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CONTROL OF OPEN FUGITIVE DUST SOURCES

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CONTROL OF OPEN FUGITIVE DUST SOURCES

FINAL REPORT

by

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1.0 INTRODUCTION

Fugitive particulate emissions are emitted by a wide variety of sources both in the industrial and in the nonindustrial sectors. Fugitive emissions refer to those air pollutants that enter the atmosphere without first passing through a stack or duct designed to direct or control their flow.

Sources of fugitive particulate emissions may be separated into two broad categories: process sources and open dust sources. Process sources of fugitive emissions are those associated with industrial operations that alter the chemical or physical characteristics of a feed material. Open dust sources are those that entail generation of fugitive emissions of solid particles by the forces of wind or machinery acting on exposed materials.

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. Generic categories of open dust sources are listed in Table 1-1. In some instances, the term fugitive dust may be further restricted to include only nonindustrial sources.

1.1 CONTROL OPTIONS

Typically, there are several options for control of fugitive particulate emissions from any given source. This is clear from the mathematical equation used to calculate the emission rate:

$$R = M\ e\ (1 - c)$$

where: R = estimated mass emission rate

M = source extent (i.e., surface area for most open dust sources)

e = uncontrolled emission factor, i.e., mass of uncontrolled emissions per unit of source extent

c = fractional efficiency of control

TABLE 1-1. GENERIC CATEGORIES OF OPEN DUST SOURCES

1. <u>Unpaved Travel Surfaces</u>

   - Roads
   - Parking lots and staging areas
   - Storage piles

2. <u>Paved Travel Surfaces</u>

   - Streets and highways
   - Parking lots and staging areas

3. <u>Exposed Areas</u> (wind erosion)

   - Storage piles
   - Bare ground areas

4. <u>Materials Handling</u>

   - Batch drop (dumping)
   - Continuous drop (conveyor transfer, stacking)
   - Pushing (dozing, grading, scraping)
   - Tilling

To begin with, because the uncontrolled emission rate is the product of the source extent and uncontrolled emission factor, a reduction in either of these two variables produces a proportional reduction in the uncontrolled emission rate.

Although the reduction of source extent results in a highly predictable reduction in the uncontrolled emission rate, such an approach in effect usually requires a change in the process operation. Frequently, reduction in the extent of one source may necessitate the increase in the extent of another, as in the shifting of vehicle traffic from an unpaved road to a paved road. The option of reducing source extent is beyond the scope of this manual and will not be discussed further.

The reduction in the uncontrolled emission factor may be achieved by process modifications (in the case of process sources) or by adjusted work practices (in the case of open sources). The degree of the possible 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 11.2 of EPA's "Compilation of Air Pollutant Emission Factors" (AP-42).

The reduction of source extent and the incorporation of process modifications or adjusted work practices which reduce the amount of exposed dust-producing material are preventive techniques for control of fugitive dust emissions. This would include, for example, the elimination of mud/dirt carryout onto paved roads at construction and demolition sites.

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.

1.2 SCOPE OF THE DOCUMENT

Prior to the use of this manual, the reader should have a general idea of what sources within the specified jurisdictional boundary may require additional control programs to achieve desired air quality goals. This determination may be based on a prior total suspended particulate

(TSP) inventory of the area, discussions with field inspection personnel, or any other information source. Because the cost of many open dust source controls is directly related to the area of the source (e.g., surface area of a storage pile to be chemically stabilized, roadway area to be swept or flushed, etc.), the user may employ the ratio:

$$\frac{\text{Uncontrolled emission rate}}{\text{Source surface area}}$$

to prioritize sources for control. Regulatory personnel may wish to also combine this ratio with some measure of the affected population (e.g., zoning areas or population density within a certain distance of the source). This would be in keeping with guidance provided in a recent EPA draft urban dust policy.

The purpose of this document is to provide regulatory personnel with sufficient information to develop control plans for open dust sources of PM_{10} (i.e., particulate matter emissions no greater than 10 microns (μm) in aerodynamic diameter). Each section deals with a different source category:

Section 2.0--Paved Roadways
- a. Public
- b. Industrial

Section 3.0--Unpaved Roadways
- a. Public
- b. Industrial

Section 4.0--Storage Piles

Section 5.0--Construction/Demolition Activities

Section 6.0--Open Area Wind Erosion

Section 7.0--Agriculture

Each section begins with an overview of the source category, describing emission characteristics and mechanisms. Following this, available emission factors are presented to provide a basis for analyzing the operative nature of control measures. Next, demonstrated control techniques are discussed in terms of estimating efficiency and determining costs of implementation. Suggested regulatory formats explain the "philosophy" used in implementing the preceding technical discussions in viable regulations and compliance actions. Example regulations for each source category are presented in an appendix. These examples are predicated on a permit and penalty system as outlined in Table 1-2. Control agencies may issue construction, operation, and use permits to owners of many sources of fugitive PM_{10} emissions. These permits can be used to specify the conditions or activities that must be provided or undertaken by the source to ensure attainment of the PM_{10} emission reduction goals of the Agency's control plan. A permit system also may specify permit fees and compliance penalties which can be used to offset the costs of administering an inspection and enforcement program. Specific sources that may be appropriate for inclusion in a permit system include the following sources.

- Industrial roads
- Storage piles
- Construction/demolition sites
- Vacant lots
- Parking lots
- Feed lots
- Staging areas
- Off-road recreational areas
- Land disposal sites
- Landfills

In addition, a series of other appendices are also included which discuss terminology used in this manual, a general costing procedure used for open dust source controls and general recordkeeping/inspection procedures.

TABLE 1-2. PERMIT AND PENALTY SYSTEM

Permits

1. Any Control Agency may establish, by regulation, a permit that requires, except as provided below, that before any person engages in any activity which will cause the issuance of fugitive PM_{10} emissions, such person obtain a permit to do so from the control officer of the agency.

2. A permit system shall:

a. Ensure that the activity for which the permit was issued shall not prevent or interfere with the attainment or maintenance of the Federal PM_{10} standard. Attainment can be demonstrated through dispersion modeling of ambient concentrations resulting from source emissions.

b. Prohibit the issuance of a permit unless the control officer is satisfied, on the basis adopted by the Control Agency, that the activity will comply with all applicable orders, rules, and regulations of the agency.

3. The control officer may impose conditions on the permit to ensure that the provisions of 2(a) and (b) are met. The control officer, at any time, may require from an applicant, or the holder of a permit, such information, analyses, plans, or specifications which will disclose the nature, extent, quantity, or degree of fugitive PM_{10} emissions which are, or may be, discharged by the source for which a permit was issued or applied.

4. The Control Agency may adopt a schedule of fees for the evaluation, issuance, and renewal of permits to cover the cost of the agency programs related to the permitted sources.

5. Exemptions:

a. Size;
b. Duration; and
c. Location

Penalties

1a. Any person who violates any PM_{10} fugitive dust order, permit, rule, or regulation of the Control Agency is guilty of a misdemeaner and is subject to a fine of not more than one thousand dollars ($1,000), or imprisonment in the county jail for not more than 6 months, or both.

1b. Each infraction on each day during any portion of which a violation of paragraph 1(a) occurs is a separate offense.

(continued)

TABLE 1-2. (continued)

Penalties (continued)

2a. Any person who negligently emits an air contaminant in violation of any PM_{10} fugitive dust order, permit, rule, or regulation of the Control Agency pertaining to emission regulations or limitations is guilty of a misdemeanor and is subject to a fine of not more than ten thousand dollars ($10,000), or imprisonment in the county jail for not more than 9 months, or both.

2b. Each infraction on each day during any portion of which a violation occurs is a separate offense.

3a. Any person who emits PM_{10} fugitive dust in violation of any order, permit, rule, or regulation of the Control Agency pertaining to emission regulations or limitations, who knew of the emission and failed to take corrective action within a reasonable time under the circumstances, is guilty of a misdemeanor and is subject to a fine of not more than twenty five thousand dollars ($25,000), or imprisonment in the county jail for not more than 1 year, or both.

For the purposes of this paragraph, "corrective action" means the termination of the emission violation or the grant of a variance from the applicable order, permit, rule, or regulation.

3b. Any person who, knowingly and with intent to deceive, falsifies any document required to be kept pursuant to any order, permit, rule, or regulation of the Control Agency is guilty of a misdemeanor and is punishable as provided in paragraph 3(a).

3c. Each infraction on each day during any portion of which a violation occurs constitutes a separate offense.

2.0 PAVED ROADS

Particulate emissions occur whenever a vehicle travels over a paved surface, such as public and industrial roads and parking lots. These emissions may originate from material previously deposited on the travel surface, or resuspension of material from tires and undercarriages. In general, emissions arise primarily from the surface material loading (measured as mass of material per unit area), and that loading is in turn replenished by other sources (e.g., pavement wear, deposition of material from vehicles, deposition from other nearby sources, carryout from surrounding unpaved areas, and litter). Because of the importance of the surface loading, available control techniques either attempt to prevent material from being deposited on the surface or to remove (from the travel lanes) any material that has been deposited. Table 2-1 presents estimated deposition rates for paved roads. Note that these estimates date from a 1977 report and may not accurately reflect current trends.[1]

The following sections present a discussion of the various types of paved sources, available emission factors, viable control measures, and methods of determining controlled emission levels.

While the mechanisms of particle deposition and resuspension are largely the same for public and industrial roads, there can be major differences in surface loading characteristics, emission levels, traffic characteristics, and viable control options. For the purpose of estimating particulate emissions and determining control programs, the distinction between public and industrial roads is not a question of ownership but rather a question of surface loading and traffic characteristics.

Although public roads generally tend to have lower surface loadings than industrial roads, the fact that these roads have far greater traffic volumes may result in a substantial contribution to the measured air quality in certain areas. In addition, many public roads in industrial areas often are heavily loaded and traveled by heavy vehicles. In that instance, better emission estimates would be obtained by treating these roads as industrial roads. In an extreme case, a road or parking lot may have such a high surface loading that the paved surface is essentially

TABLE 2-1. ESTIMATED DEPOSITION RATES[a]

Deposition process	Typical rate, lb/curb-mi/day
Mud and dirt carryout	100
Litter	40
Biological debris	20
Ice control compounds	10
Dustfall	10
Pavement wear and decomposition	10
Vehicle-related (including tire wear)	17
Spills	<2
Erosion from adjacent areas	20

[a]Source: EPA-907/9-77-007.[1] As noted in the text, these estimates date from 1977 and may not accurately reflect current conditions or deposition at a specific location.

covered and is easily mistaken for an unpaved road. In that event, use of a paved road emission factor may actually result in a higher estimate than that obtained from the unpaved factor, and the road is better characterized as unpaved in nature rather than paved.[2]

As noted in the introduction, the reader, prior to using this manual, should have a general idea of what paved roads in his/her jurisdiction require additional controls. Furthermore, he/she should also have a general idea of what sources are contributing significantly to increased surface loadings on the roads requiring control. For example, heavy trucks may spill part of their load onto public roads in industrial areas, or large amounts of salt and sand may be applied during winter months. Prior to use of the information in this section, the reader should formulate preliminary answers to the following questions:

1. What paved roads are heavily loaded and thus likely to contribute a disproportionate share of emissions?

2. What sources are likely to contribute to these elevated surface loadings?

3. Who is the responsible party for each source identified in 2 above?

4. Can the carryout/deposition from each identified source be prevented or must the affected roadway be cleaned afterward?

5. Should any responsible party be granted an exclusion and on what basis?

2.1 PUBLIC PAVED ROADS

As discussed above, the term "public" is used in this manual to denote not only ownership of the road but also its surface and traffic characteristics. Roads in this class generally are fairly lightly loaded, are used primarily by light-duty vehicles, and usually have curbs and gutters. Examples are streets in residential and commercial areas and major thoroughfares (including freeways and arterials).

2.1.1 Estimation of Emissions

The current AP-42 PM_{10} emission factor for urban paved roads is:[3]

$$e = 2.28\ (sL/0.5)^{0.8}\ (g/VKT)$$

$$e = 0.0081\ (sL/0.7)^{0.8}\ (lb/VMT) \qquad (2\text{-}1)$$

where: e = PM_{10} emission factor, in units shown above
s = surface silt content, fraction of material smaller than 75 µm in diameter
L = total surface dust loading, g/m^2 ($grains/ft^2$)
VKT = vehicle kilometers traveled
VMT = vehicle miles traveled

The above equation is not rated in AP-42 (see Appendix A).

The product sL represents the mass of silt-size dust particles per unit area of the road surface and is usually termed the "silt loading." As is the case for all predictive models in AP-42, <u>the use of site-specific</u> (i.e., measured--using the methodology presented in Appendices D and E--for the sources under consideration) <u>values of sL is strongly recommended</u>. However, because measurement is not always feasible, AP-42 presents default values for use. Tables 2-2 and 2-3 present a summary of silt loadings as a function of roadway classification and the scheme used to classify roadways, respectively. In general, roads with a higher traffic volume tend to have lower surface silt loadings. This relationship is expressed in the empirical model presented in Reference 4:

$$sL = 21.3/(V^{0.41}) \qquad (2\text{-}2)$$

where: sL = surface silt loading (g/m^2)
V = average daily traffic volume (vehicles/d)

Several items should be noted about Table 2-2 and Equation (2-2). First, samples are restricted to the eastern and midwestern portions of the country. While these can be considered representative of most large urban areas of the United States, it is generally believed that surface silt loadings in the Southwest can be quite higher. Available data,

TABLE 2-2. SUMMARY OF SILT LOADINGS (sL) FOR PAVED URBAN ROADWAYS[a]

	Roadway category							
	Local streets		Collector streets		Major streets/ highways		Freeways/ expressways	
City	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n
Baltimore	1.42	2	0.72	4	0.39	3	--	--
Buffalo	1.41	5	0.29	2	0.24	4	--	--
Granite City, Ill.	--	--	--	--	0.82	3	--	--
Kansas City	--	--	2.11	4	0.41	13	--	--
St. Louis	--	--	--	--	0.16	3	0.022	1
All	1.41	7	0.92	10	0.36	26	0.022	1

[a]Reference 3. $\bar{X}_g$ = geometric mean based on corresponding n sample size. Dash = not available. To convert g/m² to grains/ft² multiply g/m² by 1.4337.

TABLE 2-3. PAVED URBAN ROADWAY CLASSIFICATION[a]

Roadway category	Average daily traffic (vehicles)	Lanes
Freeways/expressways	>50,000	≥4
Major streets/highways	>10,000	≥4
Collector streets	500-10,000	2[b]
Local streets	<500	2[c]

[a]Reference 3.
[b]Road width ≥ 32 ft.
[c]Road width ≤ 32 ft.

however, do not necessarily support this suspicion; the following compares surface silt loadings from Table 2-2 and two counties in Arizona:

Street classification	Geometric mean sL (g/m²)		
	Table 2-2	Maricopa Co.[5]	Pima Co.[5]
Arterial/major	0.36	0.057	0.067
Collector	0.92	0.10	0.13

These differences may be partially the result of different measurement techniques and/or of lower measured silt fractions of materials on the Arizona roads. Once again, the use of site-specific data is stressed.

2.1.2 Demonstrated Control Techniques for Public Paved Roads

As mentioned in the introduction to this section, available control methods are largely designed either to prevent deposition of material on the roadway surface or to remove material which has been deposited in the driving lanes. Measurement-based efficiency values for control methods are presented in Table 2-4. Note that all values in this table are for mitigative measures applied to industrial paved roads.

In terms of public paved road dust control, only very limited field measurement data are available. One reference was found that could be used to indirectly quantify emission reductions and this, too, is for mitigative measures. Estimated PM_{10} control efficiencies (Table 2-5) were developed by applying Equation (2-1) to measurements before and after road cleaning.[6] Note that these estimates should be considered upper bounds on efficiencies obtained in practice because no redeposition after cleaning is considered. Note also that these estimated emission control efficiencies for urban roads compare fairly well with measurements at industrial roads. No airborne mass emission measurements quantifying control efficiency were found.

In general terms, one would expect that demonstrated control techniques applied to industrial paved roads could also be applied to public roads. One important point to note, however, is that it is generally recognized that mitigative measures decrease in effectiveness as

TABLE 2-4. MEASURED EFFICIENCY VALUES FOR PAVED ROAD CONTROLS[a]

Method	Cited efficiency	Comments
Vacuum sweeping	0-58 percent	Field emission measurement (PM-15) 12,000-cfm blower[b]
	46 percent	Reference 7, based on field measurement of 30 μm particulate emissions
Water flushing	69-0.231 V[c,d]	Field measurement of PM-15 emissions[b]
Water flushing followed by sweeping	96-0.263 V[c,d]	Field measurement of PM-15 emissions[b]

[a]Reference 8, except as noted. All results based on measurements of air emissions from industrial paved roads. Broom sweeping measurements presented in Section 2.3.2.1.
[b]PM_{10} control efficiency can be assumed to be the same as that tested.
[c]Water applied at 0.48 gal/yd².
[d]Equation yields efficiency in percent, V = number of vehicle passes since application.

TABLE 2-5. ESTIMATED PM_{10} EMISSION CONTROL EFFICIENCIES[a]

Method	Estimated PM_{10} efficiency, %
Vacuum sweeping	34
Improved vacuum sweeping[b]	37

[a]Reference 6. Estimated based on measured initial and residual ≤63 μm loadings on urban paved roads and Equation (2-1). Value reported represents the mean of 13 tests for each method. Broom sweeping mean (18 tests) given in Section 2.3.2.1.
[b]Sweeping improvements described in Reference 6.

the surface loadings decrease. Because mitigative measures are less effective for public paved roads, a recent EPA draft urban dust policy stresses the importance of preventive measures, especially in instances where no dominant or localized source of road loading can be identified. Example sources would include: (1) unpaved areas adjacent to the road; (2) erosion due to storm water runoff; and (3) spillage from passing trucks. Corresponding examples of preventive measures include: (1) installing curbs, paving shoulders, or painting lines near the edge of the pavement; (2) controlling storm water or using vegetation to stabilize surrounding areas; and (3) requiring trucks to be covered and to maintain freeboard (i.e., distance between top of the load and top of truck bed sides). In instances where the source of loading can be easily identified (e.g., salt or sand spread during snow or ice storms) or the effects are localized (e.g., near the entrance to construction sites or unpaved parking lots), either preventive or mitigative measures could be prescribed. Table 2-6 summarizes Agency guidance on nonindustrial paved road preventive controls.

There are few efficiency values for any of the preventive measures presented in Table 2-6. Because these measures are designed to prevent deposition of additional material onto the paved surface, quantitative measurements before and after the control are generally not possible and interpretation of results are complicated. For example, based on ambient TSP monitoring results over a 3-month period, immediate and continuous manual cleaning of the access area to a construction site was estimated to result in ~30 percent control.[1] It is unclear, however, what effect seasonal variation in the monitoring data has on the estimate of 30 percent. Also, because this estimate is based on ambient air concentrations, use of the value may be inconsistent with the other efficiency estimates given in this chapter. Consequently, one very important further development deals with efficiency estimates for preventive measures.

A recent update of AP-42 Chapter 11.2 (Fugitive Dust Sources)--compared measured controlled emissions with estimates based on the reduced loading values, using the <u>industrial</u> paved road model presented in the next section.[2] Despite the fact that the reduced surface loadings were

TABLE 2-6. NONINDUSTRIAL PAVED ROAD DUST SOURCES AND PREVENTIVE CONTROLS

Source of deposit on road	Recommended controls
-- Sanding/salt	-- Make more effective use of abrasives through planning, uniform spreading, etc. -- Improve the abrasive material through specifications limiting the amount of fines and material hardness, etc. -- Rapid cleanup after streets become clear and dry
-- Spills from haul trucks	-- Require trucks to be covered -- Require freeboard between load and top of hopper -- Wet material being hauled
-- Construction carryout and entrainment	-- Clean vehicles before entering road -- Pave access road near site exit -- Semicontinuous cleanup of exit
-- Vehicle entrainment from unpaved adjacent areas	-- Pave/stabilize portion of unpaved areas nearest to paved road
-- Erosion from stormwater washing onto streets	-- Storm water control -- Vegetative stabilization -- Rapid cleanup after event
-- Wind erosion from adjacent areas	-- Wind breaks -- Vegetative stabilization or chemical sealing of ground -- Pave/treat parking areas, drive-ways, shoulders -- Limit traffic or other use that disturbs soil surface
-- Other	-- Case-by-case determination

often outside the range of the underlying data base, predictive accuracy was found to be quite good, both for vacuum sweeping and water flushing. For those two controls, the available data suggest that adequate estimates of controlled emission can be obtained from the predictive models. For flushing combined with broom sweeping, however, the estimates substantially overpredicted (by approximately a factor of 5) controlled emissions versus the measured values.

2.2 INDUSTRIAL PAVED ROADS

As noted earlier, emission estimation for paved roads depends less upon its ownership and more upon its surface material and traffic characteristics. In this manual, the term "industrial" paved road is used to denote those roads with higher surface loadings and/or are traveled by heavier vehicles. Consequently, some publicly owned roads are better characterized as industrial in terms of emissions. Examples would include city streets in heavily industrialized areas or areas of construction as well as paved roads in industrial complexes.

2.2.1 Estimation of Emissions

The current AP-42 PM_{10} emission factor for industrial paved roads is:[3]

$$e = 220\ (sL/12)^{0.3}\ (g/VKT)$$

$$e = 0.77\ (sL/0.35)^{0.3}\ (lb/VMT) \qquad (2\text{-}3)$$

where: e = emission factor, in units given above

sL = surface silt loading, g/m^2 (oz/yd^2)

The above equation is rated "A" in AP-42 (see Appendix A).

Alternatively, AP-42 presents a single-valued emission factor for use in lieu of Equation (2-3) for PM_{10} emissions from light-duty vehicles on heavily loaded industrial roads:

$$e = 93\ (g/VKT)$$

$$e = 0.33\ (lb/VMT) \qquad (2\text{-}4)$$

where e is as defined above. These single-valued emission factors are rated "C" (see Appendix A). Although no hard and fast rules can be provided, Table 2-7 summarizes a recommended decision process for selecting industrial paved road emission factors.

Table 2-8 presents a summary of silt loading values for industrial paved roads associated with a variety of industries. As is the case with all AP-42 Chapter 11.2 emission models, the use of site-specific data is strongly recommended.

2.2.2 Demonstrated Control Techniques for Industrial Paved Roads

As noted in Section 2.1.2, the vast majority of measured control efficiency values for paved roads are based on data from industrial roads. Consequently, the information presented earlier in Table 2-4 is more applicable to this class of road.

Mitigative measures may be more practical for industrial plant roads because (1) the responsible party is known; (2) the roads may be subject to considerable spillage and carryout from unpaved areas; and (3) all affected roads are in relatively close proximity, thus allowing a more efficient use of cleaning equipment. Preventive measures, of course, can be used in conjunction with plant cleaning programs and prevention is probably the preferred approach for city streets in industrialized areas with many potential sources of paved road dust. As before, the lack of efficiency values for preventive measures remains an important data gap and requires further investigation.

2.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

2.3.1 Preventive Measures

These types of control measures prevent the deposition of additional materials on a paved surface area. As a result, it is difficult to estimate their control effectiveness. For mitigative controls, before and after measurement (of surface loadings or of particulate emissions) is possible; clearly, this is not the case for preventive measures. Limited field data suggest that a 12-month construction project (without prevention programs) could result in an additional 18 tons/yr of TSP emissions from an adjacent paved road with 1,000 vehicle passes per day.[9] In this instance, one would expect that PM_{10} emissions would increase by approximately 10 tons/yr. As noted before, however, field data available to

TABLE 2-7. DECISION RULE FOR PAVED ROAD EMISSION ESTIMATES

Silt loading (sL), g/m^2	Average vehicle weight (W), Mg	Use model
sL <2	W > 4	Equation (2-3)
sL <2	W < 4	Equation (2-1)
sL >2[a]	W > 6	Equation (2-3)
2 <sL <15	W < 6	Equation (2-3)
sL >15[a]	W < 6	Equation (2-4)

[a]For heavily loaded surfaces (i.e., sL > ~300 to 400 g/m^2, it is recommended that the resulting estimate be compared to that from the unpaved road models (Section 3.0 of this manual), and the smaller of the two values used.

TABLE 2-8. INDUSTRIAL PAVED ROAD SILT LOADINGS[a]

Industry	No. of sites	No. of samples	Silt, percent w/w		No. of travel lanes	Silt loading, g/m^2	
			Range	Mean		Range	Mean
Copper smelting	1	3	[15.4-21.7]	[19.0]	2	[188-400]	[292]
Iron and steel production	6	20	1.1-35.7	12.5	2	0.09-79	12
Asphalt batching	1	3	[2.6-4.6]	[3.3]	1	[76-193]	[120]
Concrete batching	1	3	[5.2-6.0]	[5.5]	2	[11-12]	[12]
Sand and gravel processing	1	3	[6.4-7.9]	[7.1]	1	[53-95]	[70]

[a]Reference 3. Brackets indicate values based on only one plant visit.

estimate the effectiveness of preventive programs are extremely limited and often difficult to interpret. This data gap requires further development.

Instead of assigning control effectiveness values for preventive measures, regulatory personnel may choose to require all responsible parties (e.g., general contractors, street departments spreading salt and sand, businesses/homeowners with unpaved parking lots and driveways) to either submit control plans or agree to agency-supplied programs. Note that frequent watering of access areas should be discouraged (if possible) because that practice may compound carryout problems.

As early as 1971, EPA recommended reasonable mud/dirt carryout precautions including:

- Watering or use of suppressants at construction/demolition, road grading, and land clearing sites.
- Prompt removal of materials deposited upon paved roadways.
- Covering of open trucks transporting material likely to become airborne.

While most states have adapted many of EPA's recommendations to their own regulations, the vast number and spatial distribution of potential mud/dirt carryout points, as well as the large number of potentially responsible parties, make enforcement very difficult to plan and administer. Consequently, smaller jurisdictive areas (such as cities and counties) should be used in monitoring carryout enforcement.

Note that these local agencies include several other than those involved in air pollution per se. For example, building permits may be used to require carryout controls with building inspectors enforcing the regulations. Finally, it is clear that some agreement with the local public works department would be necessary to implement modifications in street salting and sanding procedures or to ensure prompt cleanup (see Appendix G).

2.3.1.1 <u>Salting/Sanding for Snow and Ice</u>. After winter snow and ice control programs, the heavy springtime street loadings found in certain areas of the country are known to adversely affect ambient PM_{10} concentrations. For example, data collected in Montana indicates that road sanding may produce early spring silt loadings 5 to 6 times higher than the mean loadings in Table 2-2.[3] Because that increase corresponds to roughly a fourfold increase in the emission level, it is clear that residual surface loadings represent an important source potentially requiring control. As indicated in Table 2-6, appropriate controls may include: (a) clean-up as soon as practical, (b) the use of improved materials, and (c) improvements in planning or application methods. Note that option (a) uses mitigative controls which are discussed in Section 2.3.2. The preventive options are discussed below.

Some municipalities have experimented by supplementing or replacing their usual snow/ice control materials with other harder and/or coarser materials. Because the choice of usual materials is based upon local availability (salt, sand, cinders) and price, it is clear that changes in materials applied will generally result in higher costs. However, the use of antiskid materials with either a lower initial silt content or greater resistance to forming silt-size particles will result in lower road surface silt loadings. Only limited field measurements comparing resultant silt contents and no measurements of silt loading values have been identified; consequently, it is not possible at this time to accurately estimate the control efficiency afforded by use of improved materials. Local agencies should design small-scale sampling programs (using the paved road sampling method presented in Appendix D) to estimate the differences in resulting silt loadings and then apply Equation (2-1) to determine a control efficiency value appropriate for their situation.

Improvements in planning and application techniques limit the amount of antiskid material applied to roads in an area. As was the case with improved materials, no field data are known to exist. However, an adequate estimate of <u>area wide</u> control efficiency can be obtained by (a) comparing the amounts of material applied, (b) assuming that both applications are equally subject to formation of fines, removal, etc., (c) assuming that both resultant silt loadings are <u>substantially</u> greater than the "baseline" (i.e., prewinter) value, and (d) using Equation (2-1). For example, if a community, through better planning, uses 30% less antiskid material, than the resultant silt loadings may be expected to be 30% lower. Use of Equation (2-1) would then indicate an effective PM_{10} control efficiency of 24.8%. Note that if assumption (c) above does not hold, the estimated control efficiency should be viewed only as an upper bound.

2.3.1.2 Carryout from Unpaved Areas and Construction Sites. Mud and dirt carryout from unpaved areas such as parking lots, construction sites, etc., often accounts for a substantial fraction of paved road silt loadings in many areas. The elimination of this carryout can significantly reduce paved road emissions.

As noted earlier, quantification of control efficiencies for preventive measures is essentially impossible using the standard before/after measurement approach. The methodology described below results in upper bounds of emission reductions. That is, the control afforded cannot be easily described in terms of percent but rather is discussed in terms of mass emissions prevented.

Furthermore, tracking of material onto a paved road results in substantial spatial variation in loading about the access point. This variation may complicate the modeling of emission reductions as well as their estimation, although these difficulties become less important as the number of unpaved areas in an area and their access points become larger.

For an individual access point from an unpaved area to a paved road, let N represent the daily number of vehicles entering or leaving the area. Let E be given by:

$$E = \begin{cases} 5.5 \text{ g/vehicle for } N \leq 25 \\ 13 \text{ g/vehicle for } N > 25 \end{cases}$$

where E is the unit PM_{10} emission increase in g/vehicle (see Section 5.1). Finally, if M represents the daily number of vehicle passes on the paved road, then the net daily emission reduction (g/d) is given by E x M, assuming complete prevention.

The emission reduction calculated above assumes that essentially all carryout from the unpaved area is controlled and, as such, is viewed as an upper limit. In use, a regulating agency may choose to assign an effective level of carryout control by using some fraction of the E values given above to calculate an emission reduction. Also, the regulatory agency could choose a percent control efficiency and substantiate compliance with testing data.

The methods used to control carryout consist of either mitigative measures on the paved road or preventive measures at the unpaved area or construction site. Discussion of these measures are presented in Sections 2.3.2, 3.3, and 5.3.

Finally, field measurements of the increased paved silt loadings around unpaved areas may also be used to gauge the effectiveness of control programs. A discussion of this is found in Section 2.5.

2.3.1.3 Other Preventive Control Measures. As shown in Table 2-6, numerous other preventive controls have been proposed for certain sources of paved road silt loadings. These controls range from wind fences in desert regions to keep sand off highways and other roads to measures designed to prevent losses of materials transported in trucks. No data are known to exist that quantify the PM_{10} emission reductions attributable to these controls. It is recommended that, if the use of one or more of these controls is contemplated in an area, the local control agency design small-scale field tests of the surface loadings (as described in Appendix D) before and after implementation to determine a reasonable estimate of the efficiency. Note that, in the design of any program of that type, particular attention must be paid to spatial variations in both sources and controls applied. For example, while a program for wind fences in desert areas would present few complications in assessing control, a program to assess the impact of, say, storm water control or haul truck restrictions, must include provisions for the localized (and possibly, random) nature of the source and its effects on surrounding roads.

2.3.2 Mitigative Measures

While preventive measures are to be preferred under the EPA urban dust policy, some sources of road dust loadings may not be easily controlled by prevention. Consequently, some mitigative measures may be necessary to achieve desired goals. This section discusses demonstrated mitigative measures.

2.3.2.1 Broom Sweeping of Roads. Mechanical street cleaners employ rotary brooms to remove surface materials from roads and parking lots. Much of their effect is cosmetic, in the sense that, while the roadway appears much cleaner, a substantial fraction of the original loading is emitted during the process. Thus, there is some credence to claims that mechanical cleaning is as much a source as a control of particulate emissions. Note, however, that mechanical sweeping may be the only viable option for rapid cleanup of antiskid materials throughout the snow season.

Measurement-based control efficiency for industrial roads (Table 2-4) and estimated efficiencies for urban roads (Table 2-5) both indicate a maximum (initial) instantaneous control of roughly 25 to 30%. Efficiency, of course, can be expected to decrease after cleanup.

Cost elements involved with broom sweeping include the following capital and operating/maintenance (O&M) expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement brushes, truck maintenance, operator labor

Cost data presented in Reference 10 provides the following estimates for a broom sweeping program:

Initial capital expense: 6,580 to 19,700 $/truck

Annual O&M expense: 27,600 $/truck

All costs are based on April 1985 dollars. Determination of the number of trucks can be based on an assumption that 3 to 5 mi of road can be cleaned per unit per shift.[11] Additional cost data for a broom sweeping program is provided in Table 2-9.[11]

Enforcement of a broom sweeping dust control program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular cleaning program is in place. (See Appendix C for a suggested recordkeeping format.) The second approach would involve agency spot checks of controlled roads by taking a material sample from the road. The latter approach is discussed in Section 2.5. The sampling method should be essentially the same as that used in the development of the current AP-42 predictive equations. As noted earlier, an estimate of the controlled PM_{10} emission level could then be obtained.[2]

TABLE 2-9. MISCELLANEOUS OPERATION/DESIGN AND COST DATA FOR BROOM SWEEPING PAVED ROADS[a]

Purchase price:	\$18,000 (1978) \$20,000 (1980)
Estimated life expectancy:	5 yr
Approximate annual operating cost during 1981:	\$65,100--No. 1 \$57,000--No. 2
Fuel consumption:	3 mi/gal
Cleaning capacity:	69,700 ft^2/h at 3 mph
Vehicle weight:	5,000 lb
Width of area cleaned per pass:	7.5 ft
Normal sweeping speed:	3 to 5 mile/h

[a]Reference 11. Purchase cost is actual cost in year purchased; other costs in 1981 dollars.

Records must be kept that document the frequency of broom sweeping applied to paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency

2. Length of each road and area of each parking lot

3. Type of control applied to each road/area and planned frequency of application

4. Any provisions for weather (e.g., ¼ in of rainfall will be substituted for one treatment)

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets)

3. Start and stop times on a particular segment/parking lot, average speed, number of passes

4. Qualitative description of loading before and after treatment

5. Any areas of unusually high loadings, from spills, pavement deterioration

General Records to be Kept

1. Equipment maintenance records

2. Meteorological log (to the extent that weather influences the control program--see above)

3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested in Section 2.5 require that additional records be kept. These records may include surface material samples or traffic counts. A suggested format for recording paved surface samples (following the sampling/analysis procedures given in Appendices D and E) is presented as Figure 2-1. Traffic counts may be recorded either manually or using automatic devices (low frequency, 1/season, 1/yr).

Type of Material Sampled: ______________________

Site of Sampling: ______________ No. of Traffic Lanes ______________

Type of Pavement: Asphalt/Concrete ______ Surface Condition ______________

Sample No.	Vac.Bag	Time	Location*	Sample Area	Broom Swept? (y/n)

*Use code given on plant map for segment identification and indicate sample location on map.

Figure 2-1. Example paved road sample log.

2.3.2.2 Vacuum Sweeping of Roads. Vacuum sweepers remove material from paved surfaces by entraining particles in a moving air stream. A hopper is used to contain collected material and air exhausts through a filter system in a open loop. A regenerative sweeper functions in much the same way, although the air is continuously recycled. In addition to the vacuum pickup heads, a sweeper may also be equipped with gutter and other brooms to enhance collection.

Instantaneous control efficiency (cf. Appendix A) values were given earlier in Table 2-4. Available data show considerable scatter, ranging from a field measurement showing no effectiveness (over baseline uncontrolled emissions) to another field measurement of 58 percent. An average of the field measurements would indicate a efficiency of 34 percent. In addition, the estimated upper limits for PM_{10} control of urban roads (Table 2-5) compare fairly well with that average. Recall that very adequate controlled emission estimates were obtained using the industrial paved road model given as Equation (2-3). It is recommended that material loading samples be employed, if possible, in conjunction with the model to obtain a better estimate of control effectiveness.

Cost elements involved with vacuum sweeping include the following capital and operating/maintenance (O&M) expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts, truck maintenance, operator labor cost data presented in Reference 10 provides the following estimates for a vacuum sweeping program

Initial capital expense: 36,800 $/truck

Annual O&M expense: 34,200 $/truck

All costs are based on April 1985 dollars. Determination of the number of trucks necessary can be made by assuming that 6 mi can be swept per unit per 12 h.[11] Additional cost data for a broom sweeping program is provided in Table 2-10.

Enforcement of a vacuum sweeping dust control program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular cleaning program is in place. (See Appendix C for a suggested recordkeeping format.) The second

TABLE 2-10. MISCELLANEOUS OPERATION/DESIGN AND COST DATA FOR VACUUM SWEEPING PAVED ROADS[a]

Purchase price:	$72,000 (1980)
Estimated life expectancy:	5 yr
Approximate annual operating cost during 1981:	$214,000
Fuel consumption:	4 mi/gal
Hopper capacity:	10 yd^3
Vacuum blower capacity:	12,000 ft^3/min
Vehicle weight:	32,000 lb
Width of area cleaned per pass:[b]	5 ft
Normal sweeping speed:	5 mi/h
Velocity at suction head:	N/A
Type of dust control system (i.e., wet or dry):	Wet

[a]Reference 11. Purchase cost is actual cost in year purchased; other costs in 1981 dollars.
[b]Multiple passes required.

approach would involve agency spot checks of controlled roads by taking a material sample from the road. As before, the second approach is discussed in greater detail in Section 2.5. Note that some sample collection may be necessary to estimate control performance.

Records must be kept that document the frequency of vacuum sweeping paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency

2. Length of each road and area of each parking lot

3. Type of control applied to each road/area and planned frequency of application

4. Any provisions for weather (e.g., ¼ in of rainfall will be substituted for one treatment; no sprays during freezing periods, etc.)

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets)

3. Start and stop times on a particular segment/parking lot, average speed, number of passes

4. Qualitative description of loading before and after treatment

5. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

General Records to be Kept

1. Equipment maintenance records

2. Meteorological log (to the extent that weather influences the control program--see above)

3. Any equipment malfunctions or downtime

In addition to those items related to control applications, some of the regulatory formats suggested in Section 2.5 require that additional records be kept. These records may include surface material samples or traffic counts. A suggested format for recording paved surface samples (following the sampling/analysis procedures given in Appendices D and E) was presented in Figure 2-1. Traffic counts may be recorded either manually or using automatic devices.

2.3.2.3 Water Flushing of Roads. Street flushers remove surface materials from roads and parking lots using high pressure water sprays. Some systems supplement the cleaning with broom sweeping after flushing. Note that the purpose of the program is to remove material from the road surface; in some industries, water is regularly applied to roads to directly control emissions (i.e., as in unpaved roads). Unlike the two sweeping methods, flushing faces some obvious drawbacks in terms of water usage, potential water pollution, and the frequent need to return to the water source. However, flushing generally tends to be more effective in controlling particulate emissions.

Equations to estimate instantaneous control efficiency values are given in Table 2-3. Note that water flushing and flushing followed by broom sweeping represent the two most effective control methods (on the basis of field emission measurements) given in that table.

Cost elements involved with broom sweeping include the following capital and operating/maintenance (O&M) expenses:

Capital: Purchase of truck or other device

O&M: Fuel, replacement parts (possibly including brushes), truck maintenance, operator labor, water

Cost data presented in Reference 10 provides the following estimates for a flushing program;

Initial capital expense: 18,400 $/truck

Annual O&M expense: 27,600 $/truck

All costs are based on April 1985 dollars. Determination of the number of trucks required can be based on the assumption that 3 to 5 mi can be flushed or flushed and broom swept per unit per 8-h shift, respectively.[11] Additional cost/design data are provided as Table 2-11.

Enforcement of a road flushing (possibly supplemented by broom sweeping) program could consist of two approaches, as before. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular cleaning program is in place. (See Appendix C for a suggested recordkeeping format.) The second approach would involve agency spot checks of

TABLE 2-11. MISCELLANEOUS OPERATION/DESIGN AND COST DATA FOR FLUSHING PAVED ROADS[a]

Purchase price:	$68,000 (1976)
Estimated life expectancy:	10 yr
Approximate annual operating cost during 1981:	$57,000
Vehicle weight (dry):	N/A lb
Water tank capacity:	8,000 gal
Normal vehicle speed:	4 mi/h
Water pressure at nozzles:	50 psig
Vehicle weight (wet):	N/A lb
Fuel consumption:	7 mi/gal
Water flow at nozzles:	188 gal/min
Hopper capacity:	40 yd^3
Daily water consumption:	30,000 gal
Degree of water treatment:	1,800 gal/mil

[a]Reference 11. Purchase cost is actual cost in year purchased; other costs in 1981 dollars.

controlled roads by taking a material sample from the road. Recall that, while resulting estimates of controlled emissions should be adequate for a flushing program, the estimates are probably substantially overestimated in a flushing/broom sweeping program.

Records must be kept that document the frequency of broom sweeping applied to paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency
2. Length of each road and area of each parking lot
3. Type of control applied to each road/area and planned frequency of application
4. Provisions for weather (e.g., program suspended for periods of freezing temperatures)

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment
2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets)
3. Start and stop times on a particular segment/parking lot, average speed, number of passes
4. Start and stop times for refilling tanks
5. Qualitative description of loading before and after treatment
6. Any areas of unusually high loadings, from spills, pavement deterioration, etc.

General Records to be Kept

1. Equipment maintenance records
2. Meteorological log (to the extent that weather influences the control program--see above)
3. Any equipment malfunctions or downtime

In addition to those items related to control applications, some of the regulatory formats suggested in Section 2.5 require that additional records be kept. These records may include surface material samples or traffic counts. A suggested format for recording paved surface samples (following the sampling/analysis procedures given in Appendices D and E) was presented in Figure 2-1. Traffic counts may be recorded either manually or using automatic devices.

2.4 EXAMPLE DUST CONTROL PLAN

To illustrate the use of material in this chapter, this section presents an example control plan. Unlike the other open dust sources considered in this manual, preventive control of paved roads (and especially public paved roads) requires that control be applied to a wide variety of contributing loading sources. Furthermore, the contribution of any individual loading source to the total silt loading on any roadway is, at present, impossible to determine. Consequently, the approach taken in this example will employ area wide silt loading reductions and will also use limited field sampling to gauge the effectiveness of the program.

Suppose a control agency determines that a 10% decrease in urban paved road emissions is necessary to meet some goal. Equation (2-1) shows that a 10 prcent decrease in the PM_{10} emission factor requires (a) a 10 percent reduction in traffic volume, (b) a 12% decrease in silt loading, or (c) some combination of traffic and silt loading reductions. Suppose that traffic reductions are not considered feasible and suppose further that the agency desires a uniform 12 percent decrease in area wide silt loadings rather than staggering loading decreases as a function of road lengths and traffic volumes.

The types of controls that could be applied to loading sources include: use of improved antiskid materials, rapid cleaning of snow/ice control methods, haul truck ordinances (e.g., covering, freeboard, etc.), and paving unpaved access points. Selection of sources to be controlled depend on a variety of factors, such as the perceived relative contribution of a source to an area's silt loading values, responsibility for enforcement of any new ordinances, etc.

In general, unless there is good reason to suspect that one source category is responsible for a substantial fraction of the paved road loading in an area, it is probable that a series of controls will be employed (see Section 2.5.2). Assessment of the (combined) effectiveness of the controls implemented will generally be based on the field sampling measurements discussed in Appendices D and E.

2.5 POTENTIAL REGULATORY FORMATS

2.5.1 General Guidelines

Clear and specific enforceable plan provisions are needed to gain credit for claimed emission reductions in State implementation plans (SIP's), which for paved road dust sources will likely rely on record-keeping, reporting, and surrogate factors rather than short-term mass emissions or opacity limits. Surrogate factors will include control program regulations, permits, or intergovernmental agreements to institute programs such as vacuum sweeping, mud/dirt carryout precautions, spill cleanup, erosion control, and/or measures to prevent or mitigate entrainment from unpaved adjacent areas. Record review of control programs (e.g., vacuum sweeping, road sand/salt application, etc.) and field checks (i.e., road silt loading sampling) will provide the likely means of compliance determination for these sources. Because paved road emissions are directly related to the surface silt loading, the most reliable regulatory formats are based on loading. Formats viable for other open dust sources--including opacity measurements, visible emissions at the property line--are generally not applicable for paved roads because of the lower unit emission levels involved (e.g., there are usually no visible plumes from a vehicle pass).

Many States currently have regulations related to the control of paved roads. Colorado, for example, may require a control plan from any party that repeatedly deposits materials which might create fugitive emissions from a public or private roadway. Note, however, that no quantitative determination of loading levels is specified.

An alternative format is presented below to suggest how a quantitative method could be incorporated in a regulation. Figure 2-2 presents a possible format for use with public paved road sources. In this example, if the silt loading on a road with an average traffic volume of 2,000 vehicles per day ever exceeds 2.9 g/m^2 (the "action level"), the regulatory agency may require the responsible party (e.g., a construction site with mud/dirt carryout) or the owner of the road to reduce the silt loading to a level less than the action level. The action level is an agency-supplied multiple of either baseline measurements or the surface silt loading predicted by Equation (2-2) and should correspond to

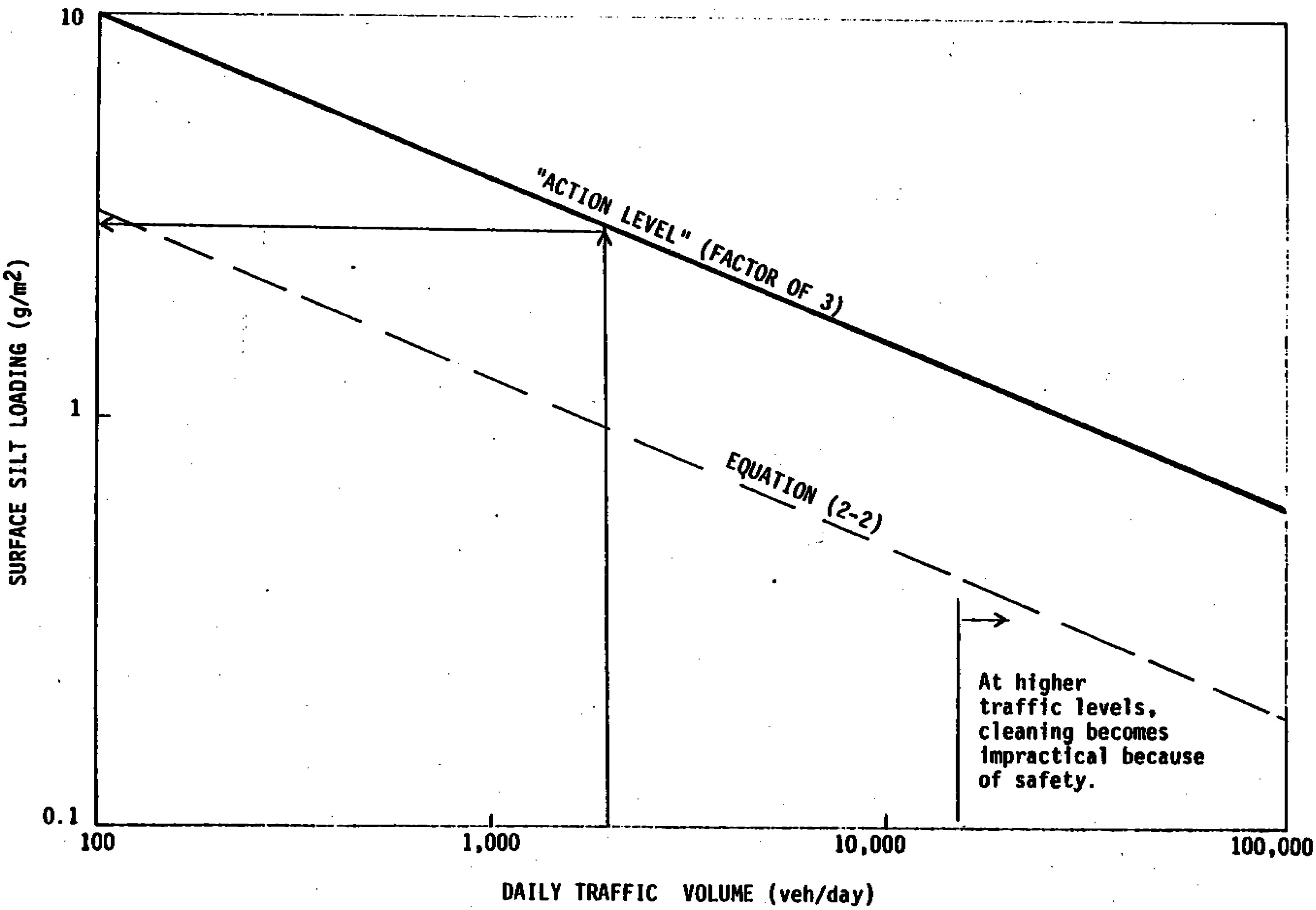

Figure 2-2. Possible use of "action levels" to trigger paved road controls.

minimum percent control efficiency level. The means of reduction will be left to the discretion of the responsible party and could consist of either preventive or mitigative controls. The maximum allowed silt loading requirement could be made part of a construction permit (as discussed in Section 5 of this manual) or an enforceable intergovernmental agreement. Note that additional traffic due to the construction activity should be included in the daily traffic volume used to determine the action level for the affected roadways. In addition, a request for permit should be accompanied with a description of the control technique(s) that will be employed. Similarly, intergovernmental agreements should clearly and specifically describe control techniques and associated recordkeeping and reporting requirements.

