of ground covered by crop canopy when viewed directly from above. USDA-ARS staff provided CARB with methodology from the RWEQ for estimating the effects of crop canopy cover on windblown dust emissions.[8] The soil loss ratio (SLRcc) is defined as the ratio of the soil loss for a soil of a given canopy cover divided by the soil loss from bare soil. SLRcc is the factor that is multiplied by the erodibility to adjust the erodibility for canopy cover. The greater the canopy cover, the smaller the SLRcc, and the greater the reduction in erodibility. SLRcc defines an exponential curve that demonstrates major differences in the erodibility reduction for the range of zero to 30 percent canopy cover (typically achieved within a few months after planting). Thereafter, reductions occur much more

slowly, and eventually the curve flattens out. This results in a rapid decrease in emissions during the first few months following planting, until the emissions are only a very small fraction of the bare soil emissions. The canopy cover then will remain, and the windblown emissions will consequently stay very low until harvest. Senescence effects (late growing season reduction in canopy) have been excluded from this model, and the rationale for that exclusion is discussed in Reference 3.

Post Harvest Soil Cover Factor. Post harvest soil cover is the fraction of ground covered by vegetative debris when viewed directly from above. USDA-ARS staff provided CARB with methodology from the RWEQ for estimating the effects of post harvest soil cover on windblown dust emissions.[8] The soil loss ratio (SLRsc) is defined as the ratio of the soil loss for a soil of a given soil cover divided by the soil loss from bare soil. SLRsc is the factor that is multiplied by the erodibility to adjust the erodibility for post harvest soil cover. The greater the post harvest soil cover, the smaller the SLRsc, and the greater the reduction in erodibility. The list of references consulted to establish the post harvest soil cover profiles is included in Reference 3.

Post Harvest "Replant-to-Different-Crop" Factor. As discussed above, the vegetative soil cover factor does not include any adjustments for harvested acreages that are quickly replanted to a different crop. This multiple cropping is very common in California, and has been accounted for in this methodology by removing from the inventory calculation the fraction of the harvested acreage that is replanted, at the estimated time of replanting. This removed fraction is based on information provided by agricultural authorities (see reference list in Reference 3). The net result of the application of the fraction is that the post disk-down acreage (one to two months after harvest), and resultant emissions, is reduced by the fraction of harvested acreage converted to a new crop.

Bare and Border Soil Adjustments. Most fields will have some cultivated areas that are barren. These bare areas could be due to uneven ground (e.g., water accumulation), uneven irrigation, pest damage, soil salinity, etc. Most fields will have some type of border. In some cases there is a large barren border, in other cases it is overgrown with vegetation. Many border areas are relatively unprotected, and prone to wind erosion. CARB staff established approximate fractions of cultivated acreage that would be barren and border areas, respectively. These barren and border acreage adjustments result in emission increases disproportionate to the acreage involved. The reason that the bare acreage-based increase is so large is that the bare acreage does not have either a crop canopy or post harvest soil cover factor applied. The same reasons apply to the border adjustment, but the border region is also assumed not to be irrigated. Therefore, no irrigation factor (wetness), and no long-term irrigation adjustment to erodibility (cloddiness) are applied. No border adjustment was applied to the pasture acreage, since pasture areas frequently lack a barren border.

Temporal Activity. For the 1989 CARB methodology, the temporal profile was based on an estimated statewide erosive wind energy profile. The profile, implemented in the ARBWEQ included wind, precipitation and temperature climatic effects, along with the addition of the effects of crop canopy, postharvest soil cover, postharvest replanting to a different crop, and irrigation. In addition, the inclusion of bare ground and field border effects also adjusted the profile in the ARBWEQ. The profile produced for the ARBWEQ is no longer a separate profile applied to annual emissions, but is now an intermediate output produced during the estimation of annual emissions.

7.3 Demonstrated Control Techniques

The emission potential of agricultural wind erosion is affected by the degree to which soil management and cropping systems provide adequate protection to the exposed soil surface during exposure periods. Table 7-3 presents a summary of demonstrated control measures and the associated PM10 control efficiencies. It is readily observed that reported control efficiencies for many of the control measures are highly variable. This may reflect differences in the operations as well as the test methods used to determine control efficiencies.

Table 7-3. Control Efficiencies for Control Measures for Agricultural Wind Erosion [1, 15-18]

Control measure	PM10 Control Efficiency	References/comments
Artificial wind barrier	64-88%	MRI, 1992. Assumes a 50% porosity fence.
	54-71%	Grantz et al, 1998. Control efficiency is for a wind fence.
	4-32%	Bilbro and Stout, 1999. Control efficiency based upon reduction in wind velocity by a wind fence made from plastic pipe with a range of optical density of from 12% to 75%.
Cover crop	90%	Washington State Univ., 1998.
Cross-wind ridges	24-93%	Grantz et al, 1998. Control efficiency is for furrows.
	40-80%	Washington State Univ., 1998.
Mulching	20-40%	Washington State Univ., 1998. Control efficiency is for straw.
Trees or shrubs planted as a windbreak	25%	Sierra Research, 1997. Control efficiency is for trees.

7.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 7-4. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

(Note: The Clark County website did not include regulatory language specific to agricultural wind erosion at the time this chapter was written.)

Table 7-4. Example Regulatory Formats for Agricultural Wind Erosion

Control measure	Goal	Threshold	Agency
Requires producers to draft and implement fugitive dust plan with approved control methods	Limits fugitive dust from agricultural sources		SJVAPCD Rule 8081 11/15/2001
Exemption from Rule 403 general requirements.	Limit PM10 Levels to 50 $\mu g/m^3$	Voluntary implementation of district approved conservation practices and complete/maintain self-monitoring plan	SCAQMD Rule 403 12/11/1998
Requires dust plan that contains procedures assuring moisture factor between 20%-40% for manure in top 3" of occupied pens and outlines manure management practices and removal	Reduce fugitive dust from livestock feed yards		ICAPCD Rule 420 8/13/2002
Dust suppressants, gravel, install shrubs/trees	Limit fugitive dust plume to 20% opacity	Commercial feedlot/livestock area; shrubs/trees 50ft-100ft from animal pens; compliance with stabilization limitation	Maricopa County Rule 310.01 02/16/2000
Record keeping for all ctrl measure taken	Ensure that appropriate ctrl measures are implemented and maintained	All ops subject to Rule 310.01, provided within 48 hrs of ctrl officer request	Maricopa County Rule 310.01 02/16/2000

7.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 7-5summarizes the compliance tools that are applicable to agricultural wind erosion.

Table 7-5. Compliance Tools for Agricultural Wind Erosion

Record keeping	Site inspection/monitoring
Land condition by date (e.g., vegetation; furrowing of fallow land; soil crusts), including residue management and percentages; meteorological log; establishment/ maintenance of windbreaks.	Observation of land condition (crusts, furrows), especially during period of high winds.

7.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from agricultural wind erosion. A sample cost-effectiveness calculation is presented below for a specific control measure (adding a straw mulch to the field) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for agricultural wind erosion, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Agricultural Wind Erosion

Step 1. Determine source activity and control application parameters.

Field size (acres)	320
Control Measure	1,000 lb mulch per acre
Control application/frequency	Once post-harvesting
Control Efficiency	30%

The field size is an assumed value, for illustrative purposes. Adding a straw mulch to the field at a rate of 1,000 lbs per acre has been chosen as the applied control measure. The control application/frequency and control efficiency are default values provided by WSU, 1998.

Step 2. Calculate Pm10 Emission Factor. The PM10 emission factor is calculated from AP-42 equation utilizing the appropriate correction parameters:

E (tons/acre-year) = 0.5 A I K C L' V'

A	0.025
I – soil erodibility (tons/acre-year)	86
K- surface roughness factor	0.50
Climatic factor	0.33
Unsheltered field width factor	0.70
Vegetative cover factor	0.25

E = 0.031 tons/acre-year

[Note: the correction parameters above were selected for illustrative purposes.]

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor (given in Step 2) is multiplied by the field size (under activity data) to compute the annual PM10 emissions in tons per year, as follows:

Annual emissions = (Emission Factor x Field Size)
Annual PM10 emissions = (0.031 x 320) = 9.9 tons

Annual PM2.5 emissions = 0.15 x PM10 emissions[7] = 0.15 x 9.9 tons = 1.5 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 conservation tilling as our control measure. Based on a control efficiency estimate of 30%, the annual controlled emissions are calculated to be:

Annual Controlled PM10 emissions = (9.9 tons) x (1 – 0.3) = 6.9 tons
Annual Controlled PM2.5 emissions = (1.5 tons) x (1 – 0.3) = 1.0 tons

Step 5. Determine Annual Cost to Control PM Emissions.

The Annual Cost of mulching is calculated by multiplying the number of acres by the cost per acre. The cost of mulching is assigned a value of $40 per acre.[17] Thus, the Annual Cost is estimated to be: 320 x 40 = $12,800

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annual cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost-effectiveness = Annual Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = $12,800 / (9.9 – 6.9) = $4,295/ton
Cost-effectiveness for PM2.5 emissions = $12,800 / (1.5 – 1.0) = $28,636/ton

7.7 References

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Chapter 8. Open Area Wind Erosion

8.1 Characterization of Source Emissions

Dust emissions may be generated by wind erosion of open areas of exposed soils or other aggregate materials within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter [cm] in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that: (a) threshold wind speeds exceed 5 meters per second (m/s) (11 miles per hour [mph]) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential. Loose soils or other aggregate materials consisting of sand-sized materials act as an unlimited reservoir of erodible material and can sustain emissions for periods of hours without substantial decreases in emission rates.

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7 to 10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude. The routinely measured meteorological variable that best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement that has passed by the 1-mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 mph), matches well with the half-life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution as follows:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \tag{1}$$

where,

u = wind speed (cm/s)
u^* = friction velocity (cm/s)
z = height above test surface (cm)
z_o = roughness height (cm)
0.4 = von Karman's constant (dimensionless)

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_o) is a measure of the roughness of the exposed surface as determined from the y-intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 8-1 for a roughness height of 0.1 cm.

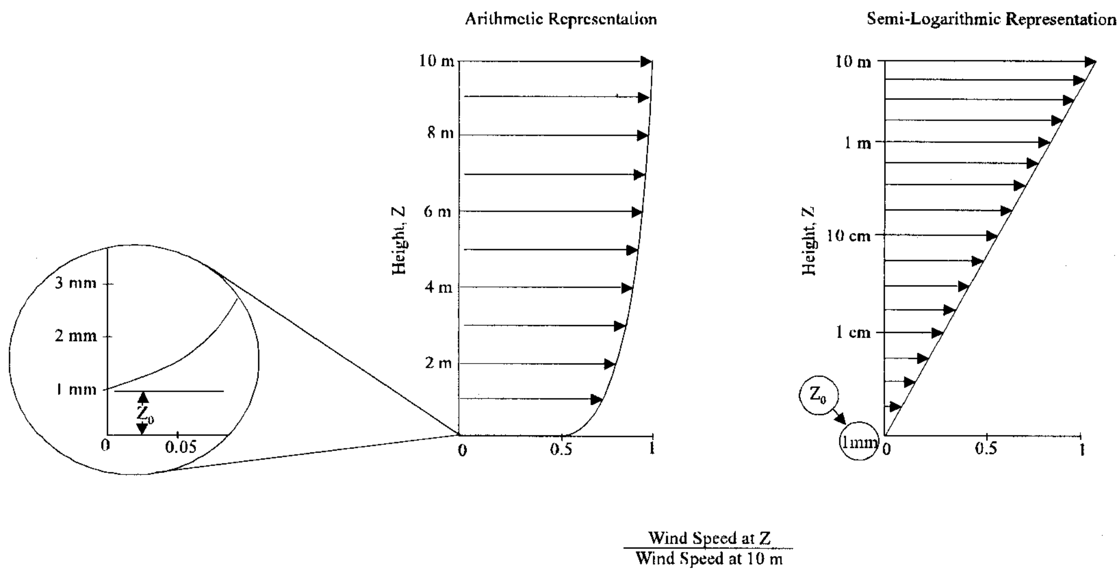

Figure 8-1. Illustration of Logarithmic Wind Velocity Profile

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action that results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

8.2 Emission Estimation: Primary Methodology[1-11]

This section was adapted from Section 13.2.5 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.5 was last updated in January 1995.

The PM10 emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter (g/m^2) per year as follows:

$$\text{PM10 Emission Factor} = 0.5 \sum_{i=1}^{N} P_i \qquad (2)$$

where,

N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances (g/m^2)

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365 per year, and for a surface disturbance once every 6 months, N = 2 per year. The erosion potential function for a dry, exposed surface is given as:

$$P = 58\,(u^* - u_t^*)^2 + 25\,(u^* - u_t^*) \qquad (3)$$
$$P = 0 \quad \text{for } u^* \leq u_t^*$$

where,

u^* = friction velocity (m/s)
u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately. The PM2.5/PM10 ratio for windblown fugitive dust posted on EPA's CHIEF website is 0.15. This ratio is based on the analysis conducted by MRI on behalf of WRAP.[11]

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady-state emission rates. For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below.

FIELD PROCEDURE FOR DETERMINING THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil[5])

Step 1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.

Step 2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm by 30 cm.

Step 3. Pour the sample into the top sieve (4-mm opening), and place a lid on the top.

Step 4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

Step 5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i.e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.

Step 6. Determine the threshold friction velocity from Table 8-1.

The results of the sieving can be interpreted using Table 8-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution using the graphical relationship described by Gillette.[5, 6] If the surface material contains nonerodible elements that are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of the elements must be taken into account by increasing the threshold friction velocity.[10]

Table 8-1 Field Procedure for Determination of Threshold Friction Velocity (Metric Units)

Tyler Sieve No.	Opening (mm)	Midpoint (mm)	u_t* (cm/s)
5	4		
9	2	3	100
16	1	1.5	76
32	0.5	0.75	58
60	0.25	0.375	43

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 8-2.

Table 8-2. Threshold Friction Velocities (Metric Units)

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)	
			z_o = Actual	z_o = 0.5 cm
Overburden[a]	1.02	0.3	21	19
Scoria (roadbed material)[a]	1.33	0.3	27	25
Ground coal (surrounding coal pile)[a]	0.55	0.01	16	10
Uncrusted coal pile[a]	1.12	0.3	23	21
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12
Fine coal dust on concrete pad[c]	0.54	0.2	11	10

[a] Western surface coal mine; reference 2.
[b] Lightly crusted.
[c] Eastern power plant; reference 3.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly local climatological data (LCD) summaries for the nearest reporting weather station that is representative of the site in question.[7] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10-m reference height using Equation 1. To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\ u_{10}^+ \qquad (4)$$

where,

u^* = friction velocity (m/s)
u_{10}^+ = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat exposed areas with little penetration into the surface wind layer.

8.3 Emission Estimation: Alternate Methodology

Duane Ono with the Great Basin Unified APCD and Dale Gillette developed a method called the Dust ID method to measure fugitive PM10 dust emissions due to wind erosion that has been approved for use in PM10 SIPs.[12, 13] This method has been applied to the dry lake bed at Owens Lake, CA using an extensive sand flux monitoring network. Owens Lake is the largest single source of fugitive dust in the United States (estimated to be ~80,000 tons PM10/year). The network consisted of co-located electronic Sensits and passive Cox Sand Catchers (CSCs) deployed on a 1 km x 1 km grid covering 135 square kilometers of the lake bed with their sensor or inlet positioned 15 cm above the surface. Sensits measure the kinetic energy or the particle counts of sand-sized particles as they saltate across the surface. Due to differences in the electronic response of individual Sensits, these units had to be co-located with passive sand flux measurement devices to calibrate their electronic output and to determine the hourly sand flux. The battery powered Sensits were augmented with a solar charging system. A data logger recorded hourly Sensit data during inactive periods and switched to 5-minute data during active erosion periods. CSC's are passive instruments that are used to collect sand-sized particles that are blown across the surface during a dust event. These instruments were designed and built by the Great Basin Unified Air Pollution Control District as a reliable, low-cost instrument that could withstand the harsh conditions at Owens Lake. CSC's have no moving parts and can collect sand for a month at Owens Lake without overloading the collector. As an alternative to hourly sand (saltation) flux measurements relying on Sensits, Ono[14] found that monthly sand flux measurements obtained with CSCs could be applied to a model developed by Gillette et al.[15] to provide a good estimate of hourly sand flux rates.

Hourly PM10 emissions from each square kilometer of the lake bed were estimated from the following equation:

$$F_a = K_f \times q$$

where, F_a = PM10 emissions flux ($g/cm^2/hr$)

q = hourly sand flux ($g/cm^2/hr$) measured at 15 cm above the surface

K_f , called the K-factor, = proportionality factor relating the PM10 emissions flux to the sand flux measured at 15 cm above the surface.

K_f values were determined by comparing CALPUFF model predictions, based on meteorological data from thirteen 10-meter towers and an Upper Air Wind Profiler to generate wind fields using the CALMET model, to observed hourly PM10 concentrations measured at six PM10 monitoring sites utilizing TEOM PM10 monitors. A K-factor of 5×10^{-5} was used to initially run the model and to generate PM10 concentration values that were close to the monitored concentrations. Hourly K-factor values were later adjusted in a post-processing step to determine the K-factor value that would have made the modeled concentration match the monitored concentration at each of the six PM10 monitor sites using the following equation:

$$K_f = K_i [(C_{obs} – C_{bac})/C_{mod}]$$

where, K_i = initial K-factor (5 x 10^{-5})

$C_{obs.}$ = observed hourly PM10 concentration ($\mu g/m^3$)

$C_{bac.}$ = background PM10 concentration (assumed to be 20 $\mu g/m^3$)

$C_{mod.}$ = model-predicted hourly PM10 concentration ($\mu g/m^3$)

The results showed that K_f changed spatially and temporally at Owens Lake and that the changes corresponded to different soil textures on the lake bed and to seasonal surface changes that affected erodibility. The results also showed that some source areas were active all year, while others were seasonal and sometimes sporadic. Wind tunnel tests at Owens Lake independently confirmed these seasonal and spatial changes in K_f. Ono et al.[12] concluded that the emission estimates using their Dust ID method were more accurate than the AP-42 method for estimating daily emissions, since the emissions estimates correspond to measured hourly wind erosion on the lake bed. For daily emissions, Ono and co-workers believe that AP-42 drastically overestimates the emissions at low wind speed conditions, and underestimates emissions at high wind speeds. This large discrepancy in the emission estimates is due to the use of a single threshold friction velocity for the entire erosion area in the AP-42 method. The AP-42 method and the Dust ID method of estimating emissions resulted in very close agreement for the annual emissions.

8.4 Emission Estimation: Other Methodologies

Several alternative emission estimation methods for open area wind erosion have been developed that are still in the developmental stage and have not yet been approved by federal or state agencies. Thus, the reader is cautioned in the use of these methods.

8.4.1 MacDougall Method

MacDougall developed a method for estimating fugitive dust emissions from wind erosion of vacant land.[16] This method, which relies heavily on emission factors developed for different vacant land parcels using wind tunnels. The availability of wind tunnel results for the types of vacant land being assessed must be considered when deciding to use this method for other applications. It should be pointed out that in 2003 Environ (under contract to the Western Governors' Association) abandoned this approach due to the paucity of sufficient wind tunnel data for many different vacant land parcels in the western U.S.[17] Also, the WRAP's fugitive dust expert panel had major reservations regarding the MacDougall method.[18] Panel members were skeptical about using the proposed methodology since wind tunnels have shortcomings and do not represent actual conditions in nature. The panel concluded that determining emission factors in the manner proposed will result in significant underestimation of windblown dust for those cases where saltation plays a role. The six steps described in the MacDougall method are summarized below.

<u>Step 1: Categorizing Vacant Land.</u> Vacant land within the study area must be categorized based upon the potential of the parcels to emit fugitive dust during wind

events. Many wind tunnel studies have been conducted in the western United States, and the vacant land descriptions of the wind tunnel test areas should be used to categorize the vacant land within the study area. When categorizing vacant land, it is especially important whether the land has vegetation, rocks or other sheltering elements, whether the soil crust is intact or disturbed, and whether there are periodic activities on the vacant land such as vehicles or plowing that will change the land from fairly stable to unstable. Not every parcel of vacant land will necessarily fit into a category that has been wind tunnel tested. For parcels without a specific vacant land type wind tunnel test, assumptions will need to be made of the best representative land type and uncertainties noted.

Step 2: Identify Wind Tunnel Emission Factors. Based upon the vacant land categorization, wind tunnel results should be reviewed and applied appropriately to each category of vacant land. Wind tunnel results should be reviewed to determine if "spikes" from the initial portion of the test are presented separately or averaged into an hourly factor. Whenever possible, spikes should not be included in an hourly factor. The spike values should be included only at the beginning of each wind event.

Step 3: Develop Meteorological Data Set. For the area to be studied, hourly average wind speeds, rainfall, and if available peak wind gust data should be gathered. If a study area is particularly large, several different meteorological data sets may need to be gathered, and each land parcel matched with the meteorological data that impacts that parcel.

Step 4: Determine Land Type Reservoirs, Threshold Wind Velocities, Wind Events, and Rainfall Events. Based upon the wind tunnel results for each vacant land type, the wind speed when emissions were first measured for the vacant land type, should be set as the threshold wind speed. Most vacant land does not have an endless reservoir of fugitive dust; however, land that has a high degree of disturbance will continue to emit throughout a wind event. Therefore, for each vacant land type, the wind tunnel results should be reviewed and a determination made on the length of time the parcel will emit for a give wind event. It is recommended that an assumption be made that parcels with sheltering elements, vegetated parcels, or parcels with a soil crust will only emit during the first hour of a wind event. Parcels with a relatively high silt component or with frequent disturbance will probably continue to emit throughout a wind event. Because most threshold wind speeds are relatively high (i.e., sustained hourly winds of 25 to 30 mph), a wind event may be defined as any time period when winds reach the threshold wind velocities separated by at least 24 hours before a new wind event is defined. Depending on the soils in an area, rain may have a large impact on wind erosion. Days with rain should not be included in the inventory.

Step 5: Develop Emission Inventory Specific Emission Factors. Using the reservoir determination, threshold wind speeds, wind event determination and rainfall factors, determine hours when wind conditions produced emissions from each vacant land parcel for the time period of the emission inventory. The number of hours with wind speeds in each wind speed category should be totaled. The number of hours can then be multiplied by the wind tunnel emission factor and a total emission factor for the time period of the inventory can be calculated. The emission factor equations for vacant land with and without sustained emissions are given as follows:

(a) With sustained emissions: $EF_1 = (\sum (H\ P))$

where, EF_1 = PM10 emission factor (lb/acre)
H = number of hours when wind conditions result in emissions
P = emission factor for a given vacant land category (lb/hour-acre)

(b) Without sustained emissions: $EF_1 = (\sum (W\ P))$

where, EF_1 = PM10 emission factor (lb/acre)
W = number of wind events when wind conditions result in emissions
P = emission factor for a given vacant land category (lb/acre)

The emission factor equation for spike emissions is given as:

$$EF_2 = (\sum (E\ S))$$

where, EF_2 = spike PM10 emission factor (lb/acre)
E = number of events producing spike emissions
S = spike mass for a given vacant land category (lb/acre)

Emission factors will vary from time period to time period and from vacant land type to vacant land type. Generally speaking, disturbed lands will have unlimited reservoirs and lower threshold wind velocities leading to much higher emissions than stable or sheltered parcels with one hour reservoirs. An emission factor should be developed for each vacant land category in the inventory.

Step 6: Apply Emission Inventory Specific Emission Factors to Vacant Land Categories. Once emission inventory emission factors have been developed, the number of acres in each category should be multiplied by the factor and the emissions totaled. It may be useful to develop certain factors over shorter time periods and then total the emissions over a longer time period. For example, one may want to develop winter factors and summer factors and then total them together for the annual inventory. For large areas, where vacant land categories will change over the duration of an inventory or different meteorological data sets will apply, it is advisable to subdivide the inventory by time period or area, and then total the inventory at the end. Annual emissions for each vacant land category are calculated as follows:

$$E = A\ (EF_1 + EF_2)$$

where, E = annual emissions for a given vacant land category
A = vacant land category acreage
EF_1 = annual emission factor for a given vacant land category
EF_2 = spike emission factor for a given vacant land category

8.4.2 Draxler Method

Based on an evaluation of available algorithms for calculating wind blown fugitive dust emissions, the WRAP expert fugitive dust panel[18] recommended the use of the algorithm developed by Draxler et al.[19] that was based on the earlier work of Marticorena et al.[20] This algorithm received the highest score on the basis of extensive field verification test results and having undergone peer review. Draxler and coworkers developed their algorithm for estimating fugitive dust emissions during desert dust storms in Iraq, Kuwait, and Saudi Arabia using a Lagrangian transport and dispersion model where the vertical dust flux was proportional to the difference in the squares of the friction velocity and threshold friction velocity. A proportionality constant was used to relate the surface soil texture to the PM10 dust emissions, and is defined as the ratio of vertical flux of PM10 to total aeolian horizontal mass flux. PM10 emissions caused by wind erosion were estimated in a stepwise process as follows:

Step I. Obtain large scale and small scale wind fields
Step II. Estimate sand movement (horizontal flux of saltation particles ≥50 μm)
Step III. Calculate vertical resuspended dust emissions

The horizontal flux of sand, Q (μg/meter-second), was modeled as follows:

$$Q = A\,(\rho/g)\,u^{*}\,(u^{*2} - u^{*2}_{t})$$

where, A = a dimensionless constant
ρ = the density of air
g = the acceleration due to gravity
u^{*} = the friction velocity (m/s)
u^{*}_{t} = the threshold friction velocity (m/s) required for initiation of sand movement by the wind.

The value of A is not constant if there is wetting followed by crusting of the surface sediments, or if there is a depletion of loose particles on the surface for a "supply-limited" surface. The value of A ranges from a maximum of ~3.5 when the surface is covered with loose sand to ~0 when the surface has a smooth crust with few loose particles larger than 1 mm. Suspended dust is proportional to saltation or sandblasting as follows:

$$F = K\,Q$$

where, F = the vertical flux of dust (μg/m^2-second)
K = proportionality factor (m^{-1}) that relates the surface soil texture to PM10 dust emissions
Q = the horizontal flux of saltating particles (μg/m-second)

The value of K is not precisely known, but data sets of F versus Q are available so that estimates of K can be made for certain soils. For sand textured soils, K is estimated to be ~5.6 x 10^{-4} m^{-1} and A is ~2.8.

