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11.2 FUGITIVE DUST SOURCES

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include unpaved roads, agricultural tilling operations, aggregate storage piles, and heavy construction operations.

For the above categories of fugitive dust sources, the dust generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).

2. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 19 kilometers per hour (12 miles/hr).

The air pollution impact of a fugitive dust source depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a local nuisance problem), considerable amounts of fine particles are also emitted and dispersed over much greater distances from the source.

The potential drift distance of particles is governed by the initial injection height of the particle, the particle's terminal settling velocity, and the degree of atmospheric turbulence. Theoretical drift distances, as a function of particle diameter and mean wind speed, have been computed for fugitive dust emissions.[1] These results indicate that, for a typical mean wind speed of 16 kilometers per hour (10 miles/hr), particles larger than about 100 micrometers are likely to settle out within 6 to 9 meters (20 to 30 ft) from the edge of the road. Particles that are 30 to 100 micrometers in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the road. Smaller particles, particularly those less than 10 to 15 micrometers in diameter, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence. Thus, based on the presently available data, it appears appropriate to report only those particles smaller than 30 micrometers. Future updates to this document are expected to define appropriate factors for other particle sizes.

Several of the emission factors presented in this Section are expressed in terms of total suspended particulate (TSP). TSP denotes what is measured by a standard high volume sampler. Recent wind tunnel studies have shown that the particle mass capture efficiency curve for the high volume sampler is very broad, extending from 100 percent capture of particles smaller than 10 micrometers to a few percent capture of particles as large as 100 micrometers. Also, the capture efficiency curve varies with

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wind speed and wind direction, relative to roof ridge orientation. Thus, high volume samplers do not provide definitive particle size information for emission factors. However, an effective cutpoint of 30 micrometers aerodynamic diameter is frequently assigned to the standard high volume sampler.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, or reduction of surface wind speed with windbreaks or source enclosures. Watering, the most common and generally least expensive method, provides only temporary dust control. The use of chemicals to treat exposed surfaces provides longer dust suppression but may be costly, have adverse effects on plant and animal life, or contaminate the treated material. Windbreaks and source enclosures are often impractical because of the size of fugitive dust sources.

11.2.1 UNPAVED ROADS

11.2.1.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

11.2.1.2 Emissions And Correction Parameters

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Also, field investigations have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.[1-4]

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.[1] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. Table 11.2.1-1 summarizes measured silt values for industrial and rural unpaved roads.

The silt content of a rural dirt road will vary with location, and it should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used. However, tests show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions because of precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [0.01 inches] of precipitation).

The following empirical expression may be used to estimate the quantity of size specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT), with a rating of A:

$$E = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(kg/VKT)} \qquad (1)$$

$$E = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(lb/VMT)}$$

TABLE 11.2.1-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIALS ON INDUSTRIAL AND RURAL UNPAVED ROADS[a]

Industry	Road Use Or Surface Material	Plant Sites	Test Samples	Silt (%, w/w) Range	Silt (%, w/w) 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

[a]References 4 - 11. Brackets indicate silt values based on samples from only one plant site.
NA = Not available.

where: E = emission factor
k = particle size multiplier (dimensionless)
s = silt content of road surface material (%)
S = mean vehicle speed, km/hr (mph)
W = mean vehicle weight, Mg (ton)
w = mean number of wheels
p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

The particle size multiplier, k, in Equation 1 varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier For Equation 1

≤30 μm	≤15 μm	≤10 μm	≤5 μm	≤2.5 μm
0.80	0.50	0.36	0.20	0.095

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 11.2.1-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.

Equation 1 retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as follows:

RANGES OF SOURCE CONDITIONS FOR EQUATION 1

Equation	Road silt content (%, w/w)	Mean vehicle weight		Mean vehicle speed		Mean no. of wheels
		Mg	ton	km/hr	mph	
1	4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

Also, to retain the quality rating of the equation applied to a specific unpaved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining road surface silt content are given in Reference 4. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.1-1 may be used, but the quality rating of the equation is reduced to B.

Equation 1 was developed for calculation of annual average emissions, and thus, is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be substituted into