The field measurement of silt loading could either be made a requirement of the responsible party or be assigned to agency inspection personnel, or a combination of the two could be used. In either event, certain features of the measurement technique must be specified:

1. The sampling method used to determine silt loading for compliance inspection should conform to the technique used to develop the AP-42 urban paved road equation. That technique is specified in Appendix D and should be made part of an SOP for regulatory personnel or part of the construction permit.

2. Arrangements must be made to account for spatial variation of surface silt loading. Possible suggestions include (a) visually determining the heaviest loading on the road and selecting that spot for sampling, (b) sampling the midpoint of the road length segment of interest, and (c) sampling preselected (possibly on the basis of safety considerations) strips on the road surface (note that the samples may be aggregated).

3. Provision should be made to grant a "grace period" following a spill or other accidental increase in loading. An 8-h period is suggested to allow time for the responsible party to clean the affected area. This allowance should be made part of a construction or other permit.

For industrial paved roads, an approach similar to that described above could be applied as well, using agency-supplied action levels. Note that these levels could be specific to individual roads, apply to all roads in a plant, or be based on plant traffic levels. Because most plants will contain many roads, the regulatory agency may choose to set plant-wide goals (such as vacuum sweeping each road twice per week) rather than source-specific programs.

The control efficiency equations presented in Table 2-4 provide another potential regulatory format for industrial paved road sources. This approach involves inspection of both plant road cleaning records and traffic counts. By combining the two sets of information, regulatory personnel would be able to determine average efficiency values for the plant's controlled paved roads. Provision must be made to collect traffic information. The traffic data may require more frequent inspection visits than surface loading samples; however, analysis is more easily accomplished. Surface loading sampling provides an additional means for checking the success of achieving the estimated control efficiency.

2.5.2 Example SIP Language for Reduction of Public Paved Road Surface Contaminants

Public paved roads are important PM_{10} sources in areas across the country. Unlike the industrial sources described in this manual, control of municipal paved roads generally requires a close working agreement between various government bodies and the general public.

A number of States have developed enforceable regulations, permit conditions, or provisions in intergovernmental agreements (between State agencies, and with municipalities) that attempt to address sources contributing to the silt loading of paved roads. The following example regulations are drawn from existing State regulations and intergovernmental agreement provisions.

Material Transport

-- No person shall cause or permit the handling or transporting of any material in a manner which allows or may allow controllable particulate matter to become airborne. Visible dust emissions from the transportation of materials must be eliminated by covering stock loads in open-bodied trucks or other equivalently effective controls.

-- Earth or other material that is deposited by trucking and earth-moving equipment on paved streets shall be reported to the (local Department of Sanitation at ______) and removed immediately subject to safety considerations by the party or person responsible for such deposits.

Motor Vehicle Parking Areas

-- Effective __________, no person shall cause, permit, suffer, or allow the operation, use, or maintenance of an unsealed or unpaved motor vehicle parking area.

Low use parking area exemption: Motor vehicle parking area requirements shall not apply to any parking area from which less than ___ (e.g., 10) vehicles exit on each day. Any person seeking such an exemption shall: (1) submit a petition to the Control Officer in writing identifying the location, ownership, and person(s) responsible for control of the parking area, and indicating the nature and extent of daily vehicle use; and (2) receive written approval from the regulating agency that a low use exemption has been granted.

Erosion and Entrainment From Nearby Areas

-- The City of _________ will revegetate, pave, or treat by using water, calcium chloride, or acceptable equivalent materials the following: paved road shoulders and approach aprons for unpaved roads and parking areas that connect to paved roads, which are within the City's right-of-ways or under the City's control and within X feet (e.g., 25) of roadways [specify location or entire roads by name], in amounts and frequencies as is necessary to effectively control PM_{10} emissions to a level of x percent control efficiency (e.g., paving--90 percent; vegetation per specified requirements--50 percent; chemical treatment per specified requirements--70 percent). [Include list of roads in memorandum of understanding and specify whether those areas will be revegetated, paved, or treated.]

-- If loose sand, dust, or dust particles are found to contribute to excessive silt loadings on nearby paved roads, the Control Officer shall notify the owner, lessee, occupant, operator, or user of said land that said situation is to be corrected within a specified period of time, dependent upon the scope and extent of the problem, but in no case may such a period of time exceed x (e.g., 2) days.

The Control Officer, or a designated agent, after due notice, may enter upon the subject land where said sand or dust problem exists, and take such remedial and corrective action as may be deemed appropriate to relieve, reduce, or remedy the existent dust condition, where the owner, occupant, operator, or any tenant, lessee, or holder of any possessory interest or right in the subject land, fails to do so.

Any cost incurred in connection with any such remedial or corrective action by the Control Officer shall be assessed against the owner of the involved property, and failure to pay the full amount of such costs shall result in a lien against said real property, which lien shall remain in full force and effect until any and all such costs shall have been fully paid, which shall include, but not be limited to, costs of collection and reasonable attorney's fee therefore.

Road Sanding/Salting and Traffic Reduction

-- The City of ___________ will, beginning with the (year) winter season, restrict the use of sand used for anti skid operations to a material with greater than x percent (e.g., 95) grit retained by a number 100 mesh sieve screen and a degradation factor of x.

-- The City of ___________ will provide alternative traffic flow patterns--such as a by-pass plan to reduce vehicular traffic (especially truck traffic) in the central business district to reduce the effects of vehicular reentrainment.

-- The City of ___________ will conduct its vacuum street sweeping throughout the year with wintertime sweeping done whenever shaded pavement temperatures--as determined by the use of infrared thermometer--allow for the application of water spray from the vacuum sweeper without jeopardizing the safety of pedestrian and vehicular traffic on the swept areas. The street vacuuming program shall be designed to provide for maximum sweeping efforts throughout the winter and spring months and shall provide for adequate personnel and equipment to ensure thorough cleanup when possible within temperature and safety constraints. As soon as temperature conditions permit (melt periods), the City will begin vacuuming the road sand/salt loadings from streets per the following priority schedule: [include schedule in memo of understanding]. (Quality control provisions for recordkeeping/reporting requirements are presented in Section 2.3.2.2 and Appendix C.2.1. of this report.)

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3.0 UNPAVED ROADS

As is the case for paved roads, particulate emissions occur whenever a vehicle travels over an unpaved surface. Unlike paved roads, however, the road itself is the source of the emissions rather than any "surface loading." Within the various categories of open dust sources in industrial settings, unpaved travel surfaces have historically accounted for the greatest share of particulate emissions in industrial settings. For example, unpaved sources were estimated to account for roughly 70 percent of open dust sources in the iron and steel industry during the 1970's. Recognition of the importance of unpaved roads led naturally to an interest in their control. As a result of these control programs, the portion of total open source dust emissions due to unpaved travel surfaces has decreased dramatically over the past 5 to 10 years. Nevertheless, the need for continued control of these sources is apparent.

This section presents a discussion of the various types of unpaved sources, available emission factors, viable control measures, and methods to determine compliance of controlled sources.

Travel surfaces may be unpaved for a variety of reasons. Possibly the most common type of unpaved road is that found in rural regions throughout the country; these roads may experience only sporadic traffic which, taken with the often considerable road length involved, makes paving impractical.

Other important travel surfaces are found in industrial settings. During the 1980's, industry has paved many previously unpaved roads as part of emissions control programs. Some industrial roads are, by their nature, not suitable for paving. These roads may be used by very heavy vehicles or may be subject to considerable spillage from haul trucks. Other roads may have poorly constructed bases which make paving impractical. Because of the additional maintenance costs associated with a paved road under these service environments, emissions from these roads are usually controlled by regular applications of water or chemical dust suppressants.

In addition to roadways, many industries often contain important unpaved travel areas. Examples include scraper traffic patterns related to stockpile/reclaim activities in coal yards, compactor traffic in areas proximate to lifts at landfills, and travel related to open storage of finished products (such as coil at steel plants). These areas may often account for a substantial fraction of traffic-generated emissions from individual plants. In addition, these areas tend to be much more difficult to control than stretches of roadway (e.g., changing traffic patterns make semipermanent controls impractical, increased shear forces from cornering vehicles rapidly deteriorate chemically controlled surfaces, chemical suppressants may damage raw materials or finished products, etc.).

3.1 ESTIMATION OF EMISSIONS FROM UNPAVED ROADS

As was the case for paved roads, unpaved roads may be divided into the two classes of public and industrial. However, for the purpose of estimating emissions, there is no need to distinguish between the two, because the AP-42 emission factor equation takes source characteristics (such as average vehicle weight and road surface texture) into consideration:[1]

$$E = 0.61 \left(\frac{s}{12}\right) \left(\frac{S}{48}\right) \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{(365-p)}{365} \ (\text{kg/VKT}) \tag{3-1}$$

$$E = 2.1 \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \frac{(365-p)}{365} \ (\text{lb/VMT})$$

where: E = PM_{10} emission factor in units stated
s = silt content of road surface material, percent
S = mean vehicle speed, km/h (mi/h)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels (dimensionless)
p = number of days with $\geq$0.254 mm (0.01 in.) of precipitation per year

Using the scheme given in Appendix A, the above equation is rated "A" in AP-42. Measured silt values are given in Table 3-1. As is the case with all AP-42 emission factors, the use of site-specific data is strongly encouraged.

TABLE 3-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road use or surface material	Plant sites	Test samples	Silt, weight percent	
				Range	Mean
Copper smelting	Plant road	1	3	15.9-19.1	17.0
Iron and steel production	Plant road	9	20	4.0-16.0	8.0
Sand and gravel processing	Plant road	1	3	4.1-6.0	4.8
Stone quarrying and processing	Plant road	1	5	10.5-15.6	14.1
Taconite mining and processing	Haul road	1	12	3.7-9.7	5.8
	Service road	1	8	2.4-7.1	4.3
Western surface coal mining	Access road	2	2	4.9-5.3	5.1
	Haul road	3	21	2.8-18	8.4
	Scraper road	3	10	7.2-25	17
	Haul road (freshly graded)	2	5	18-29	24
Rural roads	Gravel	1	1	NA	5.0
	Dirt	2	5	5.8-68	28.5
	Crushed limestone	2	8	7.7-13	9.6

Note: NA = Not applicable
[a]Reference 1 (AP-42).

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 3-1 gives the geographical distribution of the mean annual number of wet days per year in the United States. Maps giving similar data on a monthly basis are available from the U.S. Department of Commerce.[2]

It is important to note that for the purpose of estimating annual or seasonal controlled emissions from unpaved roads, average control efficiency values based on worst case (i.e., dry, p = 0 in Equation (3-1)) uncontrolled emission levels are required. This is true simply because the AP-42 predictive emission factor equation for unpaved roads, which is routinely used for inventorying purposes, is based on source tests conducted under dry conditions.[1] Extrapolation to annual average uncontrolled (including natural mitigation) emissions estimates 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. This assumption has never been verified in a rigorous manner; however, MRI's experience with hundreds of field tests indicate that it is a reasonable assumption if the source operates on a fairly "continuous" basis.

The uncontrolled emission factor for a specific unpaved road will increase substantially after a precipitation event as the surface dries. However, in the absence of data sufficient to describe this growth as a function of traffic parameters, amount of precipitation, time of day, season, cloud cover, and other variables, uncontrolled emissions are estimated using the simple assumption given above. Prior MRI testing has suggested that for unpaved travel areas, surface moisture levels approximately twice that for dry conditions afford control of roughly 75 to 90 percent.[3] Between the dry, uncontrolled moisture level (typically <2 percent) and approximately 3 to 4 percent, a small increase in moisture content may result in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. These relationships are discussed in greater detail in the following section.

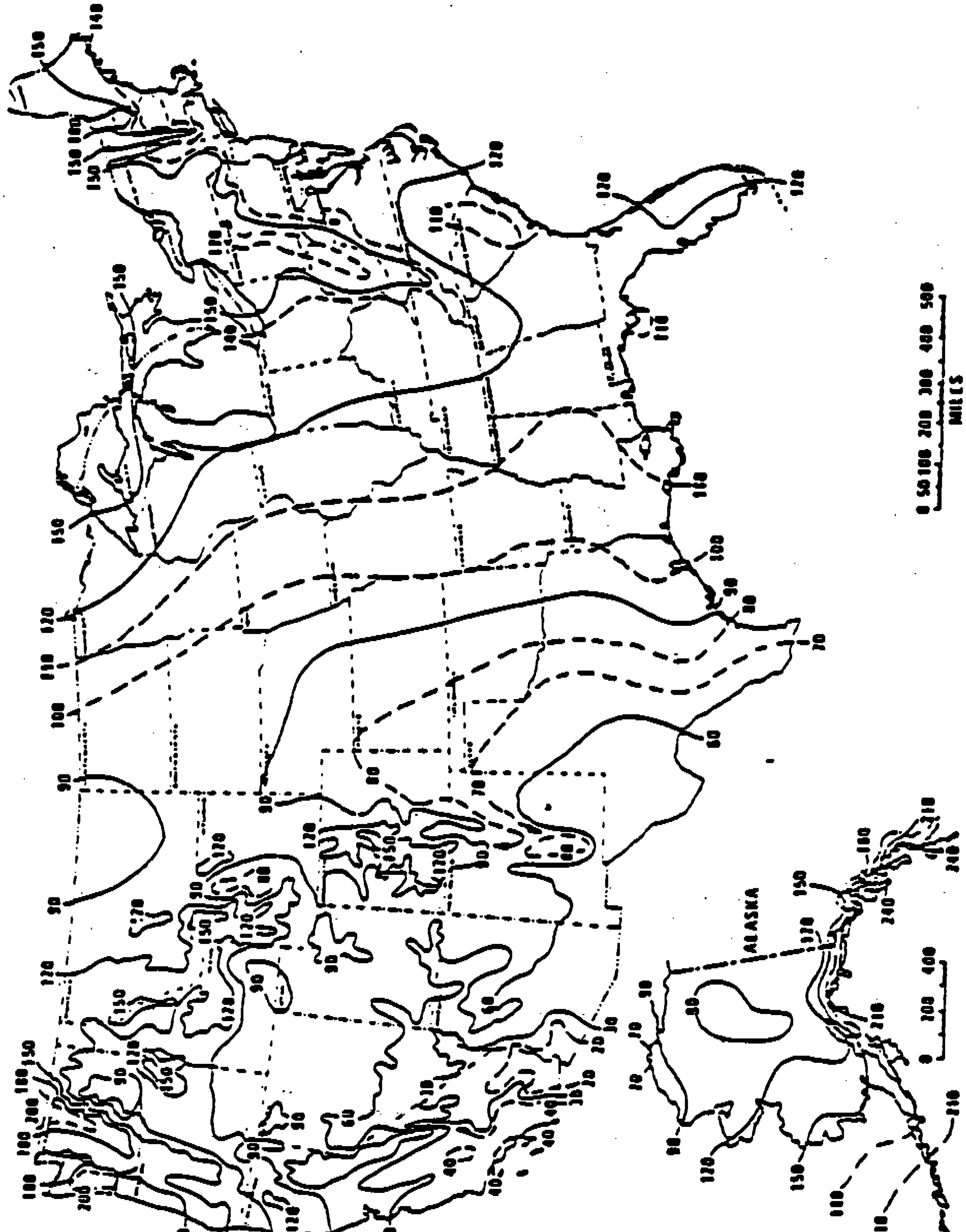

Figure 3-1. Mean annual number of days with at least 0.01 in of precipitation.[2]

3.2 DEMONSTRATED CONTROL TECHNIQUES FOR UNPAVED ROADS

There are numerous control options for unpaved travel surfaces, as shown in Table 3-2. Note that the controls fall into the three general categories of source extent reductions, surface improvements, and surface treatment. Each of these is discussed in greater detail in the following sections.

Source extent reductions. These controls either limit the amount of traffic on a road to reduce the PM_{10} emission rate or lower speeds to reduce the emission factor value given by Equation (3-1). Examples could include industrial plant bussing programs for employees, restriction of roads to only certain vehicle types, or strict enforcement of speed limits. In any instance, the control afforded by these measures is readily obtained by the application of the equation.

Surface improvements. These controls alter the road surface. Unlike surface treatments (discussed below), these improvements are largely "one-shot" control methods; that is, periodic retreatments are not normally required.

The most obvious surface improvement is, of course, paving an unpaved road. This option is expensive and is probably most applicable to high volume (more than a few hundred passes per day) public roads and industrial plant roads that are not subject to very heavy vehicles (e.g., slag pot carriers, haul trucks, etc.) or spillage of material in transport. Clearly, control efficiency estimates can be obtained by applying the information of Section 2.0 of this manual; this is discussed in greater detail in Section 3.3.

Other improvement methods cover the road surface material with another material of lower silt content (e.g., covering a dirt road with gravel or slag, or using a "road carpet" under ballast). Because Equation (3-1) shows a linear relationship between the emission factor and the silt content of the road surface, any reduction in the silt value is accompanied by an equivalent reduction in emissions. This type of improvement is initially much less expensive than paving; however, the reader is cautioned that maintenance (such as grading and spot reapplication of the cover material) may be required.

TABLE 3-2. CONTROL TECHNIQUES FOR UNPAVED TRAVEL SURFACES[a]

Source extent reduction:	Speed reduction Traffic reduction
Source improvement:	Paving Gravel surface
Surface treatment:	Watering Chemical stabilization[b] - Asphalt emulsions - Petroleum resins - Acrylic cements - Other

[a]Table entries reflect EPA draft guidance on urban fugitive dust control.
[b]See Table 3-3.

Finally, vegetative cover has been proposed as a surface improvement for low traffic volume roads. Note, however, that because vehicle related emissions would be quite low, this method is probably intended to control wind erosion of the road surface. As such, this technique is discussed in Section 5.0 of this manual.

Surface treatments. Surface treatment refers to those control techniques which require periodic reapplications. Treatments fall into the two main categories of (1) wet suppression (i.e., watering, possibly with surfactants or other additives), which keeps the surface wet to control emissions, and (2) chemical stabilization, which attempts to change the physical (and, hence, the emissions) characteristics of the roadway. Necessary reapplication frequencies may range from several minutes for plain water under hot, summertime conditions to several weeks (or months) for chemicals.

Water is usually applied to unpaved roads using a truck with a gravity or pressure feed. This is only a temporary measure, and periodic reapplications are necessary to achieve any substantial level of control efficiency. Some increase in overall control efficiency is afforded by wetting agents which reduce surface tension.

Chemical dust suppressants (Table 3-3), on the other hand, have much less frequent reapplication requirements. These suppressants are designed to alter the roadway, such as cementing loose material into a fairly impervious surface (thus simulating a paved surface) or forming a surface which attracts and retains moisture (thus simulating wet suppression).

Chemical dust suppressants are generally applied to the road surface as a water solution of the agent. The degree of control achieved is a direct function of the application intensity (volume of solution per area), dilution ratio, and frequency (number of applications per unit time) of the chemical applied to the surface and also depends on the type and number of vehicles using the road. Chemical agents have also been proven to be effective as crusting agents for inactive storage piles and for the stabilization of exposed open areas and agricultural fields. In both cases, the chemical acts as a binder to reduce the wind erosion potential of the aggregate surface. The use of chemical agents to control these sources is discussed in other chapters of this manual.

TABLE 3-3. CHEMICAL STABILIZERS[a]

A. Type: Bitumens

Product	Manufacturer
AMS 2200, 2300®	Arco Mine Sciences
Coherex®	Witco Chemical
Docal 1002®	Douglas Oil Company
Peneprime®	Utah Emulsions
Petro Tac P®	Syntech Products Corporation
Resinex®	Neyra Industries, Inc.
Retain®	Dubois Chemical Company

B. Type: Salts

Product	Manufacturer
Calcium chloride	Allied Chemical Corporation
Dowflake, Liquid Dow®	Dow Chemical
DP-10®	Wen-Don Corporation
Dust Ban 8806®	Nalco Chemical Company
Dustgard®	G.S.L. Minerals and Chemicals Corporation
Sodium silicate	The PQ Corporation

C. Type: Adhesives

Product	Manufacturer
Acrylic DLR-MS®	Rohm and Haas Company
Bio Cat 300-1®	Applied Natural Systems, Inc.
CPB-12®	Wen-Don Corporation
Curasol AK®	American Hoechst Corporation
DCL-40A, 1801, 1803®	Calgon Corporation
DC-859, 875®	Betz Laboratories, Inc.
Dust Ban®	Nalco Chemical Company
Flambinder®	Flambeau Paper Company
Lignosite®	Georgia Pacific Corporation
Norlig A, 12®	Reed Lignin, Inc.
Orzan Series®	Crown Zellerbach Corporation
Soil Gard®	Walsh Chemical

[a]Source: Reference 4, as cited by Reference 5.

Finally, note that some chemical dust suppressants may contain a considerable fraction of hydrocarbons. While these mixtures are generally not very volatile, regulators in areas with ozone problems should balance the benefits of dust control with the cost of a potential VOC emission increase.

3.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

3.3.1 Source Extent Reductions

These control methods act to reduce the emission rate due to traffic on a road. As noted in Section 3.2, control efficiency values are easily obtained by use of Equation (3-1).

The reduction may be obtained by banning certain vehicles (such as employees' cars) or strictly enforcing speed limits. Some of these methods (e.g., employee bussing) will require capital and operating and maintenance (O&M) expenditures, while others (e.g., speed reductions) may only require indirect costs associated with increased travel times. Consequently, identification of cost elements and estimation of costs are highly dependent upon the option(s) selected to reduce source extent, and no attempt is made here to generalize costs.

3.3.2 Surface Improvements

3.3.2.1 Paving. Control efficiency estimates for paving previously unpaved roads may be based on the material presented in Section 2.0 of this manual. Inherent in this process is estimating the silt loading on the paved surface; it is recommended that the reader use Table 2-2 or 2-7 for public and industrial roads, respectively. Alternatively, for public roads, the reader may wish to employ Equation (2-2) to estimate silt loading as a function of the daily traffic volume. Note, however, that use of the equation implies that curbs will be installed after paving.

Cost elements identified for paving are as follows:

Capital: Operating equipment (graders, paving equipment), paving material (asphalt, concrete), and base material

O&M: Patching materials, labor for patching, and equipment maintenance

Reference 6 provides the following cost estimates (April 1985 dollars) for asphaltic paving:

Initial capital expense: $44,700-$80,200/mile

Annual O&M costs: $6,600-$11,900/mile

These estimates are based on resurfacing every 5 years and "15 percent opportunity costs." Reference 7 estimates a cost of $140,000/mile (1983 dollars) to paved industrial unpaved roads. Because of the variety of cost estimates, it is strongly recommended that the reader obtain quotes from local paving contractors.

3.3.2.2 Gravel/Slag Improvements. As noted earlier, these types of improvements replace the present road surface material with a lower silt content material. Note that this method may increase road maintenance costs as the new aggregate fractures. This cost may be avoided by installing a "road carpet." Because Equation (3-1) indicates a linear relationship between silt content and emission levels, control efficiency can be estimated by determining the reduction in silt content. For example, if a road with a 12 percent silt content is recovered with a gravel (with an equilibrium silt content of 5 percent; see Table 3-1), then a 58 percent control efficiency would be expected.

Identified cost elements for these improvements follow:

Capital: Material (including "road carpet," if applicable), application equipment, and labor

O&M: Periodic grading including equipment and labor

No cost estimates were found in the reference documents used as the basis for this document. Because of the differences in local availability of cover materials (and civil engineering fabrics) and the amount of surface preparation, compaction, and maintenance required for various road types, it is recommended that the reader obtain quotes from local contractors.

3.3.2.3 Vegetative Cover. As noted by Turner et al.,

". . . vegetative covers are obviously impractical for roads and facilities with construction activity . . . vegetative covering may be a practical control option for many inactive sites, but it is likely to be impractical for areas of continuing activity and areas that will not support a relatively dense vegetative cover."[5]

Consequently, vegetation is probably a viable control option only for inactive area wind erosion and is discussed elsewhere in this manual.

3.3.3 Surface Treatments

3.3.3.1 Watering. The control efficiency of unpaved road watering depends upon (a) the amount of water applied per unit area of road surface, (b) the time between reapplications, (c) traffic volume during that period, and (d) prevailing meteorological conditions during the period. While several investigations have estimated or studied watering efficiencies, few have specified all the factors listed above.

An empirical model for the performance of watering as a control technique has been developed.[8] The supporting data base consists of 14 tests performed in four states during five different summer and fall months. The model is:

$$C = 100 - \frac{0.8\ p\ d\ t}{i} \qquad (3\text{-}2)$$

where: C = average control efficiency, percent

P = potential average hourly daytime evaporation rate, mm/h

d = average hourly daytime traffic rate, (h^{-1})

i = application intensity, L/m^2

t = time between applications, h

Estimates of the potential average hourly daytime evaporation rate may be obtained from

$$p = \begin{array}{l} 0.0049 \times \text{(value in Figure 3-2) for annual conditions} \\ 0.0065 \times \text{(value in Figure 3-2) for summer conditions} \end{array}$$

An alternative approach (which is potentially suitable for a regulatory format) is shown as Figure 3-3. This figure is adapted from 11 field tests conducted at a coal-fired power plant. Measured control efficiencies did not correlate well with either time or vehicle passes after application. However, this is believed due to reduced evening evaporation (logistics delayed the start of testing until 3 p.m. and testing continued through the early evening). Surface moisture grab samples were taken throughout the testing period, and not surprisingly, these show a strong correlation with control efficiency.

Figure 3-3 shows that between the average uncontrolled moisture content and a value of twice that, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. Although

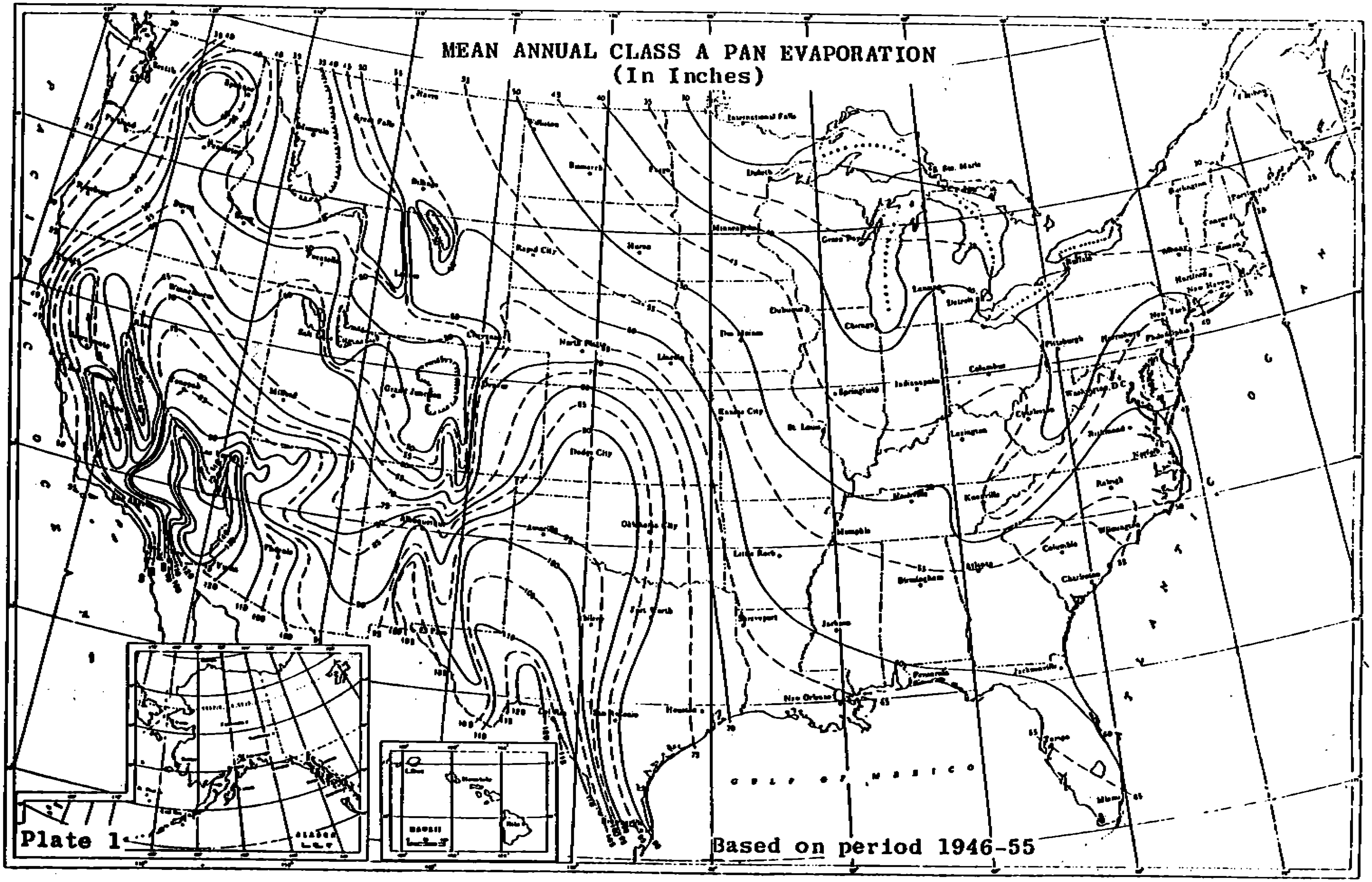

Figure 3-2. Annual evaporation data.[2]

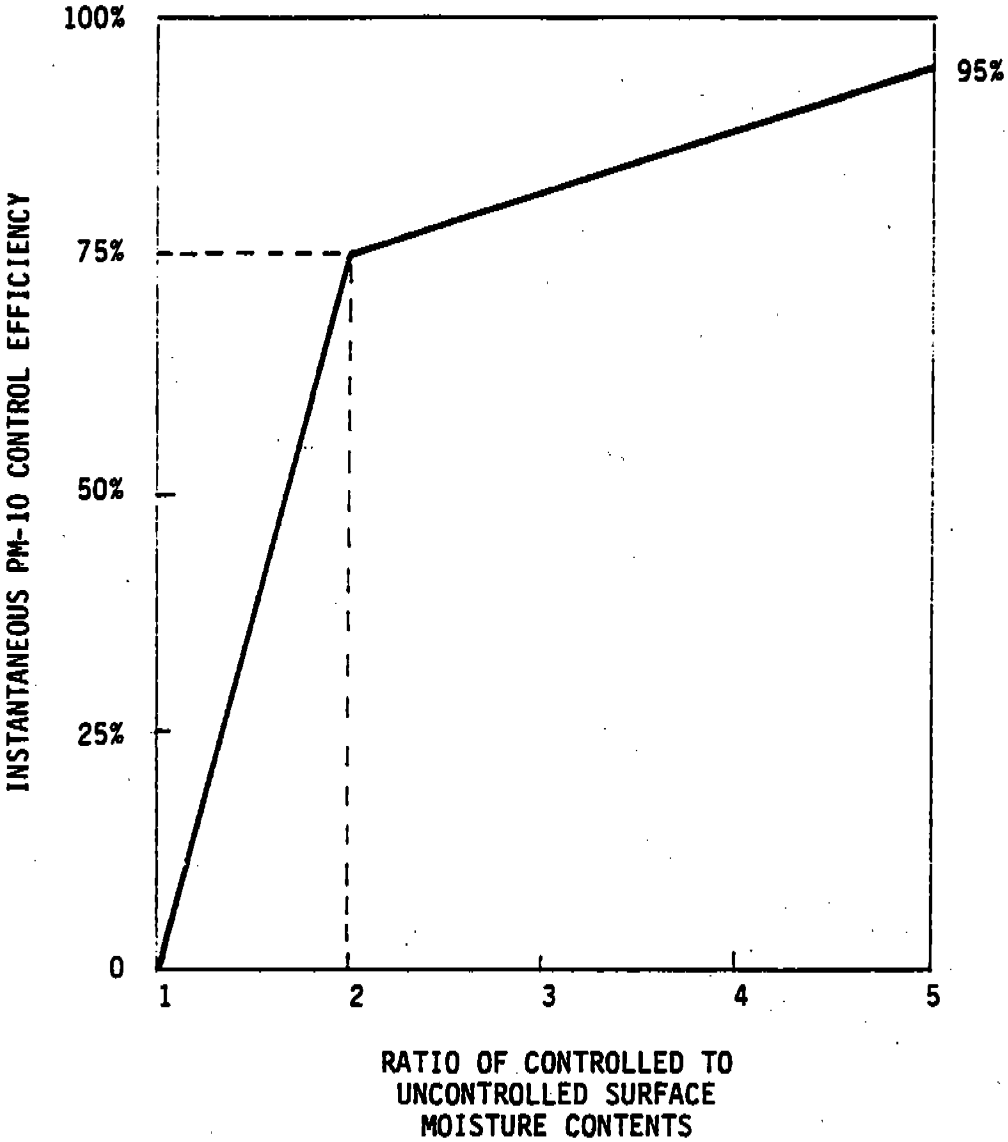

Figure 3-3. Watering control effectiveness for unpaved travel surfaces.

it is possible to fit hyperbolas to the data, the relatively simple bilinear relationship shown in the figure provides an adequate description. Furthermore, this relationship is applicable to all particle size ranges considered:

$$c = \begin{cases} 75\,(M-1) & 1 \leq M \leq 2 \\ 62+6.7M & 2 \leq M \leq 5 \end{cases} \qquad (3\text{-}3)$$

where: c = instantaneous control efficiency, percent

M = ratio of controlled to uncontrolled surface moisture contents

Costs for watering programs include the following elements:

Capital: Purchase of truck or other device

O&M: Fuel, water, truck maintenance, operator labor

Reference 6 estimates the following costs (1985 dollars):

Capital: $17,100/truck

O&M: $32,900/truck

The number of trucks required may be estimated by assuming that a single truck, applying water at 1 L/m^2, can treat roughly one mile of road every hour.

Enforcement of a watering program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular program is in place. (See Appendix C for a suggested recordkeeping format.) The second approach would involve agency spot checks of controlled roads by taking either traffic counts or material grab samples (Appendices D and E) from the road. For example, the moisture or silt content of the traveled portion of the roadway could be measured and compared against a minimum acceptable value. As noted earlier, estimates of the PM_{10} control efficiency could then be obtained from Equations (3-2) and (3-3), respectively.

Records must be kept that document the frequency of water applied to unpaved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency

2. Length of each road and area of each parking lot

3. Amount of water applied to each road/area and planned frequency of application (alternatively, a minimum moisture level could be specified)

4. Any provisions for weather (e.g., ¼ in of rainfall will be substituted for one treatment; program suspended during freezing periods; watering frequency as a function of temperature, cloud cover, etc.)

5. Source of water and tank capacity.

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets)

3. Start and stop times on a particular segment/parking lot, average speed, number of passes

4. Start and stop times for tank filling.

General Records to be Kept

1. Equipment maintenance records

2. Meteorological log (to the extent that weather influences the control program, see above)

3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested in Section 3.4 require that additional records be kept. These records may include surface material samples (following the sampling/analysis procedures given in Appendices D and E) or traffic counts. Traffic counts may be recorded either manually or using automatic devices.

3.3.3.2 Chemical Treatments. As noted in Section 3.2, some chemicals (most notably salts) simulate wet suppression by attracting and retaining moisture on the road surface. These methods are often supplemented by some watering. It is recommended that control efficiency estimates be obtained using Figure 3-3 and enforcement be based on grab sample moisture contents (see Appendices D and E).

The more common chemical dust suppressants form a hard cemented surface. It is this type of suppressant that is considered below.

Besides water, petroleum resins (such as Coherex®) have historically been the products most widely used in the iron and steel industry. However, considerable interest has been shown at both the plant and corporate level in alternative chemical dust suppressants. As a result of this continued interest, several new dust suppressants have been introduced recently. These have included asphalt emulsions, acrylics, and adhesives. In addition, the generic petroleum resin formulations developed at the Mellon Institute with funding from the American Iron and Steel Institute (AISI) have gained considerable attention. These generic suppressants were designed to be produced onsite at iron and steel plants.[9] Onsite production of this type of suppressant in quantities commonly used at iron and steel plants has been estimated to reduce chemical costs by approximately 50 percent.[9]

In an earlier test report, average performance curves were generated for four chemical dust suppressants: (a) a commercially available petroleum resin, (b) a generic petroleum resin for onsite production at an industrial facility, (c) an acrylic cement, and (d) an asphalt emulsion.[10] (Note that at the time of the testing program, these suppressant types accounted for roughly 85 percent of the market share in the iron and steel industry.) The results of this program were combined with other test results to develop a model to estimate <u>time-averaged</u> PM_{10} control performance. This model is illustrated as Figure 3-4. Several items are to be noted:

• The term "ground inventory" is a measure of residual effects from previous applications. Ground inventory is found by adding together the total volume (per unit area) of concentrate (<u>not solution</u>) since the start of the dust control season. An example is provided below.

• Note that no credit for control is assigned until the ground inventory exceeds 0.05 gal/yd^2.

• Because suppressants must be periodically reapplied to unpaved roads, use of the time-averaged values given in the figure are appropriate. Recommended minimum reapplication frequencies (as well as alternatives) are discussed later in this section.

• Figure 3-4 represents an <u>average</u> of the four suppressants given above. The basis of the methodology lies in a similar model for petroleum

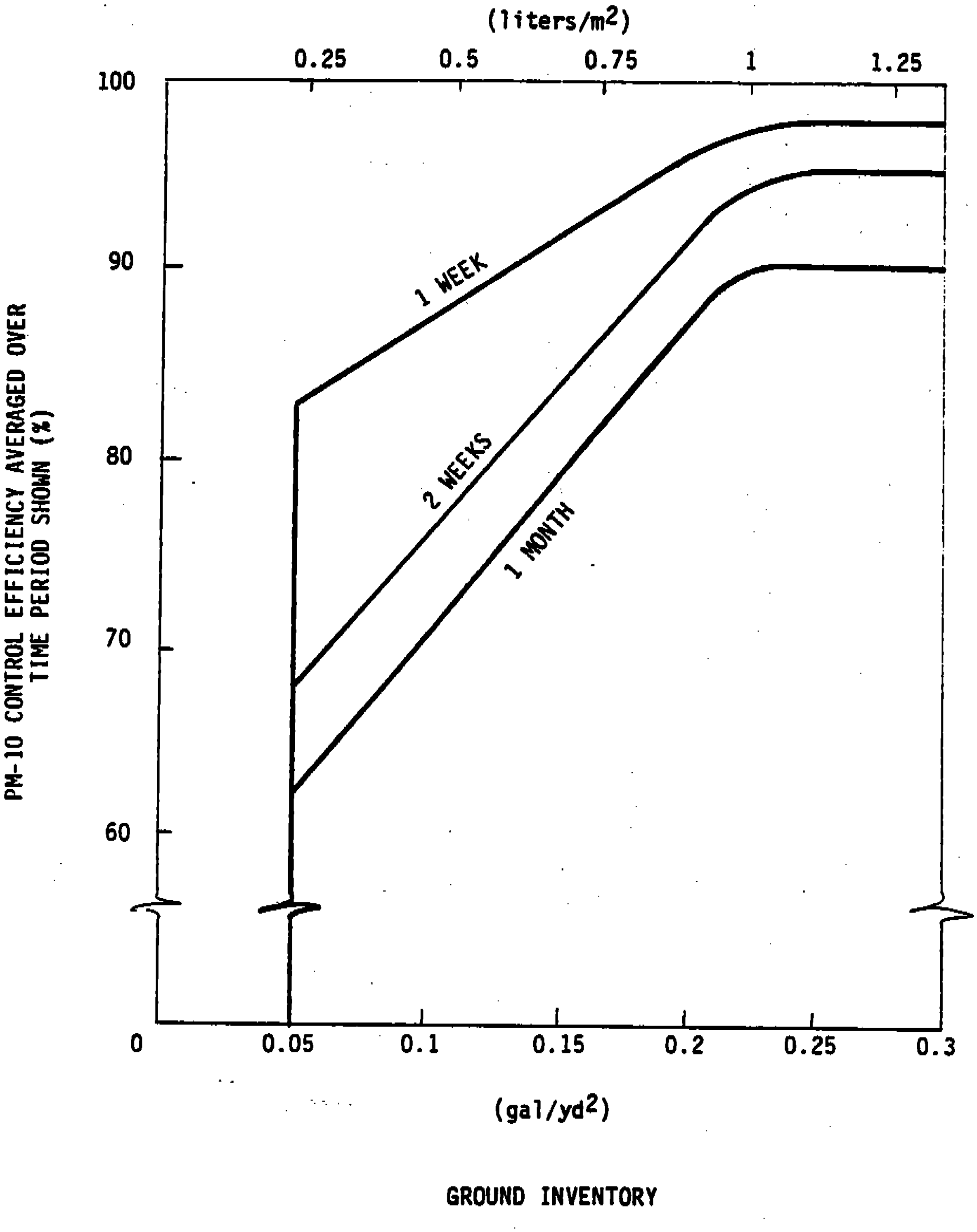

Figure 3-4. Average PM_{10} control efficiency for chemical suppressants.

resins only.[10] However, agreement between the control efficiency estimates given by Figure 3-4 and available field measurements is reasonably good.

As an example of the use of Figure 3-4, suppose that Equation (3-1) has been used to estimate a PM_{10} emission factor of 2.0 kg/VKT. Further, suppose that starting on May 1, the road is treated with 0.25 gal/yd² of a (1 part chemical to 5 parts water) solution on the first of each month until October. In this instance, the following average controlled emission factors are found:

Period	Ground inventory, gal/yd²	Average control efficiency, percent[a]	Average controlled emission factor, kg/VKT
May	0.042	0	2.0
June	0.083	68	0.64
July	0.12	75	0.50
August	0.17	82	0.36
September	0.21	88	0.24

[a]From Figure 3-3; zero efficiency assigned if ground inventory is less than 0.05 gal/yd².

A form which could be used as part of a recordkeeping format is presented in Section 3.4.

In formulating dust control plans for chemical dust suppressants, additional topics must be considered. These are briefly discussed below.

Use of paved road controls on chemically treated unpaved roads. Repeated use of chemical dust suppressants tend, over time, to form fairly impervious surfaces on unpaved roads. The resulting surface may admit the use of paved road cleaning techniques (such as flushing, sweeping, etc.) to reduce aggregate loading due to spillage and track-on. A field program conducted tests on surfaces that had been flushed and vacuumed 3 days earlier.[10] (The surfaces themselves had last been chemically treated 70 days before.) Control efficiency values of 90 percent or more (based on the uncontrolled emission factor of the unpaved roads) were found for each particulate size fraction considered.

The use of paved road techniques for "housekeeping" purposes would appear to have the benefits of both high control (referenced to an uncontrolled unpaved road) and potentially relatively low cost (compared to followup chemical applications). Generally, it is recommended that these methods not be employed until the ground inventory exceeds approximately 0.2 gal/yd² (0.9 L/m²). Plant personnel should, of course, first examine the use of paved road techniques on chemically treated surfaces in limited areas prior to implementing a full-scale program.

Minimum reapplication frequency. Because unpaved roads in industry are often used for the movement of materials and are often surrounded by additional unpaved travel areas, spillage and carryout onto the chemically treated road require periodic "housekeeping" activities. In addition, gradual abrasion of the treated surface by traffic will result in loose material on the surface which should be controlled.

It is recommended that at least dilute reapplications be employed every month to control loose surface material unless paved road control techniques are used (as described above). More frequent reapplications would be required if spillage and track-on pose particular problems for a road.

Weather considerations. Roads generally have higher moisture contents during cooler periods due to decreased evaporation. Small increases in surface moisture may result in large increases in control efficiency (as referenced to the dry summertime conditions inherent in the AP-42 unpaved road predictive equation).[11] In addition, application of chemical dust suppressants during cooler periods of the year may be inadvisable for traffic safety reasons.

Weather-related application schedules should be considered prior to implementing any control program. Responsible parties and regulatory agency personnel should work closely in making this joint determination.

Compared to the other open dust sources discussed in this manual, there is a wealth of cost information available for chemical dust suppressants on unpaved roads. Note that many salt products are delivered and applied by the same truck. For those products, costs are easily obtained by contacting a local distributor.

For other chemicals, identified cost elements include:

Capital: Distributor truck, tanks, pumps, piping

O&M: Chemical suppressants, water, fuel, replacement parts, labor

Many plants contract out application and thus have minimal capital expenditures.

Because each plant faces a unique set of needs, no attempt has been made here to include all possible costs involved in a dust control program. For example, some facilities may be forced to install new storage tanks while others may only need to refurbish unused tanks in the plant. Still others may find it more efficient to retain an outside contractor to store and apply the suppressants. Extensive discussions, comparing rental and capital expenses, have been prepared; one is shown in Appendix B.

In order to provide preliminary estimates of costs associated with chemical dust suppressants, the reader may employ the following average costs:

	Chemical suppressant cost, 1985 $/gal	
	Small lot	Bulk
Salts	0.70[a]	0.46[a]
Other	2.60[b]	1.48[c]

[a]Cost includes delivery and application.
[b]FOB costs for 55-gal drums.
[c]FOB; note that at the time this manual was prepared, bulk costs of suppressants are slightly lower than that stated.

Delivery and contracted application costs may be estimated by increasing bulk costs by 10 and 15 percent, respectively.

At application intensities and dilution ratios common in the iron and steel industry, an adequate estimate of applied unit costs for chemical suppressants is $3,000 per treatment per mile of unpaved road.[10] For treatments at the higher intensities recommended by the chemical supplier, the corresponding unit cost is approximately $5,000 per treatment per mile.[11] Note that in the iron and steel industry, lighter application intensities have been found to be more cost-effective over typical time intervals between treatments.[10]

Enforcement of a chemical dust control program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular program is in place. (See Appendix C for a suggested recordkeeping format.) The second approach would involve agency spot checks of controlled roads by taking a material sample from the road. The latter approach is discussed in Section 3.4. The sampling method should be essentially the same as that used in the development of the current AP-42 predictive equations.

Records must be kept that document the frequency of chemicals applied to unpaved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include the following.

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency
2. Length of each road and area of each parking lot
3. Type of chemical applied to each road/area, dilution ratio, application intensity, and planned frequency of application
4. Provisions for weather.

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment
2. Operator's initials (note that the operator may keep a separate log of whose information is transferred to the environmental staff's data sheets)
3. Start and stop times on a particular segment/parking lot, average speed, number of passes, amount of solution applied
4. Qualitative description of road surface condition.

General Records to be Kept

1. Equipment maintenance records
2. Meteorological log (to the extent that weather influences the control program--see above)
3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats suggested in Section 3.4 require that additional records be kept. These records may include surface material samples (following the sampling/analysis procedures given in Appendices D and E) or traffic counts. Traffic counts may be recorded either manually or using automatic devices.