8.4.3 UNLV Method

James and co-workers with the University of Nevada Las Vegas (UNLV) developed a wind blown dust inventory for Clark County, NV based on wind tunnel measurements.[21] The method involved deriving estimates of wind blown fugitive dust emission factors for three categories of vacant land: disturbed vacant land, stabilized vacant land, and undisturbed native desert soils. The emission factors included geometric mean hourly "spike" corrected emission rates (tons/acre-hour) for disturbed vacant land, stabilized vacant land and undisturbed native desert soils as well as geometric mean spike emissions (ton/acre) for disturbed vacant land and undisturbed native desert soils as a function of wind speed and soil type. The emission inventory assumed that the particulate reservoir for disturbed vacant land had no limit. For every hour the sustained wind speeds were within a given wind speed category above the "spike" wind speed, the emissions were calculated. A single "spike" mass was added for each acre of vacant land for those days that the wind speed exceeded a threshold wind speed, assuming each day represented a single wind event and reservoir recharging would not have occurred during a 24-hour period. Wind speeds less than the "spike" speed were not included in the emission calculations. Because the native desert parcels have a limited PM10 reservoir, it was assumed that the reservoir would be depleted within one hour of sustained winds above the "spike" wind speed. Therefore, only one hour of emissions were calculated during each day that winds exceeded the threshold friction velocity ("spike" wind speed) for native desert parcels.

The wind speed threshold for generating fugitive dust emissions was estimated by James et al.[21] to be 20 mph for disturbed vacant land and 25 mph for native desert parcels. Because the parcels stabilized with dust suppressants had been subjected to some disturbance by vehicle traffic that may have caused some dust palliatives to break down, the initial wind threshold for this category was lower than the other categories, namely 15 mph. However, the use of dust palliatives greatly reduced the overall emission factors. Spikes were generally not observed from the stabilized parcels, and emission factors without spike corrections were used for stabilized parcels. As with native desert, it was assumed that the stabilized parcels have a limited PM10 reservoir that would be depleted within one hour of sustained winds above the threshold wind velocity. Therefore, only one hour of emissions was calculated during each day for stabilized parcels.

For a sustained wind speed of 25 mph, the geometric mean hourly spike corrected emission factors across all soil types for Clark County were estimated to be ~5 x 10^{-3} ton/acre-hour for disturbed vacant land, ~2 x 10^{-3} ton/acre-hour for native desert, and ~2 x 10^{-4} ton/acre-hour for stabilized land. The geometric mean spike emissions for a sustained wind speed of 25 mph were estimated to be ~2 x 10^{-3} ton/acre for disturbed vacant land and ~5 x 10^{-4} ton/acre for undisturbed native desert parcels. It should be pointed out that there was significant scatter in the observed data, with within category variability ranging over 1 to 2 orders of magnitude.

8.4.4 WRAP RMC Method

The Dust Emissions Joint Forum (DEJF) of the Western Regional Air Partnership contracted with ENVIRON to develop a particulate emission calculation method for open area wind erosion in 2003. The DEJF extended ENVIRON's original contract (Phase 2) to provide windblown dust emissions inventories, and perform modeling simulations of the effects of those emissions on regional haze for calendar year 2002 and future year projections. The purpose of this additional effort was to improve the windblown dust emissions model developed as part of Phase 1. The results of the initial model runs and subsequent sensitivity simulations had demonstrated a need to revise and/or update various assumptions associated with the development of the emission inventory. To this end, revised estimation methodologies and algorithms were evaluated in Phase 2 in order to address various shortcomings and limitations of the Phase 1 version of the model. Many of the assumptions employed in the Phase 1 methodology were necessitated by a lack of specificity in the underlying data used to characterize vacant land types and soil conditions in relation to the potential for wind erosion. Even in Phase 2, it was necessary to rely on some assumptions where data were lacking.

Summary of the WRAP RMC Method

The WRAP RMC windblown dust method utilizes wind tunnel-based emission algorithms for different soils and accounts for land use and local meteorology. The complete set of documents that describe the method in full detail may be found at www.wrapair.org. The summary of the method presented below is based on ENVIRON's final report submitted to the DEJF on May 5, 2006.[22]

There are two important factors for characterizing the dust emission process from an erodible surface. They are (a) the threshold friction velocity that defines the inception of the emission process as a function of the wind speed as influenced by the surface characteristics, and (b) the strength of the emissions that follow the commencement of particle movement. The two critical factors affecting emission strength are the wind speed (wind friction velocity) that drives the saltation system, and the soil characteristics.

Friction Velocities Surface friction velocities are determined from the aerodynamic surface roughness lengths and the 10-meter wind speeds based on MM5 model simulations. Friction velocity, u_*, is related to the slope of the velocity versus the natural logarithm of height through the relationship:

$$\frac{u_z}{u_*} = \frac{1}{\kappa} \ln \frac{z}{z_o}$$

where u_z = wind velocity at height z (m/s)
u_* = friction velocity (m/s)
κ = von Karman's constant (0.4)
z_0 = aerodynamic roughness height (m)

The threshold friction velocities, u_{*t}, are determined from the relationships developed by Marticorena et al.[20] as a function of the aerodynamic surface roughness length, z_0. Figure 8-2 shows the comparison between Marticorena's modeled relationship of threshold friction velocity and aerodynamic surface roughness length and wind tunnel data obtained by different investigators.[23 – 26]

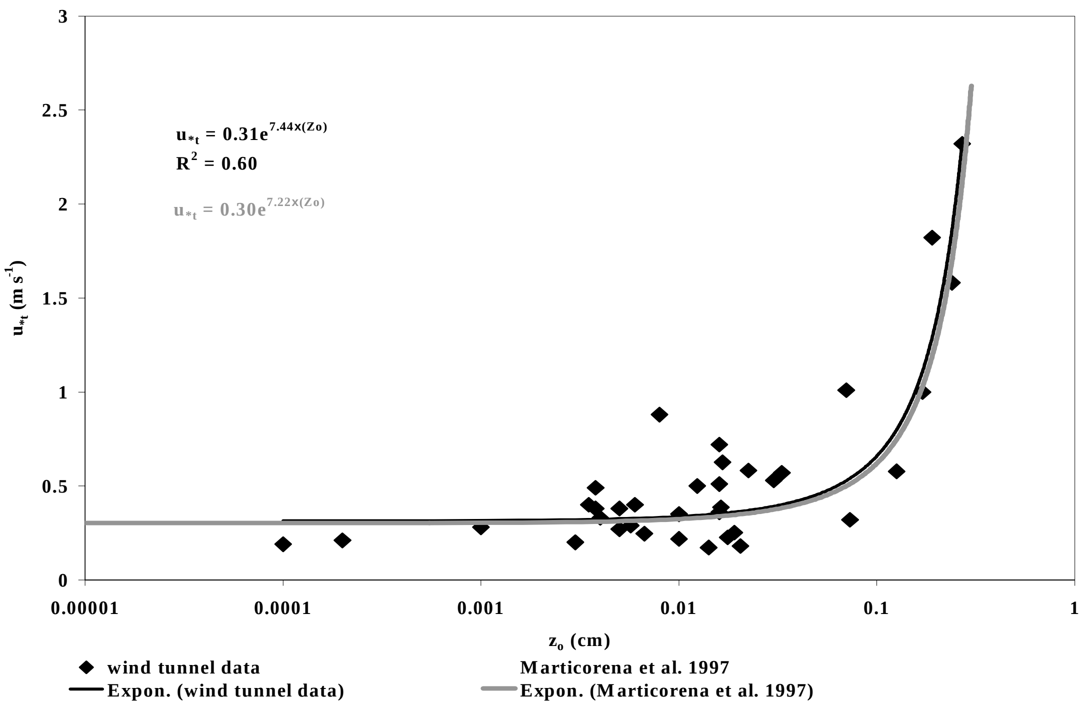

Figure 8-2. Threshold Friction Velocity vs. Aerodynamic Roughness Length

Surface friction velocities, including the threshold friction velocity, are a function of the aerodynamic surface roughness lengths. The surface friction velocities are in turn dependent on surface characteristics, particularly land use/land cover. While these values can vary considerable for a given land type, published data are available which provide a range of surface friction velocities for various land use types and vegetation cover. These data are presented in Table 8-3.

Table 8-3. Threshold Friction Velocities for Typical Surface Types [23-26]

Site Type	Undisturbed u_{*t} (m/s)	Disturbed u_{*t} (m/s)	% change [1-(dist./undist.)]
agricultural fields	1.29	0.55	0.57
alluvial fan	0.72	0.60	0.17
desert flat	0.75	0.51	0.32
desert pavement	2.17	0.59	0.73
fan surface	1.43	0.47	0.67
playa, crusted	2.13	0.63	0.70
playa	1.46	0.58	0.60
prairie	2.90	0.24	0.92
sand dune	0.44	0.32	0.27

Emission Fluxes Emission fluxes, or emission rates, are determined as a function of surface friction velocity and soil texture. The relationships that Chatenet et al.[27] established between the 12 soil types in the classical soil texture triangle and their four dry soil types (silt [FSS], sandy silt [FS], silty sand [MS], and sand [CS]) are of key importance. The relationships developed by Alfaro and others[28, 29] for each of the soil texture groups are used to estimate dust emission fluxes. These relationships are presented in Figure 8-3.

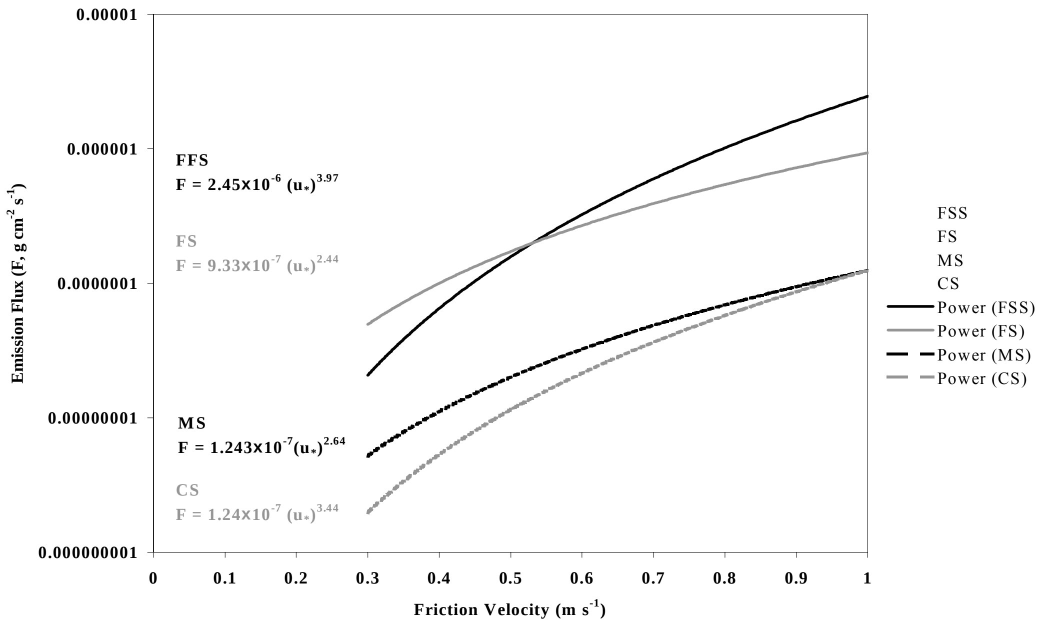

Figure 8-3. Emission Flux vs. Friction Velocity Predicted by the Alfaro and Gomes Model[28] Constrained by the Four Soil Classes of Alfaro et al.[29]

Reservoir Characteristics Reservoirs are classified as limited for stable land parcels and unlimited for unstable land parcels. Classification of reservoirs as limited or unlimited has implications with respect to the duration of time over which the dust emissions are generated. In general, the reservoirs should be classified in terms of the type of soils, the depth of the soil layer, soil moisture content and meteorological parameters. Finally, the time required for a reservoir to recharge following a wind event is influenced by a number of factors including precipitation and snow events and freezing conditions of the soils. A recharge time of 24 hours is assigned to all surfaces. In addition, it is assumed that no surface will generate emissions for more than 10 hours in any 24-hour period.

The duration and amount of precipitation and snow and freeze events will also affect the dust emissions from wind erosion. Barnard[30] has compiled a set of conditions for treating these events based on seasons, soil characteristics and the amounts of rainfall and snow cover. The time necessary to re-initiate wind erosion after a precipitation event ranges from 1 to 10 days, depending on the soil type, season of the year and whether the rainfall amount exceeds 2 inches.

Soil Disturbance The disturbance level of a surface more appropriately has the effect of lowering the threshold surface friction velocity. Except for agricultural lands, which are treated separately in the model as described below, vacant land parcels are typically undisturbed unless some activity is present such as to cause a disturbance (e.g., off-road vehicle activity in desert lands, or animal grazing on rangelands). It is recommended that all non-agricultural land types be considered undisturbed, since there is no *a priori* information to indicate otherwise for the regional scale modeling domain to be considered. Therefore, for the purpose of evaluating the sensitivity of the model to disturbance levels, all grassland, shrubland and barren land areas are assumed to have 10 % of their land area disturbed. Threshold surface friction velocities for these disturbed lands are assigned as follows: 3.1 m/s for grasslands and shrublands, and 0.82 m/s for barren land.

Soil Characteristics Application of the emission factor relations described above requires the characterization of soil texture in terms of the four soil groups considered by the model. The characteristics or type of soil is one of the parameters of primary importance for the application of the emission estimation relations derived from wind tunnel study results. The State Soil Geographic Database (STATSGO) available from the USDA[31] is used to determine the type of soils present in the modeling domain for which the emission inventory is developed. The classification of soil textures and soil group codes is based on the standard soil triangle that classifies soil texture in terms of percent sand, silt and clay. Combining the soil groups defined by the work of Alfaro et al.[29] and Chatenet et al.[27] and the standard soil triangle provides the mapping of the 12 soil textures to the four soil groups considered in their study. The soil texture mappings are summarized in Table 8-4.

Table 8-4. STATSGO Soil Texture and Soil Group Codes

STATSGO Soil Texture	Soil Texture Code	Soil Group	Soil Group Code
No Data	0	N/A	0
Sand	1	CS	4
Loamy Sand	2	CS	4
Sandy Loam	3	MS	3
Silt Loam	4	FS	1
Silt	5	FSS	2
Loam	6	MS	3
Sandy Clay Loam	7	MS	3
Silty Clay Loam	8	FSS	1
Clay Loam	9	MS	3
Sandy Clay	10	MS	3
Silty Clay	11	FSS	1
Clay	12	FS	2

Surface Roughness Lengths Surface roughness lengths can vary considerably for a given land type, as evidenced by examination of the data in Table 8-5. Surface roughness lengths are assigned as a function of land use type based on a review of the information in Table 8-5. The disturbance level of various surfaces has the effect of altering the surface roughness lengths, which in turn impact the potential for vacant lands to emit dust from wind erosion

Table 8-5. Aerodynamic Surface Aerodynamic Roughness Lengths, Z_0

Site Type	Average z_o (cm)	Reference(s)
agricultural fields (bare)	0.031	23 - 26
desert flat/pavement	0.133	23 - 26
fan surface	0.088	23 - 26
playa, crusted	0.059	23 - 26
playa	0.057	23 - 26
prairie	0.049	23 - 26
sand dune	0.007	23 - 26
scrub desert	0.045	26
sparse veg. (0.04% cover)	0.37	33
sparse veg. (8% cover)	5.4	33
sparse veg. (10.3% cover)	6.8	33
sparse veg. (13.5% cover)	7.2	33
sparse veg. (26% cover)	8.3	33
thick grass	2.3	34
thin grass	5	34
sparse grass	0.12	35
agricultural crops	2-4	35
orchards	50-100	35
decid. forests	100-600	35
conf. forests	100-600	35
agricultural crops	15	36
urban	100	36
decid. forests (closed canopy)	121	36
conif. forests (closed canopy)	134	36

An examination of Figure 8-2, which relates the threshold surface friction velocity to the aerodynamic surface roughness length, reveals that for surface roughness lengths larger than approximately 0.1 cm, the threshold friction velocities increase rapidly above values that can be realistically expected to occur in the meteorological data used in the model implementation. Therefore to simplify the model implementation, only those land types with roughness length less than or equal to 0.1 cm are considered as potentially erodible surfaces.

For a given surface roughness, as determined by the land use type[32], the threshold friction velocity has a constant value. Thus, the land use data is mapped to an internal dust code used within the model to minimize computer resource requirements and coding efforts. The mapping of land use types to dust codes 3 and above (except for code 5 that applies to orchards and vineyards) is presented in Table 8-6, which summarizes the surface characteristics by dust code. [Note: Dust codes 1 and 2 refer to water/wetlands and forest/urban, respectively.]

Table 8-6. Surface Characteristics by Dust Code and Land Use Category

Dust Code	3	4	6	7
Land use category	Agricultural	Grassland	Shrubland	Barren
Surface roughness length, $Z_{0\ (cm)}$	0.031	0.1	0.05	0.002
Threshold friction velocity (m/s)	3.72	6.17	4.30	3.04
Threshold wind velocity at 10 meter height (m/s [mph])	13.2 [29.5]	19.8 [44.3]	14.6 [32.8]	12.7 [28.5]

Meteorology Gridded hourly meteorological data, which is required for the dust estimation methodology is based on MM5 model simulation results. Data fields required include wind speeds, precipitation rates, soil temperatures and ice/snow cover.

Agricultural Land Adjustments Unlike other types of vacant land, windblown dust emissions from agricultural land are subject to a number of non-climatic influences, including irrigation and seasonal crop growth. As a result, several non-climatic correction or adjustment factors were developed for applicability to the agricultural wind erosion emissions. These factors included:

- Long-term effects of irrigation (i.e., soil "clodiness")
- Crop canopy cover
- Post-harvest vegetative cover (i.e., residue)
- Bare soil (i.e., barren areas within an agriculture field that do not develop crop canopy for various reasons, etc.)
- Field borders (i.e., bare areas surrounding and adjacent to agricultural fields)

The methodology used to develop individual non-climatic correction factors was based upon previous work performed by the California Air Resources Board in their development of California-specific adjustment factors for the USDA's Wind Erosion Equation.[37]

Other Adjustments Two other adjustments to modeled air quality impacts relate to fugitive dust transportability and partitioning between fine and coarse fractions of PM10. Transportability fractions as a function of land use are assigned on the basis of the methodology described by Pace.[38] New fine fraction values developed by Cowherd[39] from controlled wind tunnel studies of western soils are applied to determine the fine and coarse fractions of wind-generated fugitive dust emissions.

Concerns Regarding the Method

ENVIRON's methodology for calculating wind-generated fugitive dust emissions relies on several assumptions that may not be valid. As was mentioned above, many of the assumptions employed in Phase 1 were necessitated by a lack of specificity in the underlying data used to characterize vacant land types and soil conditions in relation to the potential for wind erosion. Even in Phase 2, it was necessary to rely on some assumptions where data were lacking.

The pertinent vacant land characteristics that are most difficult to characterize are the dust reservoir capacities and resuspension characteristics in relation to the levels of surface disturbance and the presence of protective surface elements (vegetation, rocks). Another complex feature is the recharge time needed to re-establish all or part of the reservoir after depletion by a wind erosion event.

Surface disturbance tends to have a much stronger impact than soil type in providing a high dust reservoir capacity. If the surface is disturbed in such a way that non-erodible elements are minimized, it can be considered as having an "unlimited" erosion potential. This means that the reservoir is large enough to support hours of fine particle emissions during a high-wind event. Therefore, it is important any PM10 emission models or empirical relationships account for not only the soil type but also the state of aggregation of the exposed surface material.

After a surface disturbance that creates an unlimited reservoir of available particles, precipitation events can have a major effect in restoring a surface crust and place the surface in a stable condition for an indefinite period. When this occurs, typically a "limited" reservoir will be present on the surface. This reservoir contains only minor amounts of accumulated deposition from previous area-wide wind erosion events or from other more localized fugitive dust sources such as unpaved roads.

Because of the complexity of determining dust reservoir characteristics and their dynamic features, the Phase 2 methodology also tends to rely on assigned characteristics that do not appear to be well founded for most areas subject to wind erosion. For example, the assumed recharge period of only 24 hours is usually unrealistic. For example in the case of agricultural land, this would require a major disturbance to the soil such as a tilling operation that brings fresh, loose and dry soil to the surface. In the absence of a major surface disturbance, actual recharge times may extend to weeks and even months.[40] In some cases, however, a stable surface can transition to a highly erodible state in the absence of mechanical disturbance. The highly alkaline soils at Owens Lake, California for instance are fairly stable during summer months, but can change to a very unstable surface in the winter and spring following periods with precipitation and cold temperatures.[12]

Another example of concern is the value assumed in the Phase 2 model for the estimated time after a precipitation event that it takes to re-initiate wind erosion. The times given for full restoration of the dust reservoir are in the range of 1 to 4 days, depending on the soil type and whether the precipitation exceeded 2 inches. These values are at variance with the results of a multiyear field study conducted by Cowherd et al. in the western Mojave Desert.[41] That study showed that precipitation events of that order could re-stabilize soil surfaces for indefinite periods pending the next major surface disturbance. In the study area, scattered reservoirs of loose sand were stabilized by the presence of desert vegetation.

Stable soils in windy areas tend to have limited reservoirs of erodible particles consisting of a thin surface layer of deposition from previous high wind events. These layers have been homogenized by successive resusupension and atmospheric mixing during wind erosion over many years. This is illustrated by a recently completed inventory of vacant lands in the Las Vegas Valley.[42] This study showed that the vast majority of the land consisted of "native desert" as characterized by a single reflectance signature from satellite imagery with visible and infrared wavelength components. Landsat TM 5 with a 30-meter pixel size was found to provide a useful reflectance averaging that eliminated the effects of micro-features associated with uneven patterns of vegetation. The thin layers of erodible particles appear to exhibit a relatively uniform chemistry. Therefore, the known soil chemistry differences below the surface layer were not a confounding factor in establishing a single spectral signature for this vacant land category. On the other hand, areas where the soil had been turned as part of land preparation processes for construction projects could not be fitted to a single spectral signature because of surface soil chemistry differences.

Due to the paucity of wind tunnel data, Mansell et al.[17] developed fugitive dust emission factors for wind erosion of vacant land, based on soil texture rather than using area-specific wind tunnel data as recommended by MacDougall.[16] The emission fluxes for four soil aggregate populations were expressed in terms of friction velocity, based on test data from a relatively large portable wind tunnel. It was assumed that the flux would remain constant at any friction velocity for a period of 1 hour or 10 hours depending on whether the surface was classified as having a limited or unlimited reservoir respectively. Mansell and coworkers did not rely on the wind tunnel emission factors derived for Clark County by James et al.[21] because they appeared to be much greater than emission factors measured by other researchers using wind tunnels with a larger cross-section than the UNLV designed wind tunnel (6” wide by 6” high by 60” long).

It should be noted that because ENVIRON’s methodology assigns a very short recovery time on (a) replenishing soil losses from high wind events, and on (b) losing the mitigating effects of precipitation, the estimated emissions are driven mostly by wind speed. There is little accounting for the natural tendency of most unlimited reservoir surfaces to re-stabilize for long periods of time in the absence of major surface disturbances or large supplies of available loose sand that can abrade stable crusts. As noted in the land inventory of the Las Vegas Valley cited above, a frequent land disturbance pattern is found only on regularly traveled surfaces, with few exceptions.

Recommendations

In order to use ENVIRON’s methodology/model for calculating wind-generated fugitive dust emissions, it is strongly recommended that the user review the necessary inputs for the model, and refine the inputs if better information is available. If a wind blown dust inventory is needed for a planning area, local wind tunnel data, or erosion monitoring using CSC sand flux samplers based on the methodology described by Ono et al.[12] (see Section 8.3) is a very practical approach.

8.5 Demonstrated Control Techniques

Control measures for open area wind erosion are designed to stabilize the exposed surface (e.g., by armoring it with a less erodible cover material) or to shield it from the ambient wind. Table 8-7 presents a summary of control measures and reported control efficiencies for open area wind erosion.

Table 8-7. Control Efficiencies for Control Measures for Open Area Wind Erosion

Control measure	Source Component	PM10 Control Efficiency	References/comments
Apply dust suppressants to stabilize disturbed area after cessation of disturbance	Disturbed areas	84%	CARB, April 2002.[43]
Apply gravel to stabilize disturbed open areas	Disturbed areas	84%	CARB, April 2002.[43] Estimated to be as effective as chemical dust suppressants.

8.6 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 8-8. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/envsvc/air/ruledesc.asp

8.7 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Table 8-8. Example Regulatory Formats for Open Area Wind Erosion

Control measure	Goal	Threshold	Agency
Watering, fencing, paving, graveling, dust suppressant, vegetative cover, restrict vehicular access	Maintain soil moisture content min 12%; or 70% min of optimum soil moisture content; reduce windblown emissions	Construction sites; fences 3ft-5ft, adjacent to roadways/urban areas;	Maricopa County Rule 310 04/07/2004
Cease ops (wind speed >25mph); applying dust suppressant 2x hr; watering and fencing (as above); for after work hours: gravel, water 3x/day (possibly 4)	Reduce amt of windblown dust leaving site; maintain soil moisture content 12%	Wind speed must be >25mph for 60 min average; fencing must be 3ft-5ft with <50% porosity; watering for after work, holidays, weekends increase to 4x/day during wind event	Maricopa County Rule 310 04/07/2004
Use of one of following for dust control on all disturbed soil to maintain in damp condition: soil crusted over by watering or other, or graveling or treated with dust suppressant	Prevent visible fugitive dust from exceeding 20% opacity, and prevent dust plume from extending more than 100 yd		Clark County Sect. 94 Air Quality Reg. 06/22/2000
Requires application of water or chemical stabilizers prior to wind event 3 times a day (possible increase to 4 times a day if evidence of wind driven dust), or establish a vegetative cover within 21 days after active operations have ceased to maintain a stabilized surface for 6 months		For operations that remain inactive for not more than 4 consecutive days	SCAQMD Rule 403 12/11/1998

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 8-9 summarizes the compliance tools that are applicable to open area wind erosion.