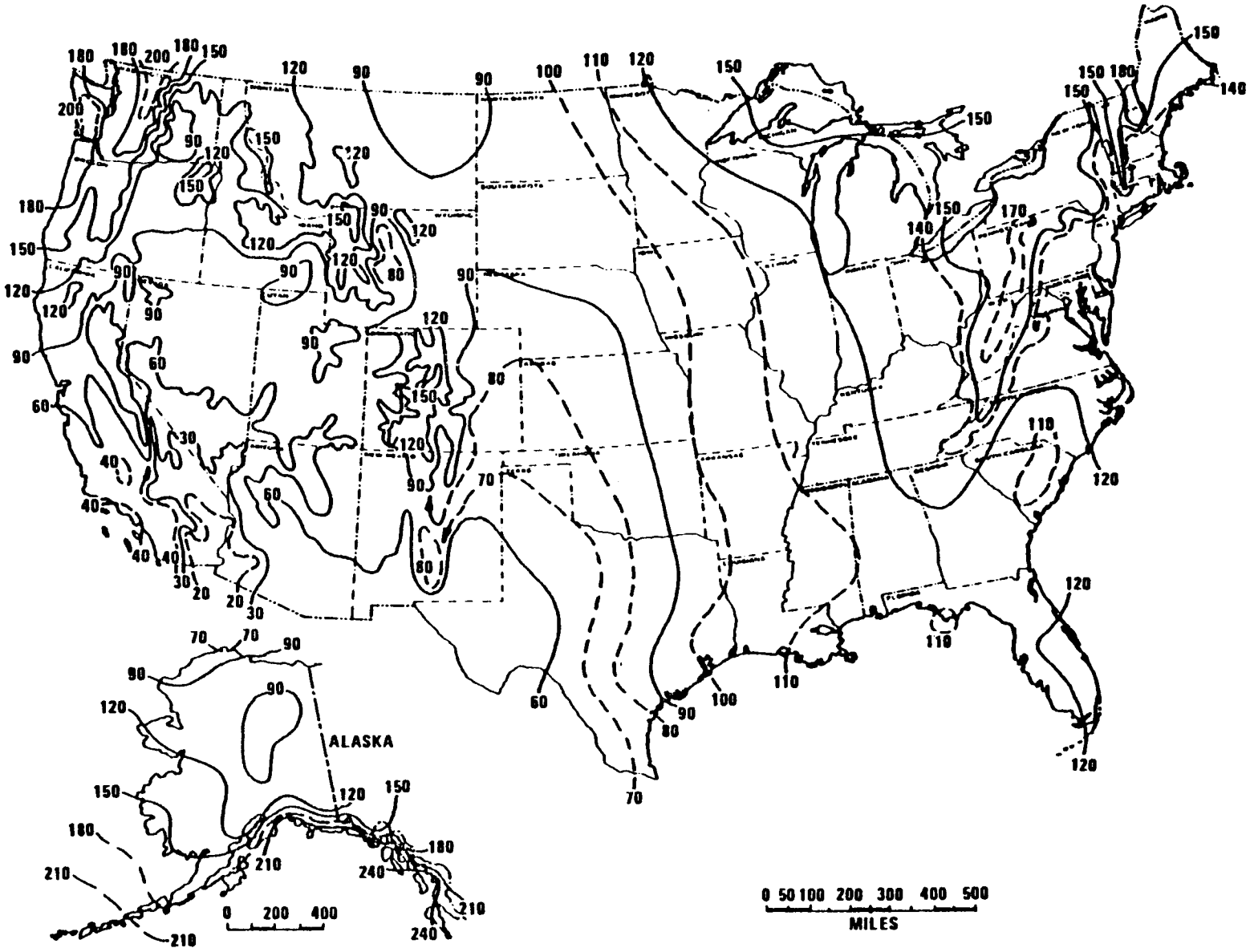


Figure 11.2.1-1. Mean number of days with 0.01 inch or more of precipitation in United States.[10]

the equation. Worst case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equation (which is equivalent to dropping the last term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst case averaging period (usually 24 hours). Similarly, to calculate emissions for a 91 day season of the year using Equation 1, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91 day period. Also, use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

11.2.1.3 Control Methods

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working into the roadbed of chemical stabilization chemicals, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished with moderate to low costs, but frequent retreatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions but may be difficult to enforce. The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 11.2.6, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters which determine control efficiency include dilution ratio, application intensity (mass of diluted chemical per road area) and application frequency. Between applications, the control efficiency is usually found to decay at a rate which is proportional to the traffic count. Therefore, for a specific chemical application program, the average efficiency is inversely proportional to the average daily traffic count. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., average weight) and road characteristics (e. g., bearing strength).

Water acts as a road dust suppressant by forming cohesive moisture films among the discrete grains of road surface material. The average moisture level in the road surface material depends on the moisture added by watering and natural precipitation and on the moisture removed by evaporation. The natural evaporative forces, which vary with geographic location, are enhanced by the movement of traffic over the road surface. Watering, because of the frequency of treatments required, is generally not feasible for public roads and is used effectively only where water and watering equipment are available and where roads are confined to a single site, such as a construction location.

References for Section 11.2.1

1. C. Cowherd, Jr., et al., Development of Emission Factors for Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. R. J. Dyck and J. J. Stukel, "Fugitive Dust Emissions from Trucks on Unpaved Roads", Environmental Science and Technology, 10(10):1046-1048, October 1976.

3. R. O. McCaldin and K. J. Heidel, "Particulate Emissions from Vehicle Travel over Unpaved Roads", Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

4. C. Cowherd, Jr., et al., Iron and Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

5. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

6. R. Bohn, Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York, U. S. Environmental Protection Agency, New York, NY, March 1979.