3.4 EXAMPLE DUST CONTROL PLAN

As an illustration of the use of material given earlier, this section considers an example dust control plan. In this example, it is assumed that a minimum of 75 percent average control is required on an uncontrolled unpaved road. Traffic and meteorological parameters for the road are given below:

Hours of operation:	9 h/day, 250 days/yr
Traffic volume:	25 vehicle passes/h
Average daylight evaporation rate:	0.2 mm/h

3.4.1 Example Water Program

If the above assumptions are substituted, Equation (3-2) may be used to estimate the necessary hourly watering requirements:

$$75 \le 100 - \frac{0.8(0.2)(25)t}{i}$$

or,

$$\frac{i}{t} \ge 0.16 \text{ L/m}^2\text{/h}$$

Thus, any watering program that applies at least 0.16 L/m² of water for every hour between applications would result in an estimated average control of at least 75 percent. Some example programs are presented below.

- 0.48 L/m² (0.11 gal/yd²) every 3 h
- 0.40 L/m² (0.088 gal/yd²) every 2 1/2 h
- 0.72 L/m² (0.16 gal/yd²) every 4 1/2 h

3.4.2 Example Chemical Dust Suppressant Program

Figure 3-3 may be used to design a chemical suppressant program resulting in a minimum of 75 percent average control. The figure indicates that 75 percent average control is achieved over 2 weeks with a ground inventory of 0.41 L/m^2 (0.09 gal/yd^2) and over 1 month with a 0.56 L/m^2 (0.125 gal/yd^2) ground inventory. Thus, any of the following programs would result in a minimum of 75 percent average control:

- 0.45 gal/yd^2 of 4 parts water to 1 part chemical applied with any reapplication every 2 weeks, monthly reapplications after ground inventory is at least 0.125 gal/yd^2
- 0.88 gal/yd^2 of a 6:1 solution applied initially, token reapplications every following month
- 1.0 gal/yd^2 of 10:1 solution applied initially, 0.38 of 10:1 solution 2 weeks later, token reapplications every following 30 days

Note that many other plans meeting the 75 percent minimum could also be formulated.

3.5 POTENTIAL REGULATORY FORMATS

There are numerous regulatory formats possible for unpaved roads. For example, some state rules have been developed using opacity readings to determine compliance. The Tennessee and Ohio visible emission methods are discussed in detail in Appendix C. Michigan and Illinois formulated rules based on opacity, and both resulted in considerable debates of merit.

It is important to note that opacity has yet to be related to emission levels from roads. (As discussed in Appendix C, Indiana has a current program which will attempt to correlate mass emission levels with opacity readings.) One often-raised question deals with prevailing wind speeds during opacity readings; ambient air concentrations (and hence, opacity levels) tend to be greater under lower wind speeds. Consequently, for a road with even a constant emission rate, opacity readings would vary indirectly with wind speed.

Recordkeeping offers another compliance tool for unpaved road dust controls. The level of detail needed varies with the control option employed. Table 3-4 summarizes the level of detail required for the various controls discussed in Section 3.3.

Recordkeeping, together with traffic records as required, will allow the regulator to estimate control performance for a variety of control programs. For example, use of the watering model presented as

TABLE 3-4. RECORDKEEPING REQUIREMENTS FOR UNPAVED ROADS

Control	Level of detail	Comments
Paving	Minimal level, starting date of paving, type, etc.	Additional records required if paved road controls employed (see Section 2.0)
Graveling	Minimal level, starting date of graveling, gravel specifications grading/reapplication dates	Before and after measurements of silt content recommended
Vegetation	See comment	Not generally applicable for traffic sources
Watering	Extensive, covering each day/ time of application, meteorological conditions, amount of water applied, traffic records	Collection of grab samples for moisture recommended
Chemicals (salts)	Fairly extensive, dates of applications and subsequent waterings	Collection of grab samples for moisture recommended
Chemicals	Moderate, dates and operating parameters for each application	Field samples recommended to bound control efficiency (see text)

Equation (3-2), together with traffic, application, and meteorological records, would allow one to estimate average control efficiency. Moreover, use of Figure 3-4, together with the form shown as Figure 3-5, allows estimation of chemical suppressant efficiency between applications. Figure 3-6 shows a completed form corresponding to the example in Section 3.3.3.2.

While recordkeeping affords a convenient method of assessing long-term control performance, it is important that regulatory personnel have "spot-check" compliance tools at their disposal. One such tool was mentioned earlier in connection with Figure 3-3. Rules could be written specifying a minimum surface moisture content (thus, corresponding to a minimum control efficiency) to be maintained on an unpaved surface which is watered or treated with salts. Inspection personnel would then collect grab samples for moisture analysis to determine compliance following the procedures in Appendices D and E.

For chemically (other than salts) controlled surfaces, it has been found that Equation (2-3) tends to overestimate the controlled emission factor (and thus, underestimate instantaneous control efficiency).[10] In this way, an inspector could collect an unpaved sample with a whisk broom and dustpan, and after laboratory analysis for silt content, have a conservatively low estimate of control efficiency due to the chemical treatment. If a rule is written to maintain a certain level of efficiency, the inspector could then instruct the responsible party to reapply the chemical or use paved road controls (if feasible).

WORKSHEET FOR DETERMINING UNPAVED ROAD CONTROL EFFICIENCY

No.	Date	Application Intensity (gal/yd^2)	Dilution Ratio (water:chem)	Ground Inventory (gal/yd^2)	Period (days)	Average PM-10 Control (%)
				DO NOT USE THIS SPACE		

Figure 3-5. Example chemical suppressant application log.

WORKSHEET FOR DETERMINING UNPAVED ROAD CONTROL EFFICIENCY

No.	Date	Application Intensity (gal/yd2)	Dilution Ratio (water:chem)	Ground Inventory (gal/yd2)	Period (days)	Average PM-10 Control (%)
				DO NOT USE THIS SPACE		
1	5/1	0.25	5:1	0.042	31	0
2	6/1	0.25	5:1	0.083	30	68
3	7/1	0.25	5:1	0.125	31	75
4	8/1	0.25	5:1	0.167	31	82
5	9/1	0.25	5:1	0.208	30	88

Figure 3-6. Example completed log.

3.4 REFERENCES FOR SECTION 3

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8. Cowherd, C., Jr., and J. S. Kinsey. 1986. Identification, Assessment and Control of Fugitive Particulate Emissions. EPA-600/8-86-023, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina.

9. Russell, D., and S. C. Caruso. 1984. The Relative Effectiveness of a Dust Suppressant for Use on Unpaved Roads Within the Iron and Steel Industry. Presented at EPA/AISI Symposium on Iron and Steel Pollution Abatement, Cleveland, Ohio. October 1984.

10. Muleski, G. E., and C. Cowherd, Jr. Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads. EPA-600/2-87-102, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. November 1987.

11. Muleski, G. E., T. Cuscino, Jr., and C. Cowherd, Jr. 1984. Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry. EPA-600/2-84-027, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 1984.

4.0 STORAGE PILES

Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. 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, during material loading onto the pile, during disturbances by strong wind currents, and during loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

4.1 ESTIMATION OF EMISSIONS

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Also, emissions depend on three correction parameters that characterize the condition of a particular storage pile: age of the pile, moisture content, proportion of aggregate fines, and friability of the material.

When freshly processed aggregate is loaded onto a storage pile, its potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents from transfer operations or high winds. As the aggregate weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles.

Field investigations have shown that emissions from certain aggregate storage operations vary in direct proportion to the percentage of silt (particles <75 μm in diameter) in the aggregate material.[1-3] The silt content is determined by measuring the proportion of dry aggregate material that passes through a 200-mesh screen, using ASTM-C-136 method. Table 4-1 summarizes measured silt and moisture values for industrial aggregate materials.

Total dust emissions from aggregate storage piles are contributions of several distinct source activities within the storage cycle:

TABLE 4-1. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES

Industry	Material	No. of test samples	Silt, percent Range	Silt, percent Mean	No. of test samples	Moisture, percent Range	Moisture, percent Mean
Iron and steel production[a]	Pellet ore	10	1.4-13	4.9	8	0.64-3.5	2.1
	Lump ore	9	2.8-19	9.5	6	1.6-8.1	5.4
	Coal	7	2-7.7	5	6	2.8-11	4.8
	Slag	3	3-7.3	5.3	3	0.25-2.2	0.92
	Flue dust	2	14-23	18.0	0	NA	NA
	Coke breeze	1		5.4	1		6.4
	Blended ore	1		15.0	1		6.6
	Sinter	1		0.7	0	NA	NA
	Limestone	1		0.4	0	NA	NA
Stone quarrying and processing[b]	Crushed limestone	2	1.3-1.9	1.6	2	0.3-1.1	0.7
Taconite mining and processing[c]	Pellets	9	2.2-5.4	3.4	7	0.05-2.3	0.96
	Tailings	2	NA	11.0	1		0.35
Western surface coal mining[d]	Coal	15	3.4-16	6.2	7	2.8-20	6.9
	Overburden.	15	3.8-15	7.5	0	NA	NA
	Exposed ground	3	5.1-21	15.0	3	0.8-6.4	3.4

[a]References 2 through 5. NA = not applicable.
[b]Reference 1.
[c]Reference 6.
[d]Reference 7.

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 piles.

4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

4.1.1 Materials Handling

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.

The following equation is recommended for estimating emissions from transfer operations (batch or continuous drop):

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

(4-1)

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

where: E = emission factor

k = particle size multiplier (dimensionless)

U = mean wind speed, m/s (mph)

M = material moisture content, percent

The particle size multiplier k varies with aerodynamic particle diameter as shown below:

Aerodynamic Particle Size Multiplier, k

≤30 μm	≤15 μm	≤10 μm	≤5 μm	≤2.5 μm
0.74	0.48	0.35	0.20	0.11

Based on the criteria presented in AP-42, the above equation is rated A.

For emissions from equipment traffic (trucks, front-end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 3-0). 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.

4.1.2 Wind Erosion

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 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 m/s (11 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.

4.1.2.1 Emissions and Correction Parameters. If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7-10 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 aggregate material surfaces. 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 which 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 which has passed by the 1-mi 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 LCD summaries can be obtained from the National Climatic Center, Asheville, North Carolina. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. 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:

$$u(z) = \frac{u^*}{0.4} \ln\left(\frac{z}{z_0}\right) \quad (z > z_0) \tag{4-2}$$

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. These parameters are illustrated in Figure 4-1 for a roughness height of 0.1 cm.

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 which 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.

4.1.2.2 Predictive Emission Factor Equation[8]. The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m²-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \tag{4-3}$$

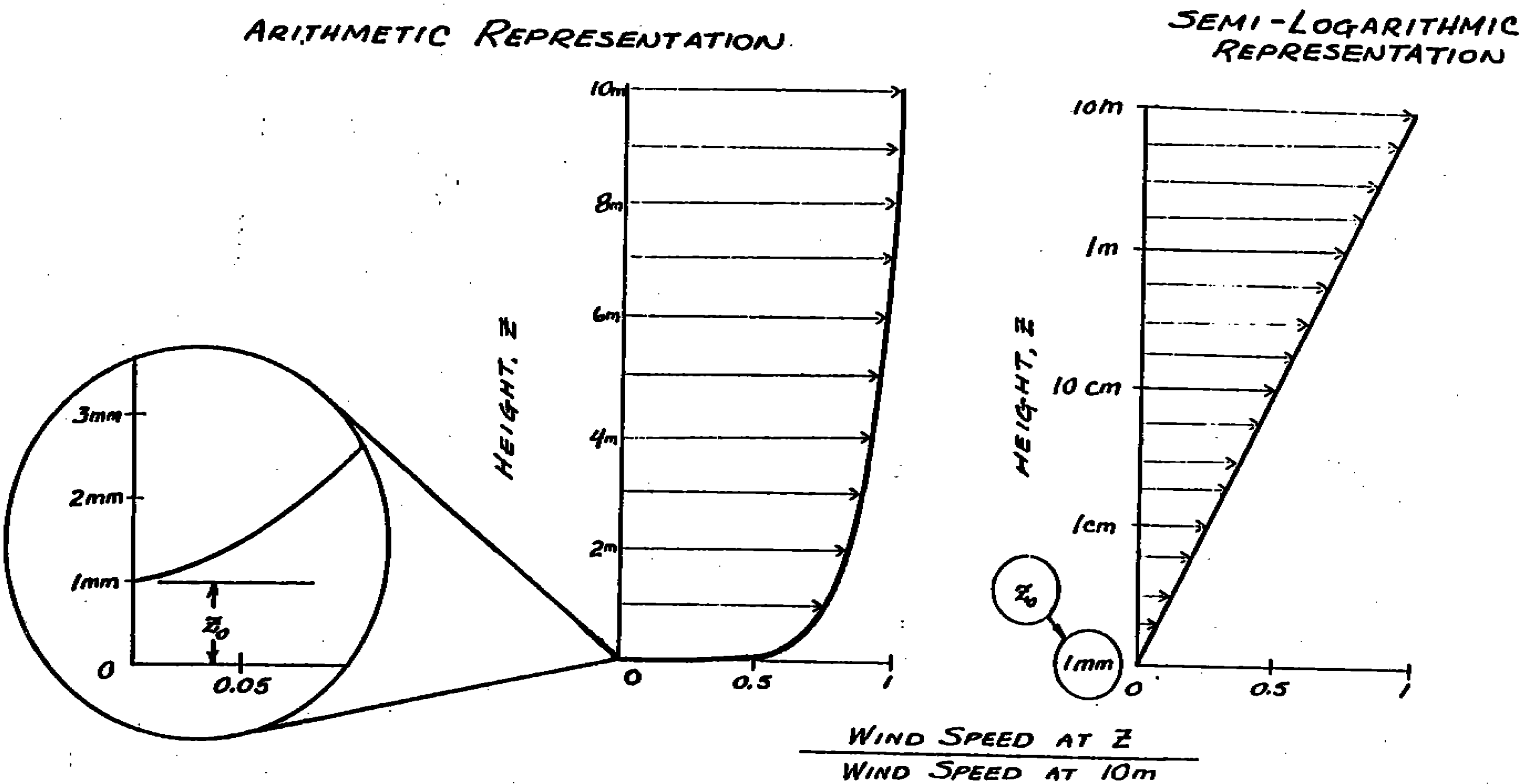


Figure 4-1. Illustration of logarithmic velocity profile.

where: k = particle size multiplier

N = number of disturbances per year

P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

The particle size multiplier (k) for Equation 4-3 varies with aerodynamic particle size, as follows:

AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 4-3

<30 µm	<15 µm	<10 µm	<2.5 µm
1.0	0.6	0.5	0.2

This distribution of particle size within the <30 µm fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see AP-42 Section 11.2.3).

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/yr, and for a surface disturbance once every 6 mo, N = 2/yr.

The erosion potential function for a dry, exposed surface has the following form:

$$P = 58\,(u^* - u_t^*)^2 + 25\,(u^* - u_t^*)$$
$$P = 0 \text{ for } u^* \le u_t^* \qquad (4\text{-}4)$$

where: u^* = friction velocity (m/s)

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

Table 4-2 presents the erosion potential function in matrix form. Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

TABLE 4-2. EROSION POTENTIAL FUNCTION

u_*, m/s		P (g/m^2)											
	u_t^* =	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
0.2		0	0	0	0	0	0	0	0	0	0	0	0
0.4		7	0	0	0	0	0	0	0	0	0	0	0
0.6		19	7	0	0	0	0	0	0	0	0	0	0
0.8		36	19	7	0	0	0	0	0	0	0	0	0
1.0		57	36	19	7	0	0	0	0	0	0	0	0
1.2		83	57	36	19	7	0	0	0	0	0	0	0
1.4		114	83	57	36	19	7	0	0	0	0	0	0
1.6		149	114	83	57	36	19	7	0	0	0	0	0
1.8		188	149	114	83	57	36	19	7	0	0	0	0
2.0		233	188	149	114	83	57	36	19	7	0	0	0
2.2		282	233	188	149	114	83	57	36	19	7	0	0
2.4		336	282	233	188	149	114	83	57	36	19	7	0
2.6		394	336	282	233	188	149	114	83	57	36	19	7
2.8		457	394	336	282	233	188	149	114	83	57	36	19
3.0		525	457	394	336	282	233	188	149	114	83	57	36

Equations 4-3 and 4-4 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 (adapted from a laboratory procedure published by W. S. Chepil[9]) can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure specified in Section 6. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.[10] This conversion is also described in Section 6.

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel.[10-13] These values are presented in Tables 4-3 and 4-4 for industrial aggregates and Arizona sites. Figure 4-2 depicts these data graphically.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.[14] 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 15, and should be corrected to a 10 m reference height using Equation 4-2.

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:

$$u^* = 0.053\, u_{10}^+ \qquad (4\text{-}5)$$

where: u^* = friction velocity (m/s)

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

TABLE 4-3. THRESHOLD FRICTION VELOCITIES--INDUSTRIAL AGGREGATES

Material	Threshold friction velocity, m/s	Roughness height, cm	Threshold wind velocity at 10 m (m/s): z_0 = actual	Threshold wind velocity at 10 m (m/s): z_0 = 0.5 cm	Ref.
Overburden[a]	1.02	0.3	21	19	7
Scoria (roadbed material)[a]	1.33	0.3	27	25	7
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	7
Uncrusted coal pile[a]	1.12	0.3	23	21	7
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	7
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	12

[a]Western surface coal mine.
[b]Lightly crusted.
[c]Eastern power plant.

TABLE 4-4. THRESHOLD FRICTION VELOCITIES--ARIZONA SITES[13]

Location	Threshold friction velocity, m/sec	Roughness height, (cm)	Threshold wind velocity at 10 m, m/sec
Mesa - Agricultural site	0.57	0.0331	16
Glendale - Construction site	0.53	0.0301	15
Maricopa - Agricultural site	0.58	0.1255	14
Yuma - Disturbed desert	0.32	0.0731	8
Yuma - Agricultural site	0.58	0.0224	17
Algodones - Dune flats	0.62	0.0166	18
Yuma - Scrub desert	0.39	0.0163	11
Santa Cruz River, Tucson	0.18	0.0204	5
Tucson - Construction site	0.25	0.0181	7
Ajo - Mine tailings	0.23	0.0176	7
Hayden - Mine tailings	0.17	0.0141	5
Salt River, Mesa	0.22	0.0100	7
Casa Grande - Abandoned agricultural land	0.25	0.0067	8

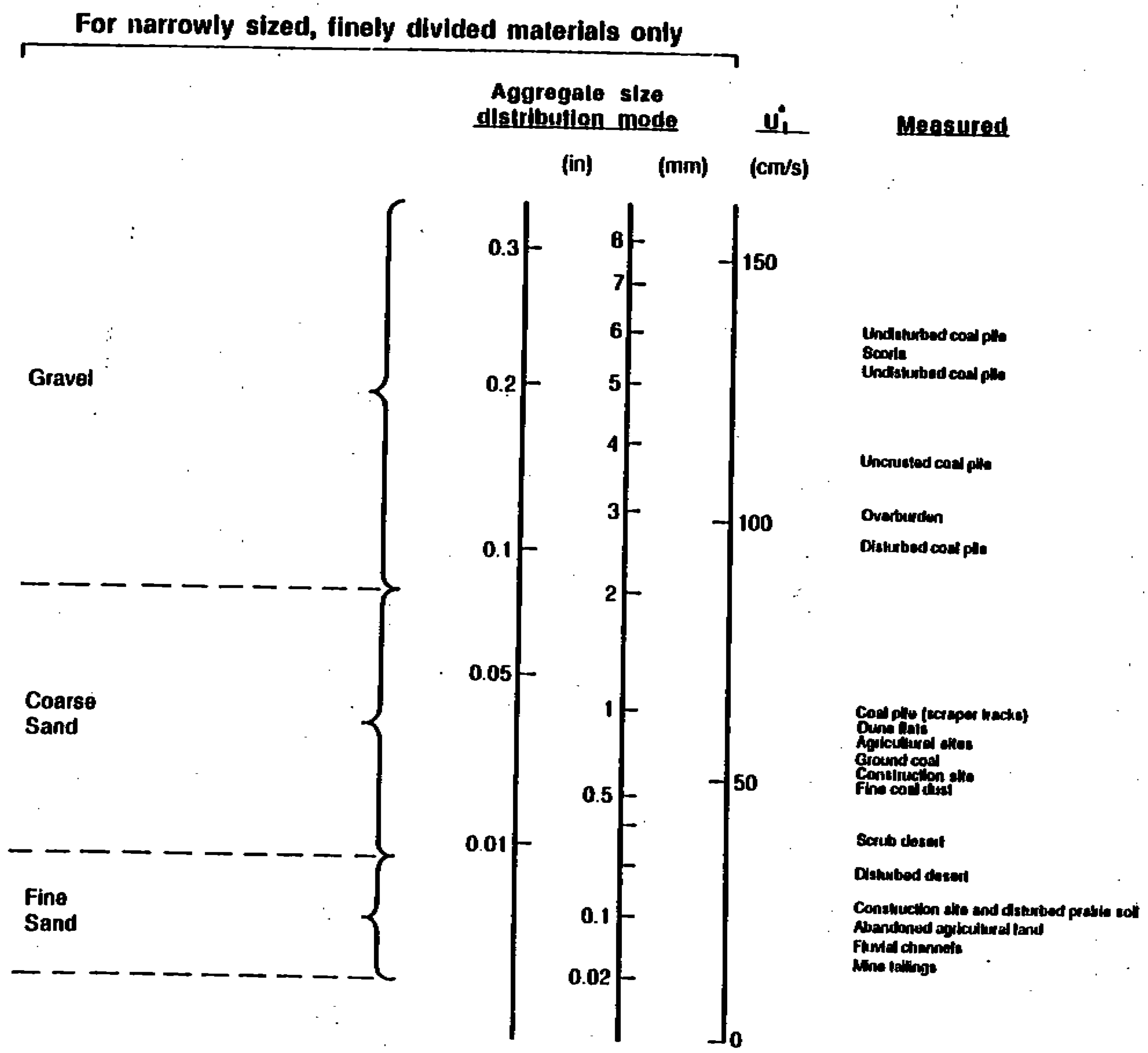


Figure 4-2. Scale of threshold friction velocities.

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4-5 is restricted to large relatively flat piles or 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 flat-top, 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.[11] The results are shown in Figure 4-3 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_0) 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 4-5.

The profiles of u_s/u_r in Figure 4-3 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

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 4-2, as follows:

$$u^+_{10} = u^+ \frac{\ln (10/0.005)}{\ln (z/0.005)} \tag{4-6}$$

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

2. Use the appropriate part of Figure 4-3 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u^+_s), i.e.,

$$u^+_s = \left(\frac{u_s}{u_r}\right) u^+_{10} \tag{4-7}$$

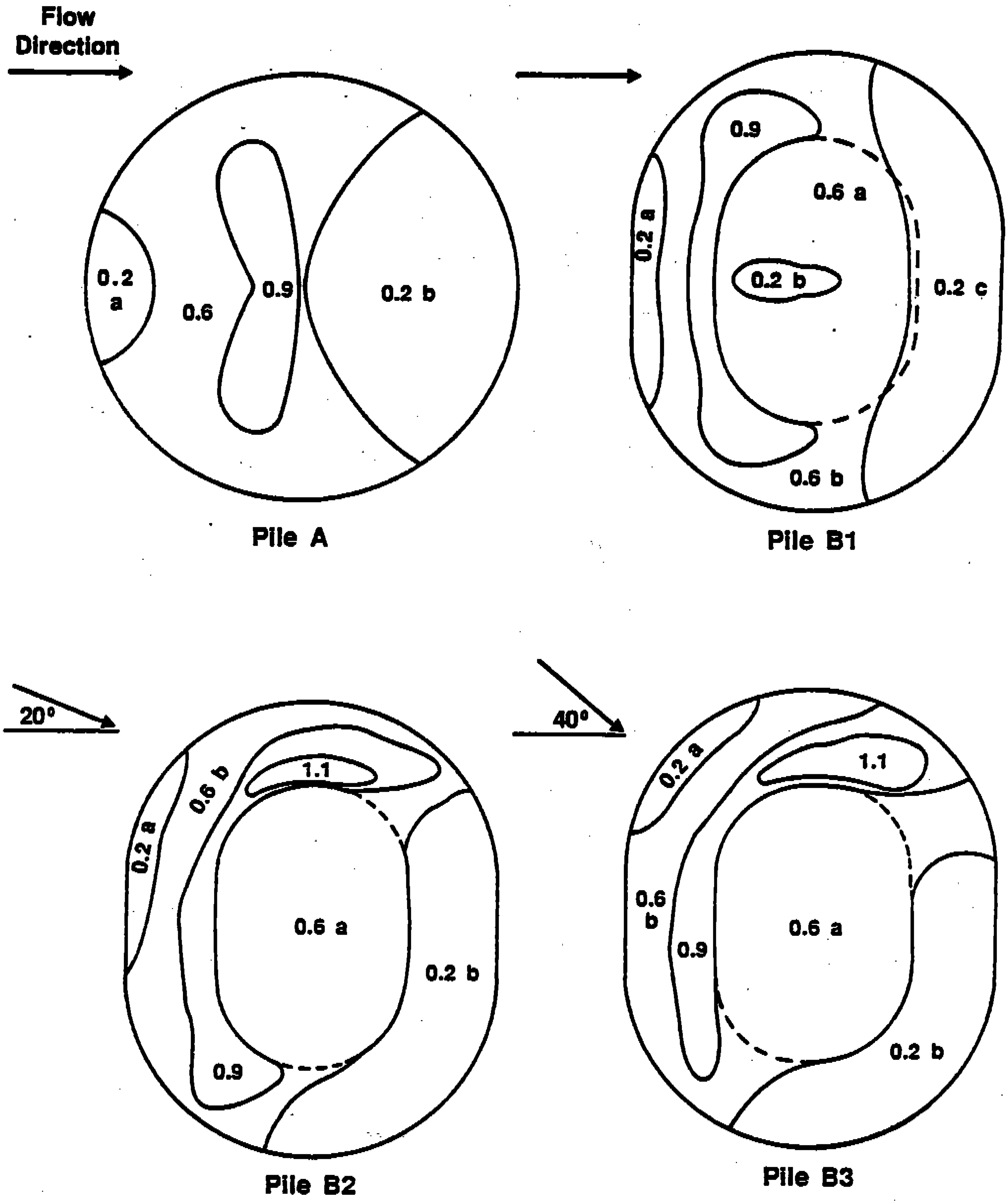


Figure 4-3. Contours of normalized surface wind speeds, u_s/u_r.

TABLE 4-5. SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r

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

3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 4-2 to calculate the equivalent friction velocity (u*), as follows:

$$u^* = \frac{0.4\, u_s^+}{\ln \frac{25}{0.5}} = 0.10\, u_s^+ \qquad (4\text{-}8)$$

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:

1. Determine threshold friction velocity for erodible material of interest (see Tables 4-3 and 4-4 or Figure 4-2 or determine from mode of aggregate size distribution).

2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).

3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u_{10}^+) using Equation 4-6.

4. Convert fastest mile values (u_{10}^+) to equivalent friction velocities (u*), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4-5, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 4-7 and 4-8.

5. 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 4-3 and Table 4-5) and determine the size of each subarea.

6. 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 4-4 and the emission factor using Equation 4-3.

7. 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-h emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single wind 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 min, 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 which offset this apparent conservatism:

1. The fastest mile event contains peak winds which 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 which contain peak gusts of the same order as the fastest mile wind speed.

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

4.1.3 Wind Emissions From Continuously Active Piles

For emissions from wind erosion of active storage piles, the following total suspended particulate (TSP) emission factor equation is recommended:

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

$$E = 1.7 \left(\frac{s}{1.5}\right) \left(\frac{365-p}{235}\right) \left(\frac{f}{15}\right) \text{ (lb/d/acre)} \qquad (4\text{-}9)$$

where: E = total suspended particulate emission factor

s = silt content of aggregate, percent

p = number of days with $\geq$0.25 mm (0.01 in.) of precipitation per year

f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s (12 mph) at the mean pile height

The fraction of TSP which is PM_{10} is estimated at 0.5 and is consistent with the PM_{10}/TSP ratios for materials handling (Section 4.1.1) and wind erosion (Section 4.1.2). The coefficient in Equation (4-9) is taken from Reference 1, based on sampling of emissions from a sand and gravel storage pile area during periods when transfer and maintenance equipment was not operating. The factor from Reference 1, expressed in mass per unit area per day, is more reliable than the factor expressed in mass per unit mass of material placed in storage, for reasons stated in that report. Note that the coefficient has been halved to adjust for the estimate that the wind speed through the emission layer at the test site was one half of the value measured above the top of the piles. The other terms in this equation were added to correct for silt, precipitation, and frequency of high winds, as discussed in Reference 2. Equation (4-9) is rated in AP-42 as C for application in the sand and gravel industry and D for other industries (see Appendix A).

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling (batch and continuous drop) operations may be calculated by substituting into Equation (4-9) appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 h. The treatment of dry conditions for vehicle traffic (Section 3.0) and for wind erosion (Equation 4-9), centering around parameter p, follows the methodology described in Section 3.0. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

4.2 DEMONSTRATED CONTROL TECHNIQUES

The control techniques applicable to storage piles fall into distinct categories as related to materials handling operations (including traffic around piles) and wind erosion. In both cases, the control can be achieved by (a) source extent reduction, (b) source improvement related to work practices and transfer equipment (load-in and load-out operations), and (c) surface treatment. These control options are summarized in Table 4-6. The efficiency of these controls ties back to the emission factor relationships presented earlier in this section.

In most cases, good work practices which confine freshly exposed material provide substantial opportunities for emission reduction without the need for investment in a control application program. For example, pile activity, loading and unloading, can be confined to leeward (downwind) side of the pile. This statement also applies to areas around

TABLE 4-6. CONTROL TECHNIQUES FOR STORAGE PILES

Material handling	
Source extent reduction	Mass transfer reduction
Source improvement	Drop height reduction Wind sheltering Moisture retention
Surface treatment	Wet suppression
Wind erosion	
Source extent reduction	Disturbed area reduction Disturbance frequency reduction Spillage cleanup
Source improvement	Spillage reduction Disturbed area wind exposure reduction
Surface treatment	Wet suppression Chemical stabilization

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 vehicle tracking 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.

The evaluation of preventative methods which change the properties or exposure of transfer streams or surface material are discussed in the following section.

4.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

Preventive methods for control of windblown emissions from raw material storage piles include chemical stabilization, enclosures, and wetting. Physical stabilization by covering the exposed surface with less erodible aggregate material and/or vegetative stabilization are seldom practical control methods for raw material storage piles.

To test the effectiveness of chemical stabilization controls for wind erosion of storage piles and tailings piles, wind tunnel measurements have been performed. Although most of this work has been carried out in laboratory wind tunnels, portable wind tunnels have been used in the field on storage piles and tailings piles.[16,17] Laboratory wind tunnels have also been used with physical models to measure the effectiveness of wind screens in reducing surface wind velocity.[11]

4.3.1 Chemical Stabilization

A portable wind tunnel has been used to measure the control of coal pile wind erosion emissions by a 17 percent solution of Coherex® in water applied at an intensity of 3.4 L/m^2 (0.74 gal/yard^2), and a 2.8 percent solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 6.8 L/m^2 (1.5 gal/yard^2).[16] The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 days before the test, under a wind of 15.0 m/s (33.8 mph) at 15.2 cm (6 in.) above the ground, was 89.6 percent for TP and approximately 62 percent for IP and FP. The control efficiency of the latex binder on a low volatility coking coal is shown in Figure 4-4.

Cost elements for chemical stabilization are presented in Table 4-7. The cost of a system for application of surface crusting chemicals to storage piles is $18,400 for the initial capital cost and $0.006 to $0.011/ft^2 for annual operating expenses based on April 1985 dollars.[18] Tables 4-8 and 4-9 provide recordkeeping forms for application of chemical dust suppressants.

4.3.2 Enclosures

Enclosures are an effective means by which to control fugitive particulate emissions from open dust sources. Enclosures can either fully or partially enclose the source. Included in the category of partial enclosures are porous wind screens or barriers. This particular type of enclosure is discussed in detail below.

With the exception of wind fences/barriers, a review of available literature reveals no quantitative information on the effectiveness of enclosures to control fugitive dust emissions from open sources. Types of passive enclosures traditionally used for open dust control include three-sided bunkers for the storage of bulk materials, storage silos for various types of aggregate material (in lieu of open piles), open-ended buildings, and similar structures. Practically any means that reduces wind entrainment of particles produced either through erosion of a dust-producing surface (e.g., storage silos) or by dispersion of a dust plume generated directly by a source (e.g., front-end loader in a three-sided enclosure) is generally effective in controlling fugitive particulate emissions. However, available data are not sufficient to quantify emission reductions.

Partial enclosures used for reducing windblown dust from large exposed areas and storage piles include porous wind fences and similar types of physical barriers (e.g., trees). The principle of the wind fence/barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier. The control efficiency of wind fences is dependent on the physical dimensions of the fence relative to the source being

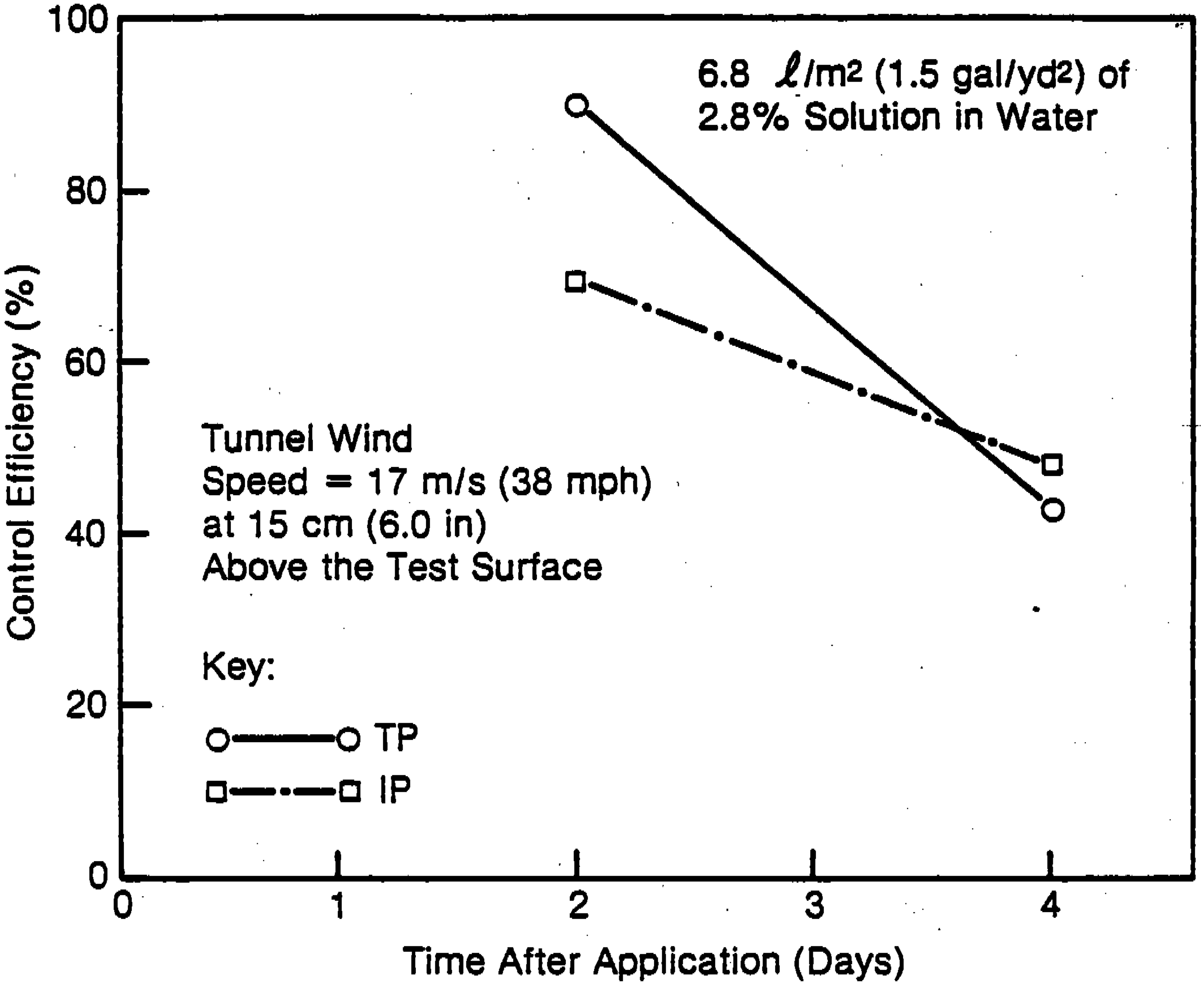


Figure 4-4. Decay in control efficiency of latex binder applied to coal storage piles.[15]

TABLE 4-7. CAPITAL AND O&M ITEMS FOR CHEMICAL STABILIZATION OF OPEN AREA SOURCES

Capital equipment

- Storage equipment
  - Tanks
  - Railcars
  - Pumps
  - Piping

- Application equipment
  - Trucks
  - Spray system
  - Piping (including winterizing)

O&M expenditures

- Utility or fuel costs
  - Water
  - Electricity
  - Gasoline or diesel fuel

- Supplies
  - Chemicals
  - Repair parts

- Labor
  - Application time
  - Road conditioning
  - System maintenance

TABLE 4-8. TYPICAL FORM FOR RECORDING CHEMICAL DUST SUPPRESSANT CONTROL PARAMETERS

Date	Time	Type of chemical	Dilution ratio	Application intensity, gal/yd^2	Area(s) treated	Equipment used	Operator initials	Comments

TABLE 4-9. TYPICAL FORM FOR RECORDING DELIVERY OF CHEMICAL DUST SUPPRESSANTS

Date	Time	Chemical delivered	Quantity delivered	Delivery agent	Facility destination[a]	Comments

[a]Denote whether suppressant will be applied immediately upon receipt or placed in storage.

controlled. In general, a porosity (i.e., percent open area) of 50 percent seems to be optimum for most applications. Wind fences/barriers can either be man-made structures or vegetative in nature.

A number of studies have attempted to determine the effectiveness of wind fences/barriers for the control of windblown dust under field conditions. Several of these studies have shown both a significant decrease in wind velocity as well as an increase in sand dune growth on the lee side of the fence.[19-22]

Various problems have been noted with the sampling methodology used in each of the field studies conducted to date. These problems tend to limit an accurate assessment of the overall degree of control achievable by wind fences/barriers for large open sources. Most of this work has either not thoroughly characterized the velocity profile behind the fence/barrier or adequately assessed the particle flux from the exposed surface.

A 1988 laboratory wind tunnel study of windbreak effectiveness for coal storage piles showed area-averaged wind speed reductions of ~50 to 70 percent for a 50 percent porosity windbreak with height equal to the pile height and length equal to the pile base. The windbreak was located three pile heights upwind from the base of the pile. This study also suggested "that fugitive dust emissions on the top of the pile may be controlled locally through the use of a windbreak at the top of the pile."

Based on the 1.3 power given in Equation (4-1), reductions of ~50 to 70 percent would correspond to ~60 to 80 percent control of material handling PM_{10} emissions. Estimation of wind erosion control requires source-specific evaluation because of the interrelation of u_t^* and u^* (for both controlled and uncontrolled conditions) in Equation (4-14).

This same laboratory study showed that a storage pile may itself serve as a wind break by reducing wind speed on the leeward face (Figure 4-3). The degree of wind sheltering and associated wind erosion emission reduction is dependent on the shape of the pile and on the approach angle of the wind to an elongated pile.

One of the real advantages of wind fences for the control of PM_{10} involves the low capital and operating costs.[21,23] These involve the following basic elements:

- Capital equipment:
  - -- Fence material and supports
  - -- Mounting hardware
- Operating and maintenance expenditures:
  - -- Replacement fence material and hardware
  - -- Maintenance labor

The following cost estimates (in 1980 dollars) were developed for wind screens applied to aggregate storage piles:[24]

- Artificial wind guards:
  - -- Initial capital cost = $12,000 to $61,000
- Vegetative wind breaks
  - -- Initial capital costs = $45 to $425 per tree

Due to the lack of quantitative data on costs associated with wind screens, it is recommended that local vendors be contacted to obtain more detailed data for capital and operating expenses. Also, since wind fences and screens are relatively "low tech" controls, it may be possible for the site operator to construct the necessary equipment using site personnel with less expense.

As with other options mentioned above, the main regulatory approach involved with wind fences and screens would involve recordkeeping by the site operator. Parameters to be specified in the dust control plan and routinely recorded are:

General Information to be Specified in Plan

1. Locations of all materials storage and handling operations to be controlled with wind fences referenced on a plot plan available to the site operator and regulatory personnel

2. Physical dimensions of each source to be controlled and configuration of each fence or screen to be installed

3. Physical characteristics of material to be handled or stored for each operation to be controlled by fence(s) or screen(s)

4. Applicable prevailing meteorological data (e.g., wind speed and direction) for site on an annual basis

Specific Operational Records

1. Date of installation of wind fence or screen and initials of installer

2. Location of installation relative to source and prevailing winds

3. Type of material being handled and stored and physical dimensions of source controlled

4. Date of removal of wind fence or screen and initials of personnel involved

General Records to be Kept

1. Fence or screen maintenance record

2. Log of meteorological conditions for each day of site operation

4.3.3 Wet Suppression Systems

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. This section addresses two types of wet suppression systems--liquid sprays which use water or water/surfactant mixtures as the wetting agent and systems which 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. For systems using water only, addition of surfactant can reduce the quantity of water necessary to achieve a good control by a ratio of 4:1 or more.[25,26]

The design specifications for wet suppression systems are generally based on the experience of the design engineer rather than on established design equations or handbook calculations. Some general design guidelines that have been reported in the literature as successful are listed below:

1. A variety of nozzle types have been used on wet suppression systems, but recent data suggest that hollow cone nozzles produce the greatest control while minimizing clogging.[27]

2. Optimal droplet size for surface impaction and fine particle agglomeration is about 500 µm; finer droplets are affected by drift and surface tension and appear to be less effective.[28]

3. Application of water sprays to the underside of a conveyor belt improves the performance of wet suppression systems at belt-to-belt transfer points.[29]

Micron-sized foam application is an alternative to water spray systems. The primary advantage of foam systems is that they provide equivalent control at lower moisture addition rates than spray systems.[29] However, the foam system is more costly and requires the use of extra materials and equipment. The foam system also achieves control primarily through the wetting and agglomeration of fine particles. The following guidelines to achieve good particle agglomeration have been suggested:[30]

1. The foam can be made to contact the particulate material by any means. High velocity impact or other brute force means are not required.

2. The foam should be distributed throughout the product material. Inject the foam into free-falling material rather than cover the product with foam.

3. The amount applied should allow all of the foam to dissipate. The presence of foam with the product indicates that either too much foam has been used or it has not been adequately dispersed within the material.

Available data for both water spray and foam wet suppression systems are presented in Tables 4-10 and 4-11, respectively. The data primarily included estimates of control efficiency based on concentrations of total particulate or respirable dust in the workplace atmosphere. Some data on mass emissions reduction are also presented. The data should be viewed with caution in that test data ratings are generally low and only minimal data on process or control system parameters are presented.

The data in Tables 4-10 and 4-11 do indicate that a wide range of efficiencies can be obtained from wet suppression systems. For conveyor transfer stations, liquid spray systems had efficiencies ranging from 42 to 75 percent, while foam systems had efficiencies ranging from 0 to

TABLE 4-10 SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WATER SPRAYS

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency, percent[c]
25	Chain feeder to belt transfer	Coal	3 ft drop, 8 tons coal per load	8 sprays, 2.5 gal/min, above belt only	Personnel samplers, Type 1 test scheme	10	C	RP 56 TP 59
				8 sprays, 2.5 gal/min and one one spray on underside of belt	Personnel samplers, Type 1 test scheme	4	C	RP 81 TP 87
	Belt-to-belt transfer	Coal	Not specified	8 sprays, 2.5 gal/min above belt only[d]	Personnel samplers, Type 1 test scheme	10	C	RP 53
				8 sprays, 2.5 gal/min and one one spray on underside of belt[d]	Personnel samplers, Type 1 test scheme	4	C	RP 42
27	Grizzly transfer to the bucket elevator	Run of mill sand	Not specified	Liquid volume 757 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 46
				Liquid volume 1,324 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 58
				Liquid volume 1,324 mL[e]	Personnel samplers, Type 1 test scheme	NA	C	RP 54
				Liquid volume 1,324 mL[f]	Personnel samplers, Type 1 test scheme	NA	C	RP 54
28	Conveyor transport and transfer	Coal	2 belts 0.91 m and 1.07 m widths, ~500 m length	3 spray bars/belt, underside of tail pulley, 5-10 cc H_2O/s per bar, Delevan "Fanjet" sprays	Personnel samplers, Type 1 test scheme[g]	NA	D	RP-65-75

[a] RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.
[b] Test rating scheme defined in Section 4.4.
[c] TP = Total particulate; RP = respirable particulate.
[d] Control applied at a point five transfers upstream.
[e] Water+1.5 percent surfactant.
[f] Water+2.5 percent surfactant.
[g] Individual test values not specified; no airflow data or QA/QC data.

TABLE 4-11. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR FOAM SUPPRESSION SYSTEMS

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control efficiency, percent[c]
27	Belt-to-belt transfer	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 20[d]
	Belt-to-bin transfer	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 33[d]
	Bulk loadout	30-mesh glass sand	Sand temp. ~120°F	Not specified	Personnel samplers, Type 1 test scheme	NA	C	RP 65[d]
	Screw-to-belt transfer	Cleaned run-of-mine sand	174 tons/h, sand temp. ~190°F	Moisture = 0.25 percent	Grav/RAM samplers, Type 1 scheme	4	C	RP 10[d]
	Bucket elevator discharge	Cleaned run-of-mind sand	179 tons/h, sand temp. ~190°F	Moisutre = 0.18 percent	RAM/personnel samplers, Type 1 test scheme	5	C	RP 8[d]
	Belt-to-belt transfer	Cleaned run-of-mine sand	193 tons/h, sand temp. ~190°F	Moisture = 0.18 percent	RAM/personnel samplers, Type 1 test scheme	8	C	RP 7[d]
	Feeder bar discharge	Cleaned run-of-mine sand	191 tons/h, sand temp. ~190°F	Moisutre = 0.19 percent	RAM/personnel samplers, Type 1 test scheme	6	C	RP 2[d]
	Grizzley transfer to bucket elevator	Dried run of mine sand	Not specified	Foam rate = 10.5 ft^3/ton sand Liquid rate = 0.38 gal/min	Personnel samplers, Type 1 test scheme	2	C	RP 92
				Foam rate = 8.2 ft^3/ton sand Liquid rate = 0.34 gal/min	Personnel samplers, Type 1 test scheme	1	C	RP 74
				Foam rate = 7.5 ft^3/ton sand Liquid rate = 0.20 gal/min	Personnel samplers, Type 1 test scheme	1	C	RP 68
25	Chain feeder to belt transfer	Coal	3-ft drop, 8 tons coal per load	50 psi H_2O, 2.5 percent reagent[f], four nozzles 15 to 20 ft^3 foam applied[d]	Personnel samplers, Type 1 test scheme	9	C	RP 96 TP 92
	Belt-to-belt transfer	Coal	Not specified	50 psi H_2O, 2.5 percent reagent[f], four nozzles 15 to 20 ft^3 foam applied[e]				RP 71

(continued)

TABLE 4-11. (continued)

Ref. No.	Type of process	Type of material	Process design/ operating parameters	Control system parameters	Measurement technique[a]	No. of tests	Test data rating[b]	Control effi- ciency, percent[c]
27	Grizzley	Dried run-of-mine sand	Not specified	Foam rate = 4.8 ft^3/ton sand Liquid rate = 0.18 gal/min	Personnel samplers, Type 1 test scheme	2	C	RP 0
				Foam rate = 2.6 ft^3/ton sand Liquid rate = 0.13 gal/min	Personnel samplers, Type 1 test scheme	NA	C	RP 0
				Liquid volume 1,420 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 91
				Liquid volume 1,330 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 73
				Liquid volume 764 mL	Personnel samplers, Type 1 test scheme	NA	C	RP 68

[a]RAM samples are from Realtime Aerosol Monitors, light scattering type instruments. Type 1 tests include measurements of a single source with and without control.
[b]Test rating scheme defined in Section 4.4.
[c]RP = respirable particulate.
[d]Efficiency based on concentrations only.