Table 8-9. Compliance Tools for Open Area Wind Erosion

Record keeping	Site inspection/monitoring
Soil stabilization methods; application frequencies, rates, and times for dust suppressants; establishment/ maintenance of wind breaks.	Crust strength determination (e.g., drop ball test); observation of operation of dust suppression systems; inspection of heights and porosities of windbreaks.

8.8 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from open area wind erosion. A sample cost-effectiveness calculation is presented below for a specific control measure (apply gravel) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for open area wind erosion, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation For Open Area Wind Erosion (Dirt Parking Lot)

Step 1. Determine source activity and control application parameters.

Area of dirt parking lot	10,000 m^2
Disturbance frequency per day	1
Duration of exposure (months)	12
Roughness height (cm)	0.5
Threshold peak wind speed at height of 10 m (m/s)	10

Control Measure	Apply gravel
Control application/frequency	Once every years
Economic Life of Control System (yr)	5
Threshold friction velocity for gravel (m/s)	1.9
Control Efficiency (%)	84
Reference for Control Efficiency	Sierra Research (2003) [44]

The field size, source activity parameters, and control measure parameters are assumed values for illustrative purposes. Applying a 3" deep gravel bed over the dirt has been chosen as the applied control measure.

Step 2. Obtain PM10 Emission Factor.

The PM10 emission factor is obtained from AP-42: PM10 EF = $0.5 \sum_{i=1}^{N} P_i$

P—erosion potential (g/m^2)	$P = 58 (u^* - u^*_t)^2 + 25 (u^* - u^*_t)$ $P = 0$ for $u^* \leq u_t^*$
Threshold friction velocity u^*_t (m/s) = $0.053\ u^+_{10}$	0.53

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor (obtained in Step 2) is applied to each day for which the peak wind exceeds the threshold velocity for wind erosion. The following monthly climatic data are used for illustrative purposes and are assumed to apply to each month of the year.

Monthly erosion potential (P) [a]				
Day of Month	Peak Wind (u^+_{10}) mph	Peak Wind (u^+_{10}) m/s	u^* m/s	P g/m^2
6	29	13.0	0.69	5.36
7	30	13.4	0.71	6.41
11	38	17.0	0.90	17.21
22	25	11.2	0.59	1.78
			Sum of P	30.77

[a] Assumed to apply to 12 months of the year.

The annual PM10 emissions are equal to the PM10 emission factor (i.e., 0.5 times the monthly erosion potential) multiplied by 12 and then by the field size (under activity data) and then divided by 454 g/lb and 2,000 lb/ton to compute the annual PM10 emissions in tons per year, as follows:

Annual PM10 emissions = (Emission Factor x Field Size) / (454 x 2,000)
Annual PM10 emissions = (0.5 x 0.77 x 12 x 10,000) / (454 x 2,000)
Annual PM10 emissions = 2.03 tons

Annual PM2.5 emissions = 0.15 x PM10 emissions[12] = 0.15 x 2.03 = 0.30 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 applying gravel over the dirt parking lot as our control measure. Based on a control efficiency estimate of 84% for this control measure, the annual controlled emissions estimate are calculated to be:

Annual Controlled PM10 emissions = 0.33 tons
Annual Controlled PM2.5 emissions = 0.049 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	50,000
Annual Operating/Maintenance costs ($)	4,000
Annual Interest Rate	3%
Capital Recovery Factor	0.2184
Annualized Cost ($/yr)	13,173

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:

$$\text{Capital Recovery Factor} = \text{AIR x } (1+\text{AIR})^{\text{Economic life}} / (1+\text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factor} = 3\% \text{ x } (1+3\%)^{5} / (1+3\%)^{5} - 1 = 0.2184$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the Annual Operating/Maintenance:

Annualized Cost = (CRF x Capital costs) + Annual Operating/Maintenance costs
Annualized Cost = (0.2084 x 50,000) + 4,000 = 14,918

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 = $14,918 / (2.03 - 0.33) = $8,735/ton
Cost-effectiveness for PM2.5 emissions = $14,918 / (0.30 - 0.049) = $58,234/ton

8.9 References

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Chapter 9. Storage Pile Wind Erosion

9.1 Characterization of Source Emissions

Dust emissions may be generated by wind erosion of open areas of exposed soils or other aggregate materials within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter [cm] in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that: (a) threshold wind speeds exceed 5 meters per second (m/s) (11 miles per hour [mph]) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential. Loose soils or other aggregate materials consisting of sand-sized materials act as an unlimited reservoir of erodible material and can sustain emissions for periods of hours without substantial decreases in emission rates.

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7 to 10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude. The routinely measured meteorological variable that best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement that has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 mph), matches well with the half-life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution as follows:

$$u(z) = \frac{u*}{0.4} \ln \frac{z}{z_0} \quad (z>z_0) \tag{1}$$

where,

- u = wind speed (cm/s)
- u^* = friction velocity (cm/s)
- z = height above test surface (cm)
- z_o = roughness height (cm)
- 0.4 = von Karman’s constant (dimensionless)

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_o) is a measure of the roughness of the exposed surface as determined from the y-intercept of the velocity profile, i.e., the height at which the wind speed is zero. These parameters are illustrated in Figure 9-1 for a roughness height of 0.1 cm.

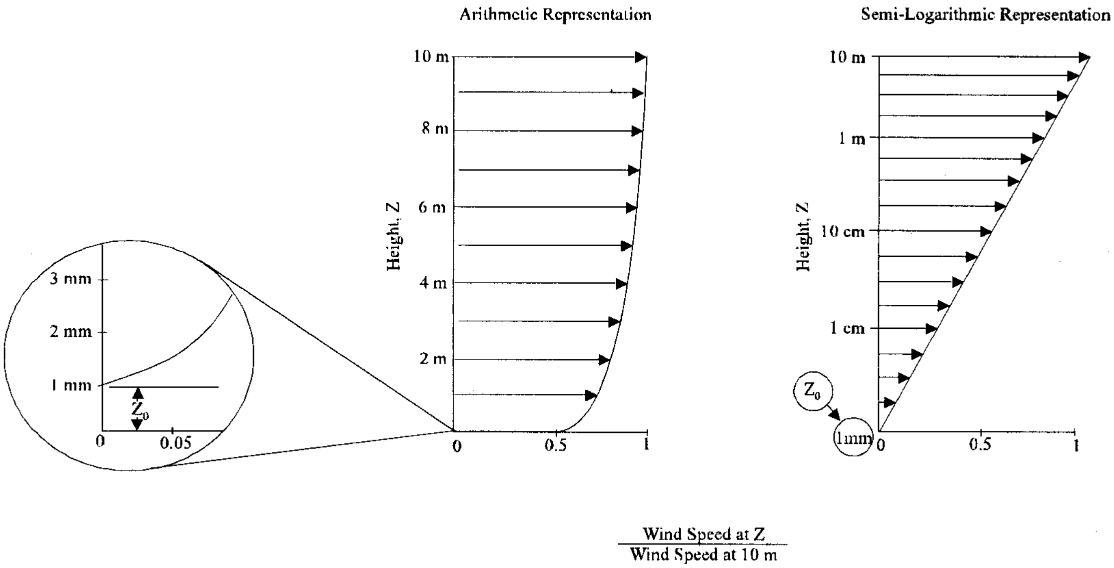

Figure 9-1. Illustration of Logarithmic Wind Velocity Profile

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action that results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

9.2 Emission Estimation: Primary Methodology [1-11]

This section was adapted from Section 13.2.5 of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*. Section 13.2.5 was last updated in January 1995.

The PM10 emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter (g/m^2) per year as follows:

$$\text{PM10 Emission Factor} = 0.5 \sum_{i=1}^{N} P_i \qquad (2)$$

where,

N = number of disturbances per year
Pi = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances (g/m^2)

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365 per year, and for a surface disturbance once every 6 months, N = 2 per year. The erosion potential function for a dry, exposed surface is given as:

$$P = 58\,(u^* - u_t^*)^2 + 25\,(u^* - u_t^*) \qquad (3)$$

$$P = 0 \quad \text{for } u^* \le u_t^*$$

where,

u^* = friction velocity (m/s)

u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately. The PM2.5/PM10 ratio for windblown fugitive dust posted on EPA's CHIEF website is 0.15 based on the analysis conducted by MRI on behalf of WRAP.[11]

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady-state emission rates. For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below.

FIELD PROCEDURE FOR DETERMINING THRESHOLD FRICTION VELOCITY
(from a 1952 laboratory procedure published by W. S. Chepil[5])

Step 1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.

Step 2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm by 30 cm.

Step 3. Pour the sample into the top sieve (4-mm opening), and place a lid on the top.

Step 4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

Step 5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i.e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.

Step 6. Determine the threshold friction velocity from Table 9-1.

The results of the sieving can be interpreted using Table 9-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution using the graphical relationship described by Gillette.[5, 6] If the surface material contains nonerodible elements that are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of the elements must be taken into account by increasing the threshold friction velocity.[10]

Table 9-1. Field Procedure for Determination of Threshold Friction Velocity (Metric Units)

Tyler Sieve No.	Opening (mm)	Midpoint (mm)	u_t* (cm/s)
5	4		
9	2	3	100
16	1	1.5	76
32	0.5	0.75	58
60	0.25	0.375	43

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 9-2.

Table 9-2 Threshold Friction Velocities (Metric Units)

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)	
			z_o = Actual	z_o = 0.5 cm
Overburden[a]	1.02	0.3	21	19
Scoria (roadbed material)[a]	1.33	0.3	27	25
Ground coal (surrounding coal pile)[a]	0.55	0.01	16	10
Uncrusted coal pile[a]	1.12	0.3	23	21
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12
Fine coal dust on concrete pad[c]	0.54	0.2	11	10

[a] Western surface coal mine; reference 2.
[b] Lightly crusted.
[c] Eastern power plant; reference 3.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly local climatological data (LCD) summaries for the nearest reporting weather station that is representative of the site in question.[7] These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10-m reference height using Equation 1. To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*), the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053\ u_{10}^+ \qquad (4)$$

where,

u^* = friction velocity (m/s)
u_{10}^+ = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat exposed areas with little penetration into the surface wind layer.

If the pile significantly penetrates the surface wind layer (i.e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

For two representative pile shapes (conical and oval with flattop, 37-degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.[9] The results are shown in Figure 9-2 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_o) of 0.5 cm. The measured surface winds correspond to a height of 25 cm above the surface. The area fraction within each contour pair is specified in Table 9-3.

Table 9-3. Subarea Distribution for Regimes of u_s/u_r

Pile subarea	Percent of pile surface area			
	Pile A	Pile B1	Pile B2	Pile B3
0.2a	5	5	3	3
0.2b	35	2	28	25
0.2c	NA	29	NA	NA
0.6a	48	26	29	28
0.6b	NA	24	22	26
0.9	12	14	15	14
1.1	NA	NA	3	4

NA = not applicable.

The profiles of u_s/u_r in Figure 9-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

Step 1. Correct the fastest mile value (u^+) for the period of interest from the anemometer height (z) to a reference height of 10 m (u^+_{10}) using a variation of Equation 1:

$$u^+_{10} = u^+ \frac{\ln (10/0.005)}{\ln (z/0.005)} \quad (5)$$

where a typical roughness height (z_o) of 0.5 cm (0.005 m) has been assumed. If a site-specific roughness height is available, it should be used.

Step 2. Use the appropriate part of Figure 9-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u^+_s):

$$u^+_s = \frac{(u_s)}{u_r} u^+_{10} \quad (6)$$

Step 3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u^*): $u^* = (0.4\, u^+_s) / \ln (25 / 0.5) = 0.10\, u^+_s$ (7)

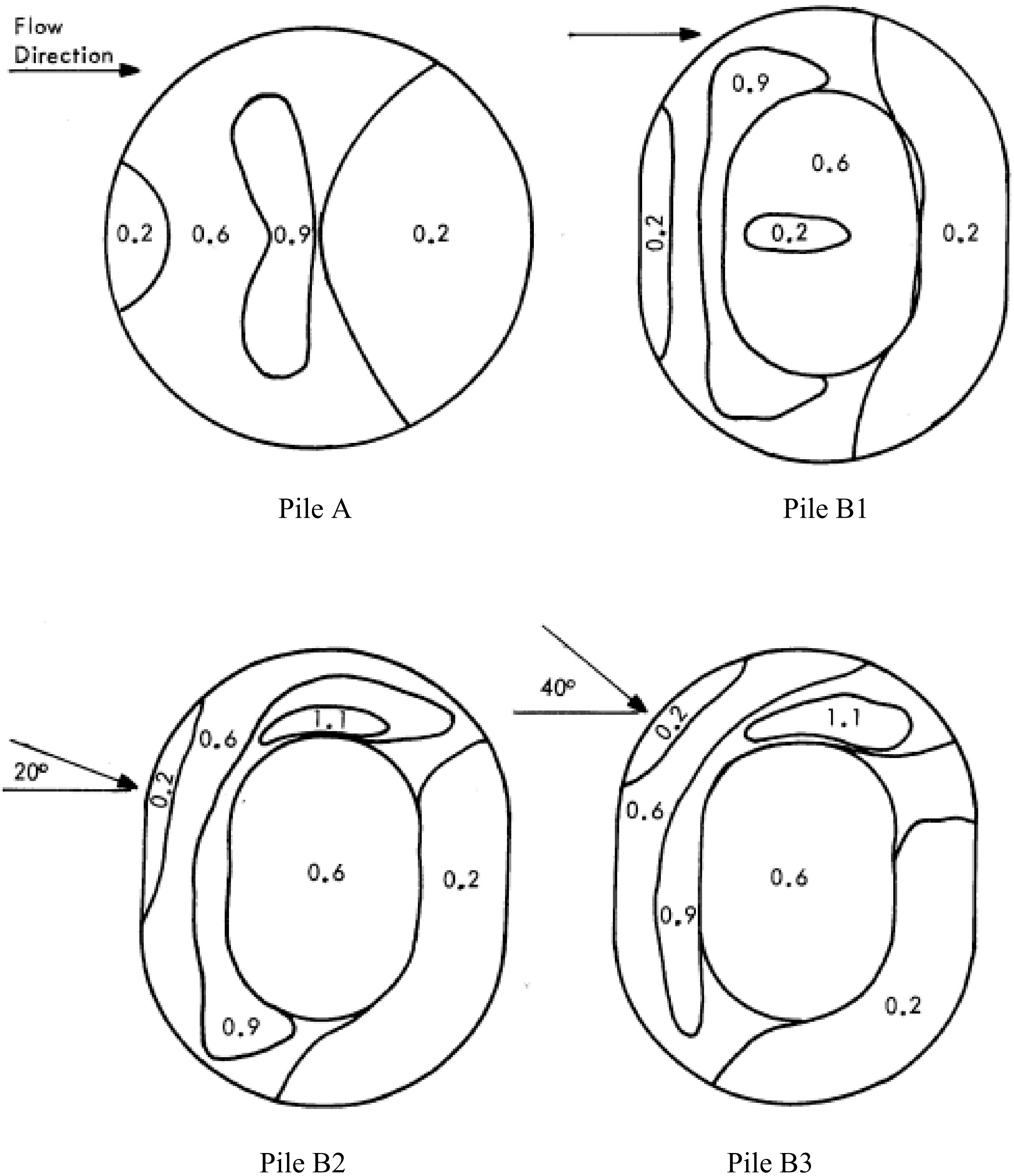

Figure 9-2. Contours of Normalized Surface Wind Speed Ratios, u_s/u_r

From this point on, the procedure is identical to that used for a flat pile, as described above. Implementation of the above procedure is carried out in the following steps:

<u>Step 1</u>. Determine threshold friction velocity for erodible material of interest (see Table 9-2 or determine from mode of aggregate size distribution).

<u>Step 2</u>. Divide the exposed surface area into subareas of constant frequency of disturbance (N).

<u>Step 3</u>. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u_{10}^+) using Equation 5.

<u>Step 4</u>. Convert fastest mile values (u_{10}) to equivalent friction velocities (u^*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.

<u>Step 5</u>. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i.e., within the isopleth values of u_s/u_r in Figure 9-2 and Table 9-3) and determine the size of each subarea.

<u>Step 6</u>. Treating each subarea (of constant N and u^*) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3 and the emission factor using Equation 2.

<u>Step 7</u>. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hour emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 minutes, which corresponds roughly to the half-life for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process that offset this apparent conservatism as follows:

1. The fastest mile event contains peak winds that substantially exceed the mean value for the event.
2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed that contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of over prediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

9.3 Emission Estimation: Alternate Methodology

EPA published a total suspended particulate (TSP) emission factor equation for wind erosion of active storage piles in 1989 that is not included in AP-42.[12] For days when there was at least 0.01 inch of precipitation, the TSP emissions were zero. The TSP emission factor equation (in units of lb/day/acre of surface) for days when there was less than 0.01 inch of precipitation was given as:

$$E_{TSP} = 1.7\ (s/1.5)\ (f/15)$$

where, s = silt content of material (weight %)
f = percentage of time the unobstructed wind speed is greater than 12 mph at the mean pile height

The annual TSP emissions factor equation for wind blown dust from active storage piles was given as follows:

$$TSP\ (lb/year/acre\ of\ surface) = 1.7\ (s/1.5)\ (365\ [365-p]\ /\ 235)\ (f/15)$$

where, s = silt content of material (weight %)
p = number of days per year with at least 0.01 inch of precipitation
f = percentage of time the unobstructed wind speed is greater than 12 mph at the mean pile height

Based on the PM10/TSP ratio of 0.5 for wind blown dust from active storage piles published in Section 13.2.5 of AP-42 and a PM2.5/PM10 ratio of 0.15 for wind blown dust[11], the PM10 and PM2.5 emission factor equations (in units of lb/day/acre) would be:

$$E_{PM10} = 0.85\ (s/1.5)\ (f/15)$$
$$E_{PM2.5} = 0.13\ (s/1.5)\ (f/15)$$

The short-term hourly TSP emission factor equation for wind blown dust from active storage piles (in units lb/acre-hour) given in the 1989 EPA report was equal to the wind speed (in units of mph) multiplied by a factor of 0.72. Thus for a wind speed that averaged 25 mph during a one-hour period, the TSP emission factor during that hour would be 18 lb/acre which is equal to 2.02 g/m^2. The corresponding PM10 and PM2.5 emission factors would be 1.01 g/m^2 and 0.15 g/m^2, respectively.

9.4 Demonstrated Control Techniques

Control measures for storage pile wind erosion are designed to stabilize the erodible surface (e.g., by increasing the moisture content of the aggregate material being stored) or to shield it from the ambient wind. Table 9-4 presents a summary of control measures and reported control efficiencies for storage pile wind erosion.

Table 9-4. Control Efficiencies for Control Measures for Storage Pile Wind Erosion

Control measure	PM10 control efficiency	References/comments
Require construction of 3-sided enclosures with 50% porosity	75%	Sierra Research, 2003.[13] Determined through modeling of open area windblown emissions with 50% reduction in wind speed and assuming no emission reduction when winds approach open side
Water the storage pile by hand or apply cover when wind events are declared	90%	Fitz et al., April 2000.[14]

9.5 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for several local air quality agencies in the WRAP region are presented in Table 9-5. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: http://www.maricopa.gov/envsvc/air/ruledesc.asp

(Note: The Clark County website did not include regulatory language specific to storage pile wind erosion at the time this chapter was written.)

9.6 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

Table 9-5. Example Regulatory Formats for Storage Pile Wind Erosion

Control Measure	Goal	Threshold	Agency
Establishes wind barrier and watering or stabilization requirements and bulk materials must be stored according to stabilization definition and outdoor materials covered	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8031 11/15/2001
Best available control measures: wind sheltering, watering, chemical stabilizers, altering load-in/load-out procedures, or coverings	Prohibits visible dust emissions beyond property line and limits upwind/downwind PM10 differential to 50 ug/m3		SCAQMD Rule 403 12/11/1998
Watering, dust suppressant (when loading, stacking, etc.); cover with tarp, watering (when not loading, etc.); wind barriers, silos, enclosures, etc.	Limit VDE to 20% opacity; stabilize soil	For storage piles with >5% silt content, 3ft high, >150 sq ft; work practices for stacking, loading, unloading, and when inactive; soil moisture content min 12%; or at least 70% min for optimum soil moisture content; 3 sided enclosures, at least equal to pile in length, same for height, porosity <50%	Maricopa County Rule 310 04/07/2004
Utilization of dust suppressants other than water when necessary; prewater; empty loader bucket slowly	Prevent wind erosion from piles; stabilize condition where equip and vehicles op	Bulk material handling for stacking, loading, and unloading; for haul trucks and areas where equipment op	Maricopa County Rule 310 04/07/2004

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 9-6 summarizes the compliance tools that are applicable to wind erosion from material storage piles.

Table 9-6. Compliance Tools for Storage Pile Wind Erosion

Record keeping	Site inspection/monitoring
Site map; work practices, including pile formation and removal times (throughputs); locations, sizes, and shapes of storage piles; moisture and silt contents of pile surface material; location/heights/densities of vegetation or other wind breaks, including maintenance times; dust suppression equipment and maintenance records; frequencies, amounts, times, and rates of watering or dust suppressant application; meteorological log.	Sampling and analysis of storage pile surface material for silt and moisture contents; observation of pile formation and removal, including wet suppression systems; observation of vehicle/ equipment operation and disturbance areas; inspection of wind sheltering including enclosures; real-time portable monitoring of PM; observation of dust plume opacity exceeding a standard.

9.7 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for fugitive dust originating from storage pile wind erosion. A sample cost-effectiveness calculation is presented below for a specific control measure (3-sided enclosure) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for storage pile wind erosion, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Storage Pile Wind Erosion

Step 1. Determine source activity and control application parameters.

Frequency of disturbance (days/yr)	365
Height of pile (m)	11
Base diameter (m)	29.2
Total surface area (m^2)	838
Portion of pile exposed to high winds (%)	12
Surface area exposed to high winds (m^2)	101
Threshold friction velocity u^*_t (m/s)	0.85

Control Measure	3-sided enclosure
Economic Life of Control System (yr)	10
Control Efficiency (%)	74.7
Reference for Control Efficiency	Sierra Research, 2003[13]

The pile size, source activity parameters and control measure parameters are assumed values for illustrative purposes. A 3-sided enclosure has been chosen as the applied control measure. The control efficiency is provided by Sierra Research.[13]

The pile surface area within each surface wind speed range (see AP-42, Section 13.2.5) is as follows:

Surface areas within each wind speed range			
Area ID	u_s / u_r	%	Pile surface Area (m^2)
A	0.9	12	101
B	0.6	48	402
C	0.2	40	335
Total Area			838

Step 2. Obtain PM10 Emission Factor.

The PM10 emission factor is obtained from AP-42: PM10 EF = $0.5 \sum_{i=1}^{N} P_i$

P—erosion potential (g/m^2)	$P = 58\,(u^*-u^*_t)^2 + 25\,(u^*-u^*_t)$
	P = 0 for $u^* \le u_t^*$

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor (given in Step 2) is applied to each day for which the peak wind exceeds the threshold velocity for wind erosion. The following monthly climatic data are used for illustrative purposes and are assumed to apply to each month of the year.

Monthly erosion potential (P)					
	Peak wind (u^+_{10})		$u^+_{s\ (m/s)}$		
Day of month	mph	m/s	Area C u_s / u_r: 0.2	Area B u_s / u_r: 0.6	Area A u_s / u_r: 0.9
6	29	13.0	2.59	7.78	11.67
7	30	13.4	2.68	8.05	12.07
11	38	17.0	3.40	10.19	15.29
22	25	11.2	2.24	6.71	10.06
28	45	20.1	4.02	12.07	18.10

Monthly erosion potential (P)[a]						
Day of month	u* (m/s)			P (g/m^2)		
	Area C	Area B	Area A	Area C	Area B	Area A
6	0.26	0.78	1.17	0	0	13.74
7	0.27	0.80	1.21	0	0	16.32
11	0.34	1.02	1.53	0	5.89	43.70
22	0.22	0.67	1.01	0	0	5.30
28	0.40	1.21	1.81	0	16.32	77.52
			Sum of P (g/m^2)	0	22.21	156.57
			Area (m^2)	335	402	101
			Monthly PM10 emissions (g) [b]	0	4,464	7,907

[a] Assumed to apply to 12 months of the year.

[b] Monthly PM10 emissions = 0.5 times monthly erosion potential times surface area for each area of the pile.

The annual PM10 emissions in units of tons for each section of the pile is equal to 12 times the monthly PM10 emissions for each section of the pile divided by 454 g/lb and 2,000 lb/ton as follows:

Annual PM10 emissions for Area A = (12 x 7,907) / (454 x 2,000) = 0.104 tons
Annual PM10 emissions for Area B = (12 x 4,464) / (454 x 2,000) = 0.059 tons
Annual PM10 emissions for Area C = 0 tons
Annual PM10 emissions for storage pile = 0.104 + 0.059 + 0 = 0.163 tons

Annual PM2.5 Emissions = 0.15 x PM10 Emissions[11] = 0.15 x 0.163 = 0.025 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 a 3-sided enclosure as our control measure with a control efficiency of 74.7% Thus, the annual controlled PM10 and PM2.5 emissions estimates are calculated to be:

Annual Controlled PM10 emissions = (0.163 tons/yr) x (1 – 0.747) = 0.041 tons
Annual Controlled PM2.5 emissions = (0.025 tons/yr) x (1 – 0.747) = 0.006 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	2,000
Annual Operating/Maintenance costs ($)	400
Annual Interest Rate	3%
Capital Recovery Factor	0.1172
Annualized Cost ($/yr)	634

The Capital costs, Annual Operating/Maintenance (O & M) costs and Annual Interest Rate (AIR) are assumed values for illustrative purposes.

The Capital Recovery Factor (CRF) is calculated as follows:

$$\text{Capital Recovery Factor} = \text{AIR} \times (1 + \text{AIR})^{\text{Economic life}} / (1 + \text{AIR})^{\text{Economic life}} - 1$$

$$\text{Capital Recovery Factor} = 3\% \times (1 + 3\%)^{10} / (1 + 3\%)^{10} - 1 = 0.1172$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor and the Capital costs to the annual O & M costs as follows:

Annualized Cost = (CRF x Capital costs) + O & M costs
Annualized Cost = (0.1172 x 2,000) + $400 = $634

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 = $634 / (0.163 – 0.041) = $5,195/ton
Cost effectiveness for PM2.5 emissions = $634 / (0.025 – 0.006) = $34,635/ton

9.8 References

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12. USEPA, 1989. Air/Superfund National Technical Guidance Study Series; Volume III – Estimation of Air Emissions from Cleanup Activities at Superfund Sites, Interim final report EPA-450/1-89-003, January.