7. C. Cowherd, Jr., and T. Cuscino, Jr., Fugitive Emissions Evaluation, Equitable Environmental Health, Inc., Elmhurst, IL, February 1977.

8. T. Cuscino, Jr., et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

9. K. Axetell and C. Cowherd, Jr., Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, PEDCo Environmental, Inc., Kansas City, MO, July 1981.

10. T. Cuscino, Jr., et al., Iron and Steel Plant Open Source Fugitive Emission Control Evaluation, EPA-600/2-83-110, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1983.

11. J. Patrick Reider, Size Specific Emission Factors for Uncontrolled Industrial and Rural Roads, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

12. C. Cowherd, Jr., and P. Englehart, Size Specific Particulate Emission Factors for Industrial and Rural Roads, EPA-600/7-85-038, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1985.

13. Climatic Atlas of the United States, U. S. Department of Commerce, Washington, DC, June 1968.

11.2.2 AGRICULTURAL TILLING

11.2.2.1 General

The two universal objectives of agricultural tilling are the creation of the desired soil structure to be used as the crop seedbed and the eradication of weeds. Plowing, the most common method of tillage, consists of some form of cutting loose, granulating and inverting the soil, and turning under the organic litter. Implements that loosen the soil and cut off the weeds but leave the surface trash in place have recently become more popular for tilling in dryland farming areas.

During a tilling operation, dust particles from the loosening and pulverization of the soil are injected into the atmosphere as the soil is dropped to the surface. Dust emissions are greatest during periods of dry soil and during final seedbed preparation.

11.2.2.2 Emissions and Correction Parameters

The quantity of dust from agricultural tilling is proportional to the area of land tilled. Also, emissions depend on surface soil texture and surface soil moisture content, conditions of a particular field being tilled.

Dust emissions from agricultural tilling have been found to vary directly with the silt content (defined as particles < 75 micrometers in diameter) of the surface soil depth (0 to 10 cm [0 to 4 in.]). The soil silt content is determined by measuring the proportion of dry soil that passes a 200 mesh screen, using ASTM-C-136 method. Note that this definition of silt differs from that customarily used by soil scientists, for whom silt is particles from 2 to 50 micrometers in diameter.

Field measurements[2] indicate that dust emissions from agricultural tilling are not significantly related to surface soil moisture, although limited earlier data had suggested such a dependence.[1] This is now believed to reflect the fact that most tilling is performed under dry soil conditions, as were the majority of the field tests.[1-2]

Available test data indicate no substantial dependence of emissions on the type of tillage implement, if operating at a typical speed (for example, 8 to 10 km/hr [5 to 6 mph]).[1-2]

11.2.2.3 Predictive Emission Factor Equation

The quantity of dust emissions from agricultural tilling, per acre of land tilled, may be estimated with a rating of A or B (see below) using the following empirical expression[2]:

$$E = k(5.38)(s)^{0.6} \quad \text{(kg/hectare)} \qquad (1)$$

$$E = k(4.80)(s)^{0.6} \quad \text{(lb/acre)}$$

where: E = emission factor
k = particle size multipler (dimensionless)
s = silt content of surface soil (%)

The particle size multiplier (k) in the equation varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier for Equation 1

Total particulate	< 30 μm	< 15 μm	< 10 μm	< 5 μm	< 2.5 μm
1.0	0.33	0.25	0.21	0.15	0.10

Equation 1 is rated A if used to estimate total particulate emissions, and B if used for a specific particle size range. The equation retains its assigned quality rating if applied within the range of surface soil silt content (1.7 to 88 percent) that was tested in developing the equation. Also, to retain the quality rating of Equation 1 applied to a specific agricultural field, it is necessary to obtain a reliable silt value(s) for that field. The sampling and analysis procedures for determining agricultural silt content are given in Reference 2. In the event that a site specific value for silt content cannot be obtained, the mean value of 18 percent may be used, but the quality rating of the equation is reduced by one level.

11.2.2.4 Control Methods[3]

In general, control methods are not applied to reduce emissions from agricultural tilling. Irrigation of fields before plowing will reduce emissions, but in many cases, this practice would make the soil unworkable and would adversely affect the plowed soil's characteristics. Control methods for agricultural activities are aimed primarily at reduction of emissions from wind erosion through such practices as continuous cropping, stubble mulching, strip cropping, applying limited irrigation to fallow fields, building windbreaks, and using chemical stabilizers. No data are available to indicate the effects of these or other control methods on agricultural tilling, but as a practical matter, it may be assumed that emission reductions are not significant.

References for Section 11.2.2

1. C. Cowherd, Jr., et al., Development of Emission Factors for Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. T. A. Cuscino, Jr., et al., The Role of Agricultural Practices in Fugitive Dust Emissions, California Air Resources Board, Sacramento, CA, June 1981.