92 percent. The data are not sufficient to develop relationships between control or process parameters and control efficiencies. However, the following observations relative to the data in Tables 4-10 and 4-11 are noteworthy:

1. The quantity of foam applied to a system does have an impact on system performance. On grizzly transfer points, foam rates of 7.5 ft^3 to 10.5 ft^3 of foam per ton of sand produced increasing control efficiencies ranging from 68 to 98 percent.[31] Foam rates below 5 ft^3 per ton produced no measurable control.

2. Material temperature has an impact on foam performance. At one plant where sand was being transferred, control efficiencies ranged from 20 to 65 percent when 120°F sand was handled. When sand temperature was increased to 190°F, all control efficiencies were below 10 percent.[31]

3. Data at one plant suggest that underside belt sprays increase control efficiencies for respirable dust (56 to 81 percent).[29]

4. When spray systems and foam systems are used to apply equivalent moisture concentrations, foam systems appear to provide greater control.[31] On a grizzly feed to a crusher, equivalent foam and spray applications provided 68 percent and 46 percent control efficiency, respectively. Capital and O&M cost elements for wet suppression are shown in Table 4-12.

In estimating the wind erosion control effectiveness of wet suppression, it can be assumed that emissions are inversely proportional to the square of the surface moisture content. The emission/moisture dependence is embedded in the agricultural wind erosion equation as described in Section 7. It also appears in the observed relationship between the role of emissions from an unpaved road and the surface moisture content, as illustrated in Figure 3-3.

In addition, a relationship between surface moisture content and daily moisture addition has been developed from field studies of storage piles exposed to natural precipitation. The results of that research are illustrated in the example problem to be presented at the end of this section.

Costs associated with wet suppression systems include the following basic elements:

TABLE 4-12. WET SUPPRESSION SYSTEM CAPITAL AND O&M COST ELEMENTS

Capital equipment

- Water spray system
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units
- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity
- Supplies
  - Surfactant
  - Screens
- Labor
  - Maintenance
  - Operation

- Capital equipment:
  - -- Spray nozzles or other distribution equipment
  - -- Supply pumps and plumbing (plus weatherization)
  - -- Water filters and flow control equipment
  - -- Tanker truck (if used)
- Operating and maintenance expenditures:
  - -- Water and chemicals
  - -- Replacement parts for nozzles, truck, etc.
  - -- Operating labor
  - -- Maintenance labor

Reference 6 estimates the following costs (in 1985 dollars):

- Regular watering of storage piles:
  - -- Initial capital cost = $18,400 per system
- Watering of exposed areas:
  - -- Initial capital cost = $1,053 per acre
  - -- Annual operating cost = $25 to 67 per acre

The costs associated with a stationary wet suppression system using chemical surfactants for the unloading of limestone from trucks at aggregate processing plants (in 1980 dollars) have been estimated at: capital = $72,000; annual = $26,000. Typical costs for wet suppression of materials transfer operations are listed in Table 4-13.

As with watering of unpaved surfaces, enforcement of a wet suppression control program would consist of two complementary approaches. The first would be record keeping to document that the program is being implemented and the other would be spot-checks and grab sampling. Both were discussed previously above.

Records must be kept that document the control plan and its implementation. Pertinent parameters to be specified in a plan and to be regularly recorded include:

<u>General Information to be Specified in Plan</u>

1. Locations of all materials storage and handling operations referenced on plot plan of the site available to the site operator and regulatory personnel

2. Materials delivery or transport flow sheet which indicates the type of material, its handling and storage, size and composition of storage piles, etc.

TABLE 4-13. TYPICAL COSTS FOR WET SUPPRESSION OF MATERIAL TRANSFER POINTS

Source method	Initial cost, April 1985 dollars[b]	Unit operating cost, April 1985 dollars[b]
Railcar unloading station (foam spray)	48,700	NR
Railcar unloading station (charged fog)	168,000	NR
Conveyor transfer point (foam spray)	23,700	0.02 to 0.05/ton material treated
Conveyor transfer point (charged fog)	19,800	NR

[a]Reference 18. NR = not reported.
[b]January 1980 costs updated to April 1985 cost by Chemical Engineering Index. Factor = 1.315.
[c]Based on use of 16 large devices at $10,500 each.
[d]Based on use of three small devices at $6,600 each.

3. The method and application intensity of water, etc., to be applied to the various materials and frequency of application, if not continuous

4. Dilution ratio for chemicals added to water supply, if any

5. Complete specifications of equipment used to handle the various materials and for wet suppression

6. Source of water and chemical(s), if used

Specific Operational Records

1. Date of operation and operator's initials

2. Start and stop time of wet suppression equipment

3. Location of wet suppression equipment

4. Type of material being handled and number of loads (or other measure of throughput) loaded/unloaded between start and stop time (if material is being pushed, estimate the volume or weight)

5. Start and stop times for tank filling

General Records to be Kept

1. Equipment maintenance records

2. Meteorological log of general conditions

3. Records of equipment malfunctions and downtime

4.4 EXAMPLE DUST CONTROL PLAN--WATERING OF COAL STORAGE PILE

Description of Source

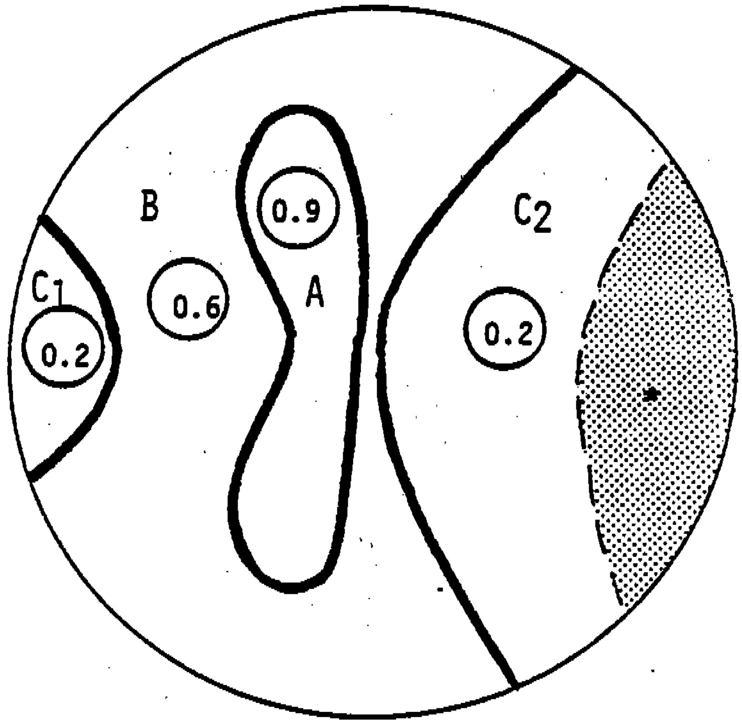
- Conically shaped pile (uncrusted coal)
- Pile height of 11 m; 29.2 m base diameter; 838 m^2 surface area
- Daily reclaiming of downwind face of pile; pile replenishment every 3 d affects entire pile surface (Figure 4-5)
- LCD as shown in Figure 4-6 for a typical month
- Coal surface moisture content of 1.5 percent

Calculation of Uncontrolled Emissions

Step 1: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 m/s is obtained from Table 4-3.

Step 2: Except for a small area near the base of the pile (see Figure 4-5), the entire pile surface is disturbed every 3 d, corresponding to a value of N = 120/yr. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Prevailing
Wind
Direction



Circled values refer to u_s/u_r

* A portion of C_2 is disturbed daily by reclaiming activities.

Area ID	$\frac{u_s}{u_r}$	Pile Surface %	Pile Surface Area (m^2)
A	0.9	12	101
B	0.6	48	402
$C_1 + C_2$	0.2	40	335
			838

Figure 4-5. Example 1: Pile surface areas within each wind speed regime.

Local Climatological Data

MONTHLY SUMMARY

WIND					
			FASTEST MILE		
RESULTANT DIR.	RESULTANT SPEED M.P.H.	AVERAGE SPEED M.P.H.	SPEED M.P.H.	DIRECTION	DATE
13	14	15	16	17	22
30	5.3	6.9	9	36	1
01	10.5	10.6	14	01	2
10	2.4	6.0	10	02	3
13	11.0	11.4	16	13	4
12	11.3	11.9	15	11	5
20	11.1	19.0	29	30	6
29	19.6	19.8	30	30	7
29	10.9	11.2	17	30	8
22	3.0	8.1	15	13	9
14	14.6	15.1	23	12	10
29	22.3	23.3	31	29	11
17	7.9	13.5	23	17	12
21	7.7	15.5	18	18	13
10	4.5	9.6	22	13	14
10	6.7	8.8	13	11	15
01	13.7	13.8	21	36	16
33	11.2	11.5	15	34	17
27	4.3	5.8	12	31	18
32	9.3	10.2	14	35	19
24	7.5	7.8	18	24	20
22	10.3	10.6	15	20	21
32	17.1	17.3	25	32	22
29	2.4	8.5	14	13	23
07	5.9	8.8	15	02	24
34	11.3	11.7	17	32	25
31	12.1	12.2	16	32	26
30	8.3	8.5	16	26	27
30	8.2	8.3	13	32	28
33	5.0	6.6	10	32	29
34	3.1	5.2	9	31	30
29	4.9	5.5	8	25	31
FOR THE MONTH:					
30	3.3	11.1	31	29	
—	—	—	DATE:	11	

Figure 4-6. Daily fastest miles of wind for periods of interest.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 4-6 shows a representative set of values (for a 1-mo period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3-d periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 m, so that a height correction to 10 m is needed for the fastest mile values.

From Equation (4-6)

$$u_{10}^{+} = u_{7}^{+} \frac{\ln (10/0.005)}{\ln (7/0.005)}$$

$$u_{10}^{+} = 1.05\ u_{7}^{+}$$

Step 4: The next step is to convert the fastest mile value for each 3-d period into the equivalent friction velocities for each surface wind regime (i.e., u_s/u_r ratio) of the pile, using Equations 4-7 and 4-8. Figure 4-5 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 m). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 4-14. As indicated, only three of the periods contain a friction velocity which exceeds the threshold value of 1.12 m/s for an uncrusted coal pile. These three values all occur within the u_s/u_r = 0.9 regime of the pile surface.

Step 5: This step is not necessary because there is only one frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the u_s/u_r = 0.2 regime) is never subject to wind speeds exceeding the threshold value.

Steps 6 and 7: The final set of calculations (shown in Table 4-15) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation (4-4).

TABLE 4-14. EXAMPLE 1: CALCULATION OF FRICTION VELOCITIES

3-day period	u_7^+ mph	u_7^+ m/s	u_{10}^+ mph	u_{10}^+ m/s	u_s/u_r {	$u^* = 0.1\ u_s^+$ (m/s) 0.2	0.6	0.9
1	14	6.3	15	6.6		0.13	0.40	0.59
2	29	13.0	31	13.7		0.27	0.82	1.23
3	30	13.4	32	14.1		0.28	0.84	1.27
4	31	13.9	33	14.6		0.29	0.88	1.31
5	22	9.8	23	10.3		0.21	0.62	0.93
6	21	9.4	22	9.9		0.20	0.59	0.89
7	16	7.2	17	7.6		0.15	0.46	0.68
8	25	11.2	26	11.8		0.24	0.71	1.06
9	17	7.6	18	8.0		0.16	0.48	0.72
10	13	5.8	14	6.1		0.12	0.37	0.55

TABLE 4-15. EXAMPLE 1: CALCULATION OF PM_{10} EMISSIONS[a]

3-Day period	u^*, m/s	$u^* - u_t^*$, m/s	P, g/m^2	ID	Pile Surface Area, m^2	kPA, g
2	1.23	0.11	3.45	A	101	170
3	1.27	0.15	5.06	A	101	260
4	1.31	0.19	6.84	A	101	350
			Total PM_{10} emissions = 780			

[a]Where u_t^* = 1.12 m/s for uncrusted coal and k = 0.5 for PM_{10}.

For example, the calculation for the second 3-d period is:

$$P_2 = 58(1.23-1.12)^2+25(1.23-1.12)$$

$$= 0.70+2.75 = 3.45 \text{ g/m}^2$$

The PM_{10} emissions generated by each event are found as the product of the PM_{10} multiplier (k = 0.5), the erosion potential (P), and the affected area of the pile (A).

As shown in Table 4-15, the results of these calculations indicate a monthly PM_{10} emission total of 780 g.

Target Control Efficiency: 60 percent

Method of Control: Daily watering of erodible surfaces of coal pile (2 gal/m²)

Demonstration of Control Program Adequacy: Wind-generated dust emissions are known to be strongly dependent (inverse square) on moisture content as described in Section 4.3.3. In addition, coal storage pile surface moisture, M, is correlated with weighted precipitation, P_w, as follows:[3]

$$M_c = 0.13\ P_w + 1.41 \qquad (4\text{-}10)$$

where: M = surface moisture content (percent)

$$P_w = \sum_{n=1}^{4\ d} P_n \exp[-(n - 0.5)]\ \text{(mm)}$$

P_n = daily precipitation or watering amount (mm) for the nth day in the past

For uniform daily water application, $P_w - P_n$.

Uncontrolled PM_{10} wind erosion emissions, E_u, from the storage pile were shown to be 780 g for the month. To achieve a control efficiency of 60 percent, calculate the controlled emissions, E_c, using the following relationship.

$$E_c = E_u\ (1 - 0.60)$$

$$= 312\ g$$

The inverse square relationship of wind emissions with surface moisture content can be written as follows:

$$E_c = \frac{(M_u)^2}{(M_c)^2} E_u$$

Solving for the controlled surface moisture content, M_c, using an uncontrolled moisture content, M_u = 1.5 percent, produces:

$$M_c = M_u \quad \frac{E_u}{E_c} = 2.4 \text{ percent}$$

To achieve this moisture content, use Equation 4-10 to determine the daily water application rate.

$$P_w = \frac{M_c - 1.41}{0.13}$$

$$= 7.4\ mm$$

Convert this daily watering amount to gal/m² of erodible pile surface to obtain a recommended daily water application rate of 1.95 gal H_2O/m^2.

The upper pile area where $U_s/U_r \geq 0.9$ is the only surface which needs to be controlled in the example month since this area has been shown to produce virtually all the emissions. In this instance, it is only necessary to water the pile surface impacted by winds producing U_s/U_r values ≥ 0.9. This area can be estimated from Figure 4-5 if the 0.9 subarea is rotated about the pile center to represent the possible 360 degree impact of winds on the pile.

The surface area to be controlled is equivalent to the area of a cone with base diameter of about 21.3 m. This upper cone has an area of 53 percent of the entire coal pile surface, e.g., about 450 m². Consequently, 900 gal of water applied daily to the 450 m² of erodible surface will achieve a control efficiency of 60 percent.

4.5 POTENTIAL REGULATORY FORMATS

There are several possible regulatory formats for control of dust emissions from storage piles. Opacity standards are suitable for a standard observed at the point of emissions, such as continuous drop from a stacker; however, they may not be legally applied at the property line.

For wet suppression and chemical stabilization, suitable recordkeeping forms, such as those provided above, would provided evidence of control plan implementation. In addition, simple measurements of moisture level in transferred material or of the crust strength of the chemically treated surface could be used to verify compliance. In addition, the loading as well as the texture of material deposited around the pile could be used to check whether good work practices are being employed relative to pile reclamation and maintenance operations. The suitability of these measurements of surrogate parameters for source emissions stems from the emission factor models which relate the parameters directly to emission rate.

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5.0 CONSTRUCTION AND DEMOLITION ACTIVITIES

Construction and demolition activities are temporary but important sources of PM_{10} in urban areas. These activities involve a number of separate dust-generating operations which must be quantified to determine the total emissions from the site and thus its impact on ambient air quality. Also, the specific type of activities which are conducted onsite will depend of the nature of the construction or demolition project taking place.

In the case of construction, a project may involve the erection of a building(s), single- or multifamily homes, or the installation of a road right-of-way. Operations commonly found in these types of construction projects consist of: land clearing, drilling and blasting, excavation, cut-and-fill operations (i.e., earthmoving), materials storage and handling, and associated truck traffic on unpaved surfaces.

In addition, secondary impacts associated with construction sites involve mud/dirt carryout onto paved surfaces. The additional loading caused by carryout can substantially increase PM_{10} emissions on city streets over the life of the project.

With regard to demolition, a particular project may involve the razing and removal of an entire building(s), a major interior renovation of a structure, or a combination of the two. Dust-producing operations associated with demolition are: mechanical or explosive dismemberment; debris storage, handling, and transport operations; and truck traffic over unpaved surfaces onsite.

Like construction, demolition activities can also create mud/dirt carryout onto paved surfaces with its associated increase in emissions. Also, since building debris is usually being removed from the site, spillage from trucks can also be of concern in increasing the amount of surface loading deposited on the paved street(s) providing access to the site. The generic sources of PM_{10} involved in construction and demolition sites are shown in Table 5-1.[1]

TABLE 5-1. GENERIC OPEN DUST SOURCES ASSOCIATED WITH CONSTRUCTION AND DEMOLITION SITES

<u>Construction Sites</u>

- Pushing (land clearing and earthmoving)
- Drilling and blasting
- Batch drop operations (loader operation)
- Storage piles (soil and construction aggregates)
- Exposed areas
- Vehicle traffic on unpaved surfaces
- Mud/dirt carryout onto paved surfaces

<u>Demolition Sites</u>

- Explosive and mechanical dismemberment (blasting and wrecking ball operations)
- Pushing (dozer operation)
- Batch drop operations (loading debris into trucks)
- Storage piles (debris)
- Exposed areas
- Vehicular traffic on unpaved surfaces
- Mud/dirt/debris carryout onto paved surfaces

This section presents a discussion of available emission factors, demonstrated control techniques, alternative control measures, and possible formats for determining compliance for controlled construction and demolition sites. It must be cautioned, however, that the information presented is for generic sites and site-specific analyses will be necessary for compliance determination.

5.1 ESTIMATION OF EMISSIONS

5.1.1 Construction Emissions

At present, the only emission factor available in AP-42 is 1.2 tons/acre/month (related to particles <30 μm Stokes' diameter) for an entire construction site. No factor has been published for demolition in AP-42. However, PM_{10} emission factors have been developed for construction site preparation using test data from a study conducted in Minnesota for topsoil removal, earthmoving (cut-and-fill), and truck haulage operations.[2] For these operations, the PM_{10} emission factors based on the level of vehicle activity (i.e., vehicle kilometers traveled or VKT) occurring onsite are:[3]

- Topsoil removal: 5.7 kg/VKT for pan scrapers
- Earthmoving: 1.2 kg/VKT for pan scrapers
- Truck haulage: 2.8 kg/VKT for haul trucks

PM_{10} emissions due to materials handling and wind erosion of exposed areas can be calculated using the emission factors presented in Sections 4.0 and 6.0, respectively.

5.1.2 Demolition Emissions

For demolition sites, the operations involved in demolishing and removing structures from a site are:

- Mechanical or explosive dismemberment
- Debris loading
- Onsite truck traffic
- Pushing (dozing) operations

5.1.2.1 Dismemberment. Since no emission factor data are available for blasting or wrecking a building, the first operation is addressed through the use of the revised AP-42 materials handling equation:[3,4]

$$E_D = k(0.0016)\frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \quad (5\text{-}1)$$

where E_D = PM_{10} emission factor in kg/Mg of material

k = particle size multiplier = 0.35 for PM_{10}

U = mean wind speed in m/s (default = 2.2 m/s)

M = material moisture content in percent (default = 2 percent)

and E_D = 0.00056 kg/Mg (with default parameters)

The above factor can be modified for waste tonnage related to structural floor space where 1 m^2 of floor space represents 0.45 Mg of waste material (0.046 ton/ft^2).[3] The revised emission factor related to structural floor space (using default parameters) can be obtained by:

$$E_D = 0.00056 \text{ kg/Mg} \cdot \frac{0.45 \text{ Mg}}{m^2}$$

$$= 0.00025 \text{ kg/m}^2$$

5.1.2.3 Debris Loading. The emission factor for debris loading is based on two tests of the filling of trucks with crushed limestone using a front-end loader which is part of the test basis for the batch drop equation in AP-42, § 11.2.3.[5] The resulting emission factor for debris loading is:[3]

$$E_L = k(0.029)\ \text{kg/Mg} \cdot \frac{0.45\ \text{Mg}}{\text{m}^2}$$

$$= 0.0046\ \text{kg/m}^2$$

where 0.029 kg/Mg is the average measured TSP emission factor and k is the particle size multiplier (0.35 for PM_{10}).

5.1.2.4 Onsite Truck Traffic. Emissions from onsite truck traffic is generated from the existing AP-42 unpaved road equation presented in Section 3.0 above.[5]

$$E = 1.7\ k\ \left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365 - p}{365}\right) \qquad (5\text{-}2)$$

where E = PM_{10} emission factor in kg/vehicle kilometer traveled (VKT)
k = particle size multiplier = 0.36 for PM_{10}
s = silt content in percent (default = 12 percent)
S = truck speed in km/h (default = 16 km/h)
W = truck weight in Mg (default = 20 Mg)
w = number of truck wheels (default = 10 wheels)
p = number of days with measurable precipitation (default = 0 days)

and E_T = 1.3 kg/VKT (with default values)

The above factor is converted from kg/VKT to kg/m² of structural floor space by:[3]

$$E_T = \frac{0.40\ \text{km}}{23\ \text{m}^3\ \text{waste}} \cdot \frac{1\ \text{m}^3\ \text{waste}}{4\ \text{m}^3\ \text{volume}} \cdot \frac{7.65\ \text{m}^3\ \text{volume}}{0.836\ \text{m}^2\ \text{floor space}} \cdot \frac{1.3\ \text{kg}}{\text{VKT}}$$

$$= 0.052\ \text{kg/m}^2$$

5.1.2.5 Pushing Operations. For pushing (bulldozer) operations, the AP-42 emission factor equation for overburden removal at Western surface coal mines can be used.[5] Although this equation actually relates to particulate <15 µmA, it would be expected that the PM_{10} emissions from such operations would be generally comparable. The AP-42 dozer equation is:

$$E_p = \frac{0.45\ (S)^{1.5}}{(M)^{1.4}} \tag{5-3}$$

where E_p = PM_{10} emission rate in kg/h
S = silt content of surface material in percent (default = 6.9 percent)
M = moisture content of surface material in percent (default = 7.9 percent)

and E_p = 0.45 kg/h (with default parameters)

Finally, PM_{10} emissions due to wind erosion of exposed areas can be calculated as discussed in Section 6.0. In general, these emissions are expected to be minor as compared to other sources.

5.1.3 Mud/Dirt Carryout Emissions

Finally, the increase in emissions on paved roads due to mud/dirt carryout have been developed based on surface loading measurements at eight sites.[6] Tables 5-2 and 5-3 provide these emission factors in terms of gm/vehicle pass which represent PM_{10} generated over and above the "background" for the paved road sampled. Table 5-2 expresses the emission factors according to the volume of traffic entering and leaving the site whereas Table 5-3 expresses the same data according to type of construction.

5.2 DEMONSTRATED CONTROL TECHNIQUES

As discussed above, similar generic open dust sources exist at both construction and demolition sites. Therefore, similar types of controls would also apply. In this section, a discussion is provided on the various techniques available for the control of open dust sources associated with construction and demolition. Detailed information on control efficiency, implementation cost, etc., will be presented in Section 5.3 below.

TABLE 5-2. EMISSIONS INCREASE (ΔE) BY SITE TRAFFIC VOLUME[a]

Particle size fraction[b]	Sites with >25 vehicle/d			Sites with <25 vehicle/d		
	Mean, $\bar{x}$	Standard deviation, σ	Range	Mean, $\bar{x}$	Standard deviation, σ	Range
<~30 μm	52	28	15-80	19	7.8	14-28
<10 μm	13	6.7	4.4-20	5.5	2.3	4.2-8.1
<2.5 μm	5.1	2.6	1.7-7.8	2.2	0.88	1.6-3.2

[a]ΔE expressed in g/vehicle pass.
[b]Aerodynamic diameter.

TABLE 5-3. EMISSIONS INCREASE (ΔE) BY CONSTRUCTION TYPE[a]

Particle size fraction[b]	Commercial			Residential		
	Mean, $\bar{x}$	Standard deviation, σ	Range	Mean, $\bar{x}$	Standard deviation, σ	Range
<~30 μm	65	39	15-110	39	22	10-72
<10 μm	16	9.3	4.2-25	10	5.4	2.8-19
<2.5 μm	6.3	3.6	1.6-9.7	3.9	2.1	1.1-7.3

[a]ΔE expressed in g/vehicle pass.
[b]Aerodynamic diameter.

5.2.1 Work Practice Controls

Work practice controls refer to those measures which reduce either emissions potential and/or source extent. These will be discussed below for both construction and demolition activities.

For construction activities, a number of work practice controls can be applied to reduce PM_{10} emissions from the site. These include paving of roads and access points early in the project, compaction or stabilization (chemical or vegetative) of disturbed soil, phasing of earthmoving activities to reduce source extent, and reduction of mud/dirt carryout onto paved streets. Each of these techniques is pretty much site-specific. However, subdivisions, for example, can be constructed in phases (or plats) whereby the amount of land disturbed is limited to only a selected number of home sites. Also, subdivision streets can be constructed and paved when the utilities are installed, thus reducing the duration of land disturbance.

Finally, increased surface loading on paved city streets due to mud/dirt carryout can be reduced to mitigate secondary site impacts. This may involve the installation of a truck wash at access points to remove mud/dirt from the vehicles prior to exiting the site or periodic cleaning of the street near site entrances. All of these techniques require preplanning for implementation without substantially interfering with the conduct of the project.

In the case of demolition sites, the work practice controls which can be employed are far more limited than is the case of construction. Normally, demolition is an intense activity conducted over a relatively short time frame. Therefore, measures to limit emissions potential or source extent are not usually possible. The only technique which seems feasible is the control of carryout onto paved city streets. This could be conducted by installing a truck wash and grizzly to remove mud and debris from the vehicles as they leave the site. Also the use of freeboard over the load will reduce blow-off dust from the truck beds. It should also be remembered that asbestos removal is also of concern at some sites which involve additional controls not normally necessary for most demolition activities.

As a final note, there are no quantitative control efficiency values for any of the above work practices. Estimates can be obtained by a site-specific analysis of alternative site preparation schemes based on the planned level of activity for the entire project using the emission factors provided in Section 5.1 above. For mud/dirt carryout, a quantitative value for control efficiency could be obtained if street surface loading data for uncontrolled (i.e., those which do not employ any measures to reduce carryout) and controlled sites were collected. Also, alternative methods for reducing mud/dirt carryout could be explored by a properly designed study of available techniques.

5.2.2 Traditional Control Technology

In addition to work practices, a number of open source controls are also available for reducing PM_{10} emissions from construction and demolition sites. These traditional controls are: watering of unpaved surfaces; wet suppression for materials storage, handling, and transfer operations; wind fences for control of windblown dust; and water injection and filters for drilling operations. Each will be discussed briefly with detailed information included in Section 5.3 below.

The use of water is probably the most widely used method to control open source emissions. However, very little quantitative data are available on the efficacy of wet suppression for the control of fugitive PM_{10}. This is especially true for materials storage and handling operations. Some limited data are available for watering of unpaved surfaces, but estimation of control efficiency (and thus a watering control plan) is difficult. Those data which are available are presented below.

It should be noted that wet suppression of unpaved surfaces using chemical dust palliatives has not been included in the list of available controls for construction/demolition. This is due to the fact that the temporary nature of these operations generally preclude their use. The same travel surface is not used for extended periods which is usually required for cost-effective application of chemical suppressants. The only possibility that might be considered is the use of hydroscopic salts which require only one application at the beginning of the project. Therefore, the use of chemical suppressants will not be discussed further in this section.

With regard to wind fences, only three studies have been identified for this particular control technique which attempt to quantify the degree of control achieved. Wind fences (and other types of barriers) are extremely cost effective in that they incur little or no operating and maintenance costs. For this reason wind fences are an attractive control alternative for windblown PM_{10} emissions.

Finally, both water injection and fabric filters have been used to control dust generation during drilling operations. Since this is a relatively minor source associated with construction operations, these controls do not offer significant emissions reductions. It should be noted, however, that drilling may be important at certain sites.

5.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

In this section, the various alternative control measures for fugitive PM_{10} at construction and demolition sites will be discussed in some detail. Included in this discussion will be the manner in which each technique controls emissions, methods for estimating control efficiency, an identification of cost elements to be considered, and available cost estimates for each in terms of capital and operating expenditures. Each control will be presented in the order shown previously in Section 5.2.

5.3.1 Watering of Unpaved Surfaces

5.3.1.1 Control Efficiency. Watering of unpaved roads is one form of wet dust suppression. This technique prevents (or suppresses) the fine particulate from leaving the surface and becoming airborne through the action of mechanical disturbance or wind. The water acts to bind the smaller particles to the larger material thus reducing emissions potential.

The control efficiency of watering of unpaved surfaces is a direct function of the amount of water applied per unit surface area (liters per square meter), the frequency of application (time between reapplication), the volume of traffic traveling over the surface between applications, and prevailing meteorological conditions (e.g., wind speed, temperature, etc.). As stated previously, a number of studies have been conducted with regard to the efficiency of watering to control dust, but few have quantified all parameters listed above.

The only specific control efficiency data which are available for construction and demolition involve the use of watering to control truck haulage emissions for a road construction project in Minnesota.[2] Using the geometric means of the important source characteristics (i.e., silt content, traffic volume, and surface moisture) and the regression equation developed from the downwind concentration data, a PM_{10} control efficiency of approximately 50 percent was obtained for a water application intensity of approximately 0.2 gal/yd²/hour.

It should be noted that truck travel at road construction sites is only somewhat similar to travel on unpaved roads. The road bed surface is generally not as compacted as a well-constructed unpaved road. There are also subtle differences in surface composition. Care should be taken, therefore, in estimating control efficiency for noncompacted surfaces.

For more compacted unpaved surfaces found in construction and demolition sites, an empirical model for the performance of a watering as a control technique has been developed. The supporting data base consists of 14 tests performed in four states during five different summer and fall months. The model is:[1]

$$C = 100 - \frac{0.8\ p\ d\ t}{i} \qquad (5\text{-}4)$$

where C = average control efficiency, in percent

p = potential average hourly daytime evaporation rate in mm/h

d = average hourly daytime traffic rate in vehicles per hour

i = application intensity in L/m²

t = time between applications in h

The term p in the above equation is determined using Figure 5-1 and the relationship:

$$p = \begin{cases} 0.0049\ e\ \text{(annual average)} & (5\text{-}5a) \\ 0.0065\ e\ \text{(worst case)} & (5\text{-}5b) \end{cases}$$

where p = potential average hourly daytime evaporation rate (mm/h)

e = mean annual pan evaporation (inches) from Figure 5-1

An alternative approach (which is potentially suitable for a regulatory format) is shown as Figure 5-2. This figure was presented earlier in Section 3.0.

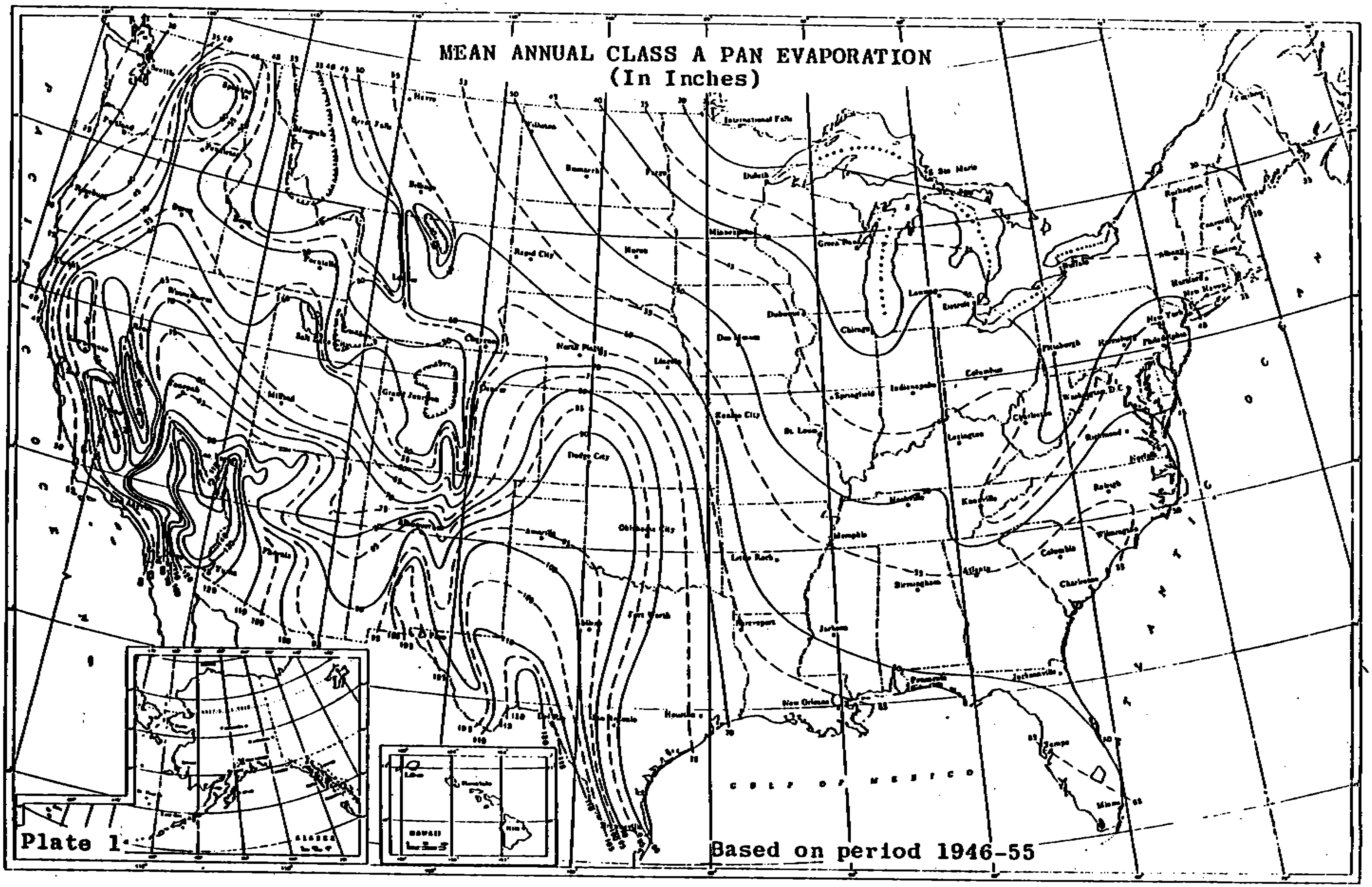

Figure 5-1. Mean evaporation for the United States.

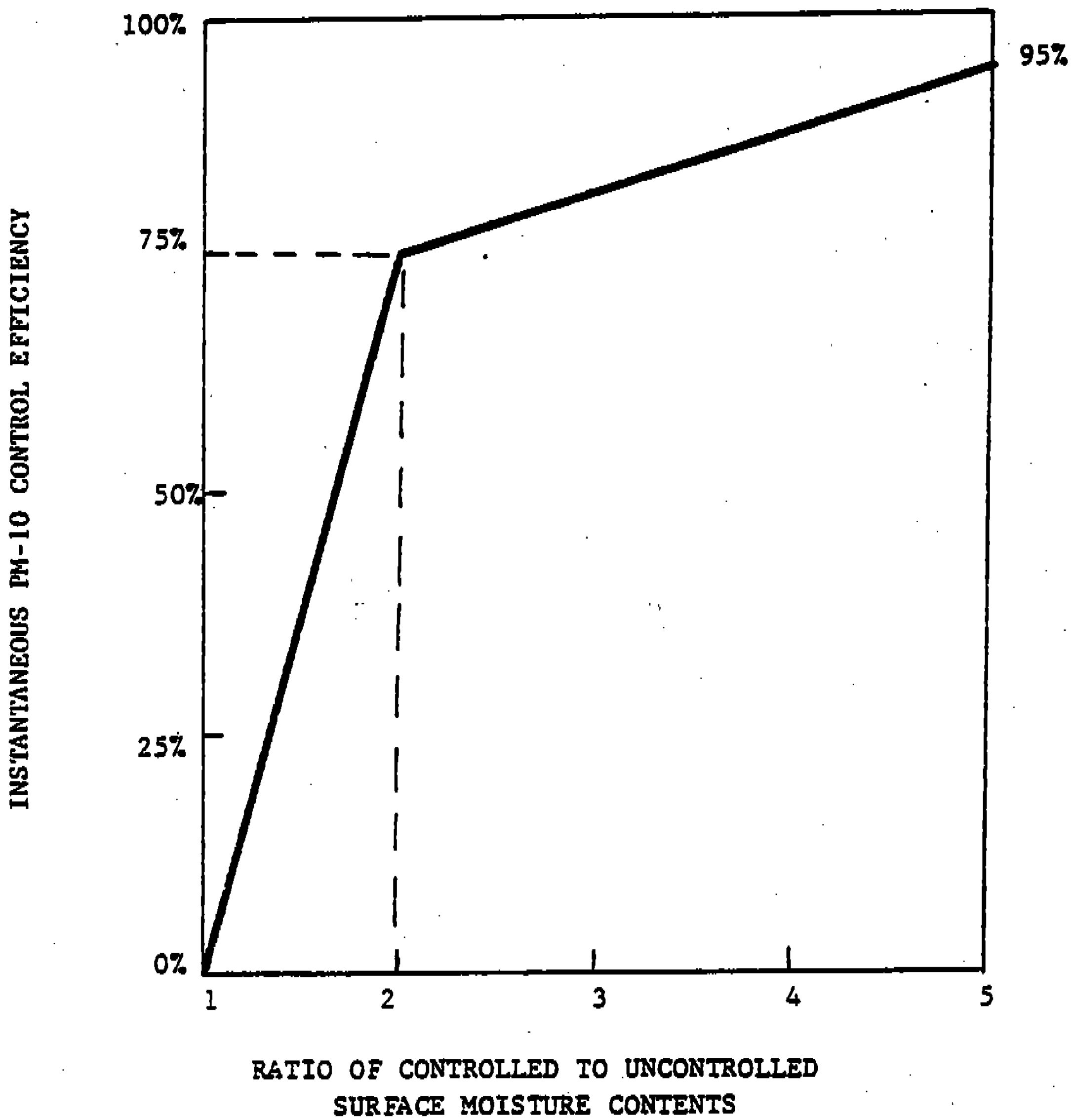

Figure 5-2. PM-10 control efficiency for watering unpaved roads.

Figure 5-2 shows that, between the average uncontrolled moisture content and a value of twice that, a small increase in moisture content results in a large increase in control efficiency. Beyond this point, control efficiency grows slowly with increased moisture content. Furthermore, this relationship is applicable to all size ranges considered:

$$c = \begin{cases} 75\,(M-1) & 1 \leq M \leq 2 \\ 62 + 6.7\,M & 2 \leq M \leq 5 \end{cases} \qquad (5\text{-}6)$$

where c = instantaneous control efficiency in percent

M = ratio of controlled to uncontrolled surface moisture contents

5.3.1.2 Control Costs. Costs for watering programs include the following elements:

- Capital: Purchase of truck or other device
- O&M: Fuel, water, truck maintenance, operator labor

Reference 6 estimates the following costs (1985 dollars):

Capital: $17,100/truck

O&M: $32,900/truck

The number of trucks required may be estimated by assuming that a single truck, applying water at 1 L/m^2, can treat roughly 4 acres of unpaved surface every hour.

5.3.1.3 Enforcement Issues. Enforcement of a watering program would ideally consist of two complementary approaches. The first facet would require the owner to maintain adequate records that would document to agency personnel's satisfaction that a regular program is in place. (See Appendix C for a suggested recordkeeping format.) The second approach would involve agency spot checks of controlled surfaces by taking material grab samples.

Records must be kept that document the frequency of water application to unpaved surfaces. Pertinent parameters to be specified in a control plan and rigorously recorded include:

General Information to be Specified.

1. All travel routes to be treated referenced on a plot plan available to both the site operator and regulatory personnel
2. Length and area of surfaces to be watered

3. Application intensity (gal/sq yd) and frequency (a minimum moisture content may be specified as an alternative)
4. Type of application vehicle, capacity of tank, and source of water

<u>Specific Records to be Kept by Truck Operator</u>

1. Date and time of treatment
2. Equipment used (this should be referred back to dust control plan specifications)
3. Operator's initials (a separate operators log may be kept and transferred later to permanent records by site operator)
4. Start and stop time, average speed, and number passes
5. Start and stop time for filling of water tank

<u>Specific Records to be Kept by Site Operator</u>

1. Equipment maintenance logs
2. Meteorological log of general conditions (e.g., sunny and warm vs. cloudy and cold)
3. Records of equipment breakdowns and downtime

An example permanent record form which may be used to record the above information is shown in Figure 5-3.

In addition to the above, some of the regulatory formats suggested in Section 5.4 require that records of surface samples or traffic counts also be kept. A suggested format for recording surface samples is shown in Figure 5-4. Traffic data may be recorded either manually or by automated counting devices.

5.3.2 Wet Suppression for Materials Storage and Handling

5.3.2.1 <u>Control Efficiency</u>. Wet suppression of materials storage and handling operations is similar to that used for unpaved surfaces. However, in addition to plain water this technique can also use water plus a chemical surfactant or micronized foam to control fugitive PM_{10}.

Surfactants added to the water supply allow particles to more easily penetrate the water droplet and increase the total number of droplets, thus increasing total surface area and contact potential. Foam is generated by adding a chemical (i.e., detergent-like substance) to a relatively small quantity of water which is then vigorously mixed to produce small bubble, high energy foam in the 100 to 200-μm size range.

Date	Time	Application intensity (gal/yd²)	Area(s) treated	Climatic parameters: Amb. temp. (°F)	Climatic parameters: Date/amt. of last rainfall	Equipment used	Operator initials	Comments

Figure 5-3. Typical form for recording watering program control parameters. (Sources: Unpaved surfaces, exposed areas, storage piles)

Sampling Data
Unpaved Roads

Date ______________
Recorded by ______________

SAMPLING DATA

Sample No.	Time	Location*	Surface Area	Depth	Quantity of Sample

*Use code given on plant map for segment identification and indicate sample location on map.

Figure 5-4. Unpaved road sample log.

The foam uses very little liquid volume, and when applied to the surface of the bulk material, wets the fines more effectively than untreated water.

As with watering of unpaved surfaces, the control efficiency of wet suppression for materials storage and handling is dependent on the same basic application parameters. These include: the amount of water, water plus surfactant, or foam applied per unit mass or surface area of material handled (i.e., liters per metric ton or square meter); if not continuous, the time between reapplications; the amount of surfactant added to the water (i.e., dilution ratio), if any; the method of application including the number and types of spray nozzles used; and applicable meteorological conditions occurring onsite.

Wet suppression can be applied to material storage and handling operations by a variety of methods depending on the material and how it is being handled. For construction sites, soil and construction aggregates may be batch transferred to or from storage using loaders or by truck dumping. In these cases, water (with or without chemicals) could be applied with a water cannon or spray bar to the material prior to or during load-in or load-out. Foam may be a good alternative in such instances when the material is handled repeatably over the period of a day. Foam can be applied once in the handling process (e.g., as it is initially loaded into trucks) and the binding action of the bubbles will carry through subsequent handling operations.

For demolition sites, water, etc., can be applied with a cannon to wrecking operations as well as to building debris being moved (pushed) with dozers and transferred into trucks by end-loaders. Control of transfer operations can also be augmented using portable wind fences to provide a wind break to reduce dust generation and improve application of water to the load during transfer to haul trucks. Wind fences are discussed later in this discussion.

Available control efficiency data for wet dust suppression for materials handling and storage are practically nonexistent. However, certain limited information was compiled by Cowherd and Kinsey which can be used to estimate control efficiencies.[1]

For suppression using plain water, the most applicable efficiency information available is for feeder to belt transfer of coal in mining operations. Control efficiencies of 56 to 81 percent are reported for respirable particulate (particles <~ 3.5μmA) at application intensities of 6.7 to 7.1 L/Mg (1.6 to 1.7 gal/ton), respectively. Assuming that respirable particulate is essentially equivalent to PM_{10}, the above control efficiencies would be representative of similar controls for construction/demolition. (The above application intensities were estimated assuming 5 min to discharge 7 Mg of coal and 1.4 L/min/spray nozzle.)

In the case of foam suppression, the most appropriate data available are for the transfer of sand from a grizzly. Using the respirable particulate control efficiencies at various foam application intensities (and assuming respirable particulate is equivalent to PM_{10}), the following equation was developed by simple linear regression of the data compiled by Cowherd and Kinsey:[1]

$$C = 8.51 + 7.96 (A) \quad (5\text{-}7)$$

where: C = PM_{10} control efficiency in percent
A = application intensity in ft^3 foam/ton of material

A coefficient of determination (r^2) of 99.97 percent was obtained for the above equation based on the three data sets used in its derivation.

An alternate approach (which is potentially suitable for regulatory formats) involves the use of the recently developed materials handling equation soon to be published in AP-42. This equation was presented as Equation 5-1 above. By determining the "uncontrolled" moisture content of the material and again after wet suppression, the control efficiency can be determined by:

$$CE = 100(E_u - E_c)/E_u \quad (5\text{-}8)$$

where CE = PM_{10} control efficiency in percent
E_u = "uncontrolled" PM_{10} emission factor
E_c = "controlled" PM_{10} emission factor

The above calculations would necessitate the determination of the amount of water added to the material by laboratory analysis. This could be accomplished by taking grab samples of the material before and after application of the wet suppression technique being employed.

5.3.2.2 Control Costs. Costs associated with wet suppression systems include the following basic elements:

- Capital equipment:
  - -- Spray nozzles or other distribution equipment
  - -- Supply pumps and plumbing (plus weatherization)
  - -- Water filters and flow control equipment
  - -- Tanker truck (if used)
- Operating and maintenance expenditures:
  - -- Water and chemicals
  - -- Replacement parts for nozzles, truck, etc.
  - -- Operating labor
  - -- Maintenance labor

Reference 6 estimates the following costs (in 1985 dollars):

- Regular watering of storage piles:
  - -- Initial capital cost = $18,400 per system
- Watering of exposed areas:
  - -- Initial capital cost = $1,053 per acre
  - -- Annual operating cost = $25 to 67 per acre

The costs associated with a wet suppression system using chemical surfactants for the unloading of limestone from trucks at aggregate processing plants (in 1980 dollars) have been estimated at: capital = $72,000; annual = $26,000. These costs are based on a stationary system and may not be indicative of those used at construction and demolition sites.

5.3.2.3 Enforcement Issues. As with watering of unpaved surfaces, enforcement of a wet suppression control program would consist of two complementary approaches. The first would be record keeping to document that the program is being implemented and the other would be spot-checks and grab sampling. Both were discussed previously above.

Records must be kept that document the control plan and its implementation. Pertinent parameters to be specified in a plan and to be regularly recorded include:

General Information to be Specified in Plan

1. Locations of all materials storage and handling operations referenced on plot plan of the site available to the site operator and regulatory personnel
2. Materials delivery or transport flow sheet which indicates the type of material, its handling and storage, size and composition of storage piles, etc.
3. The method and application intensity of water, etc, to be applied to the various materials and frequency of application, if not continuous
4. Dilution ratio for chemicals added to water supply, if any
5. Complete specifications of equipment used to handle the various materials and for wet suppression
6. Source of water and chemical(s), if used

Specific Operational Records

1. Date of operation and operator's initials
2. Start and stop time of wet suppression equipment
3. Location of wet suppression equipment
4. Type of material being handled and number of loads (or other measure of throughput) loaded/unloaded between start and stop time (if material is being pushed, estimate the volume or weight)
5. Start and stop times for tank filling

General Records to be Kept

1. Equipment maintenance records
2. Meteorological log of general conditions
3. Records of equipment malfunctions and downtime

In addition to the above, some of the regulatory formats suggested in Section 5.4 below require that records of material samples be kept. A suggested format for this purpose is shown in Figure 5-5.

5.3.3 Portable Wind Screens or Fences

5.3.3.1 Control Efficiency. The principle of wind screens or fences is to provide a sheltered region behind the fenceline to allow gravitational settling of larger particles as well as a reduction in wind erosion potential. Wind screens or fences reduce the mechanical turbulence generated by ambient winds in an area the length of which is many times the physical height of the fence.