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Chapter 10. Agricultural Harvesting

10.1 Characterization of Source Emissions

Harvesting emissions are generated by three different operations: crop handling by the harvest machine, loading of the harvested crop into trailers or trucks, and transport by trailers or trucks in the field. Emissions from these operations are in the form of solid particulates composed mainly of raw plant material and soil dust that is entrained into the air. These emissions may simply be due to the vehicles traveling over the soil, or via the mechanical processing of the plant material and underlying soil, or, as in the case of almonds, via the actual blowing or sweeping of the crop to remove waste materials and position it for pickup. Defoliants and/or desiccants are used on some crops several weeks before harvesting which can produce PM emissions from the drifting of these chemicals equal to about 1% of the product applied on the crop.[1]

10.2 EPA's Emission Estimation Methodology

Section 9 of EPA's Compilation of Air Pollutant Emission Factors (AP-42) addresses emission factors for mechanical harvesting of three different crops (cotton, wheat and sorghum). This section of AP-42 was last updated in February 1980. However, it does not list TSP or PM10 emission factors for agricultural harvesting. Instead it lists PM7 emission factors for the three crops expressed in units of pounds per square mile for crop handling by the harvest machine, loading of the harvested crop into trailers or trucks, and transport by trailers or trucks in the field. The sum of the PM7 emission factor for these three separate operations total 0.0086 lb/acre for mechanical picking of cotton, 0.041 lb/acre for mechanical stripping of cotton, 0.0027 lb/acre for wheat, and 0.012 lb/acre for sorghum.[1] The PM7 emission factors for harvesting cotton are based on an average machine speed of 3 mph for pickers and 5 mph for strippers, a basket capacity of 240 lb, a trailer capacity of 6 baskets, a lint cotton yield of 1.17 bales/acre for pickers and 0.77 bales/acre for strippers, and a transport speed of 10 mph. The weighted average stripping factors assumes that 2% of all strippers are 4-row models with baskets and, of the remainder, 40% are 2-row models pulling trailers and 60% are 2-row models with mounted baskets. The PM7 emission factors for harvesting wheat and sorghum are based on an average combine speed of 7.5 mph, a combine swath width of 20 feet, a field transport speed of 10 mph, a truck loading time of 6 minutes, a truck capacity of 13 acres for wheat and 7 acres for sorghum, and a filled truck travel time of 2 minutes per load. These AP-42 PM7 emission factors developed more than 25 years ago for the entire US are much lower than CARB's PM10 emission factors developed in early 2003 for California.

10.3 CARB's Emission Estimation Methodology

> This section was adapted from Section 7.5 of CARB's Emission Inventory Methodology. Section 7.5 was last updated in January 2003.

The California Air Resources Board (CARB) has published a PM10 emission estimation method for fugitive dust emissions originating from agricultural harvesting operations.[2] Unlike the soil preparations activities (e.g., disking, tilling, etc.), harvest operations tend to be fairly unique for each crop. Because of this, harvest emission factors combine all of the operations that go into harvesting a commodity into a single factor that includes emissions from all of the relevant operations. PM10 emission factors have been measured in California by UC Davis for harvesting cotton, almonds and wheat.[3] These emission factors are shown in Table10-1. Using these emission factors as a baseline, harvesting emission factors were assigned to other major crops grown California crops in consultation with agricultural experts. These PM10 emission factors are also included in Table 10-1.

Table 10-1. Harvesting PM10 Emission Factors

Crop	PM 10 Emission Factor (lbs/acre)
Almonds	40.8
Corn	1.7[a]
Cotton	3.4
Fruit trees	0.085[b]
Onions	1.7[a]
Potatoes	1.7[a]
Sugar beets	1.7[a]
Tomatoes	0.17[c]
Vine crops	0.17[c]
Walnuts	40.8[d]
Wheat	5.8

[a] EF = 50% EF for cotton
[b] EF = 2.5% EF for cotton
[c] EF = 5% EF for cotton
[d] EF = same EF as almonds

UC Davis has recently completed a study measuring PM10 emissions from almond harvesting that indicates that CARB's PM10 emission factor for almond harvesting may be over-estimated by 62%.[4] The complete list of harvesting emission factors assigned to over 200 crops is presented in Attachment 10-1 at the end of this chapter. The acreage data used for estimating harvest emissions for different crops are available from each state's Department of Food and Agriculture as well as from individual county agricultural commissioner reports.

Crop Calendar and Temporal Activity. Harvesting is performed at very specific times each year, so crop calendar data, which tells when harvest activities occur, is important. Temporal activity for harvesting is derived by summing, for each county, the monthly emissions from all crops. For each crop, the monthly emissions are calculated based on its monthly profile, which reflects the percentage of harvesting activities occurring in that month. An example of the monthly harvesting profile for almonds, cotton, and wheat is shown in Table 10-2. Because the mix of crops varies by county, composite temporal profiles combining all of the other county crops vary by county. An example of a composite harvesting profile by month for Fresno County, showing the combined temporal profile for all of the harvesting activities in the county, is shown in Table 10-3.

Table 10-2. Sample Monthly Harvesting Profile of Crops

Crops	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Almonds	0	0	0	0	0	0	0	0	50	50	0	0
Cotton	0	0	0	0	0	0	0	0	0	50	50	0
Wheat	0	0	0	0	0	50	50	0	0	0	0	0

Table 10-3. Sample County Harvesting Profile Composite

County	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Fresno	0.1	0.1	0.2	0.2	0.1	5.6	5.9	0.8	30.7	42.8	13.6	0.1

Assumptions. The CARB methodology is subject to the following assumptions:

1. The current harvest emission factors assume that for each crop, harvesting produces the same level emissions under all conditions for all equipment.
2. The emission factors for crops other than almonds, cotton, and wheat were assigned to reflect the relative geologic PM10 generation potential of various harvest practices.
3. Crop calendar data collected for San Joaquin Valley crops and practices were extrapolated to the same crops in the remainder of California.

PM2.5 Emission Factors. In July 2006, EPA revised the PM2.5/PM10 ratios listed in AP-42 for fugitive dust resulting from different fugitive dust source categories based on MRI's controlled laboratory experiments conducted for WRAP in 2005.[5] The revised PM2.5/PM10 ratios range from 0.1 for unpaved roads to 0.15 for paved roads, wind erosion, and transfer of aggregate material. CARB is considering adopting a PM2.5/PM10 ratio of 0.15 for both agricultural tilling and agricultural tilling based on MRI's findings.[6]

10.4 Demonstrated Control Techniques

Soil dust emissions from field transport can be reduced by lowering vehicle speed. Also, the use of terraces, contouring, and strip cropping to inhibit soil erosion will suppress the entrainment of harvested crop fragments in the wind. Shelterbelts, positioned perpendicular to the prevailing wind, will lower emissions by reducing the wind velocity across the field. By minimizing tillage and avoiding residue burning, the soil will remain consolidated and less prone to disturbance from transport activities.

Table 10-4 summarizes tested control measures and reported control efficiencies for measures that reduce the generation of fugitive dust from agricultural harvesting.[7-9] A list of control measures for agricultural harvesting operations is available from the California Air Pollution Control Officers' Association's (CAPCOA) agricultural clearing house website (http://capcoa.org/ag_clearinghouse.htm). The list of control measures for harvesting field and orchard crops include: the use of balers to harvest crops that are traditionally harvested by chopping, new drying techniques for dried fruit, increasing equipment size to reduce the number of passes, fallowing land, green chop (i.e., harvesting a forage crop without allowing it to dry in the field), hand harvesting, night harvesting, switch to a crop that requires no waste/residue burning, applying a light amount of water or other stabilizing material to the soil prior to harvest, packing commodities in an enclosed area, and utilizing a shuttle system to haul multiple trailers per trip.

Table 10-4. Control Efficiencies for Control Measures for Harvesting[7-9]

Control Measure	PM10 Control Efficiency	References / Comments
Equipment modification	50%	MRI, 1981. Control efficiency is for electrostatically charged fine-mist water spray.
Land set-aside/fallowing	100%	SJVAPCD, 2003.
Limited activity during high winds	5 - 70%	URS, 2001. Emissions reduction depends on wind speed.
Night farming	10%	SJVAPCD, 2003. Harvest when humidity and soil moisture is higher than during day.
New techniques for drying fruit Continuous tray Dried on vine (DOV)	 25% 60%	 SJVAPCD, 2003.
Precision farming	8%	SJVAPCD, 2003. Use of GPS system.
Reduced harvest activity	29 – 71 %	URS, 2001. Applicable to cotton, alfalfa, hay.
Soil moisture monitoring	30%	URS, 2001.

10.5 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. However, most air quality districts currently exempt agricultural operations from controlling fugitive dust. Air quality districts that regulate fugitive dust emissions from agricultural harvesting include Clark County, NV and several districts in California such as the Imperial County APCD, the San Joaquin Valley APCD and the South Coast AQMD. Imperial County APCD prohibits fugitive dust emissions from farming activities for farms over 40 acres. The San Joaquin Valley APCD and the South Coast AQMD prohibit fugitive dust emissions for the larger farms defined as farms with areas where the combined disturbed surface area within one continuous property line and not separated by a paved public road is greater than 10 acres. Example regulatory formats downloaded from the Internet are presented in Table 10-5. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- San Joaquin Valley APCD, CA: valleyair.org/SJV_main.asp
- South Coast AQMD, CA: aqmd.gov/rules
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/aq

CAPCOA's agricultural clearing house website (http://capcoa.org/ag_clearinghouse.htm) provides links to rules of different air quality agencies that regulate fugitive dust emissions from agricultural operations.

Table 10-5. Example Regulatory Formats for Harvesting

Control Measure	Agency
Any person engaged in agricultural operations shall take all reasonable precautions to abate fugitive dust from becoming airborne from such activities.	Clark County Reg. 41 7/01/04
Limit fugitive dust from off-field agricultural sources such as unpaved roads with more than 75 trips/day and bulk materials handling by requiring producers to develop and implement a Fugitive Dust Management Plan with district approved control methods.	SJVAPCD Rule 8081 11/15/01
Cease activities when wind speeds are greater than 25 mph.	SCAQMD Rule 403.1 4/02/04

10.6 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 10-6 summarizes the compliance tools that are applicable for harvesting.

Table 10-6. Compliance Tools for Harvesting

Record keeping	Site inspection/monitoring
Maintain daily records to document the specific dust control options taken; maintain such records for a period of not less than three years; and make such records available to the Executive Officer upon request.	Observation of dust plumes during periods of agricultural harvesting; observation of dust plume opacity (visible emissions) exceeding a standard; observation of high winds (e.g., >25 mph).

10.7 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for agricultural harvesting. A sample cost-effectiveness calculation is presented below for a specific control measure (precision farming utilizing a GPS system) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for agricultural harvesting, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Agricultural Harvesting

Step 1. Determine source activity and control application parameters.

Field size (acres)	320
Crop	Cotton
Frequency of operations per year	2 (picking & stalk cutting)
Control Measure	Precision farming
Control application/frequency	Reduce overlap of passes by 8%
Economic Life of Control System (yr)	5
Control Efficiency	8%

Precision farming utilizing a GPS system has been chosen as the applied control measure. The field size, frequency of operations, and control application/frequency are assumed values for illustrative purposes. The economic life of the control is determined from industrial records. The control efficiency of 8% is based on the proportional reduction in passes to harvest the cotton and cut the stalks after harvesting the cotton (SJVAPCD, 2003).[8]

Step 2. PM10 Emission Factor.
The PM10 emission factor for harvesting cotton includes the emissions from picking the cotton plus the emissions from cutting the stalks after picking the cotton. The PM10 emission factor for each operation is 1.7 lb/acre.[2]

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor, EF, (given in Step 2) is multiplied by the field size and the frequency of operations (both under activity data) and then divided by 2,000 lbs to compute the annual PM10 emissions in tons per year, as follows:

Annual PM10 emissions = (EF x Field Size x Frequency of Ops) / 2,000

- Annual PM10 Emissions = (1.7 x 320 x 2) / 2,000 = 0.544 tons

Annual PM2.5 emissions = (PM2.5/PM10) x PM10 emissions
Assume PM2.5/PM10 ratio for agricultural harvesting is 0.15 (MRI, 2006).[6]
Annual PM2.5 emissions = 0.15 x PM10 emissions

- Annual PM2.5 Emissions = (0.15 x 0.544 tons) = 0.0816 tons

Step 4. Calculate Controlled PM Emissions. The uncontrolled emissions (calculated in Step 3) are 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 precision farming as our control measure. Based on a control efficiency estimate of 8%, the annual controlled PM emissions are calculated to be:

Annual Controlled PM10 emissions = (0.544 tons) x (1 – 0.08) = 0.500 tons
Annual Controlled PM2.5 emissions = (0.0816 tons) x (1 – 0.08) = 0.075 tons

Step 5. Determine Annual Cost to Control PM Emissions.

The Annualized Cost of control is calculated by subtracting the cost savings from reducing the overlap of harvesting passes by 8% from the annualized cost of purchasing the GPS system.

Assuming that the cost of harvesting is equivalent to that of tilling, namely $10/acre (WSU, 1998[10]), the cost savings using GPS precision farming is $512 (i.e., 0.08 x 320 acres x $10/acre x 2 harvesting passes [i.e., one pass to harvest the cotton and a second pass to cut the stalks]).

GPS systems range in cost from $200 to $5,000 and have a lifetime of approximately five years (SJVAPCD, 2003[8]). Using an estimate of $1,000 and an economic life (EL) of five years for the GPS system together with an annual interest rate (AIR) of 5%, the annualized cost of the GPS system is calculated by adding the product of the Capital Recovery Factor (CRF) and the capital costs to the annual operating and maintenance costs, which for this example are assumed to be $200 per year.

The Capital Recovery Factor (CRF) is calculated as follows:

$$CRF = AIR \times (1+AIR)^{EL} / [(1+AIR)^{EL} - 1]$$

$$CRF = 5\% \times (1+ 5\%)^{5} / [(1+ 5\%)^{5} - 1] = 0.231$$

Annualized capital cost = CRF x capital cost = 0.231 x $1,000 = $231

Annual cost of GPS system = Annualized capital costs + Annual O & M costs

Annual cost of GPS system = $231 + $200 = $431

Annualized cost of control measure = Annual cost of GPS system minus the cost savings from reducing the overlap of harvesting passes

Annualized Cost = $431 - $512 = -$81

The annualized cost is negative and represents a net savings.

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 = -$81 / (0.544 – 0.500) = -$1,862/ton
Cost-effectiveness for PM2.5 emissions = -$81 / (0.0816 – 0.075) = -$12,412/ton

The negative cost-effectiveness values indicate cost savings.

10.8 References

1. USEPA, 2006. AP-42: Compilation of Air Pollutant Emission Factors Volume I: Stationary Point and Area Sources.

2. California Air Resources Board, 2003. Emission Inventory Procedural Manual Volume III: Methods for Assessing Area Source Emissions, Sacramento, CA, January.

3. Flocchini, R.G., James, T.A., et al., 2001. *Sources and Sinks of PM10 in the San Joaquin Valley,* Interim Report prepared for the United States Department of Agriculture Special Research Grants Program, August 10.

4. Flocchini, R.G., 2006. *Recommended PM10 Emission Factors for Almond Harvesting,* White Paper prepared for the San Joaquin Valley APCD by UC Davis, May 22.

5. MRI, 2006. *Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Emission Factors*, Final Report prepared for the WRAP by Midwest Research Institute, Project No. 110397, February 1.

6. CARB, 2006. Private communication from Patrick Gaffney, CARB Emission Inventory Branch PTSD, May 2.

7. MRI, 1981. *The Role of Agricultural Practices in Fugitive Dust Emissions,* Final Report prepared for the California Air Resources Board by Midwest Research Institute, April 17.

8. SJVAPCD, 2003. *Conservation Management Practices Program for the San Joaquin Valley*, Final Report prepared by the San Joaquin Valley Air Pollution Control District, February 5.

9. URS, 2001. *Technical Support Document for Quantification of Agricultural Best Management Practices*, Final Report prepared for Maricopa County, Arizona Department of Environmental Quality, June 8.

10. WSU, 1998. *Farming with the Wind*, Washington State University College of Agriculture and Home Economics Miscellaneous Publication N.MISC0208, December.

10.9 Attachment 10-1. PM10 Emission Factors for Harvesting Crops in CA

Crop Description	Crop Profile	Assumption	PM10 Emission Factor (lb/acre)
ALMOND HULLS	Almonds	Almonds/1	40.77
ALMONDS, ALL	Almonds	Almonds/1	40.77
ANISE (FENNEL)	Lettuce	Cotton/2	1.68
APPLES, ALL	Citrus	Cotton/40	0.08
APRICOTS, ALL	Citrus	Cotton/40	0.08
ARTICHOKES	Melon	Cotton/40	0.08
ASPARAGUS, FRESH MKT	Melon	Cotton/2	1.68
ASPARAGUS, PROC	Melon	Cotton/2	1.68
ASPARAGUS, UNSPECIFIED	Melon	Cotton/2	1.68
AVOCADOS, ALL	Citrus	Cotton/40	0.08
BARLEY, FEED	Wheat	Wheat/1	5.8
BARLEY, MALTING	Wheat	Wheat/1	5.8
BARLEY, UNSPECIFIED	Wheat	Wheat/1	5.8
BEANS FRESH UNSPECIFIED	Dry Beans	Cotton/20	0.17
BEANS, BLACKEYE (PEAS)	Dry Beans	Cotton/2	1.68
BEANS, FAVA	Dry Beans	Cotton/2	1.68
BEANS, GARBANZO	Garbanzo	Cotton/2	1.68
BEANS, GREEN LIMAS	Dry Beans	Cotton/2	1.68
BEANS, LIMAS, BABY DRY	Dry Beans	Cotton/2	1.68
BEANS, LIMAS, LG. DRY	Dry Beans	Cotton/2	1.68
BEANS, PINK	Dry Beans	Cotton/2	1.68
BEANS, RED KIDNEY	Dry Beans	Cotton/2	1.68
BEANS, SNAP FR MKT	Dry Beans	Cotton/20	0.17
BEANS, SNAP PROC	Dry Beans	Cotton/20	0.17
BEANS, UNSPECIFIED SNAP	Dry Beans	Cotton/20	0.17
BEANS,UNSPEC. DRY EDIBLE	Dry Beans	Cotton/2	1.68
BEETS, GARDEN	Sugar Beets	Cotton/2	1.68
BERRIES, BLACKBERRIES	Grapes-Table	Cotton/40	0.08
BERRIES, BOYSENBERRIES	Grapes-Table	Cotton/40	0.08
BERRIES, BUSH, UNSPECIFIED	Grapes-Table	Cotton/40	0.08
BERRIES, LOGANBERRIES	Grapes-Table	Cotton/40	0.08
BERRIES, RASPBERRIES	Grapes-Table	Cotton/40	0.08
BROCCOLI, FR MKT	Vegetables	Cotton/40	0.08
BROCCOLI, PROC	Vegetables	Cotton/40	0.08
BROCCOLI, UNSPECIFIED	Vegetables	Cotton/40	0.08
BROCCOLI,FOOD SERV	Vegetables	Cotton/40	0.08
BRUSSELS SPROUTS	Melon	Cotton/40	0.08
CABBAGE, CH. & SPECIALTY	Lettuce	Cotton/40	0.08
CABBAGE, HEAD	Lettuce	Cotton/40	0.08
CARROTS, FOOD SERV	Sugar Beets	Cotton/20	0.17
CARROTS, FR MKT	Sugar Beets	Cotton/20	0.17
CARROTS, PROC	Sugar Beets	Cotton/20	0.17
CARROTS, UNSPECIFIED	Sugar Beets	Cotton/20	0.17
CAULIFLOWER, FOOD SERV	Vegetables	Cotton/40	0.08

Crop Description	Crop Profile	Assumption	PM10 Emission Factor (lb/acre)
CAULIFLOWER, FR MKT	Vegetables	Cotton/40	0.08
CAULIFLOWER, PROC	Vegetables	Cotton/40	0.08
CAULIFLOWER, UNSPECIFIED	Vegetables	Cotton/40	0.08
CELERY, FOOD SERV	Lettuce	Cotton/40	0.08
CELERY, FR MKT	Lettuce	Cotton/40	0.08
CELERY, PROC	Lettuce	Cotton/40	0.08
CELERY, UNSPECIFIED	Lettuce	Cotton/40	0.08
CHERIMOYAS	Citrus	Cotton/40	0.08
CHERRIES, SWEET	Citrus	Cotton/40	0.08
CHESTNUTS	Almonds	Almonds/10	4.08
CHIVES	Lettuce	Cotton/40	0.08
CILANTRO	Lettuce	Cotton/40	0.08
CITRUS, MISC BY-PROD	Citrus	Cotton/40	0.08
CITRUS, UNSPECIFIED	Citrus	Cotton/40	0.08
CLOVER, UNSPECIFIED SEED	Alfalfa	Alfalfa/1	0
COLLARD GREENS	Lettuce	Cotton/40	0.08
CORN FOR GRAIN	Corn	Cotton/2	1.68
CORN FOR SILAGE	Corn	Cotton/20	0.17
CORN, SWEET ALL	Corn	Cotton/40	0.08
CORN, WHITE	Corn	Cotton/40	0.08
COTTON LINT, PIMA	Cotton	Cotton/1	3.37
COTTON LINT, UNSPEC	Cotton	Cotton/1	3.37
COTTON LINT, UPLAND	Cotton	Cotton/1	3.37
COTTONSEED	Cotton	Cotton/1	3.37
CUCUMBERS	Vegetables	Cotton/40	0.08
CUCUMBERS, GREENHOUSE	No Land Prep	Zero/1	0
DATES	Citrus	Almonds/20	2.04
EGGPLANT, ALL	Vegetables	Cotton/40	0.08
ENDIVE, ALL	Lettuce	Cotton/40	0.08
ESCAROLE, ALL	Lettuce	Cotton/40	0.08
FIELD CROP BY PRODUCTS	Cotton	Cotton/20	0.17
FIELD CROPS, UNSPEC.	Corn	Cotton/20	0.17
FIGS, DRIED	Citrus	Almonds/20	2.04
FOOD GRAINS, MISC	Corn	Cotton/2	1.68
FRUITS & NUTS, UNSPEC.	Citrus	Cotton/40	0.08
GARLIC, ALL	Garlic	Cotton/2	1.68
GRAPEFRUIT, ALL	Citrus	Cotton/40	0.08
GRAPES, RAISIN	Grapes-Raisin	Cotton/20	0.17
GRAPES, TABLE	Grapes-Table	Cotton/20	0.17
GRAPES, UNSPECIFIED	Grapes-Wine	Cotton/20	0.17
GRAPES, WINE	Grapes-Wine	Cotton/20	0.17
GREENS, TURNIP & MUSTARD	Lettuce	Cotton/40	0.08
GUAVAS	Citrus	Cotton/40	0.08
HAY, ALFALFA	Alfalfa	Alfalfa/1	0
HAY, GRAIN	Alfalfa	Cotton/2	1.68
HAY, GREEN CHOP	Alfalfa	Alfalfa/1	0

Crop Description	Crop Profile	Assumption	PM10 Emission Factor (lb/acre)
HAY, OTHER UNSPECIFIED	Alfalfa	Cotton/2	1.68
HAY, SUDAN	Alfalfa	Alfalfa/1	0
HAY, WILD	Alfalfa	Cotton/2	1.68
HORSERADISH	Onions	Cotton/40	0.08
JOJOBA	Melon	Cotton/40	0.08
KALE	Lettuce	Cotton/40	0.08
KIWIFRUIT	Citrus	Cotton/40	0.08
KOHLRABI	Lettuce	Cotton/40	0.08
KUMQUATS	Citrus	Cotton/40	0.08
LEEKS	Onions	Cotton/40	0.08
LEMONS, ALL	Citrus	Cotton/40	0.08
LETTUCE, BULK SALAD PRODS.	Lettuce	Cotton/40	0.08
LETTUCE, HEAD	Lettuce	Cotton/40	0.08
LETTUCE, LEAF	Lettuce	Cotton/40	0.08
LETTUCE, ROMAINE	Lettuce	Cotton/40	0.08
LETTUCE, UNSPECIFIED	Lettuce	Cotton/40	0.08
LIMA BEANS, UNSPECIFIED	Dry Beans	Cotton/2	1.68
LIMES, ALL	Citrus	Cotton/40	0.08
MACADAMIA NUT	Almonds	Almonds/10	4.08
MELON, CANTALOUPE	Melon	Cotton/40	0.08
MELON, HONEYDEW	Melon	Cotton/40	0.08
MELON, UNSPECIFIED	Melon	Cotton/40	0.08
MELON, WATER MELONS	Melon	Cotton/40	0.08
MUSHROOMS	No Land Prep	Zero/1	0
MUSTARD	Lettuce	Cotton/40	0.08
NECTARINES	Citrus	Cotton/40	0.08
NURSERY TURF	No Land Prep	Zero/1	0
OATS FOR GRAIN	Wheat	Wheat/1	5.8
OKRA	Lettuce	Cotton/40	0.08
OLIVES	Citrus	Cotton/40	0.08
ONIONS	Onions	Cotton/2	1.68
ONIONS, GREEN & SHALLOTS	Onions	Cotton/40	0.08
ORANGES, NAVEL	Citrus	Cotton/40	0.08
ORANGES, UNSPECIFIED	Citrus	Cotton/40	0.08
ORANGES, VALENCIAS	Citrus	Cotton/40	0.08
ORCHARD BIOMASS	Almonds	Cotton/40	0.08
PARSLEY	Lettuce	Cotton/40	0.08
PASTURE, IRRIGATED	No Land Prep	Zero/1	0
PASTURE, MISC. FORAGE	No Land Prep	Zero/1	0
PASTURE, RANGE	No Land Prep	Zero/1	0
PEACHES, CLINGSTONE	Citrus	Cotton/40	0.08
PEACHES, FREESTONE	Citrus	Cotton/40	0.08
PEACHES, UNSPECIFIED	Citrus	Cotton/40	0.08
PEANUTS, ALL	Safflower	Cotton/2	1.68
PEARS, ASIAN	Citrus	Cotton/40	0.08
PEARS, BARLETT	Citrus	Cotton/40	0.08