3. G. A Jutze, et al., Investigation of Fugitive Dust - Sources Emissions And Control, EPA-450/3-74-036a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

11.2.3 AGGREGATE HANDLING AND STORAGE PILES

11.2.3.1 General

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.

11.2.3.2 Emissions and Correction Parameters

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 and proportion of aggregate fines.

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 aggregate transfer itself 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. Any significant rainfall soaks the interior of the pile, and the drying process is very slow.

Field investigations have shown that emissions from 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 11.2.3-1 summarizes measured silt and moisture values for industrial aggregate materials.

11.2.3.3 Predictive Emission Factor Equations

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

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

TABLE 11.2.3-1. TYPICAL SILT AND MOISTURE CONTENT VALUES OF MATERIALS AT VARIOUS INDUSTRIES

Industry	Material	Silt (%)			Moisture (%)		
		No. of test samples	Range	Mean	No. of test samples	Range	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 2-5. NA = not applicable.
[b] Reference 1.
[c] Reference 6.
[d] Reference 7.

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 quantity of particulate emissions generated by a batch drop operation, per ton of material transferred, may be estimated, with a rating of C, using the following empirical expression[2]:

$$E = k(0.00090)\ \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{1.5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{4.6}\right)^{0.33}} \quad (kg/Mg) \qquad (1)$$

$$E = k(0.0018)\ \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)^{0.33}} \quad (lb/ton)$$

where: E = emission factor
k = particle size multipler (dimensionless)
s = material silt content (%)
U = mean wind speed, m/s (mph)
H = drop height, m (ft)
M = material moisture content (%)
Y = dumping device capacity, m^3 (yd^3)

The particle size multipler (k) for Equation 1 varies with aerodynamic particle size, shown in Table 11.2.3-2.

TABLE 11.2.3-2. AERODYNAMIC PARTICLE SIZE MULTIPLIER (k) FOR EQUATIONS 1 AND 2

Equation	< 30 μm	< 15 μm	< 10 μm	< 5 μm	< 2.5 μm
Batch drop	0.73	0.48	0.36	0.23	0.13
Continuous drop	0.77	0.49	0.37	0.21	0.11

The quantity of particulate emissions generated by a continuous drop operation, per ton of material transferred, may be estimated, with a rating of C, using the following empirical expression[3]:

$$E = k(0.00090)\ \frac{\left(\frac{s}{5}\right)\left(\frac{U}{2.2}\right)\left(\frac{H}{3.0}\right)}{\left(\frac{M}{2}\right)^2} \quad (kg/Mg) \qquad (2)$$

$$E = k(0.0018)\ \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{10}\right)}{\left(\frac{M}{2}\right)^2} \quad (lb/ton)$$

where: E = emission factor
k = particle size multiplier (dimensionless)
s = material silt content (%)
U = mean wind speed, m/s (mph)
H = drop height, m (ft)
M = material moisture content (%)

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as shown in Table 11.2.3-2.

Equations 1 and 2 retain the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equations, as given in Table 11.2.3-3. Also, to retain the quality ratings of Equations 1 or 2 applied to a specific facility, it is necessary that reliable correction parameters be determined for the specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.3-1 may be used, but in that case, the quality ratings of the equations are reduced by one level.

TABLE 11.2.3-3. RANGES OF SOURCE CONDITIONS FOR EQUATIONS 1 AND 2[a]

Equation	Silt content (%)	Moisture content (%)	Dumping capacity		Drop height	
			m^3	yd^3	m	ft
Batch drop	1.3 - 7.3	0.25 - 0.70	2.10 - 7.6	2.75 - 10	NA	NA
Continuous drop	1.4 - 19	0.64 - 4.8	NA	NA	1.5 - 12	4.8 - 39

[a] NA = not applicable.

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 11.2.1). 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.

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

$$E = 1.9 \left(\frac{s}{1.5}\right) \left(\frac{365-p}{235}\right) \left(\frac{f}{15}\right) \text{ (kg/day/hectare)} \qquad (3)$$

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

where: E = total suspended particulate emission factor
s = silt content of aggregate (%)
p = number of days with ≧ 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 coefficient in Equation 3 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 Test Report 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 3 is rated C for application in the sand and gravel industry and D for other industries.

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 Equations 1 and 2 appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for vehicle traffic (Section 11.2.1) and for wind erosion (Equation 3), centering around parameter p, follows the methodology described in Section 11.2.1. 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.

11.2.3.4 Control Methods

Watering and chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical wetting agents for better wetting of fines and

longer retention of the moisture film. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[8]

References for Section 11.2.3

1. C. Cowherd, Jr., et al., Development of Emission Factors for Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

2. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

3. C. Cowherd, Jr., et al., Iron and Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

4. R. Bohn, Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York, U. S. Environmental Protection Agency, New York, NY, March 1979.