Storage Pile Data

Date__________
Recorded by_____

AGGREGATE CHARACTERISTICS

Type: Coal ☐; Coke ☐; Iron Ore ☐; Other ____________________
Nominal Size: __________ in.
Weight Density: __________ tons/cu. yd.
Silt Content: __________ %

PILE CONFIGURATION

Total Volume: Ground Area __________ acres
Average Height __________ ft.

Configuration: ____

Location within Plant Boundaries: ______________________________

SEASONAL FACTORS

	WINTER	SPRING	SUMMER	FALL	ANNUAL
Avg. Quantity On Hand (tons; cu. yd.)					
Avg. Quantity Put Through Storage (tons; cu. yd.)					
Avg. Duration of Storage (days)					

MATERIALS HANDLING EQUIPMENT

Stationary: ____

Mobile: ____

MITIGATIVE MEASURES

____

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Figure 5-5. Storage pile sampling sheet

As stated previously, wind fences and screens are applicable to a wide variety of fugitive dust sources. They can be used to control wind erosion emissions from storage piles or exposed areas as well as providing a sheltered area for materials handling operations to reduce entrainment during load-in/load-out, etc. Fences and screens can be portable and thus capable of being moved around the site, as needed.

The control efficiency of wind fences is dependent on the physical dimensions of the fence relative to the source being controlled. In general, a porosity (i.e., percent open area) of 50 percent seems to be optimum for most applications. Note that no data directly applicable to construction/demolition activities were found. According to a recent field study of small soil storage piles, a screen length of five times the pile diameter, a screen-to-pile distance of twice the pile height, and a screen height equal to the pile height was found best.[8] Various problems were noted with the sampling methodology used, however, and it is doubtful that the study adequately assessed the particle flux from the exposed surface. These problems tend to limit an accurate assessment of the overall degree of control achievable by wind fences/barriers for large open sources.

While not entirely applicable to construction/demolition activities, results of a laboratory wind tunnel study were used to estimate 60 percent to 80 percent control efficiencies for materials handling emissions.

5.3.3.2 Control Costs. As stated above, one of the real advantages of wind fences for the control of PM_{10} involves the low capital and operating costs. These involve the following basic elements:

- Capital equipment:
  - -- Fence material and supports
  - -- Mounting hardware
- Operating and maintenance expenditures:
  - -- Replacement fence material and hardware
  - -- Maintenance labor

The following cost estimates (in 1980 dollars) were developed for wind screens applied to aggregate storage piles:[10]

- Artificial wind guards:
  - -- Initial capital cost = $12,000 to 61,000

- Vegetative wind breaks:
  - -- Initial capital cost = $45 to 425 per tree

Due to the lack of quantitative data on costs associated with wind screens, it is recommended that local vendors be contacted to obtain more detailed data for capital and operating expenses. Also, since wind fences and screens are relatively "low tech" controls, it may be possible for the site personnel to construct the necessary equipment with less expense.

5.3.3.3 Enforcement Issues. As with other options mentioned above, the main regulatory approach involved with wind fences and screens would involve recordkeeping by the site operator. Parameters to be specified in the dust control plan and routinely recorded are:

General Information to be Specified in Plan

1. Locations of all materials storage and handling operations to be controlled with wind fences referenced on a plot plan available to the site operator and regulatory personnel
2. Physical dimensions of each source to be controlled and configuration of each fence or screen to be installed
3. Physical characteristics of material to be handled or stored for each operation to be controlled by fence(s) or screen(s)
4. Applicable prevailing meteorological data (e.g., wind speed and direction) for site on an annual basis

Specific Operational Records

1. Date of installation of wind fence or screen and initials of installer
2. Location of installation relative to source and prevailing winds
3. Type of material being handled and stored and physical dimensions of source controlled
4. Date of removal of wind fence or screen and initials of personnel involved

General Records to be Kept

1. Fence or screen maintenance record
2. Log of meteorological conditions for each day of site operation

5.3.4 Drilling Control Technology

5.3.4.1 Control Efficiency. Another type of control to be discussed is the use of water injection or fabric filters for drilling operations.

Both of these controls are generally directly associated with the drilling equipment when it is purchased and is an integral part of the system.

As might be expected, water injection used on rock drills involves the application of water either into the hole being drilled by a piston pump or to a ring around the top of the hole to control dust generation. Also, dust ejector systems equipped with small fabric filters or water sprays use compressed air to eject dust particles from the hole into a tube for removal from the drilled area.

At present, there are no data available for the PM_{10} control efficiency associated with either system used to reduce emissions from drilling operations. It might be expected, however, that a fabric filter-based system should be more efficient than wet suppression in most cases.

5.3.4.2 Control Costs. Cost elements associated with drilling control systems are as follows:

- Capital equipment:
  - -- Spray nozzles, pumps, and distribution plumbing for wet suppression system
  - -- Air compressor, air lines, and filter components for dry ejection system
  - -- Water filters and flow control equipment, as required
  - -- Water tank, if needed
- Operating and maintenance expenditures:
  - -- Water and chemicals, if used
  - -- Replacement bags, etc. for dry systems
  - -- Replacement parts for nozzles, pumps, etc.
  - -- Operating labor
  - -- Maintenance labor

Jutze et al. estimate the following costs (in 1980 dollars) for drilling operations in aggregate processing facilities:[10]

- Water injection systems:
  - -- Initial capital cost = $4,700
- Dust ejection to fabric filter:
  - -- Initial capital cost = $14,600

Specific cost data should be obtained from manufacturers relative to the capital costs associated with the above systems to update the above. No information is available at present for O&M costs for such systems.

5.3.4.3 Enforcement Issues. As with the other methods discussed previously, the regulation of drilling emissions would involve at least some recordkeeping as part of the overall emissions control plan for the site. The parameters to be specified in the plan and subsequently recorded by onsite personnel include:

General Information to be Specified in Plan

1. Location of all drilling operations to be conducted referenced to a plot plan of the site available to the site operator and regulatory personnel
2. Schedule for all drilling operations to be conducted onsite, number of holes to drilled, equipment used and hours of operation
3. Complete specifications of drilling and dust control equipment for each rock drill to be used
4. Amount of water to be used per unit time for wet systems or airflows for dry systems
5. Source of water and chemical(s), if used, and tank(s) capacity(ies)

Specific Operational Records

1. Date of operation and operator's initials
2. Start and stop time of drilling and control equipment
3. Number of holes drilled between start and stop time
4. Start and stop time for tank filling

General Records to be Kept

1. Equipment maintenance records
2. Meteorological log of general conditions
3. Records of equipment malfunctions and downtime

Because of the relatively confined nature of drilling operations, regulatory formats different from those discussed previously may be possible. For example, opacity as a measure of performance could be a viable approach. This is discussed further in Section 5.4 below.

5.3.5 Control of Mud/Dirt Carryout

5.3.5.1 Control Efficiency. Mud and dirt carryout from construction and demolition sites often accounts for a temporary but substantial increase in paved road emissions in many areas. Elimination of carryout can thus significantly reduce increases in paved road emissions.

At present, the efficacy of various methods to prevent or reduce mud/dirt carryout have not been quantified. These techniques include both methods to remove material from truck underbodies and tires prior to leaving the site (e.g., a temporary grizzley with high pressure water sprays) as well as techniques to periodically remove mud/dirt carryout from paved streets at the access point(s). The following method has been developed, however, to conservatively estimate the reduction in mass emissions due to carryout using the data contained in Reference 6.

As noted earlier, quantification of control efficiencies for preventive measures is essentially impossible using the standard before/after measurement approach. The methodology described below results in conservatively high control estimates in terms of emissions prevention. That is, the control afforded cannot be easily described in terms of a percent reduction but rather is discussed in terms of mass emissions prevented. Furthermore, tracking of material onto a paved road results in substantial spatial variation in loading about the access point. This variation may complicate the modeling of emission reductions as well as their estimation.

For an individual access point from a paved road to a typical construction or demolition site, let N represent the number of vehicles entering or leaving the area on a daily basis. Let E be given by:

$$E = \begin{cases} 5.5 \text{ g/vehicle for } N \leq 25 \\ 13 \text{ g/vehicle for } N > 25 \end{cases}$$

where E is the unit PM_{10} emission increase in g/vehicle pass (see Section 5.1). Finally, if M represents the daily number of vehicle passes <u>on the paved road</u>, then the net daily emission reduction (g/day) is given by ExM, assuming complete prevention.

The emission reduction calculated above assumes that essentially all carryout from the unpaved area is either prevented or removed periodically from the paved surface and, as such, is viewed as an upper limit. In use, a regulatory agency may choose to assign an effective level of carryout control by using some fraction of the E values given above to calculate an emission reduction.

Finally, field measurements of the increased paved silt loadings around unpaved areas may also be used to gauge the effectiveness of control programs. A discussion of this is found in Section 2.4.

5.3.5.2 Control Costs. The individual cost elements associated with the prevention of mud/dirt carryout will vary with the method used. For traditional street cleaning, the costs elements discussed in Section 2.0 would apply to construction and demolition sites as well. In this case, however, only the amount of surface to be cleaned would be limited to the area(s) near access point(s). For an onsite grizzley/water spray system, the cost elements are as follows:

- Capital equipment:
  - -- Grizzley, catch basin, and clarifier (as needed)
  - -- Spray nozzles, pumps, and distribution plumbing
  - -- Water tank, filters, and flow controllers, as required
- Operating and maintenance expenditures:
  - -- Water and replacement nozzles, plumbing, etc.
  - -- Removal of wastewater or residues, as required
  - -- Operating labor
  - -- Maintenance labor

At present, no cost data are available for the prevention of mud/dirt carryout.

5.3.5.3 Enforcement Issues. As with some other techniques, two complimentary approaches can be used for enforcement of mud/dirt carryout control. These are recordkeeping and grab sampling. The later would include the sampling of the paved surface loading near access points to determine the level of prevention being achieved by the method(s) employed. Surface sampling is discussed in more detail above.

Adequate records must be kept to document the types and level of preventative measures being taken to control mud/dirt carryout from the site. Appropriate parameters to be specified in the control plan and rigorously recorded are:

General Information to be Specified

1. A detailed plot plan available to both the site operator and regulatory personnel showing site access points and impacted paved city streets.

2. Details on the control method to be applied at each access point including the amount and types of vehicles entering and exiting the site on a daily basis at each.
3. For mitigative control techniques (i.e., surface cleaning), a description and schedule for implementation of the control method to be employed (see Section 2.0 above).
4. For preventive control techniques (e.g., onsite grizzley), specifications on the type(s) of equipment to be used and operation and maintenance of the system.
5. Source of water, if used.

Specific Records to be Kept by Site Operator (Mitigative Controls)

1. Date of cleaning operation and operator's initials.
2. Other applicable cleaning parameters as specified in Section 2.0 above.

General Records to be Kept

1. Equipment maintenance records.
2. Meteorological log of general conditions.
3. Records of equipment malfunctions and downtime.

In addition to the above, some of the regulatory formats suggested in Section 5.4 require that records of material samples also be kept. A suggested format for this purpose has been shown previously in Section 2.4.

5.4 EXAMPLE DUST CONTROL PLAN

To illustrate the development of an appropriate dust control plan for construction and demolition sites, Figure 5-6 provides example calculations for the demolition of a 167,200 m^2 (200,000 ft^2) building located on a one acre site in an urban area. These calculations include the determination of uncontrolled PM_{10} emissions, methods used for control, and demonstration of the adequacy of the various methods to achieve a target control efficiency of 90 percent.

5.5 POTENTIAL REGULATORY FORMATS

In this section, regulatory formats will be discussed relative to the control of fugitive PM_{10} emissions at construction and demolition sites. This section discusses a permit system, recordkeeping, measures of control performance, and enforcement as well as an example rule which implements

- Source Description:
  - 167,200 m² (floor space) building on a one acre site
  - 1 access point to a paved city street (2,000 ADT)
  - 30 vehicles/day removing building debris
  - 30 days project duration

- Assumptions:
  - No detailed data are available for debris removal activities
  - No dozing will be performed onsite
  - Negligible exposed areas
  - 8 h/day operation

- Calculation of Uncontrolled Emissions:
  From Section 5.1.2 the uncontrolled PM_{10} emissions from dismemberment, debris loading, and onsite traffic are calculated as:

$$E_{DLT} = (E_D + E_L + E_T) \text{ kg/m}^2 \times \text{m}^2 \text{ floor space}$$

$$= (0.00025 + 0.0046 + 0.052) \text{ kg/m}^2 \times 167{,}200 \text{ m}^2$$

$$= 9.5 \text{ Mg } PM_{10}$$

For mud/dirt carryout from haul trucks entering and leaving the site, the mean <u>increase</u> in paved road emissions is calculated using Table 5-2 for sites with greater than 25 vehicles/day:

$$E_{MD} = 13 \text{ g/vehicle pass} \times 2{,}000 \text{ vehicles/day} \times 30 \text{ days}$$

$$= 780 \text{ Mg } PM_{10} \text{ emissions}$$

Therefore, the total emissions over the duration of the project are:

$$E_T = E_{DLT} + E_{MD} = 9.5 \text{ Mg} + 780 \text{ Mg}$$

$$= 789.5 \text{ Mg total } PM_{10} \text{ emissions}$$

- Target Control Efficiency: 90%

- Methods of Control:

  -- Wet suppression of debris handling and transfer (6.7 L/Mg application intensity)
  -- Watering of unpaved travel surfaces (2 L/m²/h application)
  -- Broom sweeping/flushing for removal of mud/dirt carryout

Figure 5-6. Example PM_{10} control plan for building demolition.

- Demonstration of Control Program Adequacy:

  As stated in Section 5.3.2.1, an efficiency of 56% is typical for wet suppression of debris transfer. Thus, the controlled emissions would be:

  E_{CL} = 0.0046 kg PM_{10}/m^2 x 167,200 m^2 x (1 - 0.56) = 0.34 Mg PM_{10}

  Using water for dust control from unpaved surfaces, Equations 5-4 and 5-5 as well as Figure 5-1 will allow calculation of controlled emissions (assuming the site is located in Los Angeles, California):

  p = 0.0049 e = 0.0049 (60 inches) = 0.29 mm/h

  and

  $$C = 100 - \frac{0.8\ pdt}{i}$$
  $$= 100 - \frac{0.8(0.29)(30/8)(1)}{2}$$
  $$= 99.6\%$$

  Therefore, the controlled PM_{10} emissions for haul truck traffic would be:

  E_{CT} = 0.052 kg/m^2 x 167,200 m^2 x (1 - 0.996)

  = 0.035 Mg PM_{10} from haul trucks

  Finally, for removal of mud/dirt carryout using a combination of broom sweeping and flushing, no prevention efficiency data are available. However, if it is assumed that the emissions increase on the paved road for this source is reduced by 90 percent, E_{CMD} = 78 Mg PM_{10} from mud/dirt carryout (see Section 5.3.5.1).

  From the above calculations, the overall reduction in PM_{10} due to the various controls employed would be:

  $E_C = E_{CL} + E_{CT} + E_{CMD}$

  = 0.34 + 0.035 + 78

  = 78 Mg PM_{10} after control

Figure 5-6. (continued)

Thus,

$$CE = \frac{E_T - E_{CT}}{E_T} \times 100\% = \frac{789.5 - 78}{789.5} \times 100 = 90.1\%$$

As shown, the target control efficiency of 90 percent has not only been achieved but exceeded.

Figure 5-6. (continued)

the permit system. Example regulatory formats are provided for the following sources associated with construction/demolition: unpaved roads, haul roads, disturbed soil, mud carryout. These example formats provide a starting point for development of construction rules in a specific area.

5.5.1 Permit System

The first regulatory approach involves the implementation and enforcement of a permit program for construction and demolition sites. This has been used to some extent in the Denver metropolitan area for large construction projects and offers promise as a general regulatory format.

A permit system would require the site owner or operator to file an application with the appropriate regulatory agency having jurisdiction. This permit application would include the specific dust control plan to be implemented at the site which would involve the individual elements discussed in Section 5.3.

The air permit for construction and demolition sites would be coupled to the standard building or demolition permit process whereby no permit to conduct such activity would be issued by the county or city until such time that the air permit is approved. To reduce the burden of processing large numbers of such permits, a de minimus level would be established whereby construction and demolition projects below a certain cut-off size would not require an air permit. This de minimus level would depend on local factors such as the amount of emissions reduction required to meet the applicable PM_{10} NAAQS. For the sake of further discussion, a de minimus level of <25 vehicles entering and leaving the site per day for construction was used to determine the emissions increase associated with mud/dirt carryout and thus might be used for this purpose.[5]

As part of the permit application, recordkeeping should be one of the main conditions for approval. Records of site activity and control should be submitted to the regulatory agency on a monthly basis as indicated above. These records must be certified by a responsible party as to their completeness and accuracy. All site records should be maintained by the local agency for the duration of the project.

To enforce the dust control plan submitted as part of the permit application, field audits of key control parameters should be made by regulatory personnel. The results of these audits would then be compared to site records for that period to determine compliance with permit conditions. If differences are found between application of the control(s) observed onsite and those recorded by site operating personnel, this would constitute a violation and would be grounds for further enforcement action. An example form to be used by regulatory personnel during inspection of the site is shown in Figure 5-7. To illustrate this process an abbreviated example will be given.

Assume a large demolition project consisting of the demolishing of a block of buildings is to be conducted in a large metropolitan area. The site dust control plan calls for watering of all truck routes to and from the active demolition every two hours as well as cleanup of mud/dirt carryout from the access point on a twice daily basis. Also, watering of debris during demolition and load-out to haul trucks is to be conducted on days without measurable rainfall. An agency inspector observes the site activity from the public street for a period of 3 hours. During this period, no water truck is observed to be in operation and debris are not watered prior to loading into trucks.

At the end of the month, the inspector checks the submittal from the site operators and finds start and stop times for the water truck operator which indicates operation during the observation period. The inspector also notes that the water cannon used for debris control was broken down and was in a repair shop. It is clear from this analysis that the operator is in clear violation of the dust control plan for watering of unpaved surfaces. In this case, a citation or other enforcement action could be taken against the site operator.

As noted by the above example, no quantitative data are required for enforcement of the dust control plan. This eliminates the need for a set performance standard (e.g., opacity limits) against which the site operator is evaluated. This approach is, however, predicated on the fact that strict implementation of the dust control plan will achieve certain reductions in PM_{10} emissions associated with site operation.

1. Type of construction activity (check one)

   a. Residential ____
   b. Commercial ____
   c. Industrial ____

   Additional description (i.e., multi unit, residential or suburban commercial, etc.)

2. How long have you worked at this location? ____________

   Note: In the case of a multi-year project, we are only interested in the current season.

3. How long is the job projected to last? ____________

4. What percentage of the work is completed, percent? ________

5. What construction activities are you currently performing?

6. What construction activities have you been performing over the past week to 10 days?

7. What is the construction activity's source extent which is currently being performed (e.g., tons of earth moved/day or yards of concrete poured/day)?

8. Estimate the number of daily vehicle passes through the site entrance (check 1).

9. What types of vehicle enter the site daily and what percentage of the traffic is of each type?

Vehicle type	Percent
a. Cars	______
b. Pickups/vans	______
c. Medium duty trucks	______
d. Other	______

10. Do you employ control measures to keep dust down? If yes, what type?

11. What is the usual frequency and intensity of application? When was the most recent application?

Figure 5-7. Questionnaire for construction site personnel.

5.5.2 Opacity Standards

Another regulatory format which could be used is the use of visible emissions (i.e., opacity) as a semiquantitative measure of the performance of the dust control measure being employed. One state, Tennessee, has developed a formalized procedure for reading and recording of visible emissions (VE) from fugitive sources which is the basis for enforcement of a VE standard.

The use of visible emissions for determination of compliance for fugitive dust sources has been discussed previously in this document and thus will not be belabored here. In general, fugitive sources are extremely diffuse in nature and the plume generated is dependent on a number of factors including wind speed and the physical dimensions of the source. Therefore, it is difficult, if not impossible, to derive even semiquantitative relationships between particulate mass and visible emissions for most source types and thus a measure of control performance.

There is one particular source at construction sites where observation of visible emissions might be used with some degree of confidence as an enforcement tool. This source is rock drills which emit dust from one confined area (i.e., the hole being drilled) and thus might be considered as a point emissions source under traditional definitions. Additional work will be necessary, however, to determine appropriate visible emissions limits for rock drills based on the control techniques currently available.

5.5.3 Other Indirect Measures of Control Performance

The final regulatory format to be presented in this section relates to various indirect measures of control performance. These could be used in conjunction with or in lieu of the other approaches discussed above. They will, however, require more effort and expense to implement but should be at least somewhat defensible as measures of control efficiency.

The most obvious approach to indirectly measuring control performance involves the collection and analysis of material samples from various sources operating onsite. For mud/dirt carryout, collection of surface samples at site access points and analysis of these samples for silt content would indicate the efficacy of control for this particular source. The silt loadings obtained could be compared with "typical" surface loading values for similar uncontrolled sites to determine the degree of loading (and thus emissions) reductions achieved. This would, of course, necessitate the availability of a data base of "uncontrolled" silt loadings due to mud/dirt carryout for a wide variety of construction and demolition sites for comparison with site-specific data. An example form to be used for collection of paved surface loading samples has been provided previously in Section 2.4 above which has been reproduced as Figure 5-8.

Another indirect measure of control efficiency is the collection and analysis of material samples from unpaved surfaces and materials handling and storage operations. In this case, analysis of the moisture content of these samples would indicate the amount of water applied and thus the degree of control achieved by wet suppression. Appropriate equations presented in Section 5.3 would be used to determine control efficiency based on the sample data.

5.5.4 Example Rule

The following is a discussion of an example regulatory format for construction activities. A more detailed discussion is presented in Appendix G.

5.5.4.1 Conditions for Construction.

Conditions for Construction: No person shall engage in any construction-related activity at any work site unless all of the following conditions are satisfied:

(1) Dust control implements in good working condition are available at the site, including water supply and distribution equipment adequate to wet any disturbed surface areas and any building part up to a height of 60 feet above grade.

(2) A dust control plan is approved by the APCO which demonstrates that an overall x percent (e.g., 75 percent) reduction of PM_{10} emissions from construction/demolition and related activities will be achieved by applying reasonably available control measures. Such measures may include, but need not be limited to, the following: application of water or other liquids during dust-producing mechanical activities including earth moving and demolition operations; application of water or other liquids to or chemical stabilization of, disturbed surface areas; surrounding the work site with wind breaks to reduce surface erosion; restricting the access of motor vehicles on the work site; securing loads and cleaning vehicles leaving the work site; enclosing spraying operations; and other means as specified by the APCO.

Paved Road Loading

Run No. ________________ Date ________________

MRI Project No. ________________ Recorded By ________________

Type of Material Sampled: ________________

Site of Sampling: ________________ No. of Traffic Lanes ________________

Type of Pavement: Asphalt/Concrete Surface Condition ________________

Sample No.	Vac. Bag	Time	Location*	Sample Area	Broom Swept? (y/n)

*Use code given on plant map for segment identification and indicate sample location on map.

Figure 5-8. Example paved road sample log.

(3) The owner and/or operator is in possession of a currently valid permit which has been issued by the APCO. (Example permit attached, see Figures 5-9 and 5-10).

5.5.4.2 Control Mud/Dirt Carryout.

Street Cleaning: No person shall engage in any dust-producing construction related activity at any work site unless the paved streets (including shoulders) adjacent to the site where the construction-related activity occurs are cleaned at a frequency of not less than x (e.g., once) a day unless,

(1) vehicles do not pass from the work site onto adjacent paved streets, or

(2) vehicles that do pass from the work site onto adjacent paved streets are cleaned and have loads secured to effectively prevent the carryout of dirt or mud onto paved street surfaces.

The measures used to clean paved roads may include, but are not limited to: water flushing, vacuum sweeping, and manual cleaning of the access point.

5.5.4.3 Control of Haul Road Emissions.

Construction Site Haul Roads: No person shall allow the operation, use, or maintenance of any unpaved or unsealed haul road of more than x (e.g., 50) feet in length at any work site engaged in any construction-related activity, unless no more than x (e.g., 10) vehicular trips are made on such haul road per day and vehicular speeds do not exceed x (e.g.,10) miles per hour.

5.5.4.4 Stabilize Soils at Work Sites.

Stabilization of Soils at Completed Work Sites: No owner and/or operator shall allow a disturbed surface site to remain subject to wind erosion for a period in excess of x (e.g., 6) months after initial disturbance of the soil surface or construction-related activity without applying all reasonably available dust control measures necessary to prevent the transport of dust or dirt beyond the property line. Such measures may include, but need to be limited to: sealing, revegetating, or otherwise stabilizing the soil surface.

5.5.4.5 Record Control Application. The owner and or operator shall record the evidence of the application of the control measures. Records shall be submitted upon request from APCO and shall be open for inspection during unscheduled audits.

5.5.4.6 Modification of Permit Provisions

The provisions of this permit may be modified after sufficient construction is completed by the mutual consent of the APCO and the permittee; or, by the APCO if it determines that the stipulated controls

THIS PERMIT WILL BE PROMINENTLY DISPLAYED IN THE ONSITE CONSTRUCTION OFFICE

Location: ______________________________ No. of Acres: ______

Name of Project: ______________________________________

PERMITTEE: ____________________________ Telephone No. ________

Address: ____

Prime Contractor: ______________________ Telephone No. ________

Subcontractor: _________________________ Telephone No. ________

Issue Date of Permit: __________ Expiration Date of Permit: ________

PERMIT NO: ________________ FEE $________ RECEIPT NO. ________

THE PERMITTEE SHALL COMPLY WITH THE FOLLOWING CONDITIONS:

1. (Reference to local APCD regulation for construction/demolition-related activities)

2. The PERMITTEE is responsible for dust control from commencement of project to final completion. Areas which will require particular ATTENTION:

   a. Unimproved access roads used for entrance to or exit from construction site.
   b. Areas in and around building(s) being constructed.
   c. Dirt and mud deposited on adjacent improved streets and roads.

3. If wind conditions are such that PERMITTEE cannot control dust, PERMITTEE shall shut down operations (except for equipment used for dust control).

4. The PERMITTEE is responsible for ensuring his contractor(s) and/or subcontractor(s) and all other persons abide by the conditions of the permit from commencement of project to final completion.

5. The PERMITTEE also is subject to compliance with all applicable State, county, and local ordinances and regulations. Issuance of this permit shall not be a defense to violation of above-referenced statutes, ordinances, and regulations.

6. Onsite permit conditions (attached)

____

Air Pollution Control Division (date)

Figure 5-9. Example dust permit.

ONSITE PERMIT CONDITIONS

Condition number	Source category[a]	Minimum control efficiency	Control measure	Application level (frequency amount, etc.)	Recordkeeping	Reporting requirements
6a.	(e.g., unpaved roads)	(e.g., 80 percent)	(e.g., chemical stabilization, 39 percent call in water and supplemental watering)	(e.g., sufficient to maintain an average surface moisture content of 2 times the the offroad soil moisture)	(e.g., log of salt solution and supplemental water volume, time, and date)	Records submitted upon request (in writing) and open for inspection during unscheduled audits)

[a]Other source categories that also could be regulated with permit conditions include open areas, grading, streets, and haul trucks.

Figure 5-10. Example permit for construction/demolition activities.

are inadequate. Deviations from the dust control plan (e.g., increased source activity) may result in modifications to the permit.

5.6 REFERENCES FOR SECTION 5

1. Cowherd, C., Jr., and J. S. Kinsey. 1986. Identification, Assessment and Control of Fugitive Particulate Emissions. EPA-600/8-86-023, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina.

2. Kinsey, J. S., et al. 1983. Study of Construction Related Dust Control. Contract No. 32200-07976-01, Minnesota Pollution Control Agency, Roseville, Minnesota. April 19, 1983.

3. Grelinger, M. A. 1988. Gap Filling PM_{10} Emission Factors for Selected Open Area Dust Sources. EPA-450/4-88-003, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

4. Muleski, G. E. 1987. Update of Fugitive Dust Emission Factors in AP-42 Section 11.2. Final Report, U. S. Environmental Protection Agency, Contract 68-02-3891, Work Assignment 19.

5. U. S. Environmental Protection Agency. 1985. Compilation of Air Pollution Emission Factors, AP-42. U. S. Environmental Protection Agency, Research Triangle Park, North Carolina.

6. Englehart, P. J., and J. S. Kinsey. 1983. Study of Construction Related Mud/Dirt Carryout. EPA Contract 68-02-3177, Assignment 21. July 1983.

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9. Struder, B. J. B., and S. P. S. Arya. 1988. Windbreak Effectiveness for Storage Pile Fugitive Dust Control: A Wind Tunnel Study. Journal of the Air Pollution Control Association, 38:135-143.

10. Ohio Environmental Protection Agency. 1980. Reasonably Available Control Measures for Fugitive Dust Sources. Columbus, Ohio. September 1980.

6.0 OPEN AREA WIND EROSION

Dust emissions may be generated by wind erosion of open agricultural land or exposed ground areas on public property or within an industrial facility.

With regard to estimating particulate emissions from wind erosion of exposed surface material, site inspection can be used to determine the potential for continuous wind erosion. The two basic requirements for wind erosion are that the surface be dry and exposed to the wind. For example, if the contaminated site lies in a swampy area or is covered by unbroken grass, the potential for wind erosion is virtually nil. If, on the other hand, the vegetative cover is not continuous over the exposed surface, then the plants are considered to be nonerodible elements which absorb a fraction of the wind stress that otherwise acts to suspend the intervening soil.

For estimating emissions from wind erosion, either of two emission factor equations are recommended depending on the erodibility of the surface material. Based on the site survey, the exposed surface must be placed in one of two erodibility classes described below. The division between these classes is best defined in terms of the threshold wind speed for the onset of wind erosion.

Nonhomogeneous surfaces impregnated with nonerodible elements (stones, clumps of vegetation, etc.) are characterized by the finite availability ("limited reservoir") of erodible material. Such surfaces have high threshold wind speeds for wind erosion, and particulate emission rates tend to decay rapidly during an erosion event. On the other hand, bare surfaces of finely divided material such as sandy agricultural soil are characterized by an "unlimited reservoir" of erodible particles. Such surfaces have low threshold wind speeds for wind erosion, and particulate emission rates are relatively time independent at a given wind speed.

For surface areas not covered by continuous vegetation, the classification of surface material as either having a "limited reservoir" or an "unlimited reservoir" of erodible surface particles is determined by estimating the threshold friction velocity. Based on analysis of wind erosion research, the dividing line for the two erodibility classes is a threshold friction velocity of about 50 cm/s. This somewhat arbitrary division is based on the observation that highly erodible surfaces, usually corresponding to sandy surface soils that are fairly deep, have threshold friction velocities below 50 cm/s. Surfaces with friction velocities larger than 50 cm/s tend to be composed of aggregates too large to be eroded mixed in with a small amount of erodible material or of crusts that are resistant to erosion.[1]

The cutoff friction velocity of 50 cm/s corresponds to an ambient wind speed of about 7 m/s (15 mph), measured at a height of about 7 m. In turn, a specific value of threshold friction velocity for the erodible surface is needed for either wind erosion emission factor equation (model).

Crusted surfaces are regarded as having a "limited reservoir" of erodible particles. Crust thickness and strength should be examined during the site inspection, by testing with a pocket knife. If the crust is more than 0.6 cm thick and not easily crumbled between the fingers (modulus of rupture >1 bar), then the soil may be considered non-erodible. If the crust thickness is less than 0.6 cm or is easily crumbled, then the surface should be treated as having a limited reservoir of erodible particles. If a crust is found beneath a loose deposit, the amount of this loose deposit, which constitutes the limited erosion reservoir, should be carefully estimated.

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 is highly desirable to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure specified in Figure 6-1. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, following a relationship derived by Gillette (1980) as shown in Figure 6-1.[2]

A more approximate basis for determining threshold friction velocity would be based on hand sieving with just one sieve, but otherwise follows the procedure specified in Figure 6-2. Based on the relationship developed by Bisal and Ferguson (1970), if more than 60 percent of the

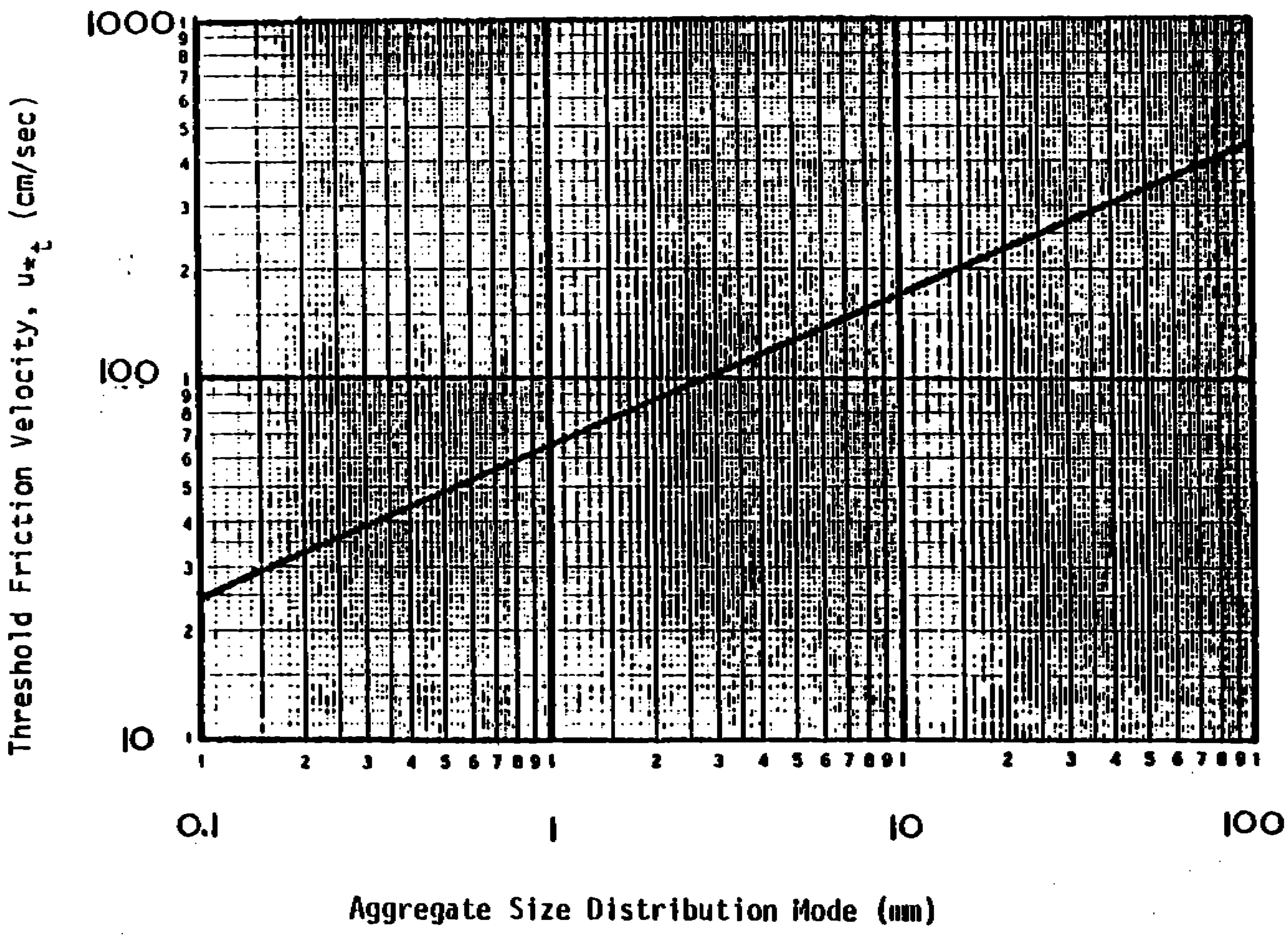

Figure 6-1. Relationship of threshold friction velocity to size distribution mode.

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY*

1. PREPARE A NEST OF SIEVES WITH THE FOLLOWING OPENINGS: 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm. PLACE A COLLECTOR PAN BELOW THE BOTTOM SIEVE (0.25-mm OPENING).

2. COLLECT A SAMPLE REPRESENTING THE SURFACE LAYER OF LOOSE PARTICLES (APPROXIMATELY 1 cm IN DEPTH FOR AN UNCRUSTED SURFACE), REMOVING ANY ROCKS LARGER THAN ABOUT 1 cm IN AVERAGE PHYSICAL DIAMETER. THE AREA TO BE SAMPLED SHOULD NOT BE LESS THAN 30 cm x 30 cm.

3. POUR THE SAMPLE INTO THE TOP SIEVE (4-mm OPENING), AND PLACE A LID ON THE TOP.

4. ROTATE THE COVERED SIEVE/PAN UNIT BY HAND USING BROAD SWEEPING ARM MOTIONS IN THE HORIZONAL PLANE. COMPLETE 20 ROTATIONS AT A SPEED JUST NECESSARY TO ACHIEVE SOME RELATIVE HORIZONTAL MOTION BETWEEN THE SIEVE AND THE PARTICLES.

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.

*ADAPTED FROM A LABORATORY PROCEDURE PUBLISHED BY W. S. CHEPIL (1952).[5]

Figure 6-2.

soil passes a 1-mm sieve, the "unlimited reservoir" model will apply; if not, the "limited reservoir" model will apply.[3] This relationship has been verified by Gillette (1980) on desert soils.[2]

If the soil contains nonerodible elements which are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of these elements must be taken into account by increasing the threshold friction velocity. Marshall (1971) has employed wind tunnel studies to quantify the increase in the threshold velocity for differing kinds of nonerodible elements.[4] His results are depicted in terms of a graph of the rate of corrected to uncorrected friction velocity versus L_c (Figure 6-3), where L_c is the ratio of the silhouette area of the roughness elements to the total area of the bare loose soil. The silhouette area of a nonerodible element is the projected frontal area normal to the wind direction.

A value for L_c is obtained by marking off a 1-m x 1-m surface area and determining the fraction of area, as viewed from directly overhead, that is occupied by nonerodible elements. Then the overhead area should be corrected to the equivalent frontal area; for example, if a spherical nonerodible element is half embedded in the surface, the frontal area is one-half of the overhead area. Although it is difficult to estimate L_c for values below 0.05, the correction-to-friction velocity becomes less sensitive to the estimated value of L_c.

The difficulty in estimating L_c also increases for small nonerodible elements. However, because small nonerodible elements are more likely to be evenly distributed over the surface, it is usually acceptable to examine a smaller surface area, e.g., 30 cm x 30 cm.

Once again, loose sandy soils fall into the high erodibility ("unlimited reservoir") classification. These soils do not promote crust formation, and show only a brief effect of moisture addition by rainfall. On the other hand, compacted soils with a tendency for crust formation fall into the low ("limited reservoir") erodibility group. Clay content in soil, which tends to promote crust formation, is evident from crack formation upon drying.

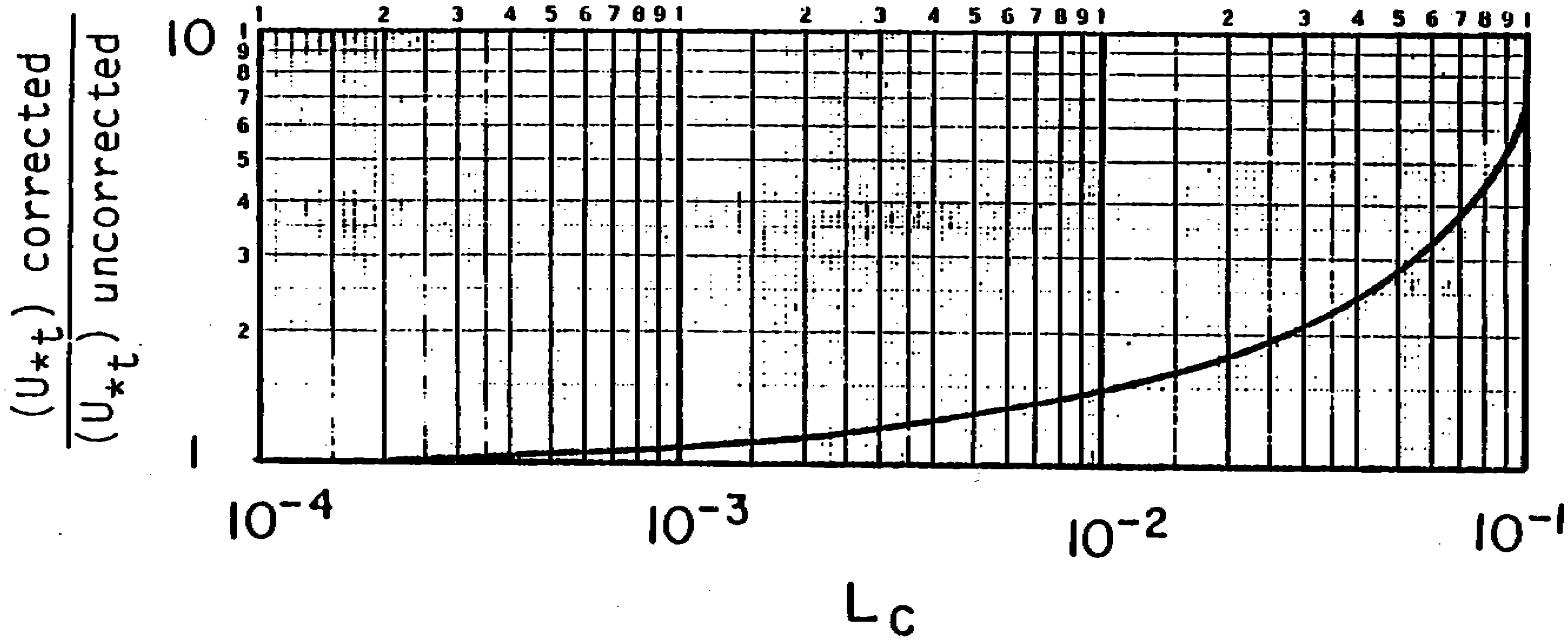

Figure 6-3. Increase in threshold friction velocity with L_c.

The roughness height, z_0, which is related to the size and spacing of surface roughness elements, is needed to convert the friction velocity to the equivalent wind speed at the typical weather station sensor height of 7 m above the surface. Figure 6-4 depicts the roughness height scale for various conditions of ground cover.[6] The conversion to the 7-m value is discussed below.

6.1 ESTIMATION OF EMISSIONS

6.1.1 "Limited" Erosion Potential

In the case of surfaces characterized by a "limited reservoir" of erodible particles, even the highest mean atmospheric wind speeds are usually not sufficient to sustain wind erosion. 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 which 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 which has passed by the 1-mi 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 LCD summaries may be obtained from the National Climatic Center, Asheville, North Carolina. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min. 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:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \qquad (6\text{-}1)$$

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

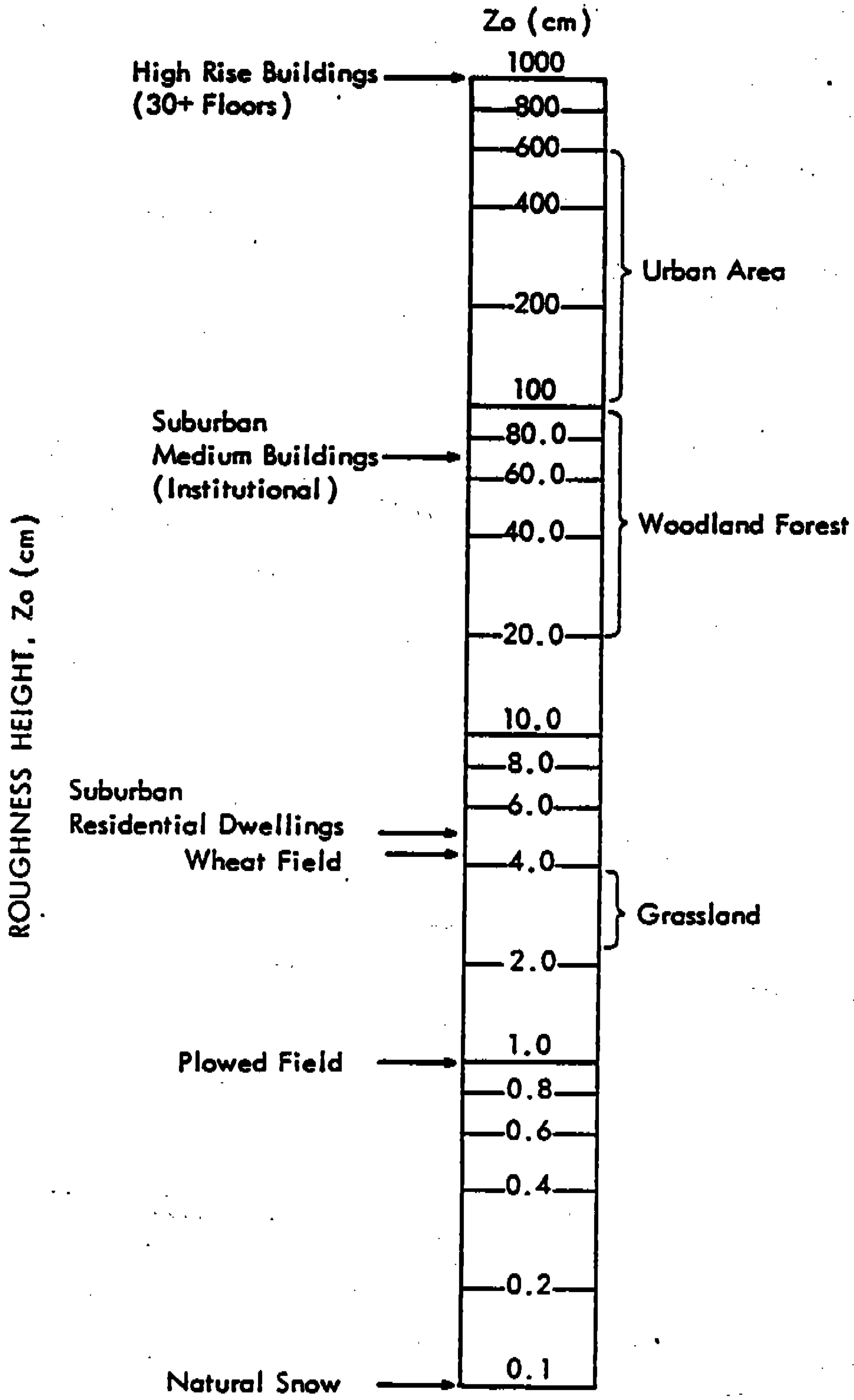

Figure 6-4. Roughness heights for various surfaces.

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. These parameters are illustrated in Figure 6-5 for a roughness height of 0.1 cm.

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 which 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.