Crop Description	Crop Profile	Assumption	PM10 Emission Factor (lb/acre)
PEARS, UNSPECIFIED	Citrus	Cotton/40	0.08
PEAS, DRY EDIBLE	Dry Beans	Cotton/20	0.17
PEAS, EDIBLE POD (SNOW)	Dry Beans	Cotton/20	0.17
PEAS, GREEN, PROCESSING	Dry Beans	Cotton/20	0.17
PEAS, GREEN, UNSPECIFIED	Dry Beans	Cotton/20	0.17
PECANS	Almonds	Almonds/10	4.08
PEPPERS, BELL	Tomatoes	Cotton/40	0.08
PEPPERS, CHILI, HOT	Tomatoes	Cotton/40	0.08
PERSIMMONS	Citrus	Cotton/40	0.08
PISTACHIOS	Almonds	Almonds/10	4.08
PLUMCOTS	Citrus	Cotton/40	0.08
PLUMS	Citrus	Cotton/40	0.08
POMEGRANATES	Citrus	Cotton/40	0.08
POTATOES SEED	Sugar Beets	Cotton/2	1.68
POTATOES, IRISH ALL	Sugar Beets	Cotton/2	1.68
PRUNES, DRIED	Citrus	Cotton/40	0.08
PUMPKINS	Melon	Cotton/20	0.17
QUINCE	Citrus	Cotton/40	0.08
RADICCHIO	Lettuce	Cotton/40	0.08
RADISHES	Sugar Beets	Cotton/40	0.08
RAPINI	Sugar Beets	Cotton/40	0.08
RHUBARB	Lettuce	Cotton/40	0.08
RICE, FOR MILLING	Rice	Cotton/2	1.68
RICE, WILD	Rice	Cotton/2	1.68
RUTABAGAS	Sugar Beets	Cotton/2	1.68
RYE FOR GRAIN	Wheat	Wheat/1	5.8
SAFFLOWER	Safflower	Wheat/1	5.8
SALAD GREENS NEC	Lettuce	Cotton/40	0.08
SEED BARLEY	Wheat	Wheat/1	5.8
SEED BEANS	Dry Beans	Cotton/2	1.68
SEED OATS	Wheat	Wheat/1	5.8
SEED PEAS	Dry Beans	Cotton/20	0.17
SEED RICE	Rice	Cotton/2	1.68
SEED RYE	Wheat	Wheat/1	5.8
SEED WHEAT	Wheat	Wheat/1	5.8
SEED, ALFALFA	Alfalfa	Alfalfa/1	0
SEED, BERMUDA GRASS	Alfalfa	Alfalfa/1	0
SEED, COTTON FOR PLANTING	Cotton	Cotton/1	3.37
SEED, GRASS, UNSPECIFIED	Alfalfa	Alfalfa/1	0
SEED, MISC FIELD CROP	Corn	Cotton/20	0.17
SEED, OTHER (NO FLOWERS)	Alfalfa	Cotton/20	0.17
SEED, SAFFLOWER, PLANTING	Safflower	Wheat/1	5.8
SEED, SUDAN GRASS	Alfalfa	Alfalfa/1	0
SEED, VEG & VINECROP	Vegetables	Cotton/20	0.17
SILAGE	Wheat	Cotton/20	0.17
SORGHUM, GRAIN	Wheat	Wheat/1	5.8

Crop Description	Crop Profile	Assumption	PM10 Emission Factor (lb/acre)
SPICES AND HERBS	Lettuce	Cotton/40	0.08
SPINACH UNSPECIFIED	Lettuce	Cotton/40	0.08
SPINACH, FOOD SERV	Lettuce	Cotton/40	0.08
SPINACH, FR MKT	Lettuce	Cotton/40	0.08
SPINACH, PROC	Lettuce	Cotton/40	0.08
SPROUTS, ALFALFA & BEAN	Lettuce	Cotton/40	0.08
SQUASH	Melon	Cotton/20	0.17
STRAW	Alfalfa	Wheat/1	5.8
STRAWBERRIES, FRESH MKT	Melon	Cotton/40	0.08
STRAWBERRIES, PROC	Melon	Cotton/40	0.08
STRAWBERRIES, UNSPECIFIED	Melon	Cotton/40	0.08
SUGAR BEETS	Sugar Beets	Cotton/2	1.68
SUNFLOWER SEED	Corn	Wheat/1	5.8
SUNFLOWER SEED, PLANTING	Corn	Wheat/1	5.8
SWEET POTATOES	Sugar Beets	Cotton/2	1.68
SWISSCHARD	Lettuce	Cotton/40	0.08
TANGELOS	Citrus	Cotton/40	0.08
TANGERINES & MANDARINS	Citrus	Cotton/40	0.08
TOMATILLO	Tomatoes	Cotton/40	0.08
TOMATOES, CHERRY	Tomatoes	Cotton/40	0.08
TOMATOES, FRESH MARKET	Tomatoes	Cotton/40	0.08
TOMATOES, GREENHOUSE	No Land Prep	Zero/1	0
TOMATOES, PROCESSING	Tomatoes	Cotton/20	0.17
TOMATOES, UNSPECIFIED	Tomatoes	Cotton/20	0.17
TURNIPS, ALL	Sugar Beets	Cotton/2	1.68
VEGETABLES, BABY	Vegetables	Cotton/40	0.08
VEGETABLES, ORIENTAL, ALL	Vegetables	Cotton/40	0.08
VEGETABLES, UNSPECIFIED	Vegetables	Cotton/20	0.17
WALNUTS, BLACK	Almonds	Almonds/1	40.77
WALNUTS, ENGLISH	Almonds	Almonds/1	40.77
WHEAT ALL	Wheat	Wheat/1	5.8

Chapter 11. Mineral Products Industry

11.1 Characterization of Source Emissions

This chapter of the handbook addresses fugitive dust emissions from mineral products industries that involve the production and processing of various ores, as discussed in Chapter 11 of AP-42 [1] In the mineral products industry, there are two major categories of emissions: ducted sources (those vented to the atmosphere through some type of stack, vent, or pipe), and fugitive sources (those not confined to ducts and vents but emitted directly from the source to the ambient air). Ducted emissions are usually collected and transported by an industrial ventilation system having one or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack.

Many operations and processes are common to all mineral products industries, including extraction of aggregate materials from the earth, loading, unloading, conveying, crushing, screening, loadout, and storage. Other operations are restricted to specific industries. These include wet and dry fine milling or grinding, air classification, drying, calcining, mixing, and bagging. Sand and gravel is typically mined in a moist or wet condition such that negligible particulate emissions occur during the mining operation. Construction aggregate processing can produce large amounts of fugitive dust, which due to its generally larger particle sizes tends to settle out within the plant. Some of the individual operations such as wet crushing and grinding, washing, screening, and dredging take place with high moisture content (>4% by weight). Such wet processes do not generate appreciable particulate emissions. For those processing and manufacturing operations that are housed in enclosed buildings with the dust captured by a control device (e.g., product recovery cyclones, fabric filters, and wet scrubber/suppression systems), no uncontrolled fugitive dust emissions are emitted directly into the outdoor air.

The operations at a typical western surface coal mine include drilling and blasting, removal of the overburden with a dragline or shovel, loading trucks, bulldozing and grading, crushing, vehicle traffic, and storage of coal in active storage piles that are subject to wind erosion. All operations that involve movement of soil or coal, or exposure of erodible surfaces, generate some amount of fugitive dust. During mine reclamation, which proceeds continuously throughout the life of the mine, overburden spoils piles are smoothed and contoured by bulldozers. Topsoil is placed on the graded spoils, and the land is prepared for revegetation by furrowing and mulching. From the time an area is disturbed until the new vegetation emerges, all disturbed areas are subject to wind erosion.

11.2 Emission Estimation Methodology

> This section was adapted from *EPA's documentation of methods used for the National Emission Inventory (NEI*.[2] and from Section 11, Mineral Products Industry, of EPA's *Compilation of Air Pollutant Emission Factors (AP-42)*.[1] Many of the categories addressed in AP-42 have not been updated by the EPA since the mid to late 1990's.

This section addresses three different mineral categories: (a) metallic ores (b) non-metallic ores and rock, and (c) coal. Fugitive dust emission factors for mining and quarrying activities are based on EPA's methodology used for the annual National

Emission Inventory that includes emissions from extraction of the ore or rock from the earth but not processing activities.[2] Fugitive dust emission factors for processing activities are taken from AP-42 and represent average values based on a number of tests made under a variety of conditions such as material silt content, moisture content, and wind speed. As such, the actual uncontrolled emission factors will vary depending upon actual site conditions.

The EPA methodology used to develop the annual National Emission Inventory (NEI) for fugitive PM10 dust emissions from mining and quarrying operations utilizes the sum of the emissions from the mining of metallic and nonmetallic ores and coal as well as rock quarrying, as follows:

$$E = E_m + E_n + E_c \tag{1}$$

where, E = PM10 emissions from mining and quarrying operations
E_m = PM10 emissions from metallic ore mining operations
E_n = PM10 emissions from non-metallic ore mining and rock quarrying operations
E_c = PM10 emissions from coal mining operations

The NEI PM10 emissions estimate for mining and rock quarrying operations involving extraction of ore or rock from the earth include three specific activities: (1) overburden removal, (2) drilling and blasting, and (3) loading and unloading. Ore processing activities that involve transfer and conveyance operations, crushing and screening operations, storage, and travel on haul roads are not included in the NEI emissions estimate since EPA assumes that the dust emissions from these activities are well controlled. Uncontrolled particulate emission factors for ore processing activities are presented in the subsections below for estimating fugitive dust emissions from these sources. Fugitive dust emissions from materials handling, travel on unpaved roads, and wind erosion of storage piles are addressed in Chapters 4, 6 and 9 of this handbook, respectively.

The NEI emissions estimation methodology assumes that the TSP emission factors developed for copper ore mining apply to the three activities listed above for all metallic ore mining. PM10 emission factors for each of these three activities for metallic ore mining are based on the following PM10/TSP ratios: 0.35 for overburden removal, 0.81 for drilling and blasting, and 0.43 for loading/unloading operations.[3]

In the NEI emission estimation methodology, non-metallic ore mining emissions are calculated by assuming that the PM10 emission factors for western surface coal mining apply to mining of all non-metallic ores. The PM10/TSP ratio for western surface coal mining is 0.40.[4]

Coal mining includes two additional sources of PM10 emissions compared to the sources considered for metallic and non-metallic ores, namely overburden replacement and truck loading and unloading of that overburden. EPA assumes that the amount of overburden material handled equals ten times the amount of coal mined.[5]

EPA Method 5 (or equivalent) source tests used to generate particulate emission factors include a filterable PM fraction that is captured on or prior to a filter and a condensable PM fraction that is collected in the impinger portion of the sampling train. PM emission factors presented below include the sum of the filterable and condensable PM fractions for those cases where information exists for both fractions. For those cases where information only exists for the filterable PM fraction, this is clearly identified in the text below.

Previous NEI PM emission inventories for fugitive dust from mineral products industries assumed a PM2.5/PM10 ratio of 0.29.[2] In July 2006 EPA adopted revised PM2.5/PM10 ratios for several fugitive dust source categories, including a ratio of 0.1 for heavy vehicle traffic on unpaved surfaces around aggregate storage piles and a ratio of 0.15 for transfer of aggregate associated with buckets or conveyors based on the recent findings of MRI.[6] Thus, the PM2.5/PM10 ratio for fugitive dust from mineral products industries lies somewhere between 0.1 and 0.15.

Estimates of the amount of metallic and non-metallic ores handled at surface mines are available from the U.S. Geological Survey. Production figures for coal mining operations are available from the Energy Information Administration (EIA) in the U.S. Department of Energy.

11.2.1 Metallic Ores

EPA uses the following equation to calculate PM10 emissions from overburden removal, drilling and blasting, and loading and unloading from metallic ore mining operations:

$$E_m = A_m\,[EF_o + (B \times EF_b) + EF_l + EF_d] \qquad (2)$$

where, A_m = metallic crude ore handled at surface mines (tons)
EF_o = PM10 open pit overburden removal emission factor for copper ore (lbs/ton)
B = fraction of total ore production that is obtained by blasting at metallic ore mines
EF_b = PM10 drilling/blasting emission factor for copper ore (lbs/ton)
EF_l = PM10 loading emission factor for copper ore (lbs/ton)
EF_d = PM10 truck dumping emission factor for copper ore (lbs/ton)

Utilizing the TSP emission factors and PM10/TSP ratios developed for copper ore mining operations, PM10 emissions from metallic ore mining operations are calculated as follows:

$$E_m = A_m\,[0.0003 + (0.57625 \times 0.0008) + 0.022 + 0.032] = 0.0548\,A_m \qquad (3)$$

Based on NEI's emission estimation methodology that excludes fugitive dust emissions from haul truck traffic on unpaved surfaces, PM10 emissions from loading and truck dumping account for 40% and 58%, respectively, of the total PM10 emissions from metallic ore mining operations.

Uncontrolled filterable TSP and PM10 emission factors for metallic ore processing operations are presented in Table 11-1. These emission factors are for emissions after product recovery cyclones. Uncontrolled PM emission factors for taconite ore processing are presented in Table 11-2.

Table 11-1. Filterable TSP and PM10 Emission Factors for Metallic Ore Processing[a]

Source	TSP (lb/ton)	PM10 (lb/ton)
Low-moisture ores[b]		
Primary crushing	0.5	0.05
Secondary crushing	1.2	ND
Tertiary crushing	2.7	0.16
Material handling and transfer – all minerals except bauxite	0.12	0.06
Material handling and transfer – bauxite/alumina	1.1	ND
High-moisture ores[b]		
Primary crushing	0.02	0.009
Secondary crushing	0.05	0.02
Tertiary crushing	0.06	0.02
Material handling and transfer – all minerals except bauxite	0.01	0.004
Material handling and transfer – bauxite/alumina	ND	ND
Both low- and high-moisture ores[b]		
Wet grinding	Neg	Neg
Dry grinding with air conveying and/or air classification	28.8	26
Dry grinding without air conveying and/or air classification	2.4	0.31
Drying – all minerals except titanium/zirconium sands	19.7	12

[a] Emission factors in units of lb/ton of material processed. One lb/ton is equivalent to 0.5 kg/Mg. Neg = negligible. ND = no data.

[b] Low-moisture ore has a moisture content of less than 4% by weight; high-moisture ore has a moisture content of at least 4% by weight.

Table 11-2. TSP and PM10 Emission Factors for Taconite Ore Processing[a]

Source	TSP (lb/ton)	PM10 (lb/ton)
Natural gas-fired grate/kiln	7.4	0.65
Gas-fired vertical shaft top gas stack	16	ND
Oil-fired straight grate	1.2	ND

[a] Applicable to both acid pellets and flux pellets. Emission factors in units of lb/ton of fired pellets produced. One lb/ton is equivalent to 0.5 kg/Mg. ND = no data.

11.2.2 Non-metallic Ores

EPA uses the following equation to calculate the PM10 emissions from overburden removal, drilling and blasting, and loading and unloading from non-metallic ore mining and rock quarrying operations:

$$E_n = A_n [EF_v + (D \times EF_r) + EF_a + 0.5 (EF_e + EF_t)] \quad (4)$$

where, A_n = non-metallic crude ore handled at surface mines (tons)

EF_v = PM10 open pit overburden removal emission factor at western surface coal mining operations (lbs/ton)

D = fraction of total ore production that is obtained by blasting at non-metallic ore mines
EF_r = PM10 drilling/blasting emission factor at western surface coal mining operations (lbs/ton)
EF_a = PM10 loading emission factor at western surface coal mining operations (lbs/ton)
EF_e = PM-10 truck unloading: end dump-coal emission factor at western surface coal mining operations (lbs/ton)
EF_t = PM10 truck unloading: bottom dump-coal emission factor at western surface coal mining operations (lbs/ton)

Utilizing the PM10 factors developed for western surface coal mining operations, PM10 emissions from non-metallic ore mining and rock quarrying operations are calculated as follows:

$$E_n = A_n\,[0.225 + (0.61542 \text{ x } 0.00005) + 0.05 + 0.5\,(0.0035 + 0.033)] = 0.293\,A_n \quad (5)$$

PM10 emissions from overburden removal account for 77% of the total PM10 emissions from non-metallic ore mining and rock quarrying operations.

Uncontrolled TSP and PM10 emission factors for non-metallic ore processing operations are presented in Table 11-3. The emission factors for mixer loading and truck loading for concrete batching operations were updated in June 2006.[7] These new AP-42 emission factors are approximately double the previous emission factors. Excluding road dust and windblown dust, the plant wide PM10 emission factors per yard of concrete for an average concrete batch formulation at a typical facility are 0.058 lb/yd^3 for truck mix concrete and 0.037 lb/yd^3 for central mix concrete.

Table 11-3. TSP and PM10 Emission Factors for Non-metallic Ore Processing Operations [a]

Industry	Source	TSP (lb/ton)	PM10 (lb/ton)
Sand and Gravel	Sand Dryer	2.0	ND
Crushed Stone	Tertiary crushing[b]	0.0054	0.0024
	Fines crushing	0.039	0.0150
	Screening	0.025	0.0087
	Fines screening	0.30	0.072
	Conveyor transfer point	0.0030	0.0011
	Wet drilling – unfragmented stone	ND	8.0×10^{-5}
	Truck unloading – fragmented stone	ND	1.6×10^{-5}
	Truck unloading – conveyor, crushed stone	ND	1.0×10^{-4}
Lightweight Aggregate	Rotary Kiln	131	ND
Concrete Batching	Aggregate transfer	0.0069	0.0033
	Sand transfer	0.0021	0.00099
	Cement unloading to storage silo	0.72	0.46
	Cement supplement unloading to silo	3.14	1.10
	Weigh hopper loading	0.0051	0.0024
	Mixer loading (central mix)[c]	0.524	0.156
	Truck loading (truck mix)[c]	1.122	0.311
Phosphate Rock	Dryer	5.7	4.8
	Grinder	1.5	ND
	Calciner	15	14.4
Kaolin[d]	Apron dryer	1.2	ND
	Multiple hearth furnace	34	16
	Flash calciner	1,100	560
Fire Clay[d]	Rotary dryer	65	16
	Rotary calciner	120	30
Bentonite[d]	Rotary dryer	290	20
Talc	Railcar unloading	0.00098	ND
Brick Manufacturing	Grinding and screening wet material[e]	0.025	0.0023
	Grinding and screening dry material[f]	8.5	0.53
	Brick dryer	0.077	ND
	Natural gas-fired kiln	0.96	0.87
	Coal-fired kiln	1.79	1.35
	Sawdust-fired kiln	0.93	0.85
	Sawdust-fired kiln and sawdust dryer	1.36	0.31
	Natural gas-fired kiln firing structural clay	1.0	ND
Portland Cement Manufacturing	Wet process kiln	130	31
	Preheater kiln	250	ND
Gypsum	Rotary ore dryers[f]	$0.16(FFF)^{1.7}$	$0.013(FFF)^{1.7}$
	Continuous kettle calciners and hot pit	41[d]	26
	Flash calciners	37[d]	14
Lime Manufacturing	Primary crusher	0.017[d]	ND
	Secondary crusher	0.62[d]	ND
	Product transfer and conveying	2.2[d]	ND
	Product loading, enclosed truck	0.61[d]	ND
	Product loading, open truck	1.5[d]	ND
	Coal-fired rotary kiln	352	44
	Coal- and gas fired rotary kiln	80	ND
	Gas-fired calcimatic kiln	97	ND
	Product cooler	6.8	ND

[a] Emission factors in units of lb/ton of material processed. One lb/ton is equivalent to 0.5 kg/Mg. ND = no data. FFF is the ratio of gas mass rate per unit dryer cross section area to the dry mass feed rate.[1]

[b] Emission factors for tertiary crushers can be used as an upper limit for primary or secondary crushing.

[c] Emission factors for mixer loading and truck loading for concrete batching operations were updated June 2006.

[d] Filterable PM emission factors.
[e,f] Units are lb/ton of raw material processed based on a raw material moisture content of 13% and of 4%, respectively.

11.2.3 Coal

EPA uses the following equation to calculate the PM10 emissions from overburden removal, drilling and blasting, loading and unloading, and overburden replacement from coal mining operations:

$$E_c = A_c\,[10\,(EF_{to} + EF_{or} + EF_{dt}) + EF_v + EF_r + EF_a + 0.5\,(EF_e + EF_t)] \qquad (6)$$

where, A_c = coal production at surface mines (tons)
- EF_{to} = PM10 emission factor for truck loading overburden at western surface coal mining operations (lbs/ton of overburden)
- EF_{or} = PM10 emission factor for overburden replacement at western surface coal mining operations (lbs/ton of overburden)
- EF_{dt} = PM10 emission factors for truck unloading: bottom dump-overburden at western surface coal mining operations (lbs/ton of overburden)
- EF_v = PM10 open pit overburden removal emission factor at western surface coal mining operations (lbs/ton)
- EF_r = PM10 drilling/blasting emission factor at western surface coal mining operations (lbs/ton)
- EF_a = PM10 loading emission factor at western surface coal mining operations (lbs/ton)
- EF_e = PM10 truck unloading: end dump-coal emission factor at western surface coal mining operations (lbs/ton)
- EF_t = PM10 truck unloading: bottom dump-coal emission factor at western surface coal mining operations (lbs/ton)

Utilizing the PM10 factors developed for western surface coal mining operations, PM10 emissions from coal mining operations are calculated as follows:

$$E_c = A_c\,[10\,(0.015 + 0.001 + 0.006) + 0.225 + 0.00005 + 0.05 + 0.5\,(0.0035 + 0.033)]$$
$$= 0.514\,A_c \qquad (7)$$

PM10 emissions from loading overburden into trucks and overburden removal account for 29% and 44%, respectively, of the total PM10 emissions from coal mining operations.

PM10 emission factor equations for uncontrolled fugitive dust sources at western surface coal mines are presented in Table 11-4.

Table 11-4. PM10 Emission Factor Equations for Uncontrolled Fugitive Dust from Western Surface Coal Mines[a]

Operation	Material	PM10 Emission Factor Equations	
		English Units	Metric Units
Truck loading	Coal	$0.089 / (M)^{0.9}$ lb/ton	$0.045 / (M)^{0.9}$ kg/Mg
Bulldozing	Coal	$14.0(s)^{1.5} / (M)^{1.4}$ lb/hr	$6.33(s)^{1.5} / (M)^{1.4}$ kg/hr
	Overburden	$0.75(s)^{1.5} / (M)^{1.4}$ lb/hr	$0.34(s)^{1.5} / (M)^{1.4}$ kg/hr
Dragline	Overburden	$0.0016(d)^{0.7} / (M)^{0.3}$ lb/yd^3	$0.0022(d)^{0.7} / (M)^{0.3}$ kg/m^3
Grading	Overburden	$0.031(S)^2$ lb/VMT	$0.0034(S)^2$ kg/VKT

[a] Symbols for equations: VMT = vehicle miles traveled; VKT = vehicle kilometers traveled; ND = no data. M = material moisture content (%); s = material silt content (%); d = drop height (ft); S = mean vehicle speed (mph).

In using the equations presented in Table 11-4 to estimate emissions from sources found at a specific western surface mine, it is necessary that reliable values for correction parameters be obtained for the specific sources of interest. For example, the actual silt content of coal or overburden measured at a facility should be used instead of estimated values. In the event that site-specific values for correction parameters cannot be obtained, the appropriate geometric mean values from Table 11-5 may be used.

Table 11-5. Range and Geometric Mean of Correction Factors Used to Develop Emission Factor Equations Shown in Table 11-4.

Source	Correction Factor	Range (Geometric Mean)	
		English Units	Metric Units
Blasting	Area Blasted	1,100 – 73,000 ft^2 ($17,000 ft^2$)	100 – 6,800 m^2 ($1,590 m^2$)
Coal loading	Moisture	6.8 – 38% (17.8%)	
Bulldozers			
Coal	Moisture	4 – 22% (10.4%)	
	Silt	6 – 11.3% (8.6%)	
Overburden	Moisture	2.2 – 16.8% (7.9%)	
	Silt	3.8 – 15.1% (6.9%)	
Dragline	Drop Distance	5 – 100 ft (28.1 ft)	1.5 – 30 m (8.6 m)
	Moisture	0.2 – 16.3% (3.2%)	
Scraper	Silt	7.2 – 25.2% (16.4%)	
	Weight	36 – 70 ton (53.8 ton)	33 – 64 Mg (48.8 Mg)
Grader	Speed	5.0 – 11.8 mph (7.1 mph)	8 – 19 kph (11.4 kph)
Haul truck	Silt content	1.2 – 19.2% (4.3%)	
	Moisture	0.3 – 20.1% (2.4%)	
	Weight	23 – 290 ton (120 ton)	20.9 – 260 Mg (110 Mg)

TSP emission factors for fugitive dust sources not covered in Table 11-4 are presented in Table 11-6. These factors were determined through source testing at various western surface coal mines. It should be pointed out that AP-42 does not list PM10/TSP ratios for fugitive dust sources. Instead it lists TSP and PM15 emission factor equations and PM10/PM15 ratios that range from 0.52 for blasting and 0.60 for grading to 0.75 for other operations. Calculating TSP and PM15 emission factors using typical correction factors provided in Table 11-5 together with the published PM10/PM15 ratios produces PM10/TSP ratios ranging from 0.15 to 0.30 for open area fugitive dust sources at western surface coal mines.

Table 11-6. Uncontrolled TSP Emission Factors for Western Surface Coal Mines[a]

Source	Material	TSP Emission Factor	
		English Units	Metric Units
Blasting	Coal or overburden	$0.000014 (A)^{1.5}$ lb/blast	$0.00022 (A)^{1.5}$ kg/blast
Drilling	Overburden	1.3 lb/hole	0.59 kg/hole
Topsoil removal by scraper	Topsoil	0.058 lb/ton	0.029 kg/Mg
Overburden replacement	Overburden	0.012 lb/ton	0.006 kg/Mg
Train loading by power shovel	Coal	0.028 lb/ton	0.014 kg/Mg
Bottom dump truck unloading	Overburden	0.066 lb/ton	0.033 kg/Mg
Wind erosion of exposed areas[b]	Seeded land, stripped or graded overburden	0.38 ton/acre-yr	0.85 Mg/hectare-yr
Wind erosion of storage pile	Coal	0.72 (u) lb/acre-hr	1.8 (u) kg/hectare-hr

[a] A = horizontal area (ft^2 or m^2) with blasting depth ≤ 70 ft (≤21 m); not for a vertical face of a bench. U = wind speed (mph or m/s)

[b] To estimate wind erosion on a shorter time scale (e.g., worst-case day); see Chapter 8 of the handbook.