5. C. Cowherd, Jr., and T. Cuscino, Jr., Fugitive Emissions Evaluation, Equitable Environmental Health, Inc., Elmhurst, IL, February 1977.

6. T. Cuscino, et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

7. K. Axetell and C. Cowherd, Jr., Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, PEDCo Environmental, Inc., Kansas City, MO, July 1981.

8. G. A. Jutze, et al., Investigation of Fugitive Dust Sources Emissions and Control, EPA-450/3-74-036a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

11.2.4 Heavy Construction Operations

11.2.4.1 General – Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are the prevalent construction categories with the highest emissions potential. Emissions during the construction of a building or road are associated with land clearing, blasting, ground excavation, cut and fill operations, and the construction of the particular facility itself. Dust emissions vary substantially from day to day depending on the level of activity, the specific operations, and the prevailing weather. A large portion of the emissions result from equipment traffic over temporary roads at the construction site.

11.2.4.2 Emissions and Correction Parameters – The quantity of dust emissions from construction operations are proportional to the area of land being worked and the level of construction activity. Also, by analogy to the parameter dependence observed for other similar fugitive dust sources,[1] it is probable that emissions from heavy construction operations are directly proportional to the silt content of the soil (that is, particles smaller than 75 μm in diameter) and inversely proportional to the square of the soil moisture, as represented by Thornthwaite's precipitation-evaporation (PE) index.[2]

11.2.4.3 Emission Factor – Based on field measurements of suspended dust emissions from apartment and shopping center construction projects, an approximate emission factor for construction operations is:

1.2 tons per acre of construction per month of activity

This value applies to construction operations with: (1) medium activity level, (2) moderate silt content ($\sim$30 percent), and (3) semiarid climate (PE $\sim$50; see Figure 11.2-2). Test data are not sufficient to derive the specific dependence of dust emissions on correction parameters.

The above emission factor applies to particles less than about 30 μm in diameter, which is the effective cut-off size for the capture of construction dust by a standard high-volume filtration sampler[1], based on a particle density of 2.0-2.5 g/cm^3.

11.2.4.4 Control Methods – Watering is most often selected as a control method because water and necessary equipment are usually available at construction sites. The effectiveness of watering for control depends greatly on the frequency of application. An effective watering program (that is, twice daily watering with complete coverage) is estimated to reduce dust emissions by up to 50 percent.[3] Chemical stabilization is not effective in reducing the large portion of construction emissions caused by equipment traffic or active excavation and cut and fill operations. Chemical stabilizers are useful primarily for application on completed cuts and fills at the construction site. Wind erosion emissions from inactive portions of the construction site can be reduced by about 80 percent in this manner, but this represents a fairly minor reduction in total emissions compared with emissions occurring during a period of high activity.

References for Section 11.2.4

1. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze. Development of Emissions Factors for Fugitive Dust Sources. Midwest Research Institute, Kansas City, Mo. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0619. Publication No. EPA-450/3-74-037. June 1974.

2. Thornthwaite, C. W. Climates of North America According to a New Classification. Geograph. Rev. *21*: 633-655, 1931.

3. Jutze, G. A., K. Axetell, Jr., and W. Parker. Investigation of Fugitive Dust-Sources Emissions and Control, PEDCo Environmental Specialists, Inc., Cincinnati, Ohio. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-0044. Publication No. EPA-450/3-74-036a. June 1974.

11.2.5 PAVED URBAN ROADS

11.2.5.1 General

Various field studies have indicated that dust emissions from paved street are a major component of the material collected by high volume samplers. Reentrained traffic dust has been found to consist primarily of mineral matter similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicle traffic itself. Other particulate matter is emitted directly by the vehicles from, for example, engine exhaust, wear of bearings and brake linings, and abrasion of tires against the road surface. Some of these direct emissions may settle to the street surface, subsequently to be reentrained. Appreciable emissions from paved streets are added by wind erosion when the wind velocity exceeds a threshold value of about 20 kilometers per hour (13 miles per hour).[2] Figure 11.2.5-1 illustrates particulate transfer processes occurring on urban streets.

11.2.5.2 Emission Factors And Correction Parameters

Dust emission rates may vary according to a number of factors. The most important are thought to be traffic volume and the quantity and particle size of loose surface material on the street. On a normal paved street, an equilibrium is reached whereby the accumulated street deposits are maintained at a relatively constant level. On average, vehicle carryout from unpaved areas may be the largest single source of street deposit. Accidental spills, street cleaning and rainfall are activities that disrupt the street loading equilibrium, usually for a relatively short duration.