The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of g/m^2-yr as follows:

$$\text{Emission factor} = k \sum_{i=1}^{N} P_i \qquad (6\text{-}2)$$

where: k = particle size multiplier

N = number of disturbances per year

P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

The particle size multiplier (k) for Equation 6-2 varies with aerodynamic particle size, as follows:

AERODYNAMIC PARTICLE SIZE MULTIPLIERS FOR EQUATION 6-2

<30 µm	<15 µm	<10 µm	<2.5 µm
1.0	0.6	0.5	0.2

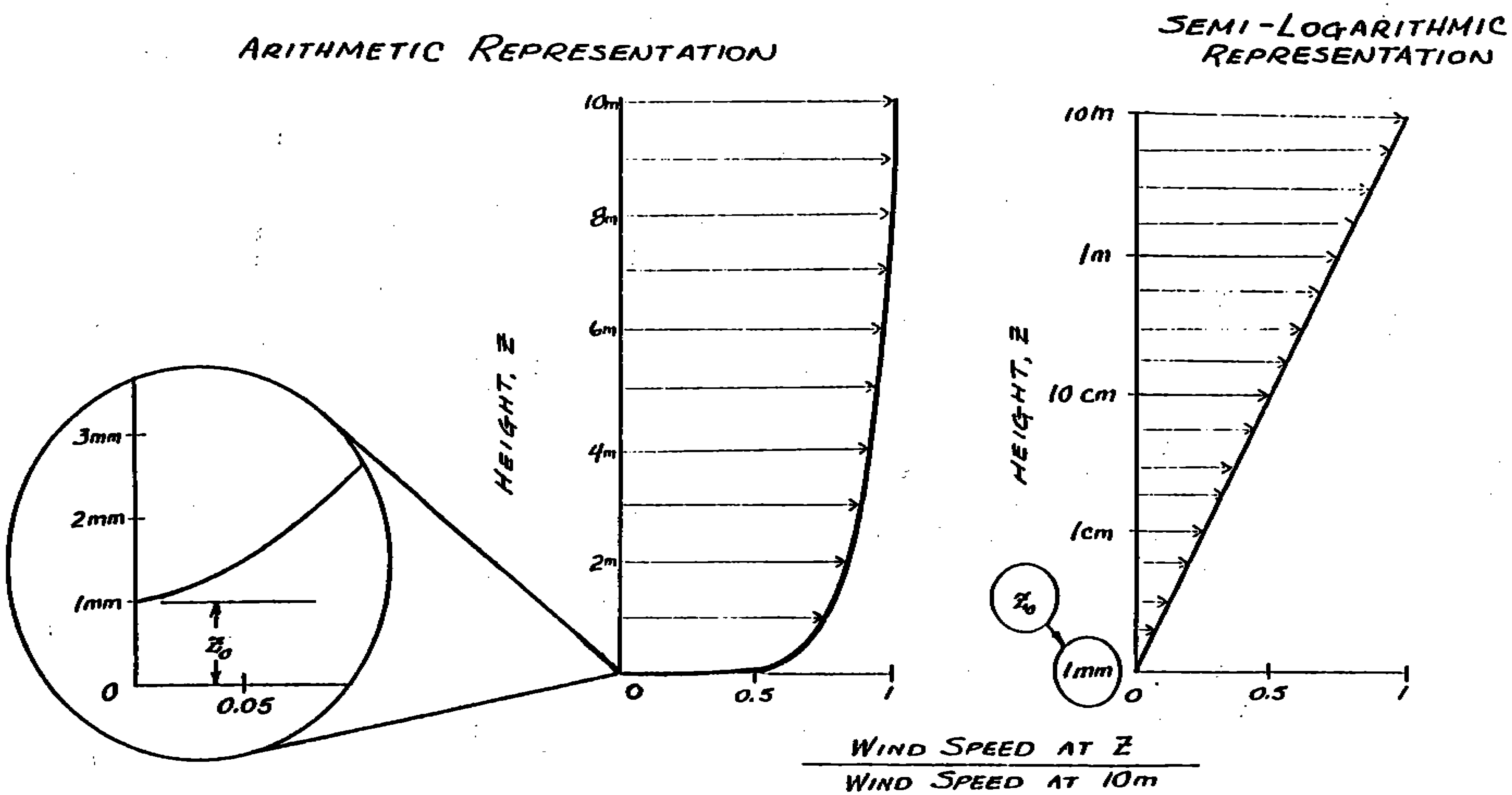

Figure 6-5. Illustration of logarithmic velocity profile.

This distribution of particle size within the <30 μm fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see AP-42 Section 11.2.3).

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/yr, and for a surface disturbance once every 6 mo, N = 2/yr.

The erosion potential function for a dry, exposed surface has the following form:

$$P = 58\ (u^* - u_t^*)^2 + 25\ (u^* - u_t^*) \qquad (6\text{-}3)$$

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

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.

Equations 6-2 and 6-3 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 (adapted from a laboratory procedure published by W. S. Chepil[5]) can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure specified in Figure 6-2. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, as described by Gillette.[6] This conversion is presented in Figure 6-1.

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Tables 6-1 and 6-2 and Figure 6-6.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly 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 6-1.

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:

$$u^* = 0.053\ u^+_{10} \qquad (6\text{-}4)$$

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 6-4 is restricted to large relatively flat areas with little penetration into the surface wind layer.

Implementation of the above procedure is carried out in the following steps:

1. Determine threshold friction velocity for erodible material of interest (see Tables 6-1 and 6-2 and Figure 6-6 or determine from mode of aggregate size distribution).
2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u^+_{10}) using Equation 6-5.

TABLE 6-1. THRESHOLD FRICTION VELOCITIES

Material	Threshold friction velocity (m/s)	Roughness height (cm)	Threshold wind velocity at 10 m (m/s)		Ref.
			z_0 = Actual	z_0 = 0.5 cm	
Overburden[a]	1.02	0.3	21	19	2
Scoria (roadbed material)[a]	1.33	0.3	27	25	2
Ground coal[a] (surrounding coal pile)	0.55	0.01	16	10	2
Uncrusted coal pile[a]	1.12	0.3	23	21	2
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12	2
Fine coal dust on concrete pad[c]	0.54	0.2	11	10	3

[a] Western surface coal mine.
[b] Lightly crusted.
[c] Eastern power plant.

TABLE 6-2. THRESHOLD FRICTION VELOCITIES--ARIZONA SITES

Location	Threshold friction velocity, m/sec	Roughness height, cm	Threshold wind velocity at 10 m, m/sec
Mesa - Agricultural site	0.57	0.0331	16
Glendale - Construction site	0.53	0.0301	15
Maricopa - Agricultural site	0.58	0.1255	14
Yuma - Disturbed desert	0.32	0.0731	8
Yuma - Agricultural site	0.58	0.0224	17
Algodones - Dune flats	0.62	0.0166	18
Yuma - Scrub desert	0.39	0.0163	11
Santa Cruz River, Tucson	0.18	0.0204	5
Tucson - Construction site	0.25	0.0181	7
Ajo - Mine tailings	0.23	0.0176	7
Hayden - Mine tailings	0.17	0.0141	5
Salt River, Mesa	0.22	0.0100	7
Casa Grande - Abandoned agricultural land	0.25	0.0067	8

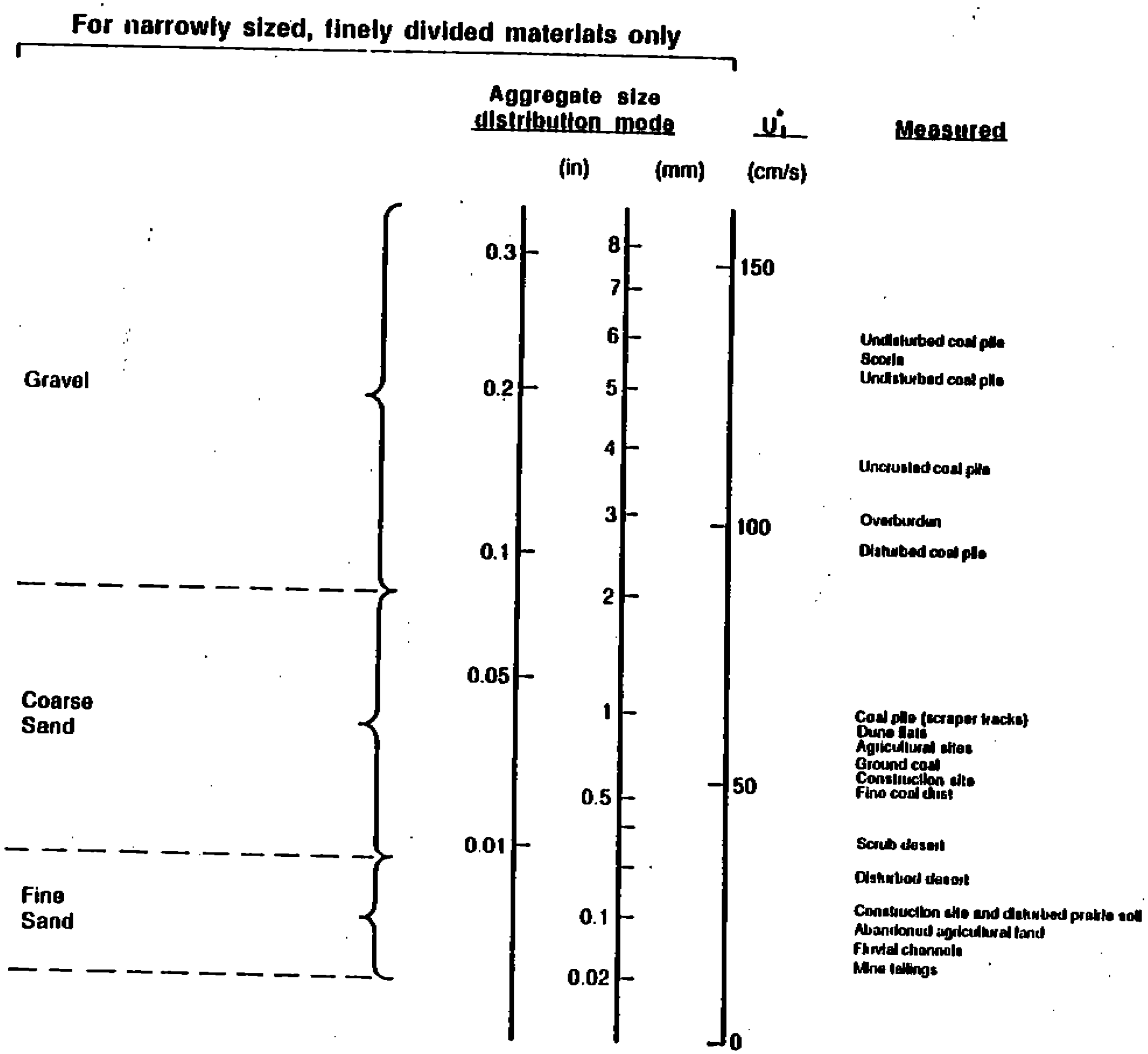

Figure 6-6. Scale of threshold friction velocities.

4. Convert fastest mile values (u^+_{10}) to equivalent friction velocities (u^*), using Equation 6-4.
5. 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 6-3 and the emission factor using Equation 6-2.
6. 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-h emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single wind 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 min, 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 which offset this apparent conservatism:

1. The fastest mile event contains peak winds which 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 which contain peak gusts of the same order as the fastest mile wind speed.

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

6.1.2 <u>"Unlimited" Erosion Potential</u>

For surfaces characterized by an "unlimited reservoir" of erodible particles, particulate emission rates are relatively time independent at a given wind speed. The technology currently used for predicting agricultural wind erosion in the United States is based on variations of the Wind Erosion Equation.[11,12] This prediction system uses erosion loss estimates that are integrated over large fields and long-time scales to produce average annual values. A simplified version of the agricultural wind erosion equation is presented in Section 7.1.2.

6.2 DEMONSTRATED CONTROL TECHNIQUES

Wind erosion of exposed areas is a recognized source of particulate air pollution associated with the mining and processing of metallic and nonmetallic minerals. Preventive methods for control of windblown emissions from open areas consist of wetting, chemical stabilization, and enclosures. Physical stabilization by covering the exposed surface with less erodible aggregate material and/or vegetative stabilization are also practical control methods for certain categories of open areas.

Wind erosion control of soil surfaces is accomplished by stabilizing erodible soil particles. The stabilization process is accomplished in three major successive stages: (a) trapping of moving soil particles, (b) consolidation and aggregation of trapped soil particles, and (c) revegetation of the surface.[13]

The trapping of eroding soil is termed "stilling" of erosion. This may be effected by roughening the surface, by placing barriers in the path of the wind, or by burying the erodible particles during tillage. Trapping is accomplished naturally by soil crusting resulting from rain followed by a slow process of revegetation. It should be stressed that the stilling of erosion is only temporary; to effect a permanent control, plant cover must be established or plant residues must be maintained.

In bare soils containing a mixture of erodible and nonerodible fractions, the quantity of soil eroded by the wind is limited by the height and number of nonerodible particles that become exposed on the surface. The removal of erodible particles continues until the height of the nonerodible particles that serve as barriers to the wind is increased to a degree that affords complete shelter to the erodible fractions. If the nonerodible barriers are low, such as fine gravel, a relatively large number of pieces are needed for protection of soil from wind erosion. The gravel in such a case would protect the erodible portion more by covering than by sheltering from the wind. Thus all nonerodible materials on the ground that control erosion have an element of cover in addition to the barrier principle which protects the soil. The principles of surface barriers and cover are, therefore, inseparable.

The above principles extend to almost all elements used in wind erosion control. All of these control methods are designed to (a) take up some or all of the wind force so that only the residual force, if any, is taken up by the erodible soil fractions; and (b) trap the eroded soil, if any, on the lee side or among surface roughness elements or barriers, thereby reducing soil avalanching and intensity of erosion.

In the sections that follow, various control methods are discussed with respect to their characteristics and effectiveness in controlling open area wind erosion. Methods include vegetative cover, soil ridges, windbreaks, crop strips, chemical stabilizers, and irrigation.

6.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

This section evaluates alternative controls for open area wind erosion. Relevant control cost information is presented in Section 4.3.

6.3.1 Chemical Stabilization

A portable wind tunnel has been used to measure the control of coal surface wind erosion emissions by a 17 percent solution of Coherex® in water applied at an intensity of 3.4 L/m² (0.74 gal/yd²), and a 2.8 percent solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 6.8 L/m² (1.5 gal/yd²).[14] The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 d before the test, under a wind of 15.0 m/s (33.8 mph) at 15.2 cm (6 in) above the ground, was 89.6 percent for TP and approximately 62 percent for IP and FP. The control efficiency of the latex binder on a low volatility coking coal is shown in Figure 6-7.

6.3.2 Wind Fences/Barriers

Wind fences/barriers are an effective means by which to control fugitive particulate emissions from open dust sources. The principle of the wind fence/barrier is to provide an area of reduced wind velocity which allows settling of the large particles (which cause saltation) and reduces the particle flux from the exposed surface on the leeward side of the fence/barrier. Wind fence/barriers can either be man-made structures or vegetative in nature.

Windbreaks consist of trees or shrubs in 1 to 10 rows, wind and snow fences, solid wooden or rock walls, and earthen banks. The effectiveness

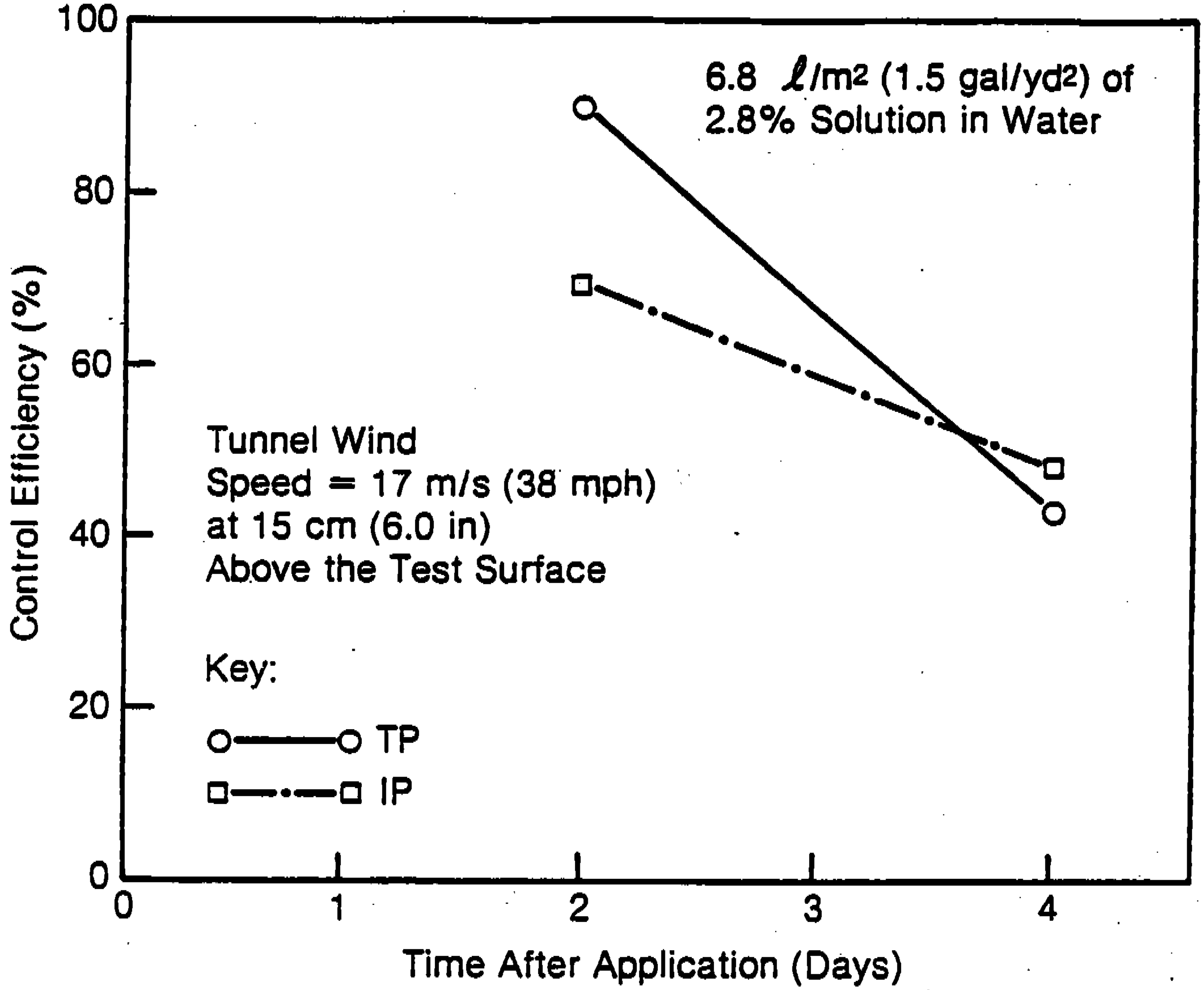

Figure 6-7. Decay in control efficiency of latex binder applied to coal storage piles.[5]

of any barrier depends on the wind velocity and direction, shape, width, height, and porosity of the barrier.

Nearly all barriers provide maximum reduction in wind velocity at leeward locations near the barrier, gradually decreasing downwind. Percentage reductions in wind velocities for rigid barriers remain constant no matter what the wind velocity.[13]

Direction of wind influences the size and location of the protected areas. Area of protection is greatest for perpendicular winds to the barrier length and least for parallel winds.

The shape of the windbreak indicates that a vertically abrupt barrier will provide large reductions in velocity for relatively short leeward distances, whereas porous barriers provide smaller reductions in velocity but for more extended distances.

Height of the barrier is, perhaps, the most important factor influencing effectiveness. Expressed in multiples of barrier height, the zone of wind velocity reduction on the leeward side may extend to 40 to 50 times the height of the barrier; however, such reductions at those distances are insignificant for wind erosion control. If complete control is desired, then barriers must be placed at close intervals.

Tree windbreaks and various artificial barriers are discussed below.

Tree windbreaks. One-, two-, three-, and five-row barriers of trees are found to be the most effective arrangement for planting to control wind erosion. The type of tree species planted also has a considerable influence on the effectiveness of a windbreak. The rate of growth governs the extent of protection that can be realized in later years.

Artificial barriers. Snow fences, fences constructed of board or lath, bamboo and willow fences, earthen banks, hand-inserted straw rows, and rock walls have been used for wind erosion control on a rather limited scale. Because of the high cost of both material and labor required for construction, their use has been limited to where high value crops are grown or where overpopulation requires intensive agriculture.

In the United States, the application of artificial barriers for wind erosion control has been limited. Snow fences constructed from strips of lath held together with wire have been used for protecting vegetable crops. Such fences provide only a relatively short zone of protection against erosion, approximately 10 times the height of the barrier.

Effectiveness. A number of studies have attempted to determine the effectiveness of wind fences/barriers for the control of windblown dust under field conditions. Several of these studies have shown both a significant decrease in wind velocity as well as an increase in sand dune growth on the lee side of the fence.[13,15-17] The degree of emissions reduction varied from study to study ranging from 0 to a maximum of about 90 percent depending on test conditions.[16,18] A summary of available test data contained in the literature on the control achieved by wind fences/ barriers is provided in Table 6-3.

Various problems have been noted with the sampling methodology used in each of the studies conducted to date. These problems tend to limit an accurate assessment of the overall degree of control achievable by wind fences/barriers for large, open sources. Most of this work has either not thoroughly characterized the velocity profile behind the fence/barrier or adequately assessed the particle flux from the exposed surface.

6.3.3 Vegetative Cover

Natural vegetative cover is the most effective, easiest, and most economical way to maintain an effective control of wind erosion. In addition to the crops such as grasses, wheat sorghum, corn legumes, and cotton, crop residues are often placed on fallow fields until a permanent crop is started. All of these methods can remove 5 to 99 percent of the direct wind force from the soil surface.[19]

Effectiveness. Grasses and legumes are most effective because they provide a dense, complete cover. Wheat and other small grains are effective beyond the crucial 2 or 3 mo after planting. Corn, sorghum, and cotton are only of intermediate effectiveness because they are planted in rows too far apart to protect the soil.

After harvesting, vegetative residue should be anchored to the surface.[20] Duley found that legume residues decay rapidly, while corn and sorghum stalks are durable.[21] He found wheat and rye straw more resistant to decay than oat straw.[21]

Maintenance. Excessive tillage, tillage with improper implements, and overgrazing are the major causes of crop cover destruction. Effective land management practices must be instituted if wind erosion is to be controlled.

TABLE 6-3. SUMMARY OF AVAILABLE CONTROL EFFICIENCY DATA FOR WIND FENCES/BARRIERS

Material or control parameter	Reference No. 16	Reference No. 18
Type of fence/barrier	Textile fabric	Wood cyclone fence
Porosity of fence/barrier	50 percent	50 percent
Height/length of fence/barrier	1.8 m/50 m	3 m/12 m
Type of erodable material	Flyash	Mixture of topsoil and coal
Material characteristics	Percent H_2O = 1.6 Percent <30 pm = 14.7 Percent <45 pm = 4.6	Unknown
Incident wind speed	Average (no screen) = 4.3 m/s (9.7 mph) Average (upwind) = 5.32 m/s (11.9 mph)	Maximum 27 m/s (60 mph)
Lee-side wind speed	Average = 2 m/s (4.0 mph) or 64 percent reduction	Unknown
Particulate measurement technique[a]	U/D = hi-vol and hi-vol w/SSI (11 tests)	U/D - Bagnold catchers (one test)
Test data rating[b]	C	C
Measured particulate control efficiency[c]	TP = 64 percent (average) TSP = 0 percent (average)	TP = 88 percent (average)

[a]Hi-vol = high volume air sampler; hi-vol w/SSI = high volume air sampler with 15 µmA size-selective inlet, SSI.
[b]Data rated using criteria specified in Section 4.4.
[c]TP = total particulate matter, TSP = total suspended particulate matter (particles <~30 µmA).

For grazing, the number of animals per acre should be controlled to maximize the use of grass and still maintain sufficient vegetative cover.

Stubble mulching and minimum tillage or plow-plant systems of farming tend to maintain vegetative residues on the surface when the land is fallow. Stubble mulching is a year-round system in which all tilling, planting, cultivating, and harvesting operations are performed to provide protection from erosion. This practice requires the use of tillage implements which undercut the residue without soil inversion.

6.3.4 Limited Irrigation of Barren Field

The periodic irrigation of a barren field controls blowing soil by adding moisture which consolidates soil particles and creates a crust upon the soil surface when drying occurs.[23] The amount of water and frequency of each irrigation during fallow to maintain a desired level of control would be a function of the season and of the crusting ability of the soil.

6.4 EXAMPLE DUST CONTROL PLAN--COVERING UNPAVED PARKING LOT WITH LESS ERODIBLE SURFACE MATERIAL

Description of Source

- Dirt parking lot of dimensions 100 m x 100 m
- Uniform daily disturbance by traffic
- Sample of surface material shows size distribution of 0.56 mm
- LCD as shown in Figure 6-8 for example month

Calculation of Uncontrolled Emissions: Wind erosion emissions from the parking lot can be calculated using the procedure described in AP-42 Section 11.2.7. Implementation of this procedure for a uniformly distributed area is carried out in the following steps:

1. Determine threshold friction velocity for surface material from the mode of the size distribution. As seen from Figure 6-1, a mode of 0.56 mm corresponds to a threshold friction velocity of 52 cm/s (u_t^*).
2. Divide the exposed surface area into subareas of constant frequency of disturbance, N. In this instance, N = 365/yr applies to the entire lot.
3. Convert the daily fastest mile values as shown in Figure 6-8 at 7 m above the surface, to equivalent friction velocities, u*, using the following variations of Equation 6-1:

Local Climatological Data

MONTHLY SUMMARY

WIND					
			FASTEST MILE		
RESULTANT DIR.	RESULTANT SPEED M.P.H.	AVERAGE SPEED M.P.H.	SPEED M.P.H.	DIRECTION	DATE
13	14	15	16	17	22
30	5.3	6.9	9	36	1
01	10.5	10.6	14	01	2
10	2.4	6.0	10	02	3
13	11.0	11.4	16	13	4
12	11.3	11.9	15	11	5
20	11.1	19.0	23	30	6
29	19.6	19.8	30	30	7
29	10.9	11.2	17	30	8
22	3.0	8.1	15	13	9
14	14.6	15.1	23	12	10
29	22.3	23.3	31	29	11
17	7.9	13.5	23	17	12
21	7.7	15.5	19	18	13
10	4.5	9.6	22	13	14
10	6.7	8.8	13	11	15
01	13.7	13.8	21	36	16
33	11.2	11.5	15	34	17
27	4.3	5.8	12	31	18
32	9.3	10.2	14	35	19
24	7.5	7.8	16	24	20
22	10.3	10.6	16	20	21
32	17.1	17.3	25	32	22
29	2.4	8.5	14	13	23
07	5.9	8.9	15	02	24
34	11.3	11.7	17	32	25
31	12.1	12.2	16	32	26
30	8.3	8.5	16	26	27
30	8.2	8.3	13	32	28
33	5.0	6.6	10	32	29
34	3.1	5.2	9	31	30
29	4.9	5.5	8	25	31
FOR THE MONTH:					
30	3.3	11.1	31	29	
—	—	—	DATE:	11	

Figure 6-8. Daily fastest miles of wind at 7 meters for periods of interest.

$$u^+_{10} = 1.05\ u^+_7$$

$$u^* = 0.053\ u^+_{10}$$

4. Calculate the erosion potential, P_i, for each day (period between disturbances) using the following equation (see Table 6-4):

$$P_i = 58\ (u^*_i - u^*_t)^2 + 25\ (u^*_i - u^*_t)$$

$$P_i = 0 \text{ for } u^* \le u^*_t$$

where: u^* = friction velocity (m/s)
u^*_t = threshold friction velocity (m/s)

5. Sum all P_i for the 31 days of interest, and multiply by the wind erosion PM_{10} multiplier, 0.5, and the affected surface area, A. This can only be done when the disturbance pattern is uniform over the entire erodible surface for each period between disturbances. The resulting uncontrolled emissions are:

$$E = kPA$$
$$= 0.5\ (32.81)(10{,}000)$$
$$= 164 \text{ kg}$$

Target Control Efficiency: 70 percent

Method of Control: Cover parking lot with any material having a high enough u^*_t to achieve 70 percent control efficiency.

Demonstration of Control Program Adequacy: Resulting control efficiencies for different u^*_t values can be calculated as shown in Table 6-5. From these calculations, it can be seen that the parking lot must be covered with a material having a u^*_t of greater than 0.64 m/s, after the loose surface material reaches an equilibrium state under the daily influence of traffic.

6.5 POTENTIAL REGULATORY FORMATS

Potential regulatory formats for control of open area wind erosion are listed in Table 6-6. These focus on appropriate measures for compliance determination. An example regulation is presented in Appendix G.

TABLE 6-4. CALCULATION OF DAILY EROSION POTENTIALS FOR UNIFORMLY DISTURBED SURFACE

Day	u_7^+, mph	u_{10}^+, mph	u^*, m/s	u_t^*, m/s	Erosion potential, g/m²
1	9	9.4	0.22	0.52	0.00
2	14	14.7	0.35	0.52	0.00
3	10	10.5	0.25	0.52	0.00
4	16	16.8	0.40	0.52	0.00
5	15	15.8	0.37	0.52	0.00
6	29	30.4	0.72	0.52	7.32
7	30	31.5	0.75	0.52	8.82
8	17	17.8	0.42	0.52	0.00
9	15	15.8	0.37	0.52	0.00
10	23	24.2	0.57	0.52	1.40
11	31	32.6	0.77	0.52	9.88
12	23	24.2	0.57	0.52	1.40
13	18	18.9	0.45	0.52	0.00
14	22	23.1	0.55	0.52	0.80
15	13	13.6	0.32	0.52	0.00
16	21	22.0	0.52	0.52	0.00
17	15	15.8	0.37	0.52	0.00
18	12	12.6	0.30	0.52	0.00
19	14	14.7	0.35	0.52	0.00
20	16	16.8	0.40	0.52	0.00
21	16	16.8	0.40	0.52	0.00
22	25	26.2	0.62	0.52	3.08
23	14	14.7	0.35	0.52	0.00
24	15	15.8	0.37	0.52	0.00
25	17	17.8	0.42	0.52	0.00
26	16	16.8	0.40	0.52	0.00
27	16	16.8	0.40	0.52	0.00
28	13	13.6	0.32	0.52	0.00
29	10	10.5	0.25	0.52	0.00
30	9	9.4	0.22	0.52	0.00
31	8	8.4	0.20	0.52	0.00
Total					32.7

TABLE 6-5. EROSION POTENTIAL (g/m^2) FOR DIFFERENT VALUES OF u_t^* (m/s)

Day	u^*, m/s	u_t^* 0.520	0.550	0.580	0.610	0.640	0.670	0.700	0.730
1	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.72	7.39	5.99	4.69	3.50	2.42	1.44	0.56	0.00
7	0.75	8.63	7.14	5.76	4.48	3.31	2.24	1.28	0.42
8	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.57	1.46	0.58	0.00	0.00	0.00	0.00	0.00	0.00
11	0.77	9.94	8.36	6.90	5.53	4.28	3.12	2.07	1.13
12	0.57	1.46	0.58	0.00	0.00	0.00	0.00	0.00	0.00
13	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.55	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.52	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.62	3.15	2.10	1.15	0.31	0.00	0.00	0.00	0.00
23	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals		32.81	24.76	18.50	13.83	10.01	6.80	3.91	1.55
Control efficiency, percent		0	25	44	58	69	79	88	95

TABLE 6-6. METHODS FOR COMPLIANCE DETERMINATION

Source types	Permits	Field audits	Work practices (recordkeeping)	Emission measurement
Construction areas	Yes	Threshold friction velocity Moisture content Visible erosion (scouring)	Wet stabilization Chemical stabilization Wind fences	% V.E. at property line/source PM_{10}/TSP concentration at property line
Vacant lots	Yes-cond. on area dist.	Threshold friction velocity Moisture content Visible erosion (scouring)	Chemical stabilization vegetation cover (% ground cover)	% V.E. at property line/source PM_{10}/TSP concentration at property line
Unpaved parking lots	Yes	Threshold friction velocity Moisture content	Graveling Chemical stabilization	% V.E. at property line/source PM_{10}/TSP concentration at property line
Feed lots	Yes-cond. on size-where allowed	Moisture content	Wet suppression (sprinklers) Wind fences	% V.E. at property line/source PM_{10}/TSP concentration at property line
Staging area	Yes	Threshold friction velocity Moisture content Visible erosion (scouring)	Wet stabilization Chemical stabilization Wind fences	% V.E. at property line/source PM_{10}/TSP concentration at property line
Off-road recreation area	Yes	-	Limit area disturbed Limit vehicles (activity emissions)	-
Land fills	Yes	-	Limit working face Wet suppression access and working area Vegetation cover	% V.E. at property line/source PM_{10}/TSP concentration at property line
Land disposal (spreading)	Yes	Threshold friction velocity Moisture content Visible erosion	Chemical stabilization Vegetative cover Wind fences	% V.E. at property line/source PM_{10}/TSP concentration at property line
Retired farm land	No	-	Vegetative cover -perennial (% ground cover)	-
H_2O mining	Yes	-	Vegetative cover -perennial (% ground cover)	-
Dry washes & river beds	No	-	Prohibit motor vehicles	-
Unpaved air strip	Yes	Threshold friction velocity Moisture content Visible erosion	Set stabilization Chemical stabilization	

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7.0 AGRICULTURE

Fugitive dust from agricultural operations is suspected of contributing significantly to the ambient particulate levels of many agricultural counties. Such agricultural operations include (a) plowing, (b) disking, (c) fertilizing, (d) applying herbicides and insecticides, (e) bedding, (f) flattening and firming beds, (g) planting, (h) cultivating, and (i) harvesting. These operations can be generically classified as soil preparation, soil maintenance, and crop harvesting operations. As discussed in Section 6, dust emissions are also generated by wind erosion of bare or partially vegetated soil. This section will focus on emissions from both wind erosion and agricultural tilling operations that are designed to (a) create the desired soil structure for the crop seed bed and (b) to eradicate weeds.

7.1 ESTIMATION OF EMISSIONS

7.1.1 Tilling

The mechanical tilling of agricultural land injects dust particles into the atmosphere as the soil is loosened or turned under by plowing, disking, harrowing, one-waying, etc. AP-42 presents a predictive emission factor equation for the estimation of dust emissions from agricultural tilling:[1]

$$E = k(5.38)(s)^{0.6} \text{ kg/ha}$$

$$E = k(4.80)(s)^{0.6} \text{ lb/acre}$$

where: s = silt content (percent) of surface soil (default value of 18 percent)

k = particle size multiplier (dimensionless)

The particle size multiplier, k is given as 0.21 for PM_{10}. The above equations are based solely on field testing information cited in AP-42. Silt content of tested soils ranged from 1.7 to 88 percent.

7.1.2 Wind Erosion

The technology currently used for predicting agricultural wind erosion in the United States is based on variations of the Wind Erosion Equation.[1,2] This prediction system uses erosion loss estimates that are integrated over large fields and long time scales to produce average annual values.

7.1.2.1 Simplified Version of Wind Erosion Equation. Presented below is a procedure for estimating windblown or fugitive dust emissions from agricultural fields. The overall approach and much of the data have been adapted from the wind erosion equation, which was developed as the result of nearly 40 yr of research by the U.S. Department of Agriculture to predict topsoil losses from agricultural fields.

Several simplifications have also been incorporated during the adaptation process. The simplified format is not expected to affect accuracy in its present usage, since wind erosion estimates using the simplified equation are almost always within 5% of those obtained with the original USDA equation. Most of the input data are not accurate to ±5%.

7.1.2.1.1 Windblown dust equation. The modified equation is of the form:

$$E = kaIKCL'V' \qquad (7\text{-}1)$$

where:
- E = PM_{10} wind erosion losses of tilled fields, tons/acre/yr
- k = 0.5, the estimated fraction of TSP which is PM_{10}
- a = portion of total wind erosion losses that would be measured as suspended particulate, estimated to be 0.025
- I = soil erodibility, tons/acre/yr
- 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, "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 temperature with little precipitation) and K, C, L', and V' as reduction factors for a ridged surface, a climate less conducive to wind erosion, smaller-sized fields, and vegetative cover, respectively.

The same equation can be used to estimate emissions from: (1) a single field, (2) a medium-sized area such as a valley or county, or (3) an entire AQCR or state. Naturally, more generalized input data must be used for the larger land areas, and the accuracy of the resulting estimates decreases accordingly.

7.1.2.1.2 Procedures for compiling input data. Procedures for quantifying the five variable factors in Equation (7-1) are explained in detail below.

Soil Erodibility, I. Soil erodibility by 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. Soil erodibility, I, is related to the percentage of dry aggregates greater than 0.84 mm as shown in Figure 7-1. 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 for use in the windblown dust equation can be obtained from the predominant soil type(s) for farmland in the area. Measured erodibilities of various soil textural classes are presented in Table 7-1.

If an area is too large to be accurately represented by a soil class or by the weighted average of several soil classes, the map in Figure 7-2 and the legend in Table 7-2 can be used to identify major soil deposits and average soil erodibility on a national basis. Other soil maps are available from the Soil Conservation Service branch of the U.S. Department of Agriculture.

Values of I obtained from Figure 7-1, from Table 7-1, or from soil maps can be substituted directly into Equation (7-1).

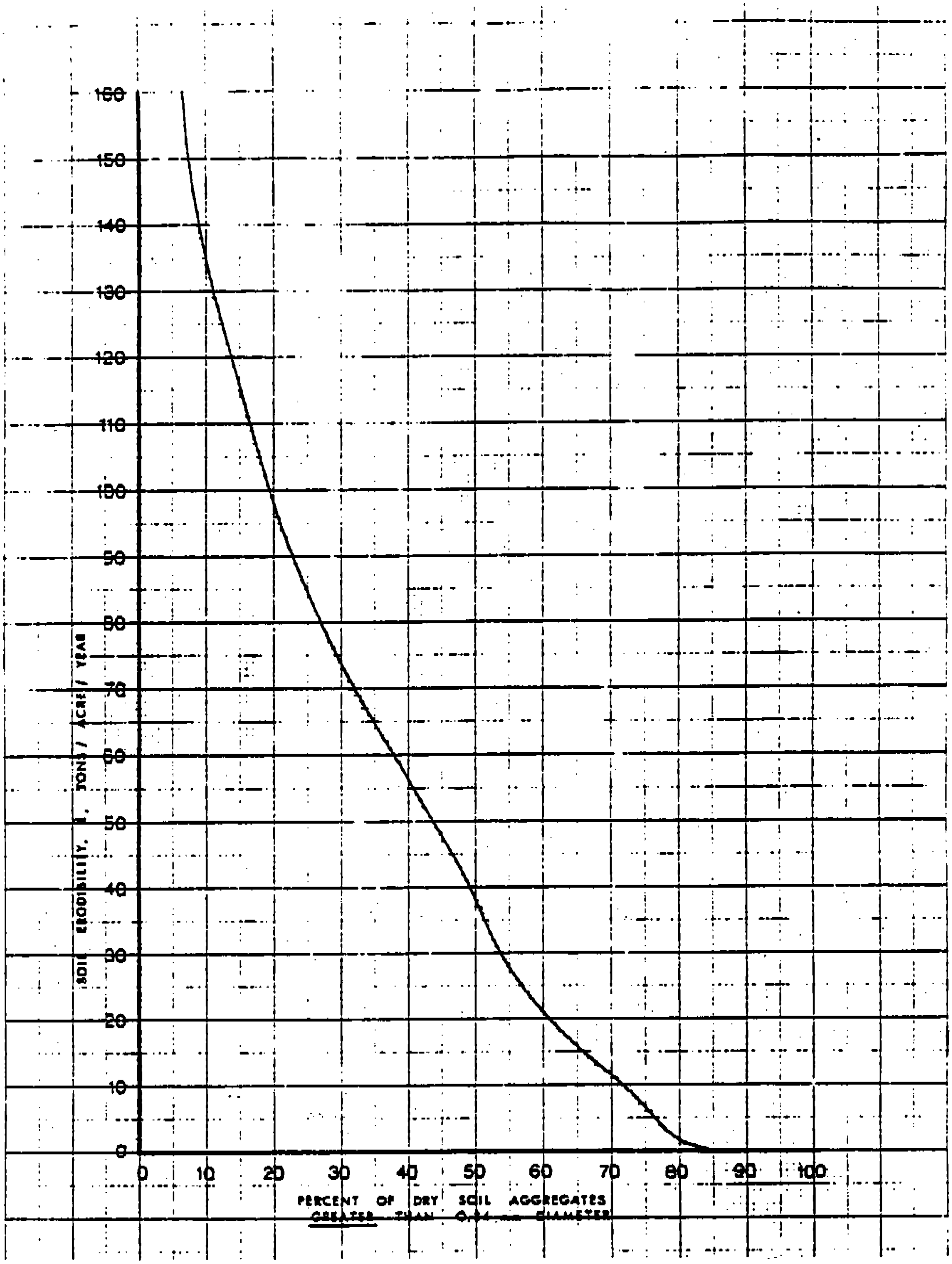


Figure 7-1. Soil erodibility as a function of particle size.

TABLE 7-1. SOIL ERODIBILITY FOR VARIOUS SOIL TEXTURAL CLASSES

Predominant soil textural class	Erodibility, I, tons/acre/yr
Sand[a]	220
Loamy sand[a]	134
Sandy loam[a]	86
Clay	86
Silty clay	86
Loam	56
Sandy clay loam[a]	56
Sandy clay[a]	56
Silt loam	47
Clay loam	47
Silty clay loam	38
Silt	38

[a]Very fine, fine, or medium sand.

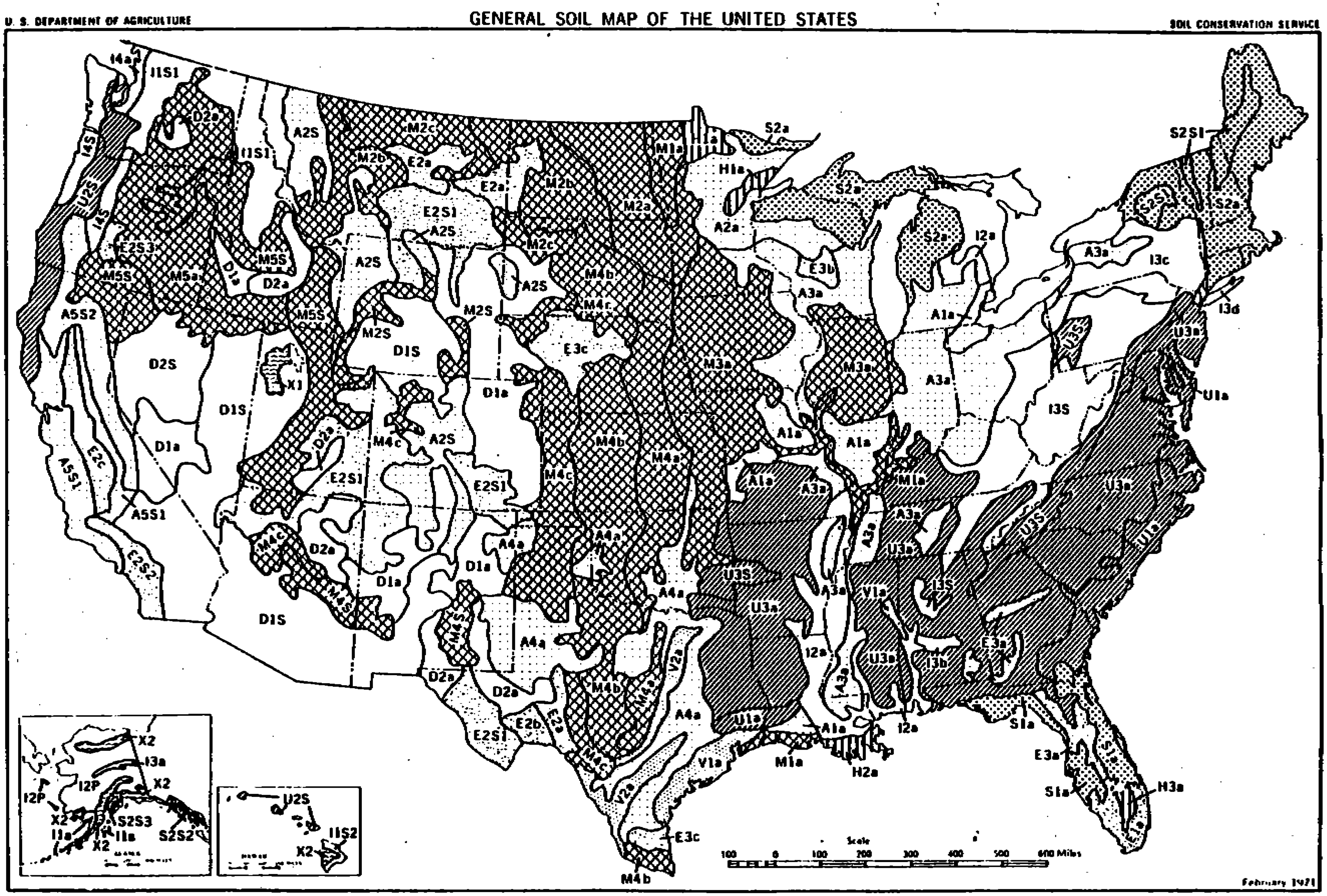


Figure 7-2. Generalized soil map of the United States.

TABLE 7-2. LEGEND FOR SOIL MAP IN FIGURE 7-2

A1, A2	Seasonally wet soils with subsurface clay accumulation
A3- A5	Cool or cold soils with subsurface clay accumulation
A6- A8	Clays
A9, A10	Burnt clay soils
A11- A13	Dry clay soils with some cementation
D1- D6	Arid soils with clay and alkali or carbonate accumulation
E1	Poorly-drained loamy sands
E2	Loamy or clayey alluvial deposits
E3- E8	Shallow clay loam deposits on bedrock
E9	Loamy sands in cold regions
E10, E12	Loamy sands in warm regions
E11, E13, E14	Loamy sands in warm, dry regions
H1, H2	Wet organic soils; peat and muck
I1	Ashy or amorphous soils in cold regions
I2	Infertile soils with large amounts of amorphous material
I3	Fertile soils of weathered volcanic ash
I4	Tundra; frozen soils
I5, I6	Thin loam surface horizon soils
I7	Clay loams in cool regions
I8- I10	Wide varying soil material with some clay horizons
I11	Rocky soils shallower than 20 in, to bedrock
I12	Clay loams in warm, moist regions
I13	Clay loams in cold regions

(continued)

TABLE 7-2 (Continued)

I14	Clay loams in temperate climates
M1- M4	Surface loam horizon underlain by clay
M5	Shallow surface loams with no underlying clays
M6- M8	Surface loamy soils
M9- M14	Semiarid loams or clay loams
M15, M16	Dry loams
O1, O2	Clays and sandy clays
S1- S4	Sandy, clay, and sandy clay loams
U1	Wet silts with some subsurface clay accumulation
U2- U6	Silty loams with subsurface clay accumulation
U7	Dry silts with thin subsurface clay accumulation
V1- V2	Clays and clay loams
V3- V5	Silty clays
X1- X5	Barren areas, mostly rock with some included soils

Surface Roughness Factor, K. This factor accounts for the resistance to wind erosion provided by ridges and furrows or large clods in the field. 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 7-3. The value of K to be used in Equation (7-1) should be rounded to the nearest 0.1 because of the large variations inherent in ridge measurement data. In cases where there are extreme variations of h or w within a field, determination of the K value should be limited to either 0.5 for a ridge surface or 1.0 for an unridged surface.

For county or regional areas, K can best be determined as a function of crop type, since field preparation techniques are relatively uniform for a specific crop. Average K values of common field crops are shown in Table 7-3. When the K (or L' or V') factors are based on crop type, separate calculations of windblown dust emissions must be made for each major crop in the survey area. This procedure is explained and demonstrated later in this presentation.

Climatic Factor, C. Research has indicated that the rate of soil movement by wind varies directly as the cube of wind velocity and inversely as the square of soil surface moisture. Surface moisture is difficult to measure directly, but precipitation-evaporation indices can be used to approximate the amount of moisture in soil surface particles. Therefore, readily available climatic data can provide a quantitative indicator of relative wind erosion potential at any geographic location.