11.2.4 Supplemental Emission Factors

TSP and PM10 emission factors for operations associated with ten mineral products industries are published in the EPA's *National Air Pollutant Emission Trends Procedures Document for 1900-1996*.[8] The PM10 emission factors and PM10/TSP ratios for these operations are presented in Table 11-7. It should be pointed out that several of the emission factors shown in Table 11-7 are not consistent with values presented in Tables 11-1 and 11-3. To be conservative, one may wish to adopt the higher of the two values.

Table 11-7. Supplemental PM10 Emission Factors for Mineral Products Industries[a]

Mineral Product Industry	Operation	PM10 (lb/ton)	PM10/TSP Ratio
Copper Ore	Crushing	2.9 to 3.9	0.45
	Open pit overburden removal	0.0003	0.37
	Drill/blasting	0.0008	0.80
	Loading	0.022	0.44
	Truck dumping	0.032	0.80
	Transfer/conveying	0.08	0.53
	Storage	0.7	0.35
Iron Ore	Mining	0.18	0.41
Lead Ore	Crushing	5.1	0.85
Zinc Ore	Crushing	2.3	0.38
Sand and Gravel	Mining	0.029	0.29
Asphalt Concrete	Fugitives	0.15	0.50
Brick Manufacturing	Material Handling	1.4	0.31
Cement Manufacturing	Fugitives	10.4	0.58
Lime Manufacturing	Fugitives	1.75	0.37
Coal	Surface Mining	0.2	0.40
	Coal Handling	0.17	0.34
	Pneumatic Dryer	1.5	0.50

[a] Emission factors in units of lb/ton of material processed. One lb/ton is equivalent to 0.5 kg/Mg.

The predictive emission factor presented in Chapter 4 may be used to calculate emissions for materials handling operations if source specific data (moisture content, wind speed, and silt content) is available.

11.3 Demonstrated Control Techniques

Emissions from mineral processing plants can be controlled by a variety of devices, including wet scrubbers, cyclones, venturi scrubbers, fabric filters, and electrostatic precipitators or baghouses. Rudimentary fallout chambers and cyclone separators can be used to control the larger particles. Conveyor belts moving dried rock may be covered and sometimes enclosed. Transfer points and bucket elevators are sometimes enclosed and evacuated to a control device. Dry rock is often stored in enclosed bins or silos, which are vented to the atmosphere, with fabric filters frequently used to control emissions. Cyclones are often used for product recovery from mechanical processes. In such cases, the cyclones are not considered to be an air pollution control device. Emissions from dryers and calciners can be controlled by a combination of a cyclone or a multiclone and a wet scrubber system. Fabric filters are used at some facilities to control emissions from mechanical processes such as crushing and grinding. Cyclones and fabric filters are used to control emissions from screening, milling, and materials handling and transfer operations.

For moderate to heavy uncontrolled emission rates from typical dry ore operations, a wet scrubber with a pressure drop of 6” to 10” of water will reduce TSP emissions by approximately 95%. With very low uncontrolled emission rates typical of high-moisture conditions, the percentage reduction will be lower (approximately 70%). Wet suppression techniques include application of water, chemicals and/or foam, usually at crusher or conveyor feed and/or discharge points. Such spray systems at transfer points and on material handling operations have been estimated to reduce TSP emissions by 70 to 95%. Spray systems can also reduce loading and wind erosion TSP emissions from storage piles of various materials by 80 to 90%. Venturi scrubbers with a relatively low pressure drop (12” of water) have reported PM10 collection efficiencies of 80 to 99%, whereas high-pressure-drop scrubbers (30” of water) have reported PM10 collection efficiencies of 96 to 99.9%, and electrostatic precipitators have PM10 collection efficiencies of 90 to 99%.

Over a wide range of inlet mass loadings, a well-designed and maintained baghouse will reduce emissions to a relatively constant outlet concentration. Such baghouses tested in the mineral processing industry consistently reduce emissions to less than 0.05 g/m^3 (0.02 $grains/ft^3$), with an average concentration of 0.015 g/m^3 (0.006 $grains/ft^3$). Under conditions of moderate to high uncontrolled emission rates of typical dry ore facilities, this level of controlled emissions represents greater than 99% removal of PM emissions. Control efficiencies depend upon local climatic conditions, source properties and duration of control effectiveness.

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Emissions from these processes can be controlled by fabric filtration (baghouses) with reported removal efficiencies of approximately 95 to 99%. The industry uses shaker, reverse air, and pulse jet filters as well as some cartridge units, but most newer facilities use pulse jet filters.

Successful control techniques used for haul roads are dust suppressant application, paving, route modifications, and soil stabilization. Controls for conveyors include covering and wet suppression; for storage piles, wet suppression, windbreaks, enclosure, and soil stabilizers; for conveyor and batch transfer points, wet suppression and various methods to reduce freefall distances (e. g., telescopic chutes, stone ladders, and hinged boom stacker conveyors); and for screening and other size classification, covering and wet suppression. Additional information on these control measures can be found in other chapters of this handbook.

AP-42 lists both uncontrolled and controlled PM10 emission factors for different control devices for many mineral processing industries. Comparing the controlled emission factor for a specific control device to the uncontrolled emission factor provides the PM10 control efficiency for that control device presented in Table 11-8.

Table 11-8. PM10 Control Efficiencies for Mineral Processing Operations

Mineral Products Industry	Source	Control Device	PM10 Control Efficiency (%)
Taconite ore	Natural gas fired kiln	Multiclone	79
Crushed stone	Tertiary crushing	Wet scrubber	78
	Fines crushing	Wet scrubber	92
	Screening	Wet scrubber	91.6
	Fines screening	Wet scrubber	96.9
	Conveyor transfer point	Wet scrubber	95.9
Pulverized mineral	Grinding	Fabric filter	>99.5%
Lightweight aggregate	Rotary Kiln	Wet scrubber	99.4
	Rotary Kiln	Fabric filter	99.8
	Rotary Kiln	Electrostatic precipitator	99.5
Kaolin	Flash calciner	Fabric filter	99.99
Fire clay	Rotary dryer	Cyclone	68
	Rotary calciner	Multiclone and wet scrubber	99.8
Bentonite	Rotary dryer	Fabric filter	99.6
Hot mix asphalt	Dryer	Fabric filter	99.4
Brick manufacturing	Grinding and screening	Fabric filter	99.4
Portland cement	Wet process kiln	Electrostatic precipitator	97.9
Cement batching	Unloading into silo	Wet scrubber	99.9
	Mixer loading (central mix)	Wet scrubber	96.5
	Truck loading (truck mix)	Wet scrubber	91.6
Gypsum manufacturing	Flash calciner	Fabric filter	99.8
Lime manufacturing	Coal-fired rotary kiln	Fabric filter	99.6
	Coal-fired rotary kiln	Electrostatic precipitator	90

11.4 Regulatory Formats

PM stack emissions from taconite ore processing facilities constructed or modified after August 24, 1982 are regulated under 40 CFR 60, subpart LL to 0.05 g/m^3 (0.022

grains/ft^3). In addition, the opacity of stack emissions is limited to 7% unless the stack is equipped with a wet scrubber, and process fugitive emissions are limited to 10%. The standard does not affect emissions from indurating furnaces. Emissions from Portland cement plants constructed or modified after August 17, 1971 are regulated to limit PM emissions from kilns to 0.15 kg/Mg (0.30 lb/ton) of feed, and to limit PM emissions from clinker coolers to 0.050 kg/Mg (0.10 lb/ton) of feed. Emissions of filterable PM from rotary lime kilns constructed or modified after May 3, 1977 are regulated to 0.30 kg/Mg (0.60 lb/ton) of stone feed under 40 CFR Part 60, subpart HH.

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Example regulatory formats downloaded from the Internet for several local air quality agencies in the WRAP region are presented in Table 11-9. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- San Joaquin Valley APCD, CA: valleyair.org/SJV_main.asp
- South Coast AQMD, CA: aqmd.gov/rules
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/aq

Table 11-9. Example Regulatory Formats for Mineral Processing Operations

Control Measure	Agency
Limits PM emissions from cement kilns to 30 pounds per hour for kiln feed rates of 75 tons per hour or greater. Limits PM emissions to 0.40 pound per ton of kiln feed for kiln feed rates less than 75 tons per hour.	SCAQMD Rule 1112.1 02/07/86
Limits opacity from cement manufacturing facilities to 20 % for open storage piles and unpaved roads and to 10 % for all other operations, Specifies covers for conveying systems and enclosures for conveying system transfer points, and loading/unloading through an enclosed system.	SCAQMD Rule 1156 11/04/05
Limits opacity from an aggregate handling facility to 20% based on an average of 12 consecutive readings, or 50% based on five individual, consecutive readings, using the SCAQMD Opacity Test Method No. 9B.	SCAQMD Rule 1157 01/07/05
Limits (a) PM emissions from stacks at a nonmetallic mineral processing plant to 0.02 grains/dry standard cubic foot (gr/dscf) (50 mg/dscm), (b) opacity of fugitive dust emissions from any transfer point on a conveying system to 7%, and (c) opacity of fugitive dust emissions from any crusher to 15%.	Maricopa Co. Rule 316 6/08/05
No owner or operator of an existing tunnel kiln at a brick or structural product manufacturing facility shall emit more than 0.42 lbs. of particulate matter per ton of fired product from a tunnel kiln with a capacity throughput ≥ 1 ton/hour.	Maricopa Co. Rule 325 8/10/05
Limits the opacity of fugitive dust emissions at metallic or non-metallic mineral mining and processing facilities (based on an aggregate of at least 3 minutes in any 1-hour period) to (a) 10% for grinding mills, screening equipment, conveyors, conveyor transfer points, bagging equipment, storage bin, storage piles, stacker, enclosed truck, or rail car loading stations, (b) 15% for crushers, and (c) 7% for emissions from a stack or exhaust from a control device or building vent.	Clark Co. Rule 34 7/01/04

11.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 11-10 summarizes the compliance tools that are applicable for mineral processing industries.

Table 11-10. Compliance Tools for Mineral Processing Industries

Record keeping	Site inspection/monitoring
Maintain daily records onsite for a period of five years, and make such records available to the Executive Officer upon request for: (a) hours of operation, (b) volume of ore or aggregate mined, (c) watering and sweeping schedule for internal paved roads, (d) number of haul trucks exiting the facility, (e) Fugitive Dust Advisories, (f) Dust Control Plan, (g) Operation and Maintenance Plan for the on-site emission control system (ECS), and (h) twice daily moisture results of aggregate material.	Observation of dust plumes during periods of mining and processing operations; observation of dust plume opacity (visible emissions) exceeding a standard; tests of surface soil stabilization and aggregate moisture content; monitoring device to record pressures, flow rates and other ECS operating conditions; posting of signs restricting speeds to 15 mph; observation of high winds (e.g., >25 mph).

11.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for mineral processing operations. The reader is directed to Sections 4.6, 6.8, and 9.6 of the handbook for examples of calculating the cost effectiveness of specific control measures for several minerals processing operations, namely materials handling, haul trucks traveling on unpaved industrial roads, and storage pile wind erosion, respectively.

A sample cost-effectiveness calculation is presented below for a specific control measure (wet scrubber for tertiary crushing of crushed stone) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for mineral processing, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Tertiary Crushing at Crushed Stone Processing Plant

Step 1. Determine source activity and control application parameters.

Material throughput (tons/year)	2,000,000
Control Measure	Wet scrubber
Control application/frequency	Continuous
Economic Life of Control System (yr)	10
Control Efficiency (Reference)	78% (AP-42)

The material throughput and economic life are assumed values for illustrative purposes. A wet scrubber system has been chosen as the control measure for reducing fugitive dust emissions. The moisture content of the crushed stone averages 0.21 to 1.3% for facilities without a wet suppression system and 0.55 to 2.88% for facilities with a wet suppression system.[1]

Step 2. Obtain Uncontrolled PM Emission Factors. The uncontrolled PM10 emission factor for tertiary crushing of crushed stone published in AP-42 is 0.0024 lb/ton of material throughput. The PM2.5/PM10 ratio for crushed stone aggregate is 0.15 (MRI, 2006).[6]

Step 3. Calculate Uncontrolled PM Emissions. The annual uncontrolled PM10 emissions are calculated by multiplying the PM10 emission factor by the material throughput and then divided by 2,000 lbs to compute the annual emissions in tons per year, as follows:

Annual emissions = (EF x Material Throughput)/2,000

Annual PM10 Emissions = (0.0024 x 2,000,000)/2000 = 2.4 tons
Annual PM2.5 Emissions = 0.15 (Annual PM10 Emissions) = 0.36 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, a wet scrubber/suppression system with a control efficiency of 78% has been selected as the control measure. Thus, the annual controlled PM10 and PM2.5 emissions estimates are calculated to be:

Annual Controlled PM10 emissions = (2.4 tons) x (1 – 0.78) = 0.53 tons
Annual Controlled PM2.5 emissions = (0.36 tons) x (1 – 0.78) = 0.079 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	16,000
Operating/Maintenance costs ($)	12,200
Annual Interest Rate	3%
Capital Recovery Factor	0.12
Annualized Cost ($/yr)	14,076

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:

$$CRF = AIR \times (1+AIR)^{\text{Economic life}} / (1+AIR)^{\text{Economic life}} – 1$$
$$CRF = 3\% \times (1+ 3\%)^{10} / (1+ 3\%)^{10} – 1 = 0.1172$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor (CRF) multiplied by the Capital costs to the sum of the Operating and Maintenance costs, as follows:

Annualized Cost = (CRF x Capital costs) + Operating/Maintenance costs
Annualized Cost = (0.1172 x $16,000) + $12,200 = $14,076

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 = $14,075 / (2.4 – 0.53) = $7,519/ton
Cost-effectiveness for PM2.5 emissions = $14,075 / (0.36 – 0.079) = $50,127/ton

11.7 References

1. USEPA, 2006. *Compilation of Air Pollutant Emission Factors*, AP-42 Section 11 (Minerals Products Industry), Fifth Edition.

2. USEPA, 2004. *Documentation for the Final 1999 National Emissions Inventory (Version 3.0) for Criteria Pollutants and Ammonia: Area Sources*, report prepared by E. H. Pechan and Associates for the USEPA OAQPS, January 31.

3. USEPA, 1986. *Generalized Particle Size Distributions for Use in Preparing Size-Specific Particulate Emissions Inventories*, EPA-450/4-86-013, July.

4. USEPA, 1990. *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, EPA-450/4-90-003, March.

5. USEPA, 2001. *Procedures Document for National Emission Inventory, Criteria Air Pollutants, 1985-1999*, EPA-454/R-01-006, March.

6. MRI, 2006. *Background Document for Revisions to Fine Fraction Ratios Used for AP-42 Fugitive Emission Factors*, prepared for the WRAP by Midwest Research Institute, Feb. 1.

7. USEPA, 2006. AP-42 *Section 11.12: Concrete Batching,* updated in June.

8. USEPA, 1998. *National Air Pollutant Emission Trends Procedure Document for 1900-1996*, EPA-454/R-98-008, May.

Chapter 12. Abrasive Blasting

12.1 Emission Estimation Methodology

> This section was adapted from Section 13.2.6 of EPA's Compilation of Air Pollutant Emission Factors (AP-42). Section 13.2.6 was last updated in September 1997.

Abrasive blasting is the use of abrasive material to clean and prepare metal or masonry surfaces prior to painting. Sand is the most widely used blasting abrasive.[1] Other abrasive materials include coal slag, smelter slag, cast iron grit, cast iron shot, steel shot, garnet, walnut shells, carbon dioxide pellets, as well as synthetic abrasives such as silicon carbide, aluminum oxide, and glass or plastic beads. The PM10 and PM2.5 emission factors listed in AP-42 for sand blasting of mild steel are 13 lb/1,000 lb abrasive and 1.3 lb/1,000 lb abrasive, respectively, giving a PM2.5/PM10 ratio of 0.1. Using grit or shot instead of sand as the abrasive media reduces total PM emissions by 76% and 90%, respectively.

12.2 Demonstrated Control Techniques

A number of different methods have been used to control the emissions from abrasive blasting. Theses methods include: blast enclosures; vacuum blasters; drapes; water curtains; wet blasting; and reclaim systems. Wet blasting controls include not only traditional wet blasting processes but also high pressure water blasting, high pressure water and abrasive blasting, and air and water abrasive blasting. For wet blasting, control efficiencies between 50 and 93 percent have been reported. Fabric filters are typically used to control emissions from enclosed abrasive blasting operations with reported control efficiencies in excess of 95%.[1]

Muleski and Downing recently tested the use of a polyurethane sponge material impregnated with different abrasive materials and compared the particulate emissions from this new sponge media with that from traditional abrasive materials.[2] The pliable nature of the sponge material allows it to surround the point of abrasive impact, thus capturing airborne dust emissions. The most commonly sold sponge media is a product containing 30 grit aluminum oxide known as "Silver 30". Using recycled sponge media mixed with fresh abrasive material per the manufacturer's recommendations reduced TSP emissions by 94% and PM10 emissions by 96% compared to traditionally used abrasives such as coal slag and silica sand. In other words, when used as recommended (i.e., recycled sponge media with fresh abrasive material added), the foam-based blasting media achieved a control level essentially identical to that of fabric filtration.

12.3 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. As an example, Maricopa County's Rule 312 states that all abrasive blasting operations shall be performed in a confined enclosure, unless one of the following conditions are met, in which case unconfined blasting may be performed: (a) the item to be blasted exceeds 8 ft. in any one dimension, or (b) the surface being blasted is fixed in a permanent location, cannot easily be moved into a confined enclosure, and the surface is not normally dismantled or moved prior to abrasive blasting.[3] Dry abrasive blasting in a confined enclosure with a forced air exhaust requires the use of either a certified abrasive (i.e., an abrasive certified by the California Air Resources Board), or venting to an emission control system (ECS) for which the operator must maintain an operation and maintenance plan. A list of abrasives currently certified by CARB as permissible for dry outdoor blasting can be obtained from Maricopa County's website (maricopa.gov/aq/divisions/planning.aspx#rules). For unconfined blasting, at least one of the following control measures shall be used: wet abrasive blasting, vacuum blasting, or dry abrasive blasting, provided that all of the following conditions are met: performed only on a metal substrate, use of certified abrasive for dry unconfined blasting, blasting paint that has a lead content of less than 0.1 percent, abrasive blasting operation directed away from unpaved surfaces, and the certified abrasive may only be used once unless contaminants are separated from the abrasive after each use. No dry unconfined abrasive blasting operation shall be conducted when the 1-hour average wind speed is greater than 25 miles per hour.

Maricopa County Rule 312 states no owner or operator shall discharge into the atmosphere from any abrasive blasting operation any air contaminant for an observation period or periods aggregating more than three minutes in any sixty minute period an opacity conducted in accordance with EPA Reference Method 9 ("Visual Determination of the Opacity of Emissions from Stationary Sources," 40 CFR 60, Appendix A) equal to or greater than 20 percent. At the end of the work shift the owner or operator shall clean up spillage, carryout, and/or track out of any spent abrasive material with a potential to be transported during periods where the wind exceeds 25 mph.

The South Coast AQMD's Rule 1140 states that before blasting all abrasives used for dry unconfined blasting shall contain no more than1% by weight material passing a No. 70 U.S. Standard sieve, and after blasting the abrasive shall not contain more than 1.8% by weight material five microns or smaller.[4] Rule 1140 states that visible emission evaluation of abrasive blasting operations shall be conducted in accordance with the following provisions:

1. Emissions shall be read in opacities and recorded in percentages.
2. The light source should be behind the observer during daylight hours.
3. The light source should be behind the emission during hours of darkness.
4. The observer position should be at approximately right angles to wind direction and at a distance no less than twice the height of the source but not more than a quarter mile from the base of the source.
5. Emissions from unconfined abrasive blasting shall be read at the densest point in the plume, which point shall be at least 25 feet from the source.

6. Where the presence of uncombined water is the only reason for failure to comply with opacity limits, the opacity limits shall not apply. The burden of proof in establishing that opacity limits shall not apply shall be upon the operator.

7. Emissions from unconfined abrasive blasting employing multiple nozzles shall be evaluated as a single source unless it can be demonstrated by the operator that each nozzle, evaluated separately, meets the requirements of this rule.

8. Emissions from confined abrasive blasting shall be read at the densest point after the air contaminant leaves the enclosure.

The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- San Joaquin Valley APCD, CA: valleyair.org/SJV_main.asp
- South Coast AQMD, CA: aqmd.gov/rules
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/aq

12.4 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Maricopa County Rule 312 states that as a minimum each owner or operator subject to this rule shall keep the following records onsite for at least 5 years at permitted Title V sources and for at least 2 years at Non-Title V sources: (a) the type and amount of solid abrasive material consumed on a monthly basis, including the name of the certified abrasive used, as applicable; and (b) Material Safety Data Sheets (MSDS) or results of any lead testing that was performed on paint that is to be removed via unconfined blasting, as applicable. In addition if blasting operations occur daily or are a part of a facility's primary work activity, then records shall be kept of the blasting equipment including a description of the type of blasting (e.g., confined, unconfined, sand, wet, etc.), the location of the blasting equipment or specify if the equipment is portable, a description of the emission control system (ECS) associated with the blasting operations, the days of the week blasting occurs, and the normal hours of operation. If blasting operations occur periodically, then records shall be kept of the dates the blasting occurs, the blasting equipment that is operating including a description of the type of blasting, and a description of the ECS associated with the blasting operations.

12.5 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for abrasive blasting operations. A sample cost-effectiveness calculation is presented below for a specific control measure (fabric filtration used to capture particulates from sand blasting of mild steel) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for abrasive blasting, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Sand Blasting of Mild Steel

Step 1. Determine source activity and control application parameters.

Silica sand abrasive use (tons/year)	10
Control Measure	Fabric Filter
Control application/frequency	Continuous
Economic Life of Control System (yr)	10
Control Efficiency (Reference)	95% (AP-42)

The amount of abrasive material used on a yearly basis and the economic life of the control system are assumed values for illustrative purposes. A fabric filter filtration system has been chosen as the control measure for reducing fugitive dust emissions from abrasive blasting of mild steel.

Step 2. Obtain Uncontrolled PM Emission Factors. The uncontrolled PM10 and PM2.5 emission factors for sand blasting of mild steel published in AP-42 are 26 lb/ton of abrasive and 2.6 lb/ton of abrasive.

Step 3. Calculate Uncontrolled PM Emissions. The annual uncontrolled PM emissions are calculated by multiplying the PM emission factors by the amount of abrasive material used per year divided by 2,000 lb/ton to produce emission estimates in tons per year, as follows:

- Annual PM10 Emissions = (26 lb/ton x 10 tons/year) / 2,000 lb/ton = 0.13 tons
- Annual PM2.5 Emissions = (2.6 lb/ton x 10 tons/year) / 2,000 lb/ton = 0.013 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, fabric filters with a control efficiency of 95%% has been selected as the control measure. Thus, the annual controlled PM10 and PM2.5 emissions estimates are calculated to be:

Annual Controlled PM10 emissions = (0.13 tons) x (1 – 0.95) = 0.0065 tons
Annual Controlled PM2.5 emissions = (0.013 tons) x (1 – 0.95) = 0.00065 tons

Step 5. Determine Annual Cost to Control PM Emissions.

Capital costs ($)	10,000
Annual operating and maintenance costs ($)	1,000
Annual Interest Rate	3%
Capital Recovery Factor	0.12
Annualized Cost ($/yr)	2,200

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:

$$CRF = AIR \times (1+AIR)^{\text{Economic life}} / (1+AIR)^{\text{Economic life}} – 1$$
$$CRF = 3\% \times (1+ 3\%)^{10} / (1+ 3\%)^{10} – 1 = 0.1172$$

The Annualized Cost is calculated by adding the product of the Capital Recovery Factor (CRF) multiplied by the Capital costs to the sum of the operating and maintenance costs, as follows:

Annualized Cost = (CRF x Capital costs) + Operating and Maintenance costs
Annualized Cost = (0.1172 x $10,000) + $1,000 = $2,172

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 = $2,172/ (0.13 – 0.0065) = $17,590/ton
Cost-effectiveness for PM2.5 emissions = $2,172/ (0.013 – 0.00065) = $175,895/ton

12.6 References

1. USEPA, 1997. *Abrasives Blasting*, Section 13.2.6 of Compilation of Air Pollutant Emission Factors, September.

2. Muleski, G. E., and Downing, J., 2006. *Control of Abrasive Blasting Emissions through Improved Materials*, paper presented at the EPA 15th International Emission Inventory Conference, New Orleans, LA, May 16-18.

3. Maricopa County, 2003. *Rule 312 - Abrasive Blasting*, July 2.

4. South Coast AQMD, 1985. *Rule 1140 – Abrasive Blasting*, August 2.

Chapter 13. Livestock Husbandry

13.1 Emission Estimation Methodology

This section was adapted from Section 7.6 of CARB's Emission Inventory Methodology. Section 7.6 was last updated in May 2004.

AP-42 does not address livestock husbandry. Thus, the methodology adopted by the California Air Resources Board (CARB) is presented here as the primary emissions estimation methodology for this fugitive dust source category.[1] The CARB methodology only provides estimates of PM10 emissions from cattle feedlot and dairy operations. For each category, the emissions are calculated by multiplying a per animal emission factor by the population of each animal type. The livestock population is available from the US Department of Agriculture. Livestock emissions research is ongoing.

CARB's PM10 emission factor for cattle feedlots is 28.9 lbs PM10/1000 head/day (i.e., 10.55 lb/head-year) based on a work performed by UC Davis.[2] The corresponding PM10 emission factor for dairy cattle is 6.72 lbs PM10/1000 head/day (i.e., 2.45 lb/head-year) based on an emission factor of 4.4 lbs PM10/1000 lactating head/day, developed by Texas A&M.[3] To make the Texas emission factor more California specific, it was multiplied by a scaling factor based on the ratio of the California feedlot PM10 emission factor to a Texas feedlot PM10 emission factor. This ratio is 29:19; thus, the scaling factor is 1.53. The PM10/TSP and PM2.5/PM10 ratios for this source category are 0.48 and 0.11, respectively.