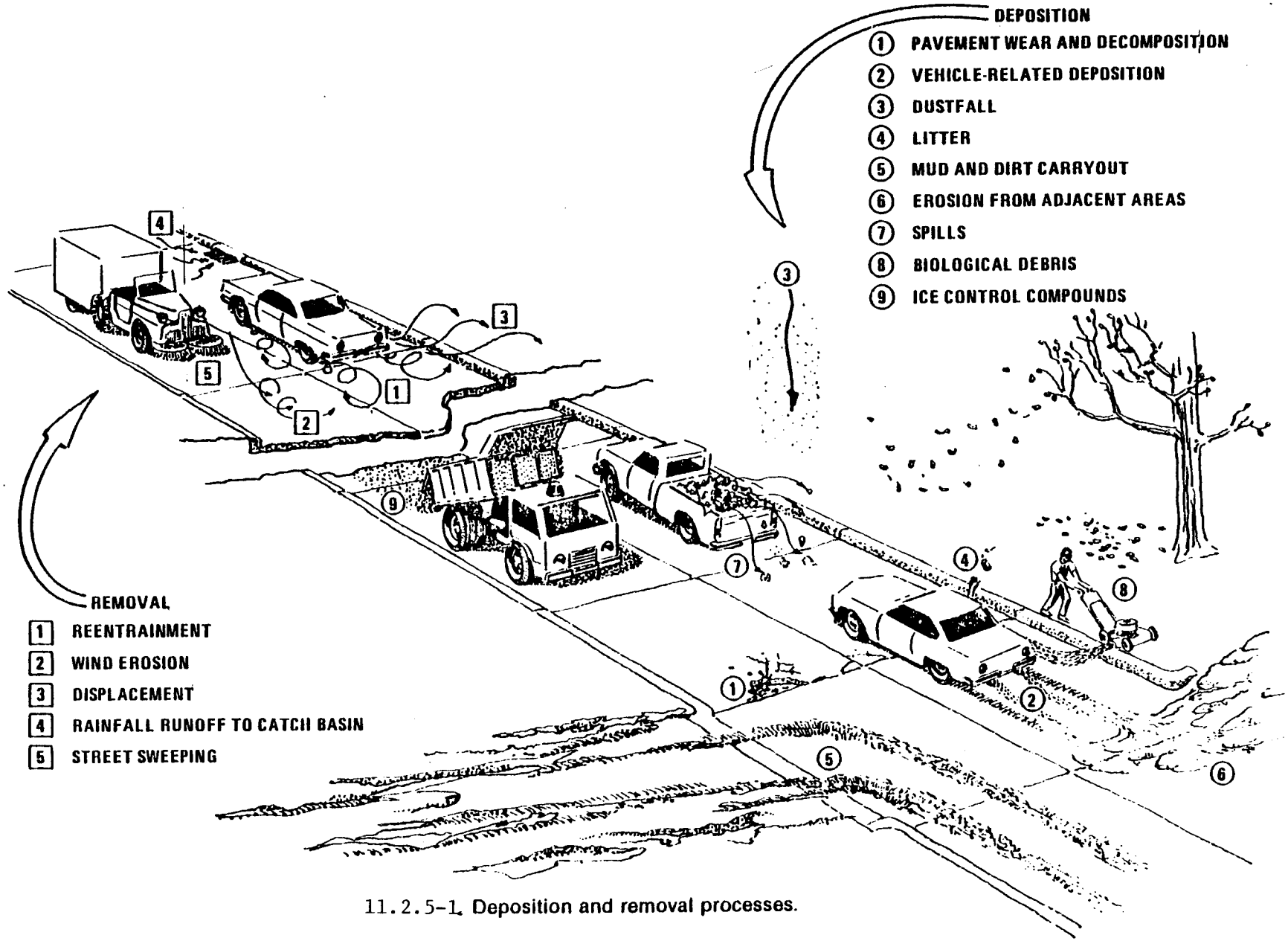
The lead content of fuels also becomes a part of reentrained dust from vehicle traffic. Studies have found that, for the 1975-76 sampling period, the lead emission factor for this source was approximately 0.03 grams per vehicle mile traveled (VMT). With the reduction of lead in gasoline and the use of catalyst equipped vehicles, the lead factor for reentrained dust was expected to drop below 0.01 grams per mile by 1980.[3]

The quantity of dust emissions of vehicle traffic on a paved roadway may be estimated using the following empirical expression[4]:

$$e = k \left(\frac{sL}{0.5}\right)^p \quad \text{(g/VKT)}$$

$$e = k \left(\frac{sL}{0.7}\right)^p \quad \text{(lb/VMT)}$$

where: e = particulate emission factor, g/VKT (lb/VMT)
L = total road surface dust loading, g/m^2 ($grains/ft^2$)
s = surface silt content, fraction of particles $\leq$ 75 μm diameter (American Association of State Highway Officials)
k = base emission factor, g/VKT (lb/VMT)
p = exponent (dimensionless)



11.2.5-1. Deposition and removal processes.

The total loading (excluding litter) is measured by sweeping and vacuuming lateral strips of known area from each active travel lane. The silt fraction is determined by measuring the proportion of loose dry road dust that passes a 200 mesh screen, using the ASTM-C-136 method. Silt loading is the product of total loading and silt content.