The C factor has been calibrated using the climatic conditions at the site of much of the research--Garden City, Kansas--as the standard base (C = 1.00). At any other geographic location, the C factor for use in Equation (7-1) can be calculated as:

$$C = 0.345 \frac{W^3}{(PE)^2} \qquad (7\text{-}2)$$

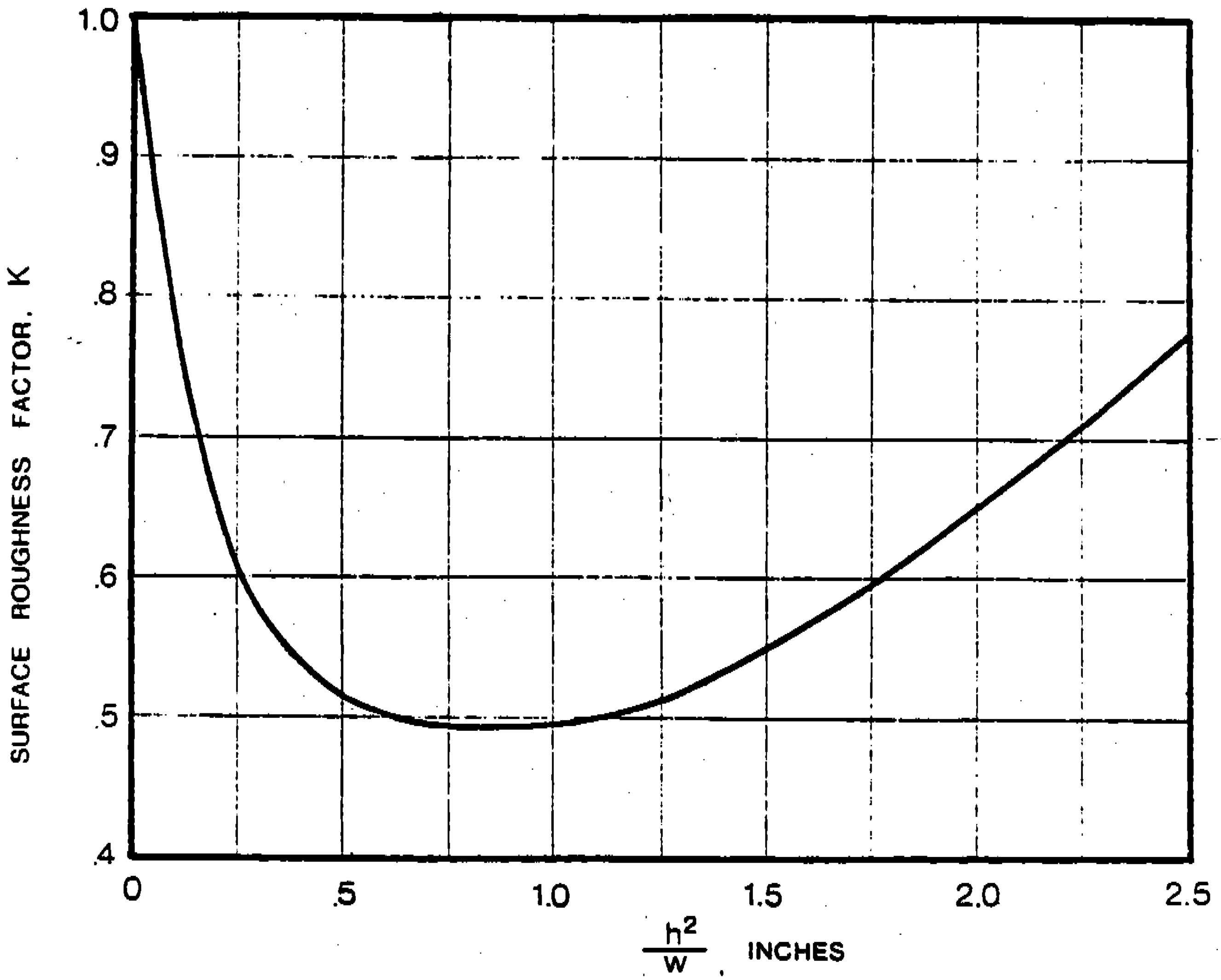


Figure 7-3. Determination of surface roughness factor.

TABLE 7-3. VALUES OF K, L, AND V FOR COMMON FIELD CROPS

Crop	K	L, ft	V, lb/acre
Alfalfa	1.0	1000	3000
Barley	0.6	2000	1100
Beans	0.5	1000	250
Corn	0.6	2000	500
Cotton	0.5	2000	250
Grain hays	0.8	2000	1250
Oats	0.8	2000	1250
Peanuts	0.6	1000	250
Potatoes	0.8	1000	400
Rice	0.8	1000	1000
Rye	0.6	2000	1250
Safflower	1.0	2000	1500
Sorghum	0.5	2000	900
Soybeans	0.6	2000	250
Sugar beets	0.6	1000	100
Vegetables	0.6	500	100
Wheat	0.6	2000	1350

where: W = mean annual wind velocity, in mph, corrected to a standard height of 30 ft

PE = Thornthwaite's precipitation-evaporation index

= 0.83 (sum of 12 monthly ratios of precipitation to actual evapotranspiration)

Monthly or seasonal climatic factors can be estimated from Equation (7-2) by substituting the mean wind velocity of the period of interest for the mean annual wind velocity. The annual PE value is used for all calculations of C.

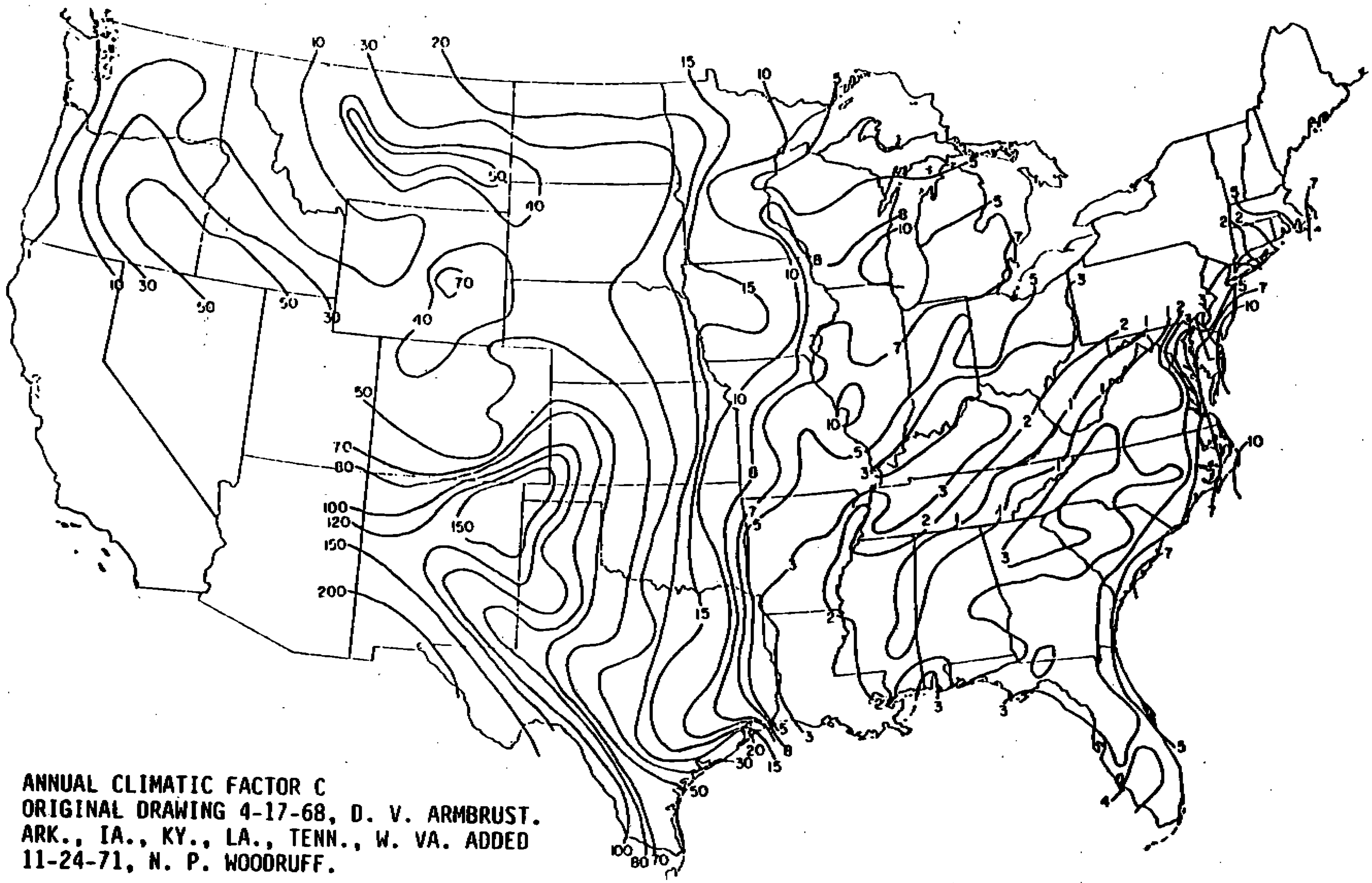
Climatic factors have been computed from Weather Bureau data for many locations throughout the country. Figure 7-4 is a map showing annual climatic factors for the USA. C values for use in Equation (7-1) may be taken from appropriate maps like this when preparing regional emission surveys. For emission estimates covering smaller areas, Equation (7-2) may be used to obtain C.

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 in Figure 7-5. If the curves of Figure 7-5 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 must 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 10 H. For example, a row of 30-ft high trees along the windward side of a field reduces the effective width of the field by 10 x 30 or 300 ft. If the

NOTE: ISOPLETHS FOR SEVERAL WESTERN AND NORTH EASTERN STATES WERE NOT AVAILABLE AT THE TIME THIS FIGURE WAS PREPARED. FACTORS FOR THESE AREAS CAN BE CALCULATED FROM EQUATION 7-2.



ANNUAL CLIMATIC FACTOR C
ORIGINAL DRAWING 4-17-68, D. V. ARMBRUST.
ARK., IA., KY., LA., TENN., W. VA. ADDED
11-24-71, N. P. WOODRUFF.

Figure 7-4. Climatic factor used in wind erosion equation.

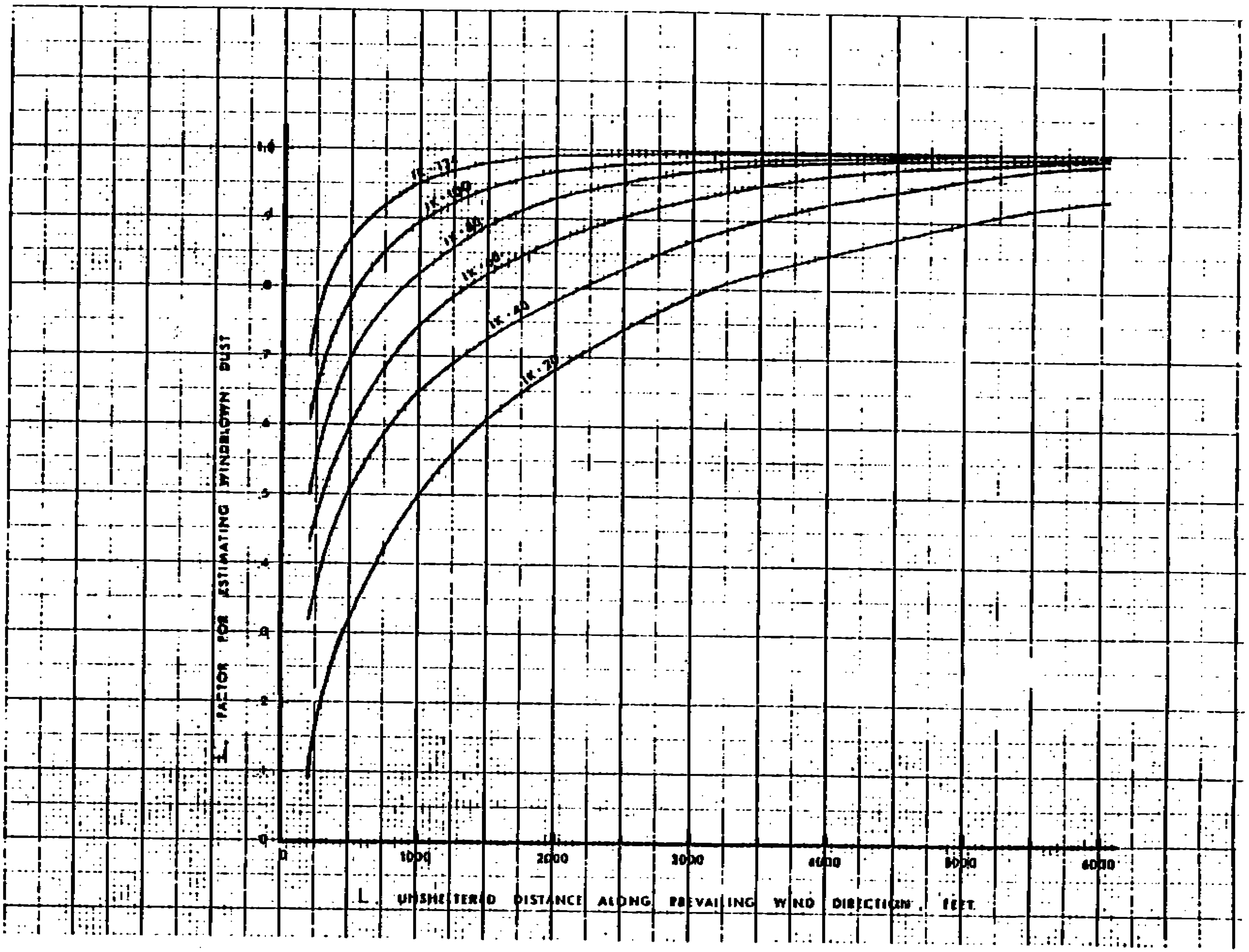


Figure 7-5. Effect of field length on relative emission rate.

prevailing wind direction differs significantly (more than 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:

$$L = \frac{W}{\cos A}$$

For multiple fields or regional surveys, measurement and calculation of L values become unwieldy. In region-wide emission estimates, average field widths should be used. Field width is generally a function of the crop being grown, topography of the area, and the amount of trees and other natural vegetation in or adjacent to the farming areas that would shelter fields from erosive winds. Since the windblown dust calculations are already split into individual crop type to accurately consider variations in K by crop, average L values have also been developed by crop; they are presented in Table 7-3. These values are representative of field sizes in relatively flat terrain devoid of tall natural vegetation, such as found in large areas of the Great Plains. The L values in Table 7-3 should be divided by 2 in areas with moderately uneven terrain and by 3 in hilly areas. Additionally, the average field width factors should be divided by 2 to account for wooded areas and fence thickets interspersed with farmland.

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 quantitatively in Figure 7-6, where IKCL' is the potential annual soil loss (in tons/acre/yr) 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. Obviously, the other four variables in Equation (7-1)--I, K, C, and L'--must be known before V' can be determined from Figure 7-6.

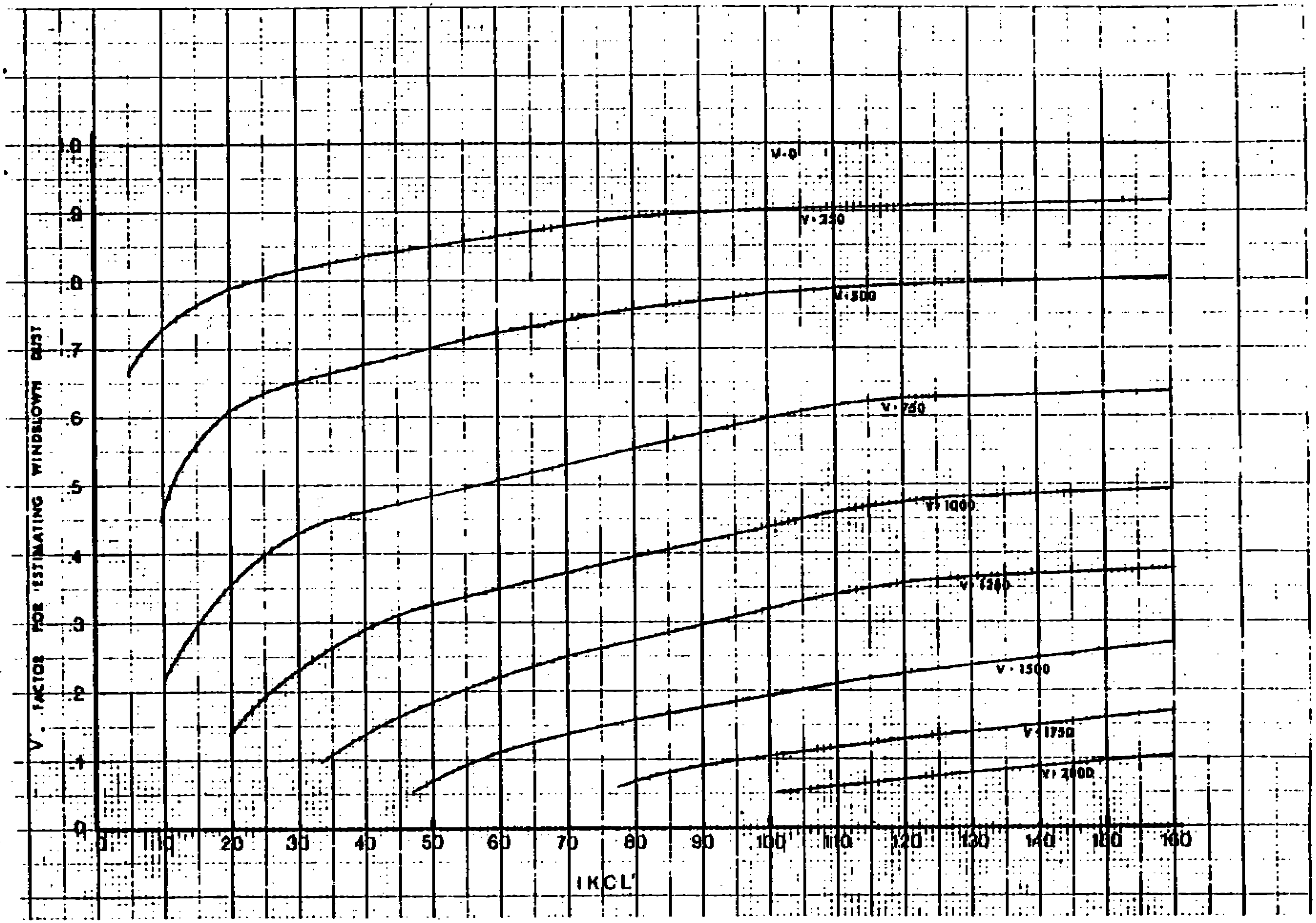


Figure 7-6. Effect of vegetative cover on relative emission rate.

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 weight obtained by either measuring method must then be converted to an equivalent weight of flat small-grain stubble before entering Figure 7-6, since different crop residues vary in their ability to reduce wind erosion. Detailed descriptions of the measuring methods or conversion procedures are too complex for this presentation. Interested readers are referred to the USDA for these descriptions.

The residue left on a field when using good soil conservation practices is closely related to the type of crop. Table 7-3 presents representative values of V for common field crops when stubble or mulch is left after the crop. These values should be used in calculating windblown dust emissions unless a knowledge of local farming practices indicates that some increase or decrease is warranted. Note that three of the five variables in the windblown dust equation are determined as functions of the crop grown on the field.

7.1.2.1.3 <u>Summary</u>. The estimated emissions in tons/acre/yr may now be calculated for each field or group of fields as the product of the five variables times the constant "a" estimated to be 0.025, and the particle size multiplier for PM_{10} estimated to be 0.5.

For regional emission estimates, the acreage in agriculture should be determined for each jurisdiction (e.g., county) by crop. "I" and "C" values can be determined for individual jurisdiction, with the remaining three variables being quantified as functions of crop type. The emission calculations are best performed in a tabular format such as the one shown in Table 7-4. The calculated emissions from each crop are summed to get agricultural wind erosion emissions by jurisdiction and these are totaled to get emissions for this source category for the entire region.

7.1.2.1.4 <u>Appropriate Usage of Results</u>. Inherent variabilities in the many parameters used in the windblown dust equation cause the results to be less accurate than emission estimates for most other sources. However, the rough estimates provided by the proposed procedure are better than not considering this source at all in particulate emission inventory

TABLE 7-4. CALCULATION SHEET FOR ESTIMATION OF DUST FROM WIND EROSION

Juris-diction (County)	I, Based on Soil Type	C, Climatic Factor	Crop	Acres	K, Surface Roughness	L, Field Length	V, Veget. Cover	L', Length Factor	V', Veget. Factor	E, = aIKC-L'V'	Total Emissions By Crop
			Alfalfa								
			Barley								
			Beans								
			Corn								
			Cotton								
			Potatoes								
			Sorghum								
			Soybeans								
			Sugar Beets								
			Vegets.								
			Wheat								
			Etc.								
										Total	
			(List of Crops Grown in Juris-diction)								
										Total	

work. Inclusion of this source category, possibly with some qualifying statement as to its relative accuracy, gives an indication of its contribution to regional air quality.

The estimation procedure is not intended for use in predicting emissions for short time periods, nor can it be used in determining emission rates for enforcement purposes.

7.1.2.2 New Wind Erosion Prediction Technology. New technology for prediction of agricultural wind erosion is currently being developed by the U.S. Department of Agriculture. This undertaking was recently described by L. J. Hagen as follows.[3]

> Currently, the U.S. Department of Agriculture is taking a leading role in combining erosion science with data bases and computers to develop what should be a significant advancement in wind erosion prediction technology. In 1986 an initial group composed of Agricultural Research Service (ARS) and Soil Conservation Service (SCS) scientists was formed to begin development of a new Wind Erosion Prediction System (WEPS). Additional scientists are now being added to the group to strengthen specific research and technology development areas. The objective of the project is to develop replacement technology for the Wind Erosion Equation.
>
> The primary user of wind erosion prediction technology is the USDA Soil Conservation Service, which has several major applications. First, as a part of the periodic National Resource Inventory, it collects data at 300,000 primary sampling points, and at central locations, calculates the erosion losses occurring under current land use practices. The analyzed results are used to aid in developing regional and national policy.
>
> Second, SCS does conservation planning of wind erosion control practices to assist farmers and ranchers in meeting erosion tolerances. Implementation of adequate conservation plans preserves land productivity and reduces both onsite and offsite damages. Conservation planning requires a prediction system that will operate on a personal computer and produce answers in a relatively short time. In addition, WEPS must serve as a communication tool between conservation planners and those who implement the plans.
>
> Various users also undertake project planning in which erosion prediction is used to evaluate erosion and deposition in areas impacted by the project. In this application, more time and resources may be expended than in conservation planning to collect input data and make analyses. Project

planning is typically carried out by multidisciplinary teams including field personnel who collect needed input data.

Other users of wind erosion prediction technology represent a wide range of problem areas. Often their problems will require development of additional models to supplement WEPS in order to obtain answers of interest. Some of these diverse problem areas include evaluating new erosion control techniques, estimating long-term soil productivity changes, calculating onsite and offsite economic costs of erosion, finding deposition loading of lakes and streams, computing the effects of dust on acid rain processes, determining impact of management strategies on public lands, and estimating visibility reductions near airports and highways.

From the preceding survey of user needs, it is apparent that the prediction technology must deal with a wide range of soil types and management factors. Wind erosion prediction technology also must cover a broad range of climatic and geographic regions in the United States. The major impact of wind erosion is in the Great Plains, but erodible areas in the Great Lakes region, the semiarid western United States, and windy coastal regions are all affected.

7.2 DEMONSTRATED CONTROL TECHNIQUES

7.2.1 Tilling

Operational modifications to tilling of the soil include the use of novel implements or the alteration of cultural techniques to eliminate some operations altogether. All operational modifications will affect soil preparation or seed planting operations. Furthermore, the suggested operational modifications are crop specific. Estimated PM_{10} efficiencies for agricultural controls are presented in Table 7-5.

The punch planter is a novel implement which might have applications for emissions reduction from planting cotton, corn, and lettuce. The punch planter is already being used in sugar beet production. The punch planter punches a hole and places the seed into it, as opposed to conventional planters which make a trough and drop the seeds in at a specified spacing. The advantage is that punch planters can leave much of the surface soil and surface crop residues undisturbed. Large-scale use of the punch planters would require initial capital investments by the farming industry for new equipment.

TABLE 7-5. ESTIMATED PM-10 EFFICIENCIES FOR AGRICULTURAL CONTROLS[3]

Control technique	Operation affected	Estimated control efficiency (percent) by crop for applicable techniques							
		Cotton	Barley	Alfalfa	Rice	Corn	Wheat	Process tomatoes	Lettuce
Punch planter	Planting	50				50			50
Herbicides	Cultivation or soil preparation	100	25[a]	25[a]	b	100	25[a]	100	100
Sprinkler irrigation	Land planing	90	90	90	c	90	90	90	90
Laser-directed land plane	Land planing or floating	30	30	30	30	30	30	30	30
Develop high quality alfalfa	All soil preparation operations			75					
Double crop corn with wheat	Disking or plowing					50[d]			
Aerial seeding	Planting			50	3		50		

[a] Eliminates only some soil preparation operations, whereas in other cases, all cultivation operations are eliminated.
[b] Herbicides already applied by airplane for majority of acreage.
[c] Flood irrigation necessary.
[d] Fifty percent control only for double-cropped acreage.
[e] Seeding already performed by airplane for majority of acreage.

Herbicides for weed control is a cultural practice which could reduce emissions from cultivation for most new crops with wide enough spacing for cultivation and for some close-grown crops like wheat. Much of the preplant tillage of wheat soil is for weed control. The use of herbicides, however, must be balanced against potential increased herbicide emissions caused by wind and by water runoffs.

Sprinkler irrigation is an existing cultural technique which could produce fugitive emission control for any crop which is currently irrigated by surface watering systems. Sprinkler irrigation eliminates the need for extensive land planing operations which surface irrigation requires. However, the capital investment for sprinkler irrigation equipment and the increased costs of pumping the water are major deterrents.

The laser-directed land plane is a novel implement which might yield some emissions controls for surface-irrigated crops. Laser-guided grading equipment has been used in construction for years and can be expected to reduce the amount of land planing required due to its more precise leveling blade. This device might be retrofitted to existing land planes, but capital investment funds are required.

The development of long lasting varieties of alfalfa with high leaf protein content would help to reduce emissions, because present practices require replanting every 3 to 5 yr. New varieties already exist which can last up to 20 yr, but the protein content is low. If longevity and quality could be combined, the soil would not have to be prepared so often, thus yielding a subsequent reduction in emissions.

Double-cropping corn with wheat or other grain instead of corn with corn might reduce fugitive emissions. Since corn provides so much stubble, it must be plowed or disked under. The beds must then be formed and shaped for the next corn seed planting. If wheat or another grain were grown on a bedded field, then corn could be planted on the beds after the wheat harvest and stubble removal. The beds would require only reshaping. This would eliminate a plowing or disking operation and a bed-forming operation while adding a less dusty wheat stubble removal operation.

Finally, aerial seeding, which is already used in rice production, would probably reduce emissions somewhat from alfalfa and wheat production. However, at least in the case of wheat, the aerially applied seed must be covered. This covering operation will produce dust, but it may be less dust than a ground planting operation would produce.

7.2.2 Wind Erosion

Agricultural wind erosion control is accomplished by stabilizing erodible soil particles. The stabilization process is accomplished in three major successive stages: (a) trapping of moving soil particles, (b) consolidation and aggregation of trapped soil particles, and (c) revegetation of the surface.[3]

The trapping of eroding soil is termed "stilling" of erosion. This may be effected by roughening the surface, by placing barriers in the path of the wind, or by burying the erodible particles during tillage. Trapping is accomplished naturally by soil crusting resulting from rain followed by a slow process of revegetation. It should be stressed that the stilling of erosion is only temporary; to effect a permanent control, plant cover must be established or plant residues must be maintained.

In bare soils containing a mixture of erodible and nonerodible fractions, the quantity of soil eroded by the wind is limited by the height and number of nonerodible particles that become exposed on the surface. The removal of erodible particles continues until the height of the nonerodible particles that serve as barriers to the wind is increased to a degree that affords complete shelter to the erodible fractions. If the nonerodible barriers are low, such as fine gravel, a relatively large number of pieces are needed for protection of soil from wind erosion. The gravel in such a case would protect the erodible portion more by covering than by sheltering from the wind. Thus all nonerodible materials on the ground that control erosion have an element of cover in addition to the barrier principle which protects the soil. The principles of surface barriers and cover are, therefore, inseparable.

The above principles extend to almost all elements used in wind erosion control. All of these control methods are designed to (a) take up some or all of the wind force so that only the residual force, if any, is taken up by the erodible soil fractions; and (b) trap the eroded soil, if any, on the lee side or among surface roughness elements or barriers, thereby reducing soil avalanching and intensity of erosion.

In the sections that follow, various control methods are discussed with respect to their characteristics and effectiveness in controlling erosion. Methods include vegetative cover, soil ridges, windbreaks, crop strips, chemical stabilizers, and irrigation.

7.3 EVALUATION OF ALTERNATIVE CONTROL MEASURES

7.3.1 Tilling

The estimates of emission control efficiency for each tillage control technique discussed above are given in Table 7-5. These estimates are derived from consideration of the reduced level of soil disturbance associated with the specified control technique.

As evidenced by the discussion in Section 7.2, many of the demonstrated control techniques are capital-intensive. In other words, identified cost elements typically include the capital expense to purchase a new implement.

O&M costs are assumed to be equal to those with the older equipment and, as such, need not be considered in assessing cost effectiveness.

Based on the fact that control of tillage practices would fall under soil conservation rather than environmental regulations (as discussed below), no cost data for control of tillage practices are presented in this section.

7.3.2 Wind Erosion

7.3.2.1 Vegetative Cover. Natural vegetative cover is the most effective, easiest, and most economical way to maintain an effective control of wind erosion. In addition to the crops such as grasses, wheat sorghum, corn legumes, and cotton, crop residues are often placed on fallow fields until a permanent crop is started. All of these methods can remove 5 to 99 percent of the direct wind force from the soil surface.[4]

Effectiveness. Grasses and legumes are most effective because they provide a dense, complete cover. Wheat and other small grains are effective beyond the crucial 2 or 3 mo after planting. Corn, sorghum, and cotton are only of intermediate effectiveness because they are planted in rows too far apart to protect the soil.

After harvesting, vegetative residue should be anchored to the surface.[5] Duley found that legume residues decay rapidly, while corn and sorghum stalks are durable.[6] He found wheat and rye straw more resistant to decay than oat straw.

Maintenance. Excessive tillage, tillage with improper implements, and overgrazing are the major causes of crop cover destruction. Effective land management practices must be instituted if wind erosion is to be controlled.

For grazing, the number of animals per acre should be controlled to maximize the use of grass and still maintain sufficient vegetative cover.

Stubble mulching and minimum tillage or plow-plant systems of farming tend to maintain vegetative residues on the surface when the land is fallow. Stubble mulching is a year-round system in which all tilling, planting, cultivating, and harvesting operations are performed to provide protection from erosion. This practice requires the use of tillage implements which undercut the residue without soil inversion.

7.3.2.2 Tillage Practices. The soil surface can be made cloddy and rough in order to control erosion by developing a surface barrier. Such practices include: (a) regular tillage processes to prepare seedbeds and to control weeds for crop production; and (b) emergency tillage practices used specifically to bring clay to the surface for possible increased cloddiness and to roughen the land to prevent wind erosion.

Regular tillage. It is important that all tillage operations be conducted sparingly because tillage leads to soil surface smoothing and clod pulverization. Soil moisture at time of tillage has an effect on cloddiness. Different soils have differing moisture contents at which soil pulverization is most severe. More clods are produced if the soil is either extremely dry or moist than if it contains an intermediate moisture content.[7]

The type of tillage implement used also has an influence on soil cloddiness and surface roughness.[7] A study conducted with a moldboard plow, a one-way disk, and a subsurface sweep in controlled soil moisture conditions demonstrated that cloddiness is more dependent on the type of machinery than soil moisture content. The moldboard plow produced a rougher, more cloddy surface with higher mechanical stability of clods than the one-way disk or subsurface sweeps. Tillage implements used in stubble mulch farming, with the exception of chisel cultivators, usually do not leave a ridged, rough surface. Subsurface sweeps provide a smooth surface and are advantageous insofar as they allow the vegetation to remain erect.

It is important that planting and seeding equipment preserve as much residue as possible, keep the soil surface rough and cloddy, and also, place the seed in moist, firm soil to promote rapid germination. Major types of planters available for small grains include hoes, single and double disks, deep furrow drills, and seeding attachments on one-ways and cultivators.

Emergency tillage. Emergency tillage to provide a rough, cloddy surface is a temporary measure, and its only purpose is to create an erosion-resistant soil surface in a short period of time. It is a last resort measure to be implemented when vegetative cover is depleted by excessive grazing, drought, improper or excessive tillage, or by growing crops that produce little or no residue or when potentially severe erosive conditions are expected.

The most common implements used are listers, duckfoot cultivators, and narrow-tooth chisel cultivators. The effectiveness of any of the above in creating cloddiness depends upon soil moisture, texture, and density. Cloddiness of soil is increased markedly by increasing density; also, the cloddiness potential of soils with a high clay content is greater than for sandy soils. Speed of travel, depth of tillage, spacing between tillage point carriers, and type of part also influence the degree of cloddiness. Speeds of 5.6 to 6.4 km/h (3.5 to 4.0 mph) provide the optimum degree of cloddiness.

As for depth, 7.6 to 15.2 cm (3 to 6 in) brings up compact clods. Spacing of lister and chisel must be governed by severity of erosion and the presence or absence of crops. Close spacing creates a rougher surface. However, if a crop is involved and there is a possibility of saving part of it, then wide spacings of 122 to 137 cm (48 to 54 in) should be used to both provide roughness for control and permit the crop to grow.

Listers and narrow chisels are most effective types of tillage points. Listers produce a high degree of roughness and are especially effective in sandy soils where clods can be produced by deep tillage. Chisel cultivators require less power and destroy less crop than do listers.

7.3.2.3 Windbreaks and Wind Barriers. Windbreaks consist of trees or shrubs in 1 to 10 rows, crops in narrow rows, snow fences, solid wooden or rock walls, and earthen banks. Windbreaks function as surface barriers to control wind erosion; i.e., they take up or deflect a sufficient amount of the wind force to lower the wind velocities to the leeward below the threshold required to initiate soil movement. The effectiveness of any barrier depends on the wind velocity and direction, shape, width, height, and porosity of the barrier.

Nearly all barriers provide maximum reduction in wind velocity at leeward locations near the barrier, gradually decreasing downwind. Percentage reductions in wind velocities for rigid barriers remain constant no matter what the wind velocity.[5]

Direction of wind influences the size and location of the protected areas. Area of protection is greatest for perpendicular winds to the barrier length and least for parallel winds.

The shape of the windbreak indicates that a vertically abrupt barrier will provide large reductions in velocity for relatively short leeward distances, whereas porous barriers provide smaller reductions in velocity but for more extended distances.

Height of the barrier is, perhaps, the most important factor influencing effectiveness. Expressed in multiples of barrier height, the zone of wind velocity reduction on the leeward side may extend to 40 to 50 times the height of the barrier; however, such reductions at those distances are insignificant for wind erosion control. If complete control is desired, then barriers must be placed at close intervals.

One-, two-, three, and five-row barriers of trees are found to be the most effective arrangement for planting to control wind erosion. The type of tree species planted also has a considerable influence on the effectiveness of a windbreak. The rate of growth governs the extent of protection that can be realized in later years.

7.3.2.4 Strip-Cropping. The practice of strip-cropping consists of dividing a field into alternate strips of erosion-resistant crops and erosion-susceptible crops or fallow. Erosion-resistant crops are the small grains and other crops that cover the ground rapidly. Erosion-susceptible crops are cotton, tobacco, sugar beets, peas, beans, potatoes, peanuts, asparagus, and most truck crops.

Strip-cropping controls erosion by reducing soil avalanching, which increases with width of eroding field. Since avalanching depends on field erodibility, the appropriate width of strips required varies with factors that influence erodibility, such as soil texture, wind velocity and direction, quantity of crop residue, and degree of soil cloddiness and surface roughness.

Available data indicate that directional deviation of erosive winds from the perpendicular requires narrower strips, and that required width of the strip increases as soil texture becomes finer, except for clays and silty clays subject to granulation.

Strip-cropping alone will not fully control wind erosion; it must be used in conjunction with other measures, such as stubble mulching, to be fully effective. In combination with strip-cropping, the supplementary practices need not be as intensive as they would have to be for large fields.

Row crop spacing. The relative effectiveness of different row spacings for wind erosion control has not been fully evaluated. In theory, the closer the row spacing, the more effective is the protection afforded against erosion. Most closely spaced crops are erosion resistant once they are established. Sorghum, corn, cotton, and other crops normally planted in rows 102 to 107 cm (40 to 42 in) apart are not as resistant. Experiments have shown that some of these crops can be grown in more closely spaced rows without being detrimental to crop yield.

Orientation of crop rows to the prevailing erosive winds has an effect on erosion. The relative amount of erosion from soil planted to wheat in rows 25.4 cm (10 in) apart is 6 times greater when the wind is blowing parallel to rows than when it blows perpendicular to the rows.[3]

7.3.2.5 Limited Irrigation of Fallow Field. The periodic irrigation of a barren field controls blowing soil by adding moisture which consolidates soil particles and creates a crust upon the soil surface when drying occurs.[8] The amount of water and frequency of each irrigation during fallow to maintain a desired level of control would be a function of the season and of the crusting ability of the soil. The drawback to irrigation control concerns the availability of water, cost of water, and interference with farming activities on the cropland.[9]

7.4 POSSIBLE REGULATORY FORMATS

The Food Security Act (FSA) contains two provisions which may significantly reduce dust emissions from agricultural tilling. The first provision requires a conservation plan on all land which is designated as "highly erodible" for either wind or water erosion. Plans must be filed by 1990 and implemented by 1995 in order for the land owner to be eligible for government (USDA) program benefits such as insurance and subsidies. The second provision is the 45-million-acre Conservation Reserve Program (CRP), a procedure for taking highly erodible cropland out of production and establishing a vegetative cover upon it.

The EPA is beginning to work with the U.S. Department of Agriculture (USDA) to explore ways in which reduction of PM_{10} in populated areas can be accomplished in part by the provisions of the FSA. The following information relative to rural fugitive dust has been obtained:

1. Many farms with highly erodible land (HEL) are already practicing wind erosion control but almost all HEL will need to make changes to comply with the FSA.

2. The air in cities (and smaller towns) surrounded by agricultural land should be cleaner because of both the CRP and HEL controls required by the FSA.

3. Towns and cities do care about reducing the impact of dust storms. There is perhaps less concern in the small, agriculturally oriented towns.

4. The CRP could provide substantial additional reductions in PM_{10} in populated areas if more of the farmland near cities were incorporated into the CRP (buffer zone). This buffer could be accomplished through zoning or by increasing the acceptable bid in the buffer area. The legal aspects of such approaches are being investigated.

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APPENDIX A.

OPEN DUST SOURCE EMISSION FACTOR RATING AND CONTROL EFFICIENCY TERMINOLOGY

APPENDIX A. OPEN DUST SOURCE EMISSION FACTOR RATING AND CONTROL EFFICIENCY TERMINOLOGY

A.1 EMISSION FACTOR RATING TERMINOLOGY

In AP-42, the reliability of emission factors is indicated by an overall Emission Factor Rating ranging from A (excellent) to E (poor). These ratings take into account the type and amount of data from which the factors were calculated. Note that measurements underlying each emission factor are rated on a similar scale of A to D.

The use of a statistical confidence interval may seem desirable as a more quantitative measure of the reliability of an emission factor. Because of the way an emission factor data base is generated, however, prudent application of statistical procedures precludes the use of confidence intervals unless the following conditions are met:

- The sample of sources from which the emission factor was determined is representative of the total population of such sources.
- The data collected at an individual source are representative of that source (i.e., no temporal variability resulting from source operating conditions could have biased the data).
- The method of measurement was properly applied at each source tested.

Because of the almost impossible task of assigning a meaningful confidence limit to the above variables and to other industry-specific variables, the use of a statistical confidence interval for an emission factor is not practical.

The following emission factor ratings are applied to the emission factors:

A - Excellent. Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough to minimize variability within the source category population.

B - Above average. Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

C - Average. Developed only from A- and B-rated data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A rating, the source category is specific enough to minimize variability within the source category population.

D - Below average. The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are footnoted in the emission factor table.

E - Poor. The emission factor was developed from C- and D-rated test data, and there may be reason to suspect that the facilities tested do not represent a random sample of the industry. There may be evidence of variability within the source category population.

Limitations on the use of these factors are always footnoted. Because the application of these factors is somwhat subjective, the reasons for each rating are documented in the background files maintained by the Office of Air Quality Procedures and Standards (OAQPS).

A.2 CONTROL EFFICIENCY TERMINOLOGY

Some control techniques often used 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 percent to 0 in a matter of hours (or minutes). The control efficiency for broom sweeping and flushing applied in combination on a paved road may decay to zero in 1 or 2 days. Chemical dust suppressants applied to unpaved roads can yield control efficiencies that will decay to zero in several months. Consequently, a single-valued control efficiency is usually not adequate to describe the performance of most intermittent control techniques for open dust sources. The control efficiency must be reported along with a time period over which the value applies. For continuous control systems (e.g., wet suppression for materials transfer), a single control efficiency is usually appropriate.

Certain terminology has been developed to aid in describing the time dependence of open dust control efficiency. These terms are:

1. Control lifetime is the time period (or amount of source activity) required for the efficiency of an open dust control measure to decay to zero.

2. Instantaneous control efficiency is the efficiency of an open dust control at a specific point in time.

3. Average control efficiency is the efficiency of an open dust source control averaged over a given period of time (or number of vehicle passes).

From the above definitions, it is clear that average control efficiency is related to instantaneous control efficiency by the following general equation:

$$C(X) = \frac{1}{X} \int_0^X c(x)dx$$

where: x = time (or number of vehicle passes) after application

X = time (or number of vehicle passes) over which an average efficiency is desired

c = instantaneous control efficiency

C = average control efficiency

Field tests of certain paved and unpaved road dust controls indicate that instantaneous control efficiency may be adequately represented as a linear function of time (or vehicle passes):

$$c(x) = a-bx$$

where a and b are constants, and $b \geq 0$. In that case, average control efficiency is given by

$$c(X) = a \frac{b}{2}X$$

APPENDIX B.

ESTIMATION OF CONTROL COSTS AND COST EFFECTIVENESS

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ESTIMATION OF CONTROL COSTS AND COST EFFECTIVENESS

Development and evaluation of particulate fugitive emissions control strategies require analyses of the relative costs of alternative control measures. Cost analyses are used by control agency personnel to develop overall strategies for an air pollution control district or to evaluate plant specific control strategies. Industry personnel perform cost analyses to evaluate control alternatives for a specific source or to develop a plant-wide emissions control strategy. Although the specifics of these analyses may vary depending upon the objective of the analysis and the availability of cost data, the general format is similar.

The primary goal of any cost analysis is to provide a consistent comparison of the real costs of alternative control measures. The objective of this section is to provide the reader with a methodology that will allow such a comparison. It will describe the overall structure of a cost analysis and provide the resources for conducting the analyses. Because cost data are continuously changing, specific cost data are not provided. However, sources of cost information and mechanisms for cost updating are provided.

The approach outlined in this section will focus on cost effectiveness as the primary comparison tool. Cost effectiveness is simply the ratio of the annualized cost of the emissions control to the amount of emissions reduction achieved. Mathematically, cost effectiveness is defined by:

$$C^* = \frac{C_a}{\Delta R} \qquad \text{(B-1)}$$

where: C^* = cost effectiveness, \$/mass of emissions reduction

C_a = annualized cost of the control measure, \$/year

ΔR = reduction (mass/year) in annual emissions

This general methodology was chosen because it is equally applicable to different controls that achieve equivalent emissions reduction on a single source and to measures that achieve varied reductions over multiple sources.

The discussion is divided into three sections. The first section describes the general cost analysis methodology, including the various types of costs that should be considered and presents methods for calculating those costs. The second identifies the primary cost elements associated with each of the fugitive emissions control systems. The final section identifies sources of cost data and discusses methods for updating cost data to constant dollars, and includes example calculation cases for estimating costs and cost effectiveness.

B.1 GENERAL COST METHODOLOGY

Calculation of cost effectiveness for comparison of control measures or control strategies can be accomplished in four steps. First, the alternative control/cost scenarios are selected. Second, the capital costs of each scenario is calculated. Third, the annualized costs for each of the alternatives is developed. Finally, the cost effectiveness is calculated, taking into consideration the level of emissions reduction.

The general approach for performing each of the above steps is described below. This approach is intended to provide general guidance for cost comparison. It should not be viewed as a rigid procedure that must be followed in detail for all analyses. The reader may choose or may be forced through resource or informational constraints to omit some elements of the analysis. However, for comparisons to be valid, cautions that should be observed are: (1) all control scenarios should be treated in the same manner; and (2) cost elements that vary radically between cost scenarios should not be omitted.

B.1.1 <u>Select Control/Cost Scenarios</u>

Prior to the cost analysis general control measures or strategies will have been identified. These measures or strategies will fall into one of the major classes of fugitive emission control techniques that were identified. The first step in the cost analysis is to select a set of specific control/cost scenarios from the general techniques. The specific scenarios will include definition of the major cost elements and identification of specific implementation alternatives for each of the cost elements.

Each of the general control techniques identified in Chapter 4 has several major cost elements. These elements include capital equipment elements and operation/maintenance elements. For example, the major cost elements for chemical stabilization of an unpaved road include: (a) chemical acquisition; (b) chemical storage; (c) road preparation; (d) mixing the chemical with water; and (e) application of the chemical solution. The first step in any cost analysis is definition of these major cost elements. Information is provided in Section B.2 on the major cost elements associated with each of the general techniques.

For each major cost element, several implementation alternatives can be chosen. Options within each cost element include such choices as buying or renting equipment; shipping chemicals by railcar, truck tanker, or in drums via truck; alternative sources of power or other utilities; and use of plant personnel or contractors for construction and maintenance. The major cost elements and the implementation alternatives for each of these elements for the chemical stabilization example described above are outlined in Table B-1.

B.1.2 Develop Capital Costs

The capital costs of a fugitive emissions control system are those direct and indirect expenses incurred up to the date when the control system is placed in operation. These capital costs include actual purchase expenses for capital equipment, labor and utility costs associated with installation of the control system, and system startup and shakedown costs. In general, direct capital costs are the costs of control equipment and the labor, material, and utilities needed to install the equipment. Indirect costs are overall costs to the facility incurred by the system but not directly attributable to specific equipment items.

Direct costs cover the purchase of equipment and auxiliaries and the costs of installation. These costs include system instrumentation and interconnection of the system. Capital costs also include any cost of site development necessitated by the control system. For example, if a fabric filter on a capture/collection system requires an access road for removal of the collected dust, this access road is included as a capital expense. The types of direct costs typically associated with fugitive emissions control systems include:

- Equipment costs
- Equipment installation
- Instrumentation
- Duct work
- Piping
- Electrical
- Site development
- Buildings
- Painting
- Insulation
- Structural support
- Foundations
- Supporting administrative structures
- Control panels
- Access roads or walkways

Indirect costs cover the expenses not attributable to specific equipment items. Items in this category are described below[1]:

1. Engineering costs--includes administrative, process, project, and general; design and related functions for specifications; bid analysis; special studies; cost analysis; accounting; reports; purchasing; procurement; travel expenses; living expenses; expediting; inspection; safety; communications; modeling; pilot plant studies; royalty payments during construction; training of plant personnel; field engineering; safety engineering; and consultant services.

2. Construction and field expenses--includes costs for temporary field offices; warehouses; craft sheds; fabrication shops; miscellaneous buildings; temporary utilities; temporary sanitary facilities; temporary roads; fences; parking lots; storage areas; field computer services; equipment fuel and lubricants; mobilization and demobilization; field office supplies; telephone and telegraph; time-clock system; field supervision; equipment rental; small tools; equipment repair; scaffolding; and freight.

3. Contractor's fee--includes costs for field-labor payroll; supervision field office; administrative personnel; travel expenses; permits; licenses; taxes; insurance; field overhead; legal liabilities; and labor relations.

4. Shakedown/startup--includes costs associated with system startup and shakedown.

5. Contingency costs--the excess account set up to deal with uncertainties in the cost estimate, including unforeseen escalation in prices, malfunctions, equipment design alterations, and similar sources.

The values for these items will vary depending on the specific operations to be controlled and the types of control systems used. Typical ranges for indirect costs based on the total installed cost of the capital equipment are shown in Table B-2.

B.1.3 Determine Annualized Costs

The most common basis for comparison of alternative control system is that of annualized cost. The annualized cost of a fugitive emission control system includes operating costs such as labor, materials, utilities, and maintenance items as well as the annualized cost of the capital equipment. The annualization of capital costs is a classical engineering economics problem, the solution of which takes into account the fact that money has time value. These 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 equipment and depreciation rates of the equipment.