The CARB methodology is subject to the following assumptions:

1. Population data and residence time data adequately represent average animal population values for each county.

2. All animals within a single class produce the same emissions (e.g., dairy cows, calves, and heifers).

3. It is assumed that all dairies or feedlots produce the same PM10 emissions on a per-head basis.

4. For dairies, the baseline PM10 emission factor includes the effects of support stock such as calves and heifers. This is because the emissions testing included these animals within its analysis.

5. For feedlots, the baseline PM10 emission factor represents the population mix at a typical feedlot.

6. The method does not include emissions for animal waste composting or land application.

7. Due to insufficient temporal information, it is assumed that air emissions occur evenly throughout the year seven days a week and 24 hours a day.

The San Joaquin Valley APCD has developed separate emission factors for different operations associated with dairies and cattle feedlots based on CARB's PM10 emission factors of 2.45 lb/head-year for dairies and 10.55 lb/head-year for cattle feedlots.[4] These emission factors are shown in Table 13-1.

Table 13-1. PM10 Emission Factors for Cattle Feedlot and Dairy Operations

Source Category	Operation	PM10 Emission Factor
Dairies	Corral/Manure Handling	1.845 lb/head-yr (freestall) 4.6 lb/head-yr (open corral)
	Overall Management/Feeding	1.845 lb/head-yr (freestall) 4.6 lb/head-yr (open corral)
	Unpaved Road	0.369 lb/head-yr
	Unpaved Area	0.123 lb/head-yr
Cattle Feedlots	Pens/Manure Handling	7.94 lb/head-yr
	Overall Management/Feeding	0.53 lb/head-yr
	Unpaved Road	1.59 lb/head-yr
	Unpaved Area	0.53 lb/head-yr

13.2 Demonstrated Control Techniques

CARB does not list any control measures for this fugitive dust source category. However, the San Joaquin Valley APCD (District) has been very proactive in identifying potential control measures for cattle feedlots and dairies. For example, fugitive dust emissions originating from the disturbance of dry and loose surface material (e.g., feed, bedding material, and manure) caused by animal movement and mechanical disturbances by vehicles can be controlled by sprinkling water on the surface of the open corral or pen, removing manure before it dries, using a layer of wood chips in dusty areas, housing dairy cattle in stalls with concrete floors rather than dirt floors, and adopting a feeding schedule when animals are less active. Wind blown fugitive dust originating from uncovered bulk materials can be controlled by applying water or chemical suppressants, covering the material with tarps or storing the material in enclosure, and erecting wind barriers. Since no data could be found in the literature on which to base a control efficiency factor for these practices, the District has conservatively assumed a minimal 10% control effectiveness. Control measures identified by the District for cattle feedlots and dairies are shown in Table 13-2. A list of control measures for cattle feedlots and dairies is available from the California Air Pollution Control Officers' Association's (CAPCOA) agricultural clearing house website (http://capcoa.org/ag_clearinghouse.htm).

Control measures for unpaved roads and unpaved parking/traffic areas include application of chemical dust suppressants, paving the surface or placing a layer of gravel over the unpaved surface, speed reduction, access restriction, and track out control measures. These control measures and their associated control efficiencies are listed in Chapter 6 of the handbook. Control measures for storage piles of bulk materials other than manure include dust suppressants, watering, covering and wind barriers. These control measures and their associated control efficiencies are listed in Chapter 9 of the handbook.

Table 13-2. Control Measures for Cattle Feedlots and Dairies[a]

Source Category	Control Measure
Manure management	Frequent manure removal (every 6 months) with equipment that leaves an evenly corral surface of compacted manure on top of the soil.
	Insert the manure directly beneath the soil.
Dust entrainment by animal	Daily water sprinkling, and timing of watering around 6PM or before sunset.
	Use of freestalls with concrete surface for animal housing/feeding areas to allow frequent manure removal.
	Stocking density adjustment in accordance to the moisture found in the unit area to reduce dust.
	Removal of loose material on surface and maintain a compacted layer of manure 1 to 2 inches thick.
	Addition of fibrous material such as wood chips to working pens.
	Delaying the last daily feeding to reduce end-of-day spike in livestock activity.
Other	Adding moisture to hay
	Using a totally enclosed delivery system and covered feeders, and using palletized feed.
	Planting rows of vegetation around a building to create a barrier for air exiting from the building.

[a] Since no data could be found in the literature on which to base a control efficiency factor for these practices, the SJVAPCD has conservatively assumed a minimal 10% control effectiveness for each control measure.

13.3 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. However, most air quality districts currently exempt agricultural operations from controlling fugitive dust. Air quality districts that regulate fugitive dust emissions from agricultural operations include Clark County, NV and several districts in California such as the Imperial County APCD, the San Joaquin Valley APCD and the South Coast AQMD. Imperial County APCD prohibits fugitive dust emissions from farming activities for farms over 40 acres. The San Joaquin Valley APCD and the South Coast AQMD prohibit fugitive dust emissions for the larger farms defined as farms with areas where the combined disturbed surface area within one continuous property line and not separated by a paved public road is greater than 10 acres. SJVAPCD's Rule 4550 applies to animal feeding operations (AFOs) that house animals for a total of at least 45 days in any 12 month period for agricultural parcels exceeding 100 acres excluding the AFO. Example regulatory formats downloaded from the Internet for several local air quality agencies in the WRAP region are presented in Table 13-3. CAPCOA's agricultural clearing house website (http://capcoa.org/ag_clearinghouse.htm) provides links to rules of different air quality agencies that regulate fugitive dust emissions from agricultural operations. The website addresses for obtaining information on fugitive dust regulations for local air quality districts within California, for Clark County, NV, and for Maricopa County, AZ, are as follows:

- Districts within California: www.arb.ca.gov/drdb/drdb.htm
- San Joaquin Valley APCD, CA: valleyair.org/SJV_main.asp
- South Coast AQMD, CA: aqmd.gov/rules
- Clark County, NV: www.co.clark.nv.us/air_quality/regs.htm
- Maricopa County, AZ: www.maricopa.gov/aq

Table 13-3. Example Regulatory Formats for Cattle Feedlots and Dairies

Control Measure	Agency
Limit fugitive dust from animal feeding operations for facilities exceeding 100 acres excluding the AFO by requiring owner/operator to implement a Conservation Management Practice (CMP) Plan with district approved control methods.	SJVAPCD Rule 4550 5/20/04
Limit fugitive dust from off-field agricultural sources such as unpaved roads with more than 75 trips/day and bulk materials handling by requiring producers to draft and implement a Fugitive Dust Management Plan with district approved control methods.	SJVAPCD Rule 8081 9/16/04
Producers that voluntarily implement district approved conservation practices and complete and maintain the self-monitoring plan can maintain an exemption from the Rule 403 general requirements.	SCAQMD Rule 403 4/02/04
Cease tilling/mulching activities when wind speeds are greater than 25 mph.	SCAQMD Rule 403.1 4/02/04
Limit fugitive dust from paved and unpaved roads and livestock operations by ceasing all hay grinding activities between 2 and 5 PM if visible emissions extend more than 50 feet from a hay grinding source, and treating all unpaved access connections to livestock operations and unpaved feed lane access areas with either pavement, gravel (maintained to a depth of 4 inches), or asphaltic road-base.	SCAQMD Rule 1186 4/02/04
Reduce fugitive dust from livestock feed yards by requiring that the moisture content in the top three inches of manure piles for occupied pens be maintained between 20% and 40%. This rule also outlines manure management practices, including removal.	SCAQMD Rule 1186 4/02/04
Reduce fugitive dust from livestock feed yards by requiring that the moisture content for manure piles be maintained between 20% and 40%.	ICAPCD Rule 420 8/13/02

13.4 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations. An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Table 13-4 summarizes the compliance tools that are applicable for cattle feedlots and dairies.

Table 13-4. Compliance Tools for Cattle Feedlot and Dairies

Record keeping	Site inspection/monitoring
Maintain daily records to document the specific dust control options taken; maintain such records for a period of not less than three years; and make such records available to the APCO upon request. Submit a Conservation Management Practice (CMP) Plan to the APCO listing the selected CMPs for implementation, contact information for the owner/operator, a site plan or map of the site.	Observation of dust plumes and dust plume opacity (visible emissions) exceeding a standard; observation of high winds (e.g., >25 mph).

13.5 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for cattle feedlots and dairies. A sample cost-effectiveness calculation is presented below for cattle feedlots for a specific control measure (frequent scraping and manure removal) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for cattle feedlots and dairies, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Cattle Feedlots

Step 1. Determine source activity and control application parameters.

Number of cattle at the feedlot	1,000
Control Measure	Scraping and manure removal

Frequency of operations per year	2
Control Efficiency	10%

Scraping and removal of manure from feedlot pens every six months has been chosen as the applied control measure. The number of cattle at the feedlot is an assumed value for illustrative purposes. Since no data could be found in the literature on which to base a control efficiency factor for control measures for cattle feedlots and dairies, the SJVAPCD has conservatively assumed a minimal 10% control effectiveness for each control measure (SVAPCD, 2004[4]).

Step 2. Obtain Uncontrolled PM10 Emission Factor.
The uncontrolled PM10 emission factor for cattle feedlots is 10.55 lb/head/year (CARB, 2004[1]).

Step 3. Calculate Uncontrolled PM Emissions. The PM10 emission factor, EF, (given in Step 2) is multiplied by the number of cattle (see activity data) and then divided by 2,000 lb/ton to compute the annual PM10 emissions in tons per year, as follows:

Annual PM10 emissions = (EF x Number of Cattle) / 2,000
Annual PM10 Emissions = (10.55 x 1,000) / 2,000 = 5.28 tons

Annual PM2.5 emissions = (PM2.5/PM10) x PM10 emissions
where the PM2.5/PM10 ratio for cattle feedlots is 0.11 (CARB, 2004[1]).

Annual PM2.5 emissions = 0.11 x PM10 emissions
Annual PM2.5 Emissions = (0.11 x 5.28 tons) = 0.58 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 frequent scraping and removal of manure as our control measure. Based on a control efficiency estimate of 10%, the annual controlled PM emissions are calculated to be:

Annual Controlled PM10 emissions = (5.28 tons) x (1 – 0.10) = 4.75 tons
Annual Controlled PM2.5 emissions = (0.58 tons) x (1 – 0.10) = 0.52 tons

Step 5. Determine Annual Cost to Control PM Emissions.

The SJVAPCD assumes that the cost for scraping and removal of manure is $3 per head.[4] Thus, the annualized cost of scraping and removal of manure from feedlot pens holding 1,000 head of cattle every six months is calculated as follows:

Annual Costs = Cost per head to remove manure x Head of Cattle x Frequency of Ops/year
Annual Costs = $3/head x 1,000 head x 2/year = $6,000

Step 6. Calculate Cost-effectiveness. The cost-effectiveness is calculated by dividing the annual cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions as follows:

Cost-effectiveness = Annual Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = \$6,000 / (5.28 – 4.75) = \$11,374/ton
Cost-effectiveness for PM2.5 emissions = \$6,000 / (0.58 – 0.52) = \$103,404/ton

Note: The actual cost-effectiveness values for this control measure are lower than the calculated values shown here since the SJVAPCD assumes that the control efficiency is at least 10%.

13.6 References

1. CARB, 2004. *Livestock Husbandry*, Section 7.6 of CARB's Emission Inventory Procedural Manual, Volume III: Methods for Assessing Area Source Emissions, May.

2. Flocchini, R.G., James, T.A., et. al., 2001. *Sources and Sinks of PM10 in the San Joaquin Valley*, Interim Report prepared by the Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis. August 10.

3. Goodrich, L.B., Parnell, C.B., Mukhtar, S., Lacey, R.E., Shaw, B.W., 2002. *Preliminary PM10 Emission Factor for Freestall Dairies,* Department of Biological and Agricultural Engineering, Texas A&M University, paper presented at the 2002 ASAE Annual International Meeting, Chicago, IL, July 28-31.

4. SJVAPCD, 2005. *Emission Reduction Calculation Methodology for Dairies and Feedlot Conservation Management Practices,* Draft Report prepared by San Joaquin Valley APCD, November 24.

Chapter 14. Miscellaneous Minor Fugitive Dust Sources

14.1 Introduction

This Chapter identifies emission estimation methods for several minor fugitive dust source categories not addressed in other chapters of the handbook. Because several of these methods have not been approved by federal or state agencies, the reader is cautioned in the use of the emission factors included in these emission estimation methods. The emission estimation methods discussed here address:

- windblown dust from unpaved roads
- uncovered haul trucks,
- unpaved shoulders,
- leaf blowers, and
- explosives detonation.

14.2 Windblown Dust from Unpaved Roads

The California Air Resources Board adopted the U.S. EPA-modified version of the USDA-ARS derived wind erosion equation (WEQ) used to estimate windblown dust from agricultural fields[1] to estimate windblown dust from unpaved roads[2] as follows:

$$E_S = a\ I\ K\ C\ L'\ V' \tag{1}$$

where,
E_S = the quantity of unpaved road dust entrained to the air by wind erosion (tons TSP/acre/year)
a = portion of total roadway wind erosion losses that are assumed to be suspended into the air; estimated to be 0.038 for TSP
I = soil erodibility (tons/acre/year)
K = surface roughness factor (dimensionless)
C = climatic factor (dimensionless)
L' = unsheltered width factor (dimensionless)
V' = vegetative cover factor (dimensionless)

In summary, the 'I' term in the windblown dust equation provides an estimate of the soil erosion from an area that is large, flat, bare, and highly erodible. The additional terms in the equation reduce emissions from this worst-case scenario. The climatic, C, factor helps to account for regional differences in wind and rainfall. If a surface is rough, as represented by K, soil erosion is decreased. If the length of the erodible area parallel to the wind is short, then the erosion is decreased, as represented by the L' factor. If there is crop residue on the erodible area, then erosion is further decreased by the V' factor. A detailed discussion of the parameters I, K, C, L', and V' is presented in Chapter 7 of the Handbook.

Soil Erodibility – I. The soil erodibility, I, of an unpaved road is related to the soil type of the road surface. Because roadway soil types are not readily available, the county specific, average soil types are used to estimate the erodibility. The county soil types are computed using a geographic information system (GIS) to average detailed county soil profile maps provided by the Natural Resources Conservation Service. This approach assumes that unpaved road surfaces have the same soil characteristics as the base soils in the vicinity of the roadway.

Climatic Factor - C. The rate of soil erosion varies directly with the wind velocity and inversely with the soil surface moisture. The climatic factor is used to adjust for these parameters. CARB staff computed the county 'C' factors based on regional rainfall and wind speed data measured in California.

Surface Roughness - K. Surface roughness can help to reduce soil erosion. The 'K' factor is used to account for ridges or furrows that help to minimize wind related erosion. Because most unpaved roads are flat, the surface roughness factor is assumed to be 1.0, indicating no reduction in emissions due to surface texture.

Unsheltered Width Factor - L'. Soil erosion is directly related to the unprotected width of the area in the prevailing wind direction. For unpaved roads, depending on the wind direction, the width of the erosive area parallel to the wind direction could be very narrow, very long, or somewhere in between. CARB assumes that the wind direction is equally distributed for all roads and that the average value of L' is 0.32.

Vegetative Cover Factor - V'. Vegetative cover reduces soil erosion. For unpaved roads, it is assumed that there is no vegetative cover, therefore a value of 1.0 is used.

Based on analysis of resuspended California soil samples, CARB estimated that the PM10/TSP ratio for windblown dust from unpaved roads is 0.5. Windblown dust emissions from unpaved roads are calculated for each county by multiplying the PM10 emission rate (i.e., 50% of the TSP emission rate calculated from the TSP emission factor equation, Equation 1) by the unpaved road mileage and the average width of the unpaved roads assumed to average 20 feet. CARB's estimates does not include windblown dust from agricultural unpaved roads since they assume that windblown emissions from agricultural unpaved roads are included in the source category for windblown dust from agricultural lands.

The CARB methodology is subject to the following assumptions and limitations:

1. It is assumed that the unpaved road soil characteristics are approximately the same as the soils in the vicinity of the unpaved road that are not used for vehicular travel. This implies that no additional gravel or other treatments have been applied to the unpaved roads.

2. It is assumed that the soil wind erosion equation may be reasonably applied to estimate windblown dust from unpaved roads. Because of the large differences between unpaved road surfaces and agricultural lands, the validity of this assumption is questionable.

3. Using the soil erosion equation, it is assumed that 3.8% of the total eroded material is
entrained to the air. ('a' factor = 0.038).

4. It is assumed that the county average soil erodibility, ‘I’, and climatic, ‘C’, factors are representative (on average) of the overall county conditions.

5. It is assumed that a value of 0.32 for the unsheltered width factor, L’, is valid.

6. It is assumed that unpaved roads have no vegetative cover and are essentially flat.

7. The typical unpaved road width is 20 feet.

8. This methodology assumes no extraordinary windstorm activity; only average annual conditions are estimated.

CARB is aware that their methodology for estimating windblown dust from unpaved roads is built on a foundation of dubious assumptions. Because of the differences between unpaved roads and agricultural lands, it is unlikely that the agricultural soil erosion equation provides very accurate estimates of windblown road dust. The emissions estimates could be improved by performing wind tunnel tests on unpaved roads, and then extrapolating the resulting emission factors to the remainder of the State. With the use of geographic information systems, it is also possible to incorporate localized climatological and soil texture properties into the emission estimates. In addition, the mileage of unpaved roads could be improved using available digital maps which include public, as well as private unpaved roads.

14.3 Uncovered Haul Trucks

A total suspended particulate (TSP) emission factors for uncovered haul trucks was included in a USEPA report published in 1989.[3] The hourly TSP emission estimate for uncovered haul trucks was estimated from the following equation:

$$\text{TSP (lb/yd}^2\text{/hour)} = 0.00015\ u$$

where, u = sum of wind speed and vehicle speed (mph)

To estimate PM10 and PM2.5 emissions, PM10/TSP and PM2.5/TSP ratios will need to be obtained for this source category.

14.4 Unpaved Shoulders

DRI developed a PM10 emission factor for the resuspension of fugitive dust from unpaved shoulders created by the wake of high-profile vehicles such as tractor-trailers (semis) traveling on paved roads at high speed (50-65 mph).[4] The emission factor for unpaved shoulder with surface loadings of 4,500 to 5,500 g/m^2, silt content of 3 to 6%, and a surface moisture content under 1% was given as:

$$\text{EF} = 0.028 \pm 0.014\ \text{lb/VMT}$$

DRI concluded that emissions from unpaved shoulders due to smaller vehicles such as cars, vans and SUVs were negligible. It should be pointed out that the PM10 emissions were estimated utilizing nephelometers that are not quantitative for coarse particles. Thus, PM10 emissions may be underestimated.

14.5 Leaf Blowers

Dennis Fitz and other researchers from CE-CERT at UC Riverside recently completed a study on behalf of the San Joaquin Valley APCD to determine PM2.5 and PM10 emissions from leaf blowing/vacuuming, raking and sweeping activities.[5] Real-time PM2.5 and PM10 measurements were obtained with DustTrak aerosol monitors calibrated against Arizona road dust (NIST SRM 8632). The precision of the DustTrak PM2.5 and PM10 measurements were determined to be 19% and 27%, respectively, based on collocated DustTrak monitors. The accuracy of the DustTrak measurements was determined by comparing the DustTrak measurements to the filter-based measurements. In general the two data sets agreed to within 50%, which was similar to the variability between replicate tests. The PM2.5 and PM10 emission factors determined by DustTrak monitors for different cleaning activities and surfaces are summarized in Table 14-1. The DustTrak results for blowing leaves on asphalt and concrete surfaces as a function of power blower type are presented in Table 14-2.

Table 14-1. PM Emission Factors for Leaf Blowing/Vacuuming, Raking and Sweeping Activities (mg/m^2)

Cleaning Action and Surface Cleaned	PM2.5	PM10
Power blowing/vacuuming over concrete surfaces	30	80
Power blowing/vacuuming over asphalt surfaces	20	60
Push broom to sweep asphalt surfaces	0	20
Push broom to sweep concrete surfaces	20	80
Raking asphalt surfaces	0	0
Raking on concrete surfaces	0	0
Raking lawns	0	1
Power blowing on lawns	1	2
Power blowing from gutters	9	30
Power blowing on packed dirt	80	120
Power blowing cut grass on walkways	2	6

Table 14-2. PM Emission Factors by Power Blower Type and Surface (mg/m^2)

Power Blower Type	Surface	PM2.5	PM10
Electric	Asphalt	20	60
Gas Hand Held	Asphalt	10	40
Gas Backpack	Asphalt	20	60
Electric: vacuum mode	Asphalt	40	120
Electric: vacuum mode, full bag	Asphalt	20	70
Electric	Concrete	40	130
Gas Hand Held	Concrete	10	40
Gas Backpack	Concrete	30	70
Electric: vacuum mode	Concrete	30	80

14.6 Explosives Detonation

Emissions from the detonation of industrial explosives and firing of small arms (excluding military operations) are addressed in Section 13.3 of AP-42.[6] This section of AP-42 was last updated in February 1980 (and reformatted in January 1995). Such large quantities of particulate are generated in the shattering of rock and earth by the explosive that the quantity of particulates from the explosive charge cannot be distinguished. With the exception of a few studies in underground mines, most studies have been performed in laboratory test chambers that differ substantially from the actual environment. Any estimates of emissions from explosives use must be regarded as approximations that cannot be made more precise because explosives are not used in a precise, reproducible manner.

14.7 References

1. USEPA, 1974. *Development of Emission Factors for Fugitive Dust Sources*, EPA 450/3-74-037, U.S. EPA, Research Triangle Park, NC, June; updated in September 1988 in *Control of Open Fugitive Dust Sources, EPA-450/3-88-008.*

2. CARB, 1997. *Windblown Dust – Unpaved Roads*, Section 7.13 in: CARB's Emission Inventory Procedural Manual, Volume III: Methods for Assessing Area Source Emissions.

3. USEPA, January 1989. Air/Superfund National Technical Guidance Study Series; Volume III – Estimation of Air Emissions from Cleanup Activities at Superfund Sites, Interim final report EPA-450/1-89-003.

4. Moosmuller, H., Gillies, J.A., Rogers, C.F., Dubois, D.W., Chow, J.C., Watson, J.G., Langston, R., 1998. *Particulate Emission Rates for Unpaved Shoulders along a Paved Road*, J.AWMA 48:398.

5. Fitz, D., et al., 2006. *Determination of Particulate Emission Rates from Leaf Blowers,* paper presented at the USEPA 15th International Emission Inventory Conference, New Orleans, LA, May 24.

6. USEPA, 2006. *Compilation of Air Pollutant Emission Factors*, AP-42 Section 13.3 (Explosives Detonation), Fifth Edition.

GLOSSARY

Areal extent—Fraction (or percentage) of the source area that is affected by the control measure.

Aerodynamic particle size—Diameter of a sphere of unit density, which behaves aerodynamically as a particle with different sizes, shapes, and densities.

Aggregate material—Mineral particles, such as sand or stone, typically derived from a mechanical process.

Agricultural tilling—Mechanical disturbance of agricultural soil by discing, shaping, chiseling, and leveling using a tractor or implement.

Annual interest rate—The yearly cost of borrowing money, expressed as a percentage of the amount borrowed.

Annualized cost of control—Average yearly costs of a control system including annual operating costs such as labor, materials, utilities and maintenance items, and annualized costs of the capital costs of purchase and installation. Annualized costs are dependent on the interest rate paid on borrowed money or collectable by the plant as interest (if available capital is used), the useful life of the control equipment, and depreciation rates of the equipment.

AP-42—Abbreviation for the U.S. EPA's publication "Compilation of Air Pollutant Emission Factors."

BACM—Abbreviation for Best Available Control Measures—techniques that achieve the maximum degree of emissions reduction from a source, as determined on a case-by-case basis considering technological and economic feasibility.

Bare soil adjustment—Adjustment to windblown emissions for the planted acreage on which plants do not establish.

Base year—Year for which the pre-control emissions inventory was performed.

Baseline Emissions—Emissions (total or source) in the base year.

Batch drop—Materials handling process involving free fall of aggregate, as from a bucket.

Border adjustment—Adjustment to windblown emissions for the nonplanted regions of the acreage dedicated to a given crop that separate it from surrounding regions.

CAPCOA—Acronym for California Air Pollution Control Officers' Association.

Capital recovery factor—Amount of money per dollar of machinery investment required to pay annual interest costs on unrecovered investment and to recover the costs of the investment within a specified number of years at the given interest rate.

Chemical wetting agent—Compound added to water in order to enhance the penetration of water into dusty material and prevent dust emissions.

Clay—Cohesive soil with individual particles not visible to the unaided human eye (less than 0.002 mm in diameter). Clay can be molded into a ball that will not crumble.

Climatic factor "C," annual—Parameter used to estimate the effects of climate on soil erodibility. Garden City, Kansas is set to 1.0 and temperature, wind, and precipitation are used to adjust the factor.

Climatic factor "C," monthly—Parameter used to modify the annual "C" factor equation for a particular month of the year. The U.S. EPA uses mean monthly wind speed in place of the annual wind speed. The ARB methodology uses the month-as-a-year method.

Cloddiness—Level of relatively stable agglomerations in soil caused by exposure to water cohort (maturation class).

Compliance tool—Means for checking whether a facility is meeting legal requirements for control of a pollutant. Compliance tools include record keeping logs, databases, and site inspection methods.

Continuous drop—Materials handling process involving continual release of aggregate, such as from a conveyor.

Control application rate/frequency—Amount of pollutant suppressant applied over a particular area and the number of times per period that the suppressant is applied.

Control efficiency—Degree (e.g., percentage) to which a control measure is effective in limiting the release of a pollutant.

Control efficiency decay rate—Decrease in control efficiency for a control measure with a limited life span.

Control extent—Fraction of emissions from a source category that will be affected by a control method.

Control measure—Procedure or course of action taken to reduce air pollution. Preventive measures reduce source extent or incorporate process modifications or adjust work practices to reduce the amount of pollutants. Mitigative measures involve the periodic removal of pollutant causing materials, such as the cleanup of spillage on travel surfaces and cleanup of material spillage at conveyor transfer points.

Controlled emissions—Estimated emissions (total or by source category) after application of control measures, i.e., remaining emissions.

Cost effectiveness— Control cost divided by the mass of emissions reduced (most typically expressed in terms of "dollars per ton").