The base emission factor coefficients, k, and exponents, p, in the equation for each size fraction are listed in Table 11.2.5-1. Total suspended particulate (TSP) denotes that particle size fraction of airborne particulate matter that would be collected by a standard high volume sampler.

TABLE 11.2.5-1. PAVED URBAN ROAD EMISSION FACTOR EQUATION PARAMETERS[a]

Particle Size Fraction[b]	k g/VKT (lb/VMT)	p
TSP	5.87 (0.0208)	0.9
$\leq$ 15 μm	2.54 (0.0090)	0.8
$\leq$ 10 μm	2.28 (0.0081)	0.8
$\leq$ 2.5 μm	1.02 (0.0036)	0.6

[a]Reference 4. See page 11.2.5-1 for equation. TSP = total suspended particulate.
[b]Aerodynamic diameter.

Microscopic analysis indicates the origin of material collected on high volume filters to be about 40 weight percent combustion products and 59 percent mineral matter, with traces of biological matter and rubber tire particles. The small particulate is mainly combustion products, while most of the large material is of mineral origin.

11.2.5.3 Emissions Inventory Applications[4]

For most emissions inventory applications involving urban paved roads, actual measurements of silt loading will probably not be made. Therefore, to facilitate the use of the previously described equation, it is necessary to characterize silt loadings according to parameters readily available to persons developing the inventories. It is convenient to characterize variations in silt loading with a roadway classification system, and this is presented in Table 11.2.5-2. This system generally corresponds to the classification systems used by transportation agencies, and thus the data necessary for an emissions inventory - number of road kilometers per road category and traffic counts - should be easy to obtain. In some situations, it may be necessary to combine this silt loading information with sound engineering judgment in order to approximate the loadings for roadway types not specifically included in Table 11.2.5-2.

TABLE 11.2.5-2. 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 4.
[b]Road width ≥ 32 ft.
[c]Road width < 32 ft.

A data base of 44 samples analyzed according to consistent procedures may be used to characterize the silt loadings for each roadway category.[4] These samples, obtained during recent field sampling programs, represent a broad range of urban land use and roadway conditions. Geometric means for this data set are given by sampling location and roadway category in Table 11.2.5-3.

TABLE 11.2.5-3. SUMMARY OF SILT LOADINGS (sL) FOR PAVED URBAN ROADWAYS[a]

City	Roadway Category							
	Local Streets		Collector Streets		Major Streets/ Highways		Freeways/ Expressways	
	$\overline{X}_g$ (g/m^2)	n	$\overline{X}_g$ (g/m^2)	n	$\overline{X}_g$ (g/m^2)	n	$\overline{X}_g$ (g/m^2)	n
Baltimore	1.42	2	0.72	4	0.39	3	-	-
Buffalo	1.41	5	0.29	2	0.24	4	-	-
Granite City (IL)	-	-	-	-	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 4. X_g = geometric mean based on corresponding n sample size. Dash = not available. To convert g/m^2 to grains/ft^2 multiply g/m^2 by 1.4337.

These sampling locations can be considered representative of most large urban areas in the United States, with the possible exception of those in the Southwest. Except for the collector roadway category, the mean silt loadings do not vary greatly from city to city, though the St. Louis mean for major roads is somewhat lower than those of the other four cities. The substantial variation within the collector roadway category is probably attributable to the effects of land use around the specific sampling locations. It should also be noted that an examination of data collected at three cities in Montana during early spring indicates that winter road sanding may produce loadings five to six times higher than the means of the loadings given in Table 11.2.5-3 for the respective road categories.[5]

Table 11.2.5-4 presents the emission factors by roadway category and particle size. These were obtained by inserting the above mean silt loadings into the equation on page 11.2.5-1. These emission factors can be used directly for many emission inventory purposes. It is important to note that the paved road emission factors for TSP agree quite well with those developed from previous testing of roadway sites in the major street and highway category, yielding mean TSP emission factors of 4.3 grams/VKT (Reference 6) and 2.6 grams/VKT (Reference 7).

TABLE 11.2.5-4. RECOMMENDED PARTICULATE EMISSION FACTORS FOR SPECIFIC ROADWAY CATEGORIES AND PARTICLE SIZE FRACTIONS

Roadway Category	Emission Factor			
	TSP	$\leq$ 15 μm	$\leq$ 10 μm	$\leq$ 2.5 μm
	g/VKT (lb/VMT)	g/VKT (lb/VMT)	g/VKT (lb/VMT)	g/VKT (lb/VMT)
Local streets	15 (0.053)	5.8 (0.021)	5.2 (0.018)	1.9 (0.0067)
Collector streets	10 (0.035)	4.1 (0.015)	3.7 (0.013)	1.5 (0.0053)
Major streets/ highways	4.4 (0.016)	2.0 (0.0071)	1.8 (0.0064)	0.84 (0.0030)
Freeways/ expressways	0.35 (0.0012)	0.21 (0.00074)	0.19 (0.00067)	0.16 (0.00057)

References for Section 11.2.5

1. D. R. Dunbar, Resuspension of Particulate Matter, EPA-450/2-76-031, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

2. M. P. Abel, "The Impact of Refloatation on Chicago's Total Suspended Particulate Levels", Purdue University, Purdue, IN, August 1974.