The components of the annualized cost of implementing a particular control technique are depicted graphically in Figure B-1. Purchase and installation costs include freight, sales tax, and interest on borrowed money. The operation and maintenance costs reflect increasing frequency of repair as the equipment ages along with increased costs due to inflation for parts, energy, and labor. On the other hand, costs recovered by claiming tax credits or deductions are considered as income. Mathematically the annualized costs of control equipment can be calculated from:

$$C_a = CRF\ (C_p) + C_o + 0.5\ C_o \qquad (B-2)$$

where: C_a = annualized costs of control equipment, \$/year

CRF = Capital Recovery Factor, 1/year

C_p = installed capital costs, \$

C_o = direct operating costs, \$/year

0.5 = plant overhead factor

The various components of this equation are briefly described below.

The annualized cost of capital equipment is calculated by using a capital recovery factor (CRF). The capital recovery factor combines interest on borrowed funds and depreciation into a single factor. It is a function of the interest rate and the overall life of the capital equipment and can be estimated by the following equation:

$$CFR = \frac{i(1+i)^n}{(1+i)^n-1} \qquad \text{(B-3)}$$

where: i = interest rate, annual percent as a fraction)

n = economic life of the control system (year)

The other major components of the annualized cost are operation and maintenance costs (direct operating costs) and associated plant overhead costs. Operation and maintenance costs generally include labor, raw materials, utilities, and by-product costs or credits associated with day-to-day operation of the control system. Elements typically included in this category are:[1]

1. Utilities--includes water for process use and cooling; steam; electricity to operate controls, fans, motors, pumps, valves, and lighting; and fuel, if required.

2. Raw materials--includes any chemicals needed to operate the system.

3. Operating labor--includes supervision and the skilled and unskilled labor needed to operate, monitor, and control the system.

4. Maintenance and repairs--includes the manpower and materials to keep the system operating efficiently. The function of maintenance is both preventive and corrective, to keep down-time to a minimum.

5. By-product costs--in systems producing a salable product, this would be a credit for that product; in systems producing a product for disposal, this would be the cost of disposal.

6. Fuel costs--includes the incremental cost of the fuel, where more than the normal supply is used.

Another component of the operating cost is overhead, which is a business expense not charged directly to a particular part of the process but allocated to it. Overhead costs include administrative, safety, engineering, legal, and medical services; payroll, employee benefits; recreation; and public relations. As suggested by Eq. B-2, these charges are estimated to be approximately 50 percent of direct operating costs.

B.1.4 Calculate Cost Effectiveness

As discussed in the introduction to this section the most informative method for comparing control measures or control strategies for particulate fugitive emissions sources is on a cost-effectiveness basis. Mathematically, cost effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R} \tag{B-1}$$

where: C^* = cost effectiveness, \$/mass of emissions reduced

C_a = annualized cost of control equipment, \$/year

ΔR = annual reduction in particulate emissions, mass/year

The annualized cost of control equipment can be calculated using Equation B-2. The annual reduction in particulate emissions can be calculated from the following equation:

$$\Delta R = M\ e\ c \tag{B-4}$$

where: M = annual source extent

e = uncontrolled emission factor (i.e., mass of uncontrolled emissions per unit of source extent)

c = average control efficiency expressed as a fraction

The methodology for calculating annualized costs and sources of data on costs of fugitive emissions control systems are contained in this section.

B.2 COST ELEMENTS OF FUGITIVE EMISSIONS CONTROL SYSTEMS

The cost methodology outlined in Section B.1 requires that the analyst define and select alternative control/cost scenarios and develop costs for the major cost elements within these scenarios. The objective of this subsection is to assist the reader in identifying the implementation alternatives and major cost elements associated with the emission reduction techniques. For open dust sources, the control techniques addressed are: wet dust suppression; surface cleaning; and paving.

Implementation alternatives for open dust source emission control measures are presented in Tables B-3 through B-5. Table B-3 presents implementation alternatives for water and chemical dust suppressant systems. Table B-4 presents alternatives for three types of street cleaning systems--sweeping, flushing, and a combination of flushing and broom sweeping. Table B-5 presents alternatives for streets or parking lot paving.

After the control scenarios are selected, the analyst must estimate the capital cost of the installed system and the operating and maintenance costs. The indirect capital costs elements are common to all systems and were identified in Table B-2. The direct capital cost elements and direct operation and maintenance cost elements which are unique to each type of fugitive emission control system are identified in Tables B-6 through B-11. These costs are provided for dust suppressant programs for open dust sources in Table B-6, street cleaning programs in Table B-7, paving in Table B-8, and wet suppression systems for process sources in Table B-9.

B.3 SOURCES OF COST DATA

Collection of the data to conduct a cost analysis can sometimes be difficult. If a well defined system is being costed, the best sources of accurate capital costs are vendor estimates. However, if the system is not sufficiently defined to develop vendor estimates, published cost data can be used. Table B-10 presents sources of cost data for both paved and unpaved roads.

Often published cost estimates are based on different time-valued dollars. These estimates must be adjusted for inflation so that they reflect the most probable capital investments for a current time and can be consistently compared. Capital cost indices are the techniques used for updating costs. These indices provide a general method for updating overall costs without having to complete in-depth studies of individual cost elements. Indices that typically are used for updating control system costs are the Chemical Engineering Plant Cost Index, the Bureau of Labor Statistics Metal Fabrication Index, and the Commerce Department Monthly Labor Review.

Operation and maintenance cost estimates typically are based on vendor or industry experience with similar systems. In the absence of such data, rough estimates can be developed from sources 3 and 6 in Table B-10.

REFERENCE FOR APPENDIX B

1. PEDCo Environmental, Inc. Cost Analysis Manual for Standards Support Document. U. S. Environmental Protection Agency. November 1978.

TABLE B-1. IMPLEMENTATION ALTERNATIVES FOR STABILIZATION OF AN UNPAVED ROAD

Cost elements/implementation alternatives
I. Purchase and Ship Chemical
A. Ship in railcar tanker (11,000 to 22,000 gal/tanker)
B. Ship in truck tanker (4,000 to 6,000 gal/tanker)
C. Ship in drums via truck (55 gal/drum)
II. Store Chemical
A. Store on plant property
1. In new storage tank
2. In existing storage tank
a. Needs refurbishing
b. Needs no refurbishing
3. In railcar tanker
a. Own railcar
b. Pay demurrage
4. In truck tanker
a. Own truck
b. Pay demurrage
5. In drums
B. Store in contractor tanks
III. Prepare Road
A. Use plant-owned grader to minimize ruts and low spots
B. Rent contractor grader
C. Perform no road preparation
IV. Mix Chemical and Water in Application Truck
A. Put chemical in spray truck
1. Pump chemical from storage tank or drums into application truck
1. Pour chemical from drums into application truck, generally using forklift
B. Put water in application truck
1. Pump from river or lake
2. Take from city water line
V. Apply Chemical Solution via Surface Spraying
A. Use plant owned application truck
B. Rent contractor application truck

TABLE B-2. TYPICAL VALUES FOR INDIRECT CAPITAL COSTS[1]

Cost item	Ranges of values
Engineering	8 to 20 percent of installed cost. High value for small projects; low value for large projects
Construction and field expenses	7 to 70 percent of installed cost
Contractor's fee	10 to 15 percent of installed cost
Shakedown/startup	1 to 6 percent of installed cost
Contingency	10 to 30 percent of total direct and indirect costs dependent upon accuracy of estimate. Generally, 20 percent is used in a study estimate

TABLE B-3. IMPLEMENTATION ALTERNATIVES FOR DUST SUPPRESSANTS APPLIED TO AN UNPAVED ROAD

Program implementation alternative	Dust suppressant type: Chemicals	Dust suppressant type: Water
I. Purchase and Ship Dust Suppressant		
A. Ship in railcar tanker (11,000 to 22,000 gal/tanker)	X	
B. Ship in truck tanker (4,000 to 6,000 gal/tanker)	X	
C. Ship in drums via truck (55 gal/drum)		
II. Store dust suppressant		
A. Store on plant property		
1. In new storage tank	X	
2. In existing storage tank	X	
a. Needs refurbishing	X	
b. Needs no refurbishing	X	
3. In railcar tanker		
a. Own railcar	X	
b. Pay demurrage	X	
III. Prepare Road		
A. Use plant-owned grader to minimize ruts and low spots	X	X
B. Rent contractor grader	X	X
C. Perform no road preparation	X	X
IV. Mix Dust Suppressant/Water in Application Truck		
A. Put suppressant in spray truck		
1. Pump suppressant from storage tank or drums into application truck	X	
2. Pour suppressant from drums into application truck, generally using forklift	X	
B. Put water in application truck		
1. Pump from river or lake	X	X
2. Take from city water line	X	X
V. Apply suppressant solution via surface spraying		
A. Use plant owned application truck	X	X
B. Rent contractor application truck	X	X

TABLE B-4. IMPLEMENTATION ALTERNATIVES FOR STREET CLEANING

Program implementation alternative	Broom-sweeping	Flushing	Flushing and broom-sweeping
I. Acquire Flusher and Driver			
A. Purchase flusher and use plant driver		X	X
B. Rent flusher and driver		X	X
C. Use existing unpaved road watering truck		X	X
II. Acquire Broom Sweeper and Driver			
A. Purchase broom sweeper and use plant driver	X		X
B. Rent broom sweeper and driver	X		X
III. Fill Flusher Tank with Water			
A. Pump water from river or lake		X	X
B. Take water from city line		X	X
IV. Maintain purchased flusher		X	X
V. Maintain purchased broom sweeper	X		X

TABLE B-5. IMPLEMENTATION ALTERNATIVES FOR PAVING

Program implementation alternative
I. Excavate Existing Surface to Make Way for Base and Surface Courses
A. 2-in. depth
B. 4-in. depth
C. 6-in depth
II. Fine Grade and Compact Subgrade
III. Lay and Compact Crushed Stone Base Course
A. 2-in. depth
B. 4-in. depth
C. 6-in depth
IV. Lay and Compact Hot Mix Asphalt (Probably AC120-150) Surface Course
A. 2-in. depth
B. 4-in. depth
C. 6-in depth

TABLE B-6. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR DUST SUPPRESSANT SYSTEMS[a]
(Open Sources)

Capital equipment

- Storage equipment

  Tanks
  Railcar
  Pumps
  Piping

- Application equipment

  Trucks
  Spray system
  Piping (including winterizing)

Q&M expenditures

- Utility or fuel costs

  Water
  Electricity
  Gasoline or diesel fuel

- Supplies

  Chemicals
  Repair parts

- Labor

  Application time
  Road conditioning
  System maintenance

[a]Not all items are necessary for all systems. Specific items are dependent on the control scenario selected.

TABLE B-7. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR STREET CLEANING

Capital equipment

- Sweeping
  - Broom
  - Vacuum system
- Flushing
  - Piping
  - Flushing truck
  - Water pumps

O&M expenditures

- Utility and fuel costs
  - Water
  - Gasoline or diesel fuel
- Supplies
  - Replacement brushes
- Labor
  - Sweeping or flushing operation
  - Truck maintenance
- Waste disposal

TABLE B-8. CAPITAL EQUIPMENT AND O&M EXPENDITURES ITEMS FOR PAVING

Capital equipment

- Operating equipment
  - Graders
  - Paving application equipment
  - Materials
  - Paving material (asphalt or concrete)
  - Base material

O&M expenditures

- Supplies
  - Patching material
- Labor
  - Surface preparation
  - Paving
  - Road maintenance
  - Equipment maintenance

TABLE B-9. CAPITAL EQUIPMENT AND O&M EXPENDITURE ITEMS FOR WET SUPPRESSION SYSTEMS (PROCESS SOURCES)

Capital equipment

- Water spray systems
  - Supply pumps
  - Nozzles
  - Piping (including winterization)
  - Control system
  - Filtering units
- Water/surfactant and foam systems only
  - Air compressor
  - Mixing tank
  - Metering or proportioning unit
  - Surfactant storage area

O&M expenditures

- Utility costs
  - Water
  - Electricity
- Supplies
  - Surfactant
  - Screens
- Labor
  - Maintenance
  - Operation

TABLE B-10. PUBLISHED SOURCES OF FUGITIVE EMISSION CONTROL SYSTEM COST DATA

1. Cuscino, Thomas, Jr., Gregory E. Muleski,and Chatten Cowherd, Jr. Iron and Steel Plant Open Source Fugitive Emission Control Evaluation. EPA-600/2-83-110, NTIS No. PB84-110568, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. october 1983.

2. Muleski, Gregory E., Thomas Cuscino, Jr., and Chatten Cowherd, Jr. Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry. EPA-600/2-84-027, NTIS No. PB84-154350, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 1984.

3. Cuscino, Thomas, Jr. Cost Estimates for Selected Dust Controls Applied to Unpaved and Paved Roads in Iron and Steel Plants. EPA Contract No. 68-01-6314, Task 17, U. S. Environmental Protection Agency, Region V, Chicago, Illinois. April 1984.

4. Richardson Engineering Services, Inc. The Richardson Rapid Construction Cost Estimating System: Volume I-Process Plant Construction Estimating Standards. 1983-84 Edition.

5. Robert Snow Means Company, Inc. Building Construction Cost Data. 1979.

6. Neveril, R. V. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA-450/5-80-002. GARD, Inc. December 1978.

TABLE B-11. EXAMPLE CALCULATION CASE: COST AND COST-EFFECTIVENESS ESTIMATE FOR TYPICAL OPEN SOURCE CONTROL

This table lists the steps necessary to calculate the cost effectiveness for two control alternatives for stabilizing unpaved travel surfaces. Following the list of nine steps is an example problem illustrating the calculations. Table B-12 through B-16 are referenced in the calculations in Table B-11.

Step 1--Specify Desired Average Control Efficiency (e.g., 50, 75, or 90 percent)

Step 2--Specify Basic Vehicle, Road and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics include:

1. Average Daily Traffic (ADT)--this is the number of vehicles using the road regardless of direction of travel (e.g., on a two lane road in an iron and steel plant, 100 vehicles in one direction, and 100 in the other direction during a single day yields 200 ADT);
2. Average vehicle weight in short tons;
3. Average number of vehicle wheels; and
4. Average vehicle speed in mph.

Required road characteristics include:

1. Actual length of roadway to be controlled in miles;
2. Width of road to be controlled;
3. Silt content (in percent)--for an existing road, these values should be measured; however, for a proposed plant, average values shown in AP-42 can be used;
4. Surface loading (for paved roads) in lb/mile--this is the total loading on all traveled lanes rather than the average lane loading; and
5. Bearing strength of the road-At this time, just a visual estimate of low, moderate, or high is required.

Required climatological characteristics (applicable only to watering of unpaved roads): potential evaporation in mm/h--the value depends on both the location and the month of concern. Control efficiency data in this report for watering unpaved roads assume a location in Detroit, Michigan, in the summer.

Step 3--Calculate the Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

The emission factor (E) should be calculated using the equations from AP-42.

The annual source extent (SE) is calculated as 365 x ADT x average one way trip distance.

Step 4--Consult the Appropriate Control Program Design Table to Determine the Time Between Applications and the Application Intensity

Select the appropriate table

Control technique	Table containing information
Coherex® applied to unpaved roads	Table B-12
Petro Tac applied to unpaved roads	Table B-13

(continued)

TABLE B-11. (continued)

Verify that the vehicle and road characteristics listed in Step 2 are similar to those listed in the footnotes of the selected table. If they are significantly different, the table cannot be used.

Step 5--Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Application (from Step 4)

Step 6--Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

Step 7--Consult the Appropriate Program Implementation Alternatives Table and Select the Desired Program Implementation Plan

Control technique	Table containing information
Coherex® applied to unpaved roads	Table B-15
Petro Tac applied to unpaved roads	Table B-16

Step 8--Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

To annualize capital investment, the capital cost is multiplied by a capital recovery factor which 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

Scale total annual cost by ratio of actual road width in feet divided by 40 ft.

Step 9--Calculate Cost Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by Desired Control Efficiency Fraction (from Step 1)

Example calculation. The following is an example cost-effectiveness calculation for controlling PM-10 using Coherex® on an unpaved road in a Detroit, Michigan, plant.

Step 1--Specify Desired Average Control Efficiency

Desired average control efficiency = 90 percent

Step 2--Specify Basic Vehicle, Road, and Climatological Parameters for the Particular Road of Concern

Required vehicle characteristics:

1. Average daily traffic = 100 vehicles per day;
2. Average vehicle weight = 40 ST;
3. Average number of vehicle wheels = 6; and
4. Average vehicle speed = 20 mph

(continued)

TABLE B-11. (continued)

Required road characteristics

1. Actual length of roadway to be controlled = 6.3 miles;
2. Width of roadway = 30 ft;
3. Silt content = 9.1 percent
4. Bearing strength of road = moderate

Step 3--Calculate Uncontrolled Annual Emission Rate as the Product of the Emission Factor and the Source Extent

$$E = k\ 5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$$

where E = emission factor
k = 0.36 for PM-10 (from Section 3.0 of this manual)
s = 9.1 percent (given in Step 2)
S = 20 mph (given in Step 2)
W = 40 ST (given in Step 2)
w = 6 (given in Step 2)
p = 140 (as per Figure 3-1 for Detroit, Michigan)

E = 4.98 lb/VMT

SE = 365xADTxaverage one-way trip distance

$$SE = 365\ \frac{\text{days}}{\text{year}} \times 100\ \frac{\text{vehicles}}{\text{day}} \times \frac{6.3\ \text{miles}}{2\ \text{vehicle}}$$

SE = 115,000 VMT/year

Emission rate = ExSE

$$\text{Emission rate} = 4.98\ \text{lb/VMT} \times 115{,}000\ \text{VMT/year} \times \frac{1\ \text{short ton}}{2{,}000\ \text{lb}}$$

Emission rate = 286 tons of PM_{10} per year

Step 4--Consult the Appropriate Control Program Design Table To Determine the Times Between Applications and the Application Intensity

Use Table B-12.

The vehicle and road characteristics listed in Step 2 are similar to those in the footnotes of Table 2-1.

From Table B-12:

Application intensity = 0.83 gal. of 20 percent solution/yd^2 (initial application)

= 1.0 gal. of 12 percent solution/yd^2 (reapplications)

Application frequency = once every 47 days

(continued)

TABLE B-11. (continued)

Step 5--Calculate the Number of Annual Applications Necessary by Dividing 365 by the Days Between Applications (from Step 4)

No. of annual applications = $\frac{365}{47}$ = 77.7 $\frac{\text{applications}}{\text{year}}$

Step 6--Calculate the Number of Treated Miles Per Year by Multiplying the Actual Miles of Road to Be Controlled (from Step 2) by the Number of Annual Applications (from Step 5)

No. of treated miles per year = 6.3 miles x 7.77 $\frac{\text{applications}}{\text{year}}$

= 49 treated miles/year

Step 7--Consult the Appropriate Program Implementation Alternatives Table and Select the Desired Program Implementation Plan

From Table B-14, the following implementation plan and associated costs are anticipated:

Selected alternative	Cost: Capital investment, $	Unit cost: $/Treated mile	Unit cost: $/Actual mile
1. Purchase Coherex® and ship in truck tanker		4,650	
2. Store in newly purchased storage tank	30,000		
3. Prepare road with plant owned grader			630
4. Pump water from river or lake	5,000	135	
5. Apply chemical with plant owned application truck (includes labor to pump water and Coherex® and apply solution)	70,000		
	105,000	4,785	630

Step 8--Calculate Total Annual Cost by Annualizing Capital Costs and Adding to Annual Operation and Maintenance Costs

Calculate annual capital investment (PI) = capital investmentxCRF

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

CRF = capital recovery factor

i = 0.15

n = 10 years

CRF = 0.199252

PI = 105,000x0.199252 = $20,900/year

Calculate annual operation and maintenance costs (MO)

MO = $4,785/treated milex49 treated miles/year +

$630/actual mile x 6.3 $\frac{\text{actual miles}}{\text{year}}$

= $238,000/year

(continued)

TABLE B-11. (continued)

Calculate total cost (D) = PI+MO

D = $20,900/year+$238,000/year
  = $258,900/year

Scale total cost by actual road width:

$$\text{Actual total cost for a 30-ft wide road} = \$258{,}900/\text{yr} \times \frac{30\ \text{ft}}{40\ \text{ft}}$$

$$= \$194{,}200/\text{yr}$$

<u>Step 9--Calculate Cost Effectiveness by Dividing Total Annual Costs (from Step 8) by the Annual Uncontrolled Emission Rate (from Step 3) and by the Desired Control Efficiency Fraction (from Step 1)</u>

$$\text{Cost effectiveness} = \frac{\$194{,}200/\text{year}}{286\ \text{ST/year} \times 0.9}$$

= $754/short ton of PM_{10} reduced

TABLE B-12. ALTERNATIVE CONTROL PROGRAM DESIGN FOR COHEREX® APPLIED TO TRAVEL SURFACES[a] [b]

Average percent control desired	Vehicle passes between applications	Days between applications as a function of ACT		
		100	300	500
50	23,300	233	78	47
75	11,600	116	39	23
90	4,650	47	16	9

[a]Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application:
- 3.7 L of 20 percent solution/m² (0.83 gallon of 20 percent solution/yd²) initial application
- 4.5 L of 12 percent solution/m² (1.0 gal. of 12 percent solution/yd²); reapplications

Vehicular traffic:
- Average weight--Mg (43 tons)
- Average wheels--6
- Average speed--29 km/h (20 mph)

Road structure: bearing strength--low to moderate

[b]PM-10 = Particles ≤10 μmA.

[c]For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

TABLE B-13. COST ESTIMATES FOR IMPROVEMENT OF PAVED TRAVEL SURFACES

Source/control method	Initial (April 1985 dollars)[a]	Annual operating cost (April 1985 dollars)[a b]
Paved road-sweeping	6,580-19,700/truck	27,600/truck
Paved road-vacuuming	36,800/truck	34,200/truck
Paved road-flushing	18,400/truck	27,600/truck

[a]January 1980 costs updated to April 1985 cost by Chemical Engineering Index Factor = 1.315. Reference 20.
[b]Cost per mile depends on nature of process and the site.

TABLE B-14. ALTERNATIVE CONTROL PROGRAM DESIGN FOR PETRO TAC APPLIED TO TRAVEL SURFACES[a] [b]

Average percent control desired	Vehicle passes between applications	Days between applications as a function of ACT		
		100	300	500
50	92,000	920	307	184
75	47,800	478	159	96
90	21,200	212	71	42

[a]Calculated time and vehicle passes between application are based on the following conditions:

Suppressant application: 3.2 L of 20 percent solution/m^2 (0.7 gal of 20 percent solution/yd^2); each application

Vehicular traffic:

- Average weight--Mg (30 tons)
- Average wheels--9.2
- Average speed--22 km/h (15 mph)

Road structure: bearing strength--low to moderate

[b]PM-10 = particles <10 μmA.

[c]For reapplications that span time periods greater than 365 days, the effects of the freeze-thaw cycle are not incorporated in the reported values.

TABLE B-15. IDENTIFICATION AND COST ESTIMATION OF COHEREX®
CONTROL ALTERNATIVES

Program implementation alternatives	Cost
I. Purchase and ship Coherex®	
A. Ship in railcar tanker (11,000-22,000 gal/tanker)	$4,650/treated mile
B. Ship in truck tanker (4,000-6,000 gal/tanker)	$4,650/treated mile
C. Ship in drums via truck (55 gal/drum)	$7,040/treated mile
II. Store Coherex®	
A. Store on plant property	
1. In new storage tank	$30,000 capital
2. In existing storage tank	
a. Needs refurbishing	$5,400 capital
b. Needs no refurbishing	-0-
3. In railcar tanker	
a. Own railcar	-0-
b. Pay demurrage	$20, $30, $60/treated mile
4. In truck tanker	
a. Own truck	-0-
b. Pay demurrage	$70/treated mile
5. In drums	-0-
B. Store in contractor tanks	$140/treated mile
III. Prepare road	
A. Use plant-owned grader to minimize ruts and low spots	$630/actual mile
B. Rent contractor grader	$1,200/actual mile
C. Perform no road preparation	-0-
IV. Mix Coherex® = and water in application truck	
A. Load Coherex®= into spray truck	
1. Pump Coherex® = from storage tank or drums into application truck	Tank--0 (included in price of storage tank) Drums--$1,000 capital
2. Pour Coherex® = from drums into application truck, using forklift	$1,000/treated mile

(continued)

TABLE B-15. (continued)

Program implementation alternatives	Cost
B. Load water into application truck	
1. Pump from river or lake	\$5,000 capital
2. Take from city water line	\$40/treated mile
V. Apply Coherex® = solution via surface spraying	
A. Use plant owned application truck	\$70,000 capital+\$135/treated mile for tank or \$270/treated mile for drums
B. Rent contractor application truck	Tank--\$500/treated mile Drums--\$1,000/treated mile

TABLE B-16. IDENTIFICATION AND COST ESTIMATION OF PETRO TAC CONTROL ALTERNATIVES

Program implementation alternatives	Cost
I. Purchase and ship Petro Tac	
A. Ship in truck tanker (4,000-6,000 gal/tanker)	$5,400/treated mile
B. Ship in drums via truck (55 gal/drum)	$11,500/treated mile
II. Store Petro Tac	
A. Store on plant property	
1. In new storage tank	$30,000 capital
2. In existing storage tank	
a. Needs refurbishing	$5,400 capital
b. Needs no refurbishing	-0-
3. In railcar tanker	
a. Own railcar	-0-
b. Pay demurrage	$20, $30, $60/treated mile
4. In truck tanker	
a. Own truck	-0-
b. Pay demurrage	$70/treated mile
5. In drums	-0-
B. Store in contractor tanks	$140/treated mile
III. Prepare road	
A. Use plant owned grader to minimize ruts and low spots	$630/actual mile
B. Rent contractor grader	$1,200/actual mile
C. Perform no road preparation	-0-
IV. Mix Petro Tac and water in application truck	
A. Load Petro Tac into spray truck	
1. Pump Petro Tac from storage tank or drums into application truck	Tank - 0 (included in price of storage tank) Drums--$1,000 capital
2. Pour Petro Tac from drums into application truck, generally using forklift	$1,000/treated mile
B. Load water into application truck	
1. Pump from river or lake	$5,000 capital
2. Take from city water line	$40/treated mile

(continued)

TABLE B-16. (continued)

Program implementation alternatives	Cost
V. Apply Petro Tac solution via surface spraying	
A. Use plant-owned application truck	$70,000 capital+$135/treated mile for tank or $270/treated mile for drums
B. Rent contractor application truck	Tank--$500/treated mile Drums--$1,000/treated mile

APPENDIX C.

METHODS OF COMPLIANCE DETERMINATION FOR OPEN SOURCES

APPENDIX C. METHODS OF COMPLIANCE DETERMINATION FOR OPEN SOURCES

Once a specific PM_{10} control strategy has been developed and implemented, it becomes necessary for either the control agency or industrial concern to assure that it is achieving the desired level of control. As stated previously, the control efficiency actually attained by a particular technique depends on its proper implementation. This section will discuss methods for determining compliance with various regulatory requirements relating to PM_{10} control strategies. These methods include visual observations and recordkeeping of key control parameters.

C.1 METHOD FOR DETERMINING VISIBLE EMISSIONS

Visible emission methods have been adopted by a number of states as a tool for compliance. Although opacity observations at the property line have commonly been employed in earlier fugitive dust control regulations, recent court decisions in Colorado and Alabama have found that rules of that type are unconstitutional (failing to provide equal protection). It is strongly recommended that property-line opacity observations serve only as an indicator of a potential problem, thus "triggering" further investigation. Source-specific opacity determinations, on the other hand, have long been a court-tested approach to regulation. The following section describes two states' approach to fugitive dust regulation using visible emission methods.

C.1.1 Tennessee Visible Emission Method

The State of Tennessee has developed a method (TVEE Method 1) for evaluating visible emissions (VE) from roads and parking lots.[1] The following discussion focuses on TVEE Method 1 (M1) in the technical areas: (1) reader position/techniques; and (2) data reduction/evaluation procedures. Table C-1 summarizes the relevant features of TVEE M1.

C.1.1.1 Reader Position/Techniques. As indicated in Table C-1, TVEE Method 1 specifies an observer location of 15 ft from the source. In most cases, this distance should allow an unobstructed view, and at the same time meet observer safety requirements.

TABLE C-1. SUMMARY OF TVEE METHOD 1 REQUIREMENTS (M1)

Reader position/techniques

- Sun in 140° sector behind the reader.
- Observer position ~15 ft from source.
- Observer line of sight should be as perpendicular as possible to both plume and wind direction.
- Only one plume thickness read.
- Plume read at ~4 ft directly above emitting surface.
- Individual opacity readings taken each 15 s, recorded to nearest 5 percent opacity.
- Readings terminated if vehicle obstructs line of sight.
- Readings terminated if vehicles passing in opposite direction creates intermixed plume.

Data reduction

- 2-min time-averages consisting of eight consecutive 15 s readings.

Certification

- Per Tennessee requirements

M1 also specifies that the plume be read at ~4 ft directly above the emitting surface. This specification presumably results from field experiments conducted to support the method. It is probably intended to represent the point (i.e., location) of maximum opacity. While there is no quantitative supporting evidence, it seems likely that the height and location of maximum opacity relative to a passing vehicle will vary depending upon ambient factors (wind speed and direction) as well as vehicle type and speed.

Implied in the M1 specification that the plume be read ~4 ft above the emitting surface, is the fact that observations will be made against a terrestrial (vegetation) background. The results of one study using a conventional smoke generator modified to emit horizontal plumes, indicated that under these conditions observers are likely to underestimate opacity levels. More specifically, the study found that as opacity levels increased, opacity readings showed an increasing negative bias. For example, at 15 percent opacity, the observers underestimated opacity by about 5 percent, and at 40 percent opacity, observations averaged about 11 percent low.[2] Black plumes were underestimated at all opacity levels.

M1 specifies that only one plume thickness be read. It includes qualifying provisions that: (1) readings terminate if vehicles passing in opposite directions create an intermixed plume; but (2) readings continue if intermixing occurs as a result of vehicles moving in the same direction. Unlike (1), the latter condition is considered representative of the surface. The intent here is probably to minimize the influence of increasing plume density which results from "overlaying" multiple plumes.

C.1.1.2 Data Reduction/Evaluation Procedures. There are two basic approaches that can be used to reduce opacity readings for comparison with VE regulations. One approach involves the time-averaging of consecutive 15-s observations over a specified time period to produce an average opacity value.

In the development of M1, the State of Tennessee concluded that a short averaging period--2 min (i.e., eight consecutive 15-s readings) was appropriate for roads and parking lots, as these sources typically produce brief, intermittent opacity peaks.

Although not specified in M1, VE from open sources could be evaluated using time-aggregating techniques. For example, the discrete 15-s readings could be employed in the time-aggregating framework. In this case, the individual observations are compiled into a histogram from which the number of observations (or equivalent percent of observation time) in excess of the desired opacity may then be ascertained. The principal advantage of using the time-aggregate technique as a method to reduce VE readings is that the resultant indicator of opacity conditions is then compatible with regulations that include a time exemption clause. Under time exemption standards, a source is permitted opacity in excess of the standard for a specified fraction of the time (e.g., 3 min/h). The concept of time exemption was originally developed to accommodate stationary source combustion processes.

Without more detailed supporting information, it is difficult to determine which of the two approaches is most appropriate for evaluating VE from open sources. With respect to time-averaging, statistics of observer bias in reading plumes from a smoke generator do indicate at least a slight decrease in the "accuracy" of the mean observed opacity value as averaging time decreases. In M1 (2-min average), this is reflected in the inclusion of an 8.8 percent buffer for observational error. This buffer is taken into account before issuing a Notice of Violation.[1]

One potential problem with applying time-averaging to opacity from roads and parking lots, is that the resulting average will be sensitive to variations in source activity. For example, interpreting one conclusion offered in support of Method 1, it is likely that under moderate wind conditions a single vehicle pass will produce only two opacity readings $\geq$ 5 percent.[1] Averaging these with six zero (0) readings yields a 2-min value below any reasonable opacity standard. Yet, under the same conditions with two or more vehicle passes, the average value will suggest elevated opacity levels. While there is no information available on the use of time aggregation for open source opacity, it appears that this approach would more easily accommodate variations in level of source activity. For this reason alone, it may be the evaluation approach better suited to roads and parking lots.

C.1.2 Ohio Draft Rule 3745-17-(03)(B)

The State of Ohio submitted a fugitive dust visible emission measurement technique which the EPA proposed to approve in the Federal Register on January 2, 1987. Unlike the Tennessee method, the Ohio draft rule contains provisions for sources other than roads and parking lots. Average opacity values are based on 12 consecutive readings. Table C-2 summarizes the Ohio method; as can be seen from the table, many features of the Ohio draft rule are similar to TVEE Method 1. Consequently, the remarks made earlier in this section are equally applicable here.

C.1.3. Correlation of Mass Emissions with Opacity Measurements

A current program conducted by the State of Indiana is intended to establish the correlation between the opacity of a plume generated by vehicles traveling on the road, and the PM_{10}/TSP mass emission measurements. The desired end-product is a PM_{10} mass estimation tool using silt content and opacity as input values. Visible emission readings (VE) will be taken by 12 readers currently certified in EPA Method 9. All VE readings will be performed in accordance with the techniques described in Ohio Draft Rule 3745-17-(03)(B), as far as practical. To assure that all the readers view the same area, the receiving area boundaries shall be clearly indicated by flags, stakes, or other indicating devices. The highest and lowest readings from each set shall be discarded leaving 10 sets of readings for evaluation.

It is anticipated that the results of this study will be available in the fall of 1988.

C.2 RECORDKEEPING AND OPEN DUST SOURCE CONTROLS

Parameter monitoring and associated recordkeeping may play important roles in determining open dust source compliance. Detailed records are particularly important for periodic dust control measures (as discussed in Appendix A) because effectiveness must be averaged over the periods between applications. The following discussion presents recordkeeping requirements for the six source categories presented in Chapters 1.0 through 6.0. Each discussion builds upon the regulatory formats suggested earlier in the body of this manual.

TABLE C-2. SUMMARY OF OHIO DRAFT RULE 3745-17-(03)(B)

Reader position/techniques

- Roadways and parking lots:
  - Line of vision approximately perpendicular to plume direction.
  - Plume read at ~4 ft above surface.
  - Readings suspended if vehicle obstructs line of sight; subsequent readings considered consecutive to that taken before the obstruction.
  - Readings suspended if vehicles passing in opposite direction create an intermixed plume; subsequent readings considered consecutive to that taken before intermixing.
  - If unusual condition (e.g., spill) occurs, another set of readings must be conducted.

- All other sources:
  - Sun behind observer.
  - Minimum of 15 ft from source.
  - Line of sight approximately perpendicular to flow of fugitive dust and to longer axis of the emissions.
  - Opacity observed for point of highest opacity.

C.2.1 Paved Roads and Parking Lots

Records must be kept that document the frequency of mitigative measures applied to paved surfaces. Pertinent parameters to be specified in a control plan and to be regularly recorded include:

C.2.1.1 General Information to be Specified in Plan.

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency:

2. Length of each road and area of each parking lot;

3. Type of control applied to each road/area and planned frequency of application; and

4. Any provisions for weather (e.g., ¼ in. of rainfall will be substituted for one treatment).

C.2.1.2 Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment;

2. Operator's initials (note that the operator may keep a separate log whose information is transferred to the environmental staff's data sheets);

3. Start and stop times on a particular segment/parking lot, average speed, number of passes;

4. For flushing programs, start and stop times for refilling tanks;

5. Qualitative description of loading before and after treatment; and

6. Any areas of unusually high loadings from spills, pavement deterioration, etc.

C.2.1.3 General Records to be Kept.

1. Equipment maintenance records;

2. Meteorological log (to the extent that weather influences the control program--see above); and

3. Any equipment malfunctions or downtime.

In addition to those items related to control applications, some of the regulatory formats may require that additional records be kept. These records may include surface material samples or traffic counts. A suggested format for recording paved surface samples (following the sampling/analysis procedures given in Appendices D and E) is presented as

Figure D-4 in Appendix D. Traffic counts may be recorded either manually or using automatic devices; suggested formats are given as Figures C-1 and C-2, respectively.

C.3 UNPAVED ROADS

Recordkeeping requirements for unpaved roads were summarized in Table 3-5. The following lists pertinent parameters to be monitored.

General Information to be Specified in the Plan

1. All road segments and parking locations referenced on a map available to both the responsible party and the regulatory agency;
2. Length of each road and area of each parking lot;
3. Type of chemical applied to each road/area, dilution ratio, application intensity, and planned frequency of application; and
4. Provisions for weather.

Specific Records for Each Road Segment/Parking Area Treatment

1. Date of treatment;
2. Operator's initials (note that the operator may keep a separate log of whose information is transferred to the environmental staff's data sheets);
3. Start and stop times on a particular segment/parking lot, average speed, number of passes, amount of solution applied; and
4. Qualitative description of road surface condition.

General Records to be Kept

1. Equipment maintenance records;
2. Meteorological log (to the extent that weather influences the control program--see above); and
3. Any equipment malfunctions or downtime.

In addition, material samples may be taken as well as traffic counts as part of the regulatory formats given in Section 3.4. Unpaved road sampling is discussed in Appendix D; traffic samples may be recorded on Figures C-1 and C-2.

Road Location: ____________________

Road Type: ____________________

Sampling Start Time: __________ Stop Time: __________

Vehicle Type	Axles/Wheels	1	2	3	4	5	6	7	8	9	10	Total
	/											
	/											
	/											
	/											
	/											
	/											
	/											
	/											
	/											
	/											

Figure C-1. Manual traffic count log.

Counter ID No.	Site Location	Start Count	Date/Time	Stop Count	Date/Time	Recorded by

Figure C-2. Example pneumatic traffic count log.

C.3 REFERENCES FOR APPENDIX C

1. Telecon. Englehart, P., Midwest Research Institute, with Walton, J., Tennessee Division of Air Pollution Control. Nashville, Tennessee. September 1984.

2. Rose, T. H. Evaluation of Trained Visible Emission Observers for Fugitive Opacity Measurement. EPA-60/3-84-093, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1984.

APPENDIX D.

PROCEDURES FOR SAMPLING SURFACE/BULK MATERIALS

APPENDIX D. PROCEDURES FOR SAMPLING SURFACE/BULK MATERIALS

The starting point for development of the recommended procedures for collection of road dust and aggregate material samples was a review of American Society of Testing and Materials (ASTM) Standards. When practical, the recommended procedures were structured identically to the ASTM standard. When this was not possible, an attempt was made to develop the procedure in a manner consistent with the intent of the majority of pertinent ASTM Standards.

D.1 UNPAVED ROADS

The main objective in sampling the surface material from an unpaved road is to collect a minimum gross sample of 23 kg (50 lb) for every 3.8 km (3 miles) of unpaved road. The incremental samples from unpaved roads should be distributed over the road segment, as shown in Figure D-1. At least four incremental samples should be collected and composited to form the gross sample.

The loose surface material is removed from the hard road base with a whisk broom and dustpan. The material should be swept carefully so that the fine dust is not injected into the atmosphere. The hard road base below the loose surface material should not be abraded so as to generate more fine material than exists on the road in its natural state.

Figure D-2 presents a data form to be used for the sampling of unpaved roads.

D.2 PAVED ROADS

Ideally, for a given paved road, one gross sample per every 8 km (5 miles) of paved roads should be collected. For industrial roads, one gross sample should be obtained for each road segment in the plant. The gross sample should consist of at least two separate increments per travel lane, or each 0.5 mile length should have a separate sample.

Figure D-3 presents a diagram showing the location of incremental samples for a four-lane road. Each incremental sample should consists of a lateral strip 0.3 to 3 m (1 to 10 ft) in width across a travel lane. The exact width is dependent on the amount of loose surface material on the paved roadway. For a visually dirty road, a width of 0.3 m (1 ft) is sufficient; but for a visually clean road, a width of 3 m (10 ft) is needed to obtain an adequate sample.

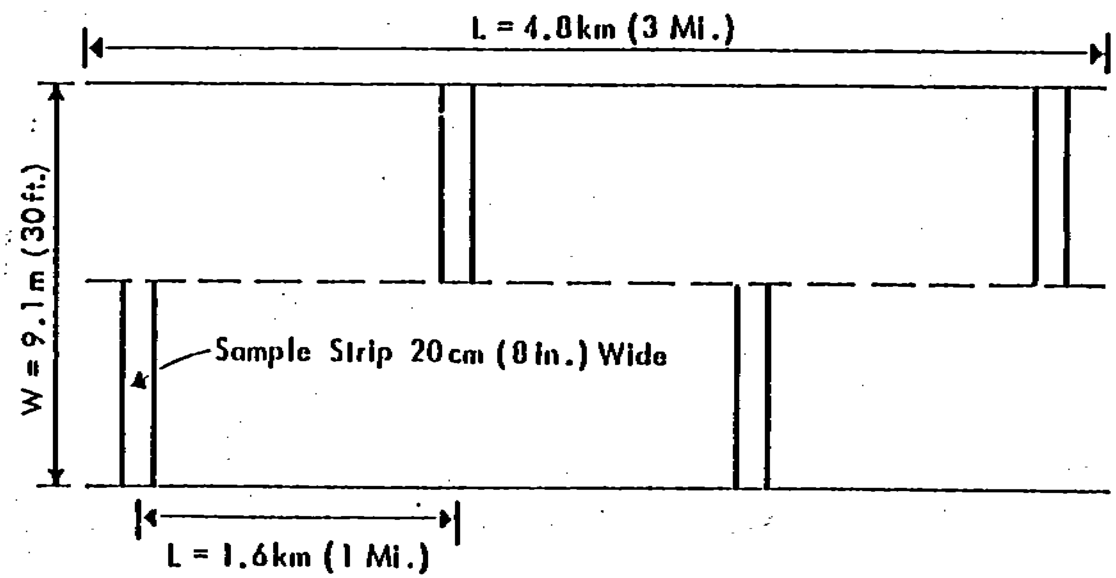

Figure D-1. Location of incremental sampling sites on an unpaved road.

Sample No.	Time	Location*	Surface Area	Depth	Quantity of Sample

*Use code given on plant map for segment identification and indicate sample location on map.

Figure D-2. Sampling data form for unpaved roads.

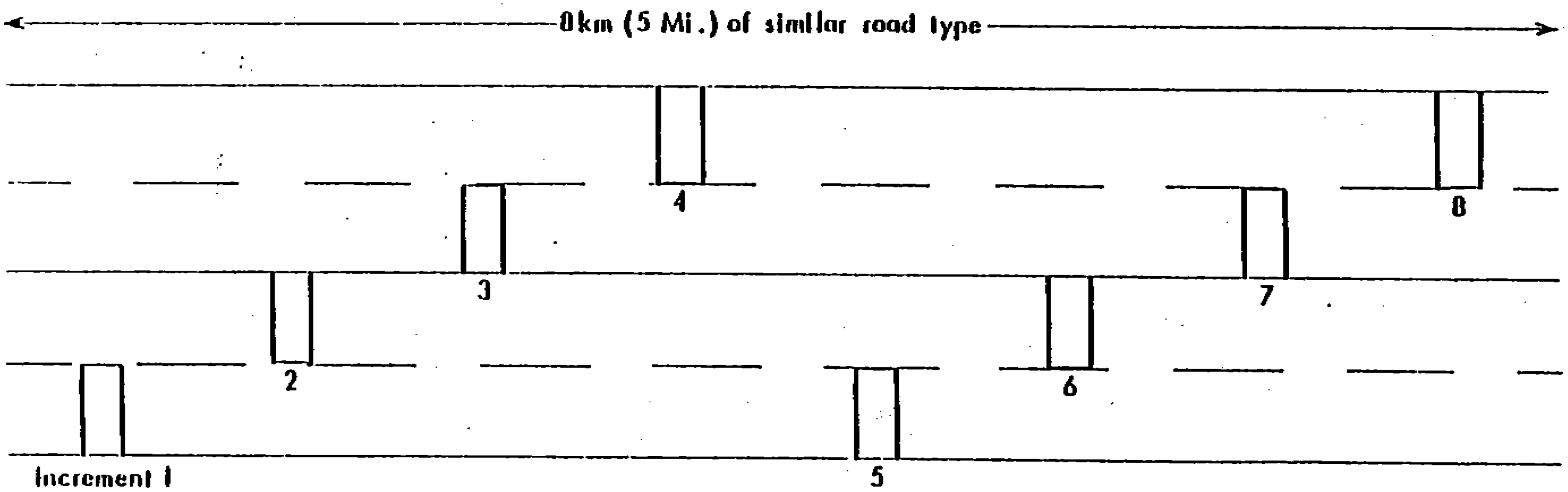

Figure D-3. Location of incremental sampling sites on a paved road.

The above sampling procedure may be considered as the preferred method of collecting surface dust from paved roadways. In many instances, however, the collection of eight sample increments may not be feasible due to manpower, equipment, and traffic/hazard limitations. As an alternative method, samples can be obtained from a single strip across all the travel lanes. When it is necessary to resort to this sampling strategy, care must be taken to select sites that have dust loading and traffic characteristics typical of the entire roadway segment of interest. In this situation, sampling from a strip 3 to 9 m (10 to 30 ft) in width is suggested. From this width, sufficient sample can be collected, and a step toward representativeness in sample acquisition will be accomplished.

Samples are removed from the road surface by vacuuming, preceded by broom sweeping if large aggregate is present. The samples should be taken from the traveled portion of the lane with the area measured and recorded on the appropriate data form. With a whisk broom and a dust pan, the larger particles are collected from the sampling area and placed in a clean, labeled container (plastic jar or bag). The remaining smaller particles are then swept from the road with an electric broom-type vacuum sweeper. The sweeper must be equipped with a preweighed, prelabeled, disposable vacuum bag. Care must be taken when installing the bags in the sweeper to avoid torn bags which can result in loss of sample. After the sample has been collected, the bag should be removed from the sweeper, checked for leaks and stored in a prelabeled, gummed envelope for transport. Figure D-4 presents a data form to be used for the sampling of paved roads.

Values for the dust loading on only the traveled portion of the roadway are needed for inclusion in the appropriate emission factor equation. Information pertaining to dust loading on curb/beam and parking areas is necessary in estimating carry-on potential to determine the appropriate industrial road augmentation factor.

D.3 STORAGE PILES

In sampling the surface of a pile to determine representative properties for use in the wind erosion equation, a gross sample made up of top, middle, and bottom incremental samples should ideally be obtained since the wind disturbs the entire surface of the pile. However, it is

Type of Material Sampled: ______________________

Site of Sampling: ______________ No. of Traffic Lanes ______________

Type of Pavement: Asphalt/Concrete ______ Surface Condition ______________

Sample No.	Vac.Bag	Time	Location*	Sample Area	Broom Swept? (y/n)

*Use code given on plant map for segment identification and indicate sample location on map.

Figure D-4. Sampling data form for paved roads.

impractical to climb to the top or even middle of most industrial storage piles because of the large size.

The most practical approach in sampling from large piles is to minimize the bias by sampling as near to the middle of the pile as practical and by selecting sampling locations in a random fashion. Incremental samples should be obtained along the entire perimeter of the pile. The spacing between the samples should be such that the entire pile perimeter is traversed with approximately equidistant incremental samples. If small piles are sampled, incremental samples should be collected from the top, middle, and bottom.

An incremental sample (e.g., one shovelful) is collected by skimming the surface of the pile in a direction upward along the face. Every effort must be made by the person obtaining the sample not to purposely avoid sampling larger pieces of raw material. Figure D-5 presents a data form to be used for the sampling of storage piles.

In obtaining a gross sample for the purpose of characterizing a loadin or load-out process, incremental samples should be taken from the portion of the storage pile surface: (1) which has been formed by the addition of aggregate material; or (2) from which aggregate material is being reclaimed.

Type of Material Sampled: ____________________

Site of Sampling: ____________________

SAMPLING METHOD

1. Sampling device: pointed shovel
2. Sampling depth: 10 - 15 cm (4 - 6 inches)
3. Sample container: metal or plastic bucket with sealed poly liner
4. Gross sample specifications:
   (a) 1 sample of 23 kg (50 lb.) minimum for every pile sampled
   (b) composite of 10 increments
5. Minimum portion of stored material (at one site) to be sampled: 25%

SAMPLING DATA

Sample No.	Time	Location (Refer to map)	Surface Area	Depth	Quantity of Sample

Figure D-5. Sampling data form for storage piles.