Crop calendar—Temporal distribution of agricultural activities (e.g., planting and harvesting dates).

Crop canopy cover factor—Adjustment to windblown emissions based on the crop canopy cover.

Crop canopy cover—Fraction of land sheltered by vegetation, as viewed directly from above.

Crust—The hard outer surface of soil (or other dust producing material) that inhibits the wind erosion of underlying fine particles.

Cut and fill—The activities of earthmoving equipment where soil or rock is removed from one area (cut) and deposited elsewhere on shallow ground (fill).

***De Minimis* source**—Facility or operation with emissions that are below a certain threshold, classifying them as insignificant sources of emissions; refer to 40 CFR, Part 52 for more details.

Demonstrated control technique—A control measure that is supported by verifiable tests as to the control efficiency the measure will achieve.

Deposition—Accumulation of airborne particles on ground-level surfaces through gravitational settling and other physical phenomena.

Disturbance—Destabilization of a land surface from its undisturbed natural condition thereby increasing the potential for fugitive dust emissions.

Dunes—Ridges or mounds of loose, wind-blown material, usually sand.

Dust—Fine, dry particles of matter able to be suspended in the air.

Dust Control Plan—Legally mandated plan for a geographical area or dust-producing operation that identifies how emissions will be controlled to attain the requirements of the Clean Air Act and Amendments.

Dust suppressants—Water, hygroscopic materials, solution of water and chemical surfactant, foam, or non-toxic chemical/ organic stabilizers not prohibited for use by the U.S. Environmental Protection Agency or any applicable law, rule or regulation, as a treatment material to reduce fugitive dust emissions.

Economic Life—Length of time during which a product or piece of property may be put to profitable use. (Usually less than its physical life)

Emission activity level—A numerical measure of the intensity of a process that emits pollutants (e.g., miles traveled by a vehicle, tons of transferred material). Also referred to as source extent or process rate.

Emission factor—A representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant.

Emission parameters—Values that affect pollutant emissions, such as moisture level and silt content of the emitting material.

Emission reduction—Amount (mass or percent) of emissions eliminated by control application.

Enforcement/Compliance costs—Expenses associated with enforcing control measures, including government agency and source facility expenditures.

Erosion potential—Value representing the potential for suspension of surface dust by wind erosion. Depending on the presence of a surface crust or surface disturbance, particle size distribution, and moisture content, a site is characterized as having 1) unlimited erosion potential, 2) limited erosion potential, or 3) no erosion potential.

Fastest mile of wind—The highest wind speed over a specified period (usually the 24-hour observational day) of any "mile" of wind. The fastest mile of wind is the reciprocal of the shortest interval (in 24 hours) that it takes one mile of air to pass a given point.

Fetch—Distance over which soil is eroded by a wind having a relatively constant direction and speed.

Friction velocity—Measure of shear stress of the wind on the exposed surface of soil or other aggregate material, causing loose particles to be lifted from the surface.

Fugitive dust source—Emitter of airborne particles where the particulate emissions cannot reasonably be passed through a stack, chimney, vent, or other functionally equivalent opening. Fugitive dust sources include roadways, construction (earthmoving and demolition), material handling operations, soil tillage, and wind erosion.

Gravel—Soil particles ranging from 1/5 inch to 3 inches in diameter.

Grid counting method—Method used to estimate areas contained between contour lines on maps.

Ground inventory—A measurement of the amount of dust suppressant applied to an unpaved surface, usually expressed as gallons of suppressant per square yard of road surface.

Growing canopy fraction (GCF)—The proportion of the acreage that will have the crop canopy cover factor applied to it.

Half life of control—The time required for control efficiency to fall to half its initial value.

Irrigation factor (wetness)—Adjustment to the erodibility due to surface wetness from irrigation.

Long-term irrigation-based erodibility adjustment—Adjustment that takes into account changes in cloddiness of the soil, based upon differences between irrigated and nonirrigated soils.

Material throughput—Output rate of processed material.

Mitigative control—Control measure that periodically removes exposed dust-producing material.

MOBILE model—Software tool developed by EPA to predict gram per mile emissions of hydrocarbons, carbon monoxide, oxides of nitrogen, carbon dioxide, particulate matter, and toxics from cars, trucks, and motorcycles under various conditions.

Mode—The most frequent value in a group of values. The approximate mode of a particle size distribution (i.e., particle size diameter) can be found by sieving a surface material sample to find the threshold friction velocity using a modification to W.S. Chepil's method.

Moisture content—A measurement, usually expressed as a percent, of the mass of water in a material sample. Moisture content is obtained by weighing the original sample and then drying the sample to obtain the mass of vaporized water.

Month-as-a-year—Term used by California Air Resources Board (ARB) staff to describe method of calculating the climatic "C" factor profile by assuming that each month's data for a given site describes a unique annual climatic regime.

Most cost-effective—Having the lowest cost per mass of PM emissions reduced.

Most efficient—Having the highest control efficiency (note that preventive controls are usually addressed before mitigative controls).

Mulch—Any material used to cover a soil surface to conserve soil moisture and prevent erosion.

Nonattainment area—Geographic area that is not in compliance with federal health-based air quality standards for an air pollutant (e.g., PM-10).

Nonerodible material—Objects larger than 1 centimeter in diameter that are not susceptible to movement even on windy days (e.g., gravel, hard-packed soil clods).

Operating/Maintenance costs—Expenses associated with personnel, materials, consumables, equipment repair, and other types of continuing expenses.

Overhead costs—A broad category of costs associated with administration.

Pan evaporation rate—The rate of evaporation from a US Class-A pan that is filled with water, with daily measurements made of the water level to compute the resulting daily water loss.

Peak wind gust—A maximum wind speed defined by U.S. weather observing practice, with gusts reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds.

Plant/harvest date pair—Methodology that uses planting cohorts split between harvest months, using the fraction of the total crop planted in a given month with the fraction of the total crop harvested in a given month.

PMx—Airborne particulate matter with aerodynamic diameters equal to or less than x µm (e.g. PM10, PM2.5)

Portable wind tunnel—Moveable air channel with an open bottom through which air is drawn at different velocities. This type of wind tunnel with a backend sampling system is used to investigate particle emissions by wind erosion, as a function of wind speed.

Postharvest soil cover factor—Adjustment to windblown emissions based on the fraction of land covered after harvest when viewed directly from above.

Precipitation effectiveness (PE)—See "Thornthwaite's precipitation-evaporation index"; the sum of 12 monthly values (ratios of precipitation to actual evapotranspiration).

Preventive control—Control measure that inhibits or minimizes the accumulation of exposed dust-producing material.

Prewatering—Application of water during construction and earthmoving operations to excavation areas and borrow pits before earth is excavated. The areas to be excavated are moistened to the full depth from the surface to the bottom of the excavation to achieve an optimum moisture content for fugitive dust control.

Quality rating—An assessment level of A through E as assigned by EPA to each emission factor in AP-42, with A being the best. A factor's rating is a general indication of the reliability, or robustness, of that factor.

Replant-to-different-crop factor—Adjustment to windblown emissions for harvested acreages that are quickly replanted to a different crop.

Reservoir—Amount of surface particles available for sustaining wind erosion. Surface soil properties determine the duration of dust events, and limited reservoirs will emit dust for a shorter duration of time (i.e., minutes) than unlimited reservoirs (i.e., days).

Revegetation—Vegetative cover that has been established on previously disturbed ground, such as a construction site.

Revised Wind Erosion Equation (RWEQ)—Model that is intermediate in complexity between the wind erosion equation (WEQ) and the wind erosion prediction system (WEPS).

Rock—Soil particles greater than 3 inches in diameter.

Roughness height—Height above ground level where the wind speed is theoretically reduced to zero because of surface obstructions; a measure of surface protrusion into the boundary layer wind flow.

Sand—Soil particles ranging from 0.05 to 2.0 mm in diameter; individual particles are visible to the unaided human eye.

Senescence—Process of plant aging and dying that is characterized by decreasing growth rates, chlorophyll breakdown, and mobilization of nitrogen out of leaves and into other plant organs.

Sheltering elements—Blockages to wind that inhibit wind erosion of soil. Examples include wind fences and trees.

SIC code—Abbreviation for Standard Industrial Classification code. A numbering system established by the Office of Management and Budget that identifies companies by industry.

Sieving—Process of passing a material through a series of woven square meshes of decreasing size to separate particles into different particle size classes. For agricultural soil classification, wet sieving disperses the material in a liquid before passing the suspension through one or more sieves. Dry sieving is used to characterize material dustiness levels and can be performed either by a mechanical sieve shaker or by rotational hand sieving.

Silt content—Percentage of particles less than 74 µm in physical diameter (i.e., fraction passing a standard 200-mesh sieve).

Silt—Noncohesive soil whose individual particles are not visible to the unaided human eye (0.002 to 0.05 mm). Silt will crumble when rolled into a ball.

Soil classes (types)—Classifications used by soil scientists: representative erodibilities have been measured, which allow soil maps to be used to estimate erodibilities for agricultural land.

Soil cover deterioration—Reduction in postharvest soil cover due to the effects of weather, sunlight, insects, microbes, etc.

Soil loss ratio (SLR)—The ratio of the soil loss for a soil of a given cover divided by the soil loss from bare soil.

Soil texture—The relative proportions of clay, silt, and sand in soil.

Soil—Surface material consisting of disintegrated rock and organic material.

Source Extent—See "Emission activity level.'

State Geographic Data Base (STATSGO)—Database of soil data produced and maintained by the NRCS.

Stepwise linear regression—Process of determining best-fit polynomials for a predictive mathematical model. The procedure involves least squares regression analysis in a forward stepping procedure

Surface disturbance—See "Disturbance."

Surface loading—Mass of loose material per paved road surface area. Total surface loading is measured by vacuuming a known area of paved road surface to obtain all material regardless of particle size. Silt surface loading is obtained by sieving the total surface loading and refers only to particles with physical diameters less than 74 µm.

Surface stabilization/treatment/improvement—The paving, graveling, chemical stabilization, or watering of a dust-emitting surface to prevent dust emissions due to mechanical disturbance and wind erosion.

Thornthwaite's precipitation-evaporation index—A measure of soil aridity, calculated as the ratio of precipitation to evapotranspiration.

Threshold friction velocity—Friction velocity that closely corresponds to the threshold wind speed for wind erosion of a specific surface. See "Friction velocity."

Threshold source size—An emission level below which a facility or dust-emitting activity is not regulated.

Threshold wind speed—Wind speed (measured at a reference height of 10 m) below which wind erosion does not occur from the exposed surface being considered.

Tillage—Practice of producing a soil surface to maintain surface residue, prepare a seed bed, conserve soil moisture, and reduce wind erosion.

Trackout—Accumulation of mud/dirt on paved roads, as deposited by vehicles that exit unpaved sites such as construction areas, agricultural fields, quarries, dumps, or batch plants.

Traffic volume—Measure of the number of vehicles traveling over a road segment. Vehicle miles traveled (VMT) on a road equals the average daily traffic (ADT) times the roadway length.

Uncontrolled emissions—Total emissions before application of any control measures.

Unit-operation emission factors—Emission factors that represent sub-processes or separate activities associated with an emission source.

Vegetative cover/residue—Organic matter, either growing or dead, that protects the soil surface from the erosive force of wind.

Visible dust—For regulatory purposes, means airborne particles that obscure an observer's view to a degree equal to or greater than a specified opacity limit.

Wet stabilization/watering—See "Surface stabilization."

Wind barrier/Wind sheltering—See "Sheltering element."

Wind erosion equation (WEQ)—Methodology originally developed to estimate wind erosion from agricultural lands. Later modified by U.S. EPA to use for estimating PM emissions.

Wind Erosion Prediction System (WEPS)—Detailed simulation model to predict wind erosion emissions; currently in development. May be useful in future, especially for episodic modeling.

Wind erosion—Removal of dry soil particles from the ground surface by wind, causing airborne particulate matter downwind of the emitting soil area.

Wind shear—Force of wind parallel to a surface that can remove loose particles, as opposed to wind directly impacting the surface.

Worst-case emissions—See "Uncontrolled emissions."

Appendix A

Emission Quantification Techniques

EMISSION QUANTIFICATION TECHNIQUES

Fugitive dust emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of such sources and the wide range of particle sizes, including particles that deposit immediately adjacent to the source. Standard source testing methods, which are designed for application to confined flows under steady-state, forced-flow conditions, are not suitable for the measurement of fugitive emissions unless the plume can be drawn into a forced-flow system. The available source testing methods for fugitive dust sources are described in the following paragraphs.

Mechanical Entrainment Processes

Because it is usually impractical to enclose open dust sources or to capture the entire emissions plume, only two methods are suitable for the measurement of particulate emissions from most open dust sources:

1. The upwind-downwind method involves the measurement of upwind and downwind particulate concentrations, utilizing ground-based samplers under known meteorological conditions, followed by a calculation of the source strength (mass emission rate) with atmospheric dispersion equations.[1]

2. The exposure-profiling method involves simultaneous, multipoint measurements of particulate concentration and wind speed over the effective cross section of the plume, followed by a calculation of the net particulate mass flux through integration of the plume profiles.[2]

In both cases it is customary to use high-volume air samplers, so that quantifiable sample mass can be accumulated in sampling periods no longer than about six hours.

Upwind-Downwind Method. The upwind-downwind method involves the measurement of airborne particulate concentrations both upwind and downwind of the pollutant source. The number of upwind sampling instruments depends on the degree of isolation of the source operation of concern (i.e., the absence of interference from other sources upwind). Increasing the number of downwind instruments improves the reliability in determining the emission rate by providing better plume definition. In order to reasonably define the plume emanating from a point source, instruments need to be located at a minimum of two downwind distances and three crosswind distances. The same sampling requirements pertain to line sources except that measurements need not be made at multiple crosswind distances.

Net downwind (i.e., downwind minus upwind) concentrations are used as input to atmospheric dispersion equations (normally of the Gaussian type) to back-calculate the particulate emission rate (i.e., source strength) required to generate the pollutant concentrations measured. Emission factors are obtained by dividing the calculated emission rate by the source extent. A number of meteorological parameters must be concurrently recorded for input to this dispersion equation. As a minimum, the wind direction and speed must be recorded on-site.

While the upwind-downwind method is applicable to virtually all types of sources, it has significant limitations with regard to the development of source-specific emission factors. Because of the impracticality of adjusting the locations of the sampling array for shifts in wind direction during sampling, it may be questionable to assume that the plume position is fixed in the application of the dispersion model. In addition, the usual assumption that a line or area source is uniformly emitting may not allow for a realistic representation of spatial variation in source activity.

Exposure-Profiling Method As an alternative to conventional upwind-downwind sampling, the exposure-profiling technique utilizes the emission profiling concept, which is the basis for the conventional ducted source testing method (i.e., USEPA Method 5[3]), except that, in the case of exposure-profiling, the ambient wind directs the plume to the sampling array. The passage of airborne particulate matter immediately downwind of the source is measured directly by means of a simultaneous, multipoint sampling of particulate concentration and wind velocity over the effective cross section of the fugitive emissions plume.

For the measurement of nonbuoyant fugitive emissions using exposure profiling, sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing at least 80% of the total mass flux. A vertical line grid of at least three samplers is sufficient for the measurement of emissions from line or moving point sources (see Figure A-1), while a two-dimensional array of at least five samplers is required for quantification of the fixed virtual point source of emissions. For quantifying emissions of particles larger than about 10 µm, the particulate samplers should have directional intakes, as discussed below. At least one upwind sampler must be operated to measure the background concentration, and wind speed and direction must be measured concurrentlv on-site.

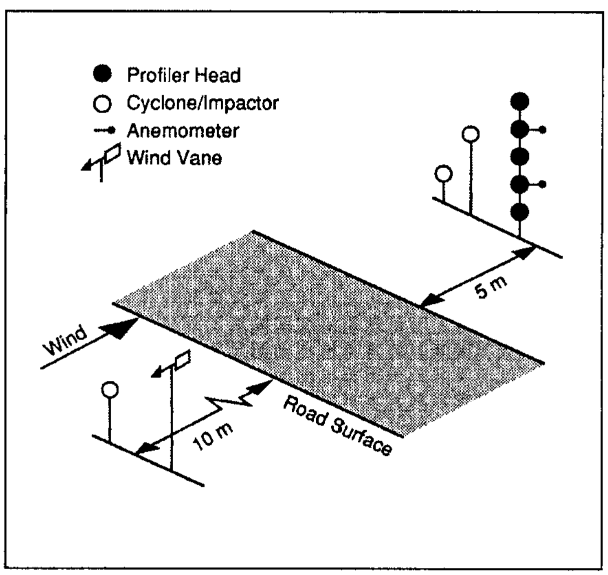

Figure A-1. Exposure Profiling Method—Roadway

The particulate emission rate is obtained by a spatial integration of the distributed measurements of exposure (accumulated mass flux), which is the product of mass concentration and wind speed:

$$R = \int_A C(h,w)u(h,w)dhdw \qquad (1)$$

where,
- R = emission rate, (g/s)
- C = net particulate concentration, (g/m^3)
- u = wind speed, (m/s)
- h = vertical distance coordinate, (m)
- w = lateral distance coordinate, (m)
- A = effective cross-sectional area of plume, (m^2)

Usually, a numerical integration scheme is used to calculate the emission rate. This mass-balance calculation scheme requires no assumptions about plume dispersion phenomena.

Isokinetic Sampling Regardless of which method is used, isokinetic sampling is required for a representative collection of particles larger than about 10 µm in aerodynamic diameter. The directional sampling intakes are pointed into the mean wind direction and the intake velocity of each sampler is periodically adjusted (usually with intake nozzles) to closely match the mean wind velocity approaching the sampling intake. Because of natural fluctuations in wind speed and direction, some anisokinetic sampling effects will always be encountered. If the angle α between the mean wind direction and the direction of the sampling axis equals 30°, the sampling error is about 10%.[4] For an isokinetic flow ratio of sampling intake speed to approach wind speed between 0.8 and 1.2, the sampling error is about 5%.[4]

Wind Erosion

The two wind erosion source testing methods of interest are the upwind-downwind method as described above and the portable wind tunnel method. The wind tunnel method involves the use of a portable open-floored wind tunnel for *in situ* measurement of emissions from representative surfaces under predetermined wind conditions.[5]

Upwind-Downwind Method The upwind-downwind method is burdened with practical difficulties for the study of wind erosion, in that the onset of erosion and its intensity is beyond the control of the investigator. In addition, background (upwind) particulate concentrations tend to be high during erosion events, making source isolation very difficult.

Wind Tunnel Method The most common version of the wind tunnel method utilizes a pull-through wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. The exit air stream from the test section passes through a circular duct fitted with a directional sampling probe at the downstream end. Air is drawn isokinetically through the probe by a high-volume sampling train. The wind tunnel method incorporates the essential features of the USEPA Method 5 stack sampling method.[3] The one prime difference, the use of single-point sampling, is justified by the high turbulence levels in the sampling module. The measurement uncertainty inherent in this method is of the same order as that in Method 5, which has been subjected to extensive collaborative testing by EPA. The wind tunnel method relies on a straightforward mass-balance technique for the calculation of emission rate. By sampling under light ambient wind conditions, background interferences from upwind erosion sources can be avoided. Although a portable wind tunnel does not generate the larger scales of turbulent motion found in the atmosphere, the turbulent boundary layer formed within the tunnel simulates the smaller scales of atmospheric turbulence. It is the smaller-scale turbulence, which penetrates the wind flow in direct contact with the erodible surface and contributes to the particle entrainment mechanisms.[6]

Particle Sizing

Concurrent with the measurement of mass emissions, the aerodynamic particle size distribution should be characterized. Chemical, biological, and morphological analyses may also be performed to characterize the nature and origin of the particles. For particle sizing, a high-volume cyclone/cascade impactor featuring isokinetic sample collection has been used.[7] A cyclone preseparator (or other device) is needed to remove the coarse particles, which otherwise would bounce off the greased substrate stages within the impactor, causing fine-particle bias. Once again, the sampling intake is pointed into the wind and the sampling velocity adjusted to the mean local wind speed by fitting the intake with a nozzle of appropriate size. This system offers the advantage of a direct determination of aerodynamic particle size.

Another particle sizing option includes an analysis of the particulate deposit by optical or electron microscopy. Disadvantages include: (a) potential artificial disaggregation of particle clusters during sample preparation, and (b) uncertainties in converting physical size data to equivalent aerodynamic diameters. In a collaborative field test of the exposure-profiling method, the cyclone/impactor method was judged to be more suitable than microscopy for the particle sizing of fugitive dust emissions.[8]

Control Efficiency Estimation

Field evaluation of the control efficiency requires that the study design include not only adequate emission measurement techniques but also a proven "control application plan." In the past, two major types of plans have been used. Under the Type-1 plan, controlled and uncontrolled emission measurements are obtained simultaneously. Under the Type-2 plan, uncontrolled tests are performed initially, followed by controlled tests.

In order to ensure comparability between the operating characteristics of the controlled and uncontrolled sources, many evaluations are forced to employ Type-2 plans. An example would be a wet suppression system used on a primary crusher. One important exception to this; however, is unpaved-road dust control. In this instance, testing under a Type-1 plan may be conducted on two or more contiguous road segments. One segment is left untreated and the others are treated with the dust suppressant. Under a Type-2 plan, a normalization of emissions may be required to allow for potential differences in source characteristics during the uncontrolled and controlled tests because they do not occur simultaneously.

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Appendix B

Estimated Costs of Fugitive Dust Control Measures

Source Category	Control Measure	Estimated Costs	Comments/Assumptions
Paved Roads	4' Paved Shoulders	$8,200/mile-year	Useful life of 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 unpaved roads	$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/ft^2-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 for two 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
	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 ft^2 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%	$138/acre	
	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 yd^3
Disturbed Open Areas	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
	Post no trespassing signs	$53/sign	Useful life of 15 years
Windblown Dust	Prohibit activities at construction sites during high winds	$3,100 per high wind day	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.

Appendix C

Methodology for Calculating Cost-Effectiveness of Fugitive Dust Control Measures

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).

Appendix D

Fugitive PM10 Management Plan

Overview

The San Joaquin Valley APCD's Regulation VIII that addresses fugitive dust specifies two general control methods for controlling fugitive dust: (1) limiting visible dust emissions and (2) maintaining a stabilized surface. Visible dust emissions (VDE) may not exceed 20 percent opacity during periods when soil or other dust-producing materials are being disturbed by vehicles, equipment, or the forces of wind. "Opacity" is a visual evaluation of the amount of one's view that is obscured by a dust plume. The VDE limit applies to construction sites, the handling and storage of bulk materials, and to unpaved roads and traffic areas. A stabilized surface is a treated surface that is resistant to wind effects. This requirement applies to vacant open areas that have previously been disturbed, unpaved roads and traffic areas, and outdoor bulk storage piles. Methods for creating and maintaining a stabilized surface may include applying chemical or organic stabilizers, road-mix or paving materials, vegetative materials, or water for soaking the soil or forming a visible crust.

For unpaved roads and unpaved traffic areas, a Fugitive PM10 Management Plan (FPMP) may be implemented as a compliance alternative to the Visible Dust Emission standard and the requirement to maintain a stabilized unpaved road surface. The FPMP identifies the control measures to be implemented whenever vehicular traffic reaches and exceeds the applicable thresholds i.e., ≥ 75 vehicles per day or ≥26 vehicles per day with 3 or more axles). Acceptable control measures are those that have demonstrated to achieve at least 50 percent PM10 control efficiency when properly applied to an unpaved surface.

A FPMP may not be prepared for unpaved haul roads and access roads as well as traffic areas at construction projects nor as an alternative to a Conservation Management Practice (CMP) Plan for agricultural sources. Non-agricultural sources choosing to implement a FPMP are required to submit a plan to the District for approval. Once approved, the owner or operator is required to implement the District-approved FPMP on all days where traffic exceeds the applicable minimum thresholds. An approved plan remains active until the District notifies the owner or operator that it is no longer valid, or until the owner or operator notifies the District that plan implementation has been permanently discontinued.

Required Information

The FPMP must include the following information:

1. The names, addresses, and phone numbers of persons responsible for the preparation, submittal, and implementation of the FPMP, and of the persons responsible for the unpaved road or traffic area.

2. A plot plan or map showing the location of each unpaved road or traffic area to be covered by the FPMP, the total length in miles of unpaved roads, and the total area in acres of unpaved traffic areas that will be subject to the plan.

3. The months (and weeks, if known) of the year when vehicle traffic is expected to exceed the minimum thresholds described in the applicable rules, and the types of vehicles (i.e. passenger vehicles, trucks, mobile equipment, etc.).

4. The control methodologies to be applied, including:
   a. Product specifications;
   b. Manufacturer's usage instructions (method, frequency, and intensity of application);
   c. Application equipment (type, number, and capacity); and
   d. Environmental impact information and approvals or certificates related to appropriate and safe use for ground application.

5. The condition of the treated surfaces to be achieved as a result of the use of suppressants or other dust control material.

Record Keeping Requirements

Owners and operators are required to maintain records and any other supporting documents to demonstrate compliance for those days when control measures were implemented. Records are to include the type of control measure implemented, the location and extent of coverage, and the date, amount and frequency of applying dust suppressants.

Record keeping forms developed by the District or a facsimile that provides the necessary information may be used for record keeping purposes. Records are to be kept for a minimum of one year following termination of dust generating activities. Title V stationary sources are required to keep the records for a minimum of five years. Records must be made available to the District inspector upon request. The matrix below lists the forms to be used for Regulation VII record keeping.

	Activity at site and corresponding record keeping forms					
Industry	Bulk Materials	Unpaved Roads	Equip & Vehicle Storage	Open Areas	Earth Moving	Trackout and Carryout
Construction	A C	A C D	A C D	A C	A	B
Oilfields	A C	A C D	A C D	A C	A	B
Off-field Ag Ops	A C	A C D	A C D			
Ag Product Processing	A C	A C D	A C D			B
Bulk Materials	A C	A C D	A C D			B
Equipment & Vehicle Storage	A C	A C D	A C D	A C		B
Truck Stops	A C	A C D	A C D	A C		B

Form A = Daily watering schedule
Form B = Sweeping/cleanup schedule for trackout and carryout
Form C = Permanent control measure (e.g., paving, gravel, a grizzly, chemical dust suppressants)
Form D = Daily schedule for water application onto unpaved roads and equipment areas