3. C. M. Maxwell and D. W. Nelson, A Lead Emission Factor for Reentrained Dust from a Paved Roadway, EPA-450/3-78-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1978.

4. Chatten Cowherd, Jr. and Phillip J. Englehart, Paved Road Particulate Emissions, EPA-600/7-84-077, U. S. Environmental Protection Agency, Washington, DC, July 1984.

5. R. Bohn, Update and Improvement of the Emission Inventory for MAPS Study Areas, State of Montana, Helena, MT, August 1979.

6. C. Cowherd, Jr., et al., Quantification of Dust Entrainment from Paved Roadways, EPA-450/3-77-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

7. K. Axetell and J. Zell, Control of Reentrained Dust from Paved Streets, EPA-907/9-77-077, U. S. Environmental Protection Agency, Kansas City, MO, August 1977.

11.2.6 INDUSTRIAL PAVED ROADS

11.2.6.1 General

Various field studies have indicated that dust emissions from industrial paved roads are a major component of atmospheric particulate matter in the vicinity of industrial operations. Industrial traffic dust has been found to consist primarily of mineral matter, mostly tracked or deposited onto the roadway by vehicle traffic itself when vehicles enter from an unpaved area or travel on the shoulder of the road, or when material is spilled onto the paved surface from haul truck traffic.

11.2.6.2 Emissions And Correction Parameters

The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading and average vehicle weight) of a particular road and associated vehicle traffic.[1-2]

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles ≤ 75 μm in diameter) in the road surface material.[1-2] The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen, using the ASTM-C-136 method. In addition, it has also been found that emissions vary in direct proportion to the surface dust loading.[1-2] The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 11.2.6-1 summarizes measured silt and loading values for industrial paved roads.

11.2.6.3 Predictive Emission Factor Equations

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved roads, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT) may be estimated, with a rating of B or D (see below), using the following empirical expression[2]:

$$E = 0.022\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \quad \text{(kg/VKT)} \qquad (1)$$

$$E = 0.077\ I \left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1,000}\right)\left(\frac{W}{3}\right)^{0.7} \quad \text{(lb/VMT)}$$

where: E = emission factor
I = industrial augmentation factor (dimensionless) (see below)
n = number of traffic lanes
s = surface material silt content (%)
L = surface dust loading, kg/km (lb/mile) (see below)
W = average vehicle weight, Mg (ton)

TABLE 11.2.6-1. TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT INDUSTRIAL FACILITIES[a]

Industry	No. of Plant Sites	No. of Samples	Silt (%, w/w) Range	Silt (%, w/w) Mean	No. of Travel Lanes	Total loading Range	Total loading Mean	Total loading Units[b]	Silt loading (g/m^2) Range	Silt loading (g/m^2) Mean
Copper smelting	1	3	[15.4-21.7]	[19.0]	2	[12.9-19.5] [45.8-69.2]	[15.9] [55.4]	kg/km lb/mi	[188-400]	[292]
Iron and steel production	6	20	1.1-35.7	12.5	2 2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	<1.0-2.3	7
Asphalt batching	1	4	[2.6-4.6]	[3.6]	1	[12.1-18.0] [43.0-64.0]	[15.7] [55.7]	kg/km lb/mi	[76-193]	[138]
Concrete batching	1	3	[5.2-6.0]	[5.5]	2	[1.4-1.8] [5.0-6.4]	[1.7] [5.9]	kg/km lb/mi	[11-12]	[12]
Sand and gravel processing	1	3	[6.4-7.9]	[7.1]	1	[2.8-5.5] [9.9-19.4]	[3.8] [13.3]	kg/km lb/mi	[53-95]	[70]

[a]References 1-5. Brackets indicate values based on samples obtained at only one plant site.
[b]Multiply entries by 1,000 to obtain stated units.

The industrial road augmentation factor (I) in the Equation 1 takes into account higher emissions from industrial roads than from urban roads. I = 7.0 for an industrial roadway which traffic enters from unpaved areas. I = 3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder. I = 1.0 for cases in which traffic does not travel on unpaved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation.

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as follows:

Silt content (%)	Surface loading kg/km	Surface loading lb/mile	No. of lanes	Vehicle weight Mg	Vehicle weight tons
5.1 - 92	42.0 - 2,000	149 - 7,100	2 - 4	2.7 - 12	3 - 13

If I is >1.0, the rating of the equation drops to D because of the subjectivity in the guidelines for estimating I.

The quantity of fine particle emissions generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the

$$E = k \left(\frac{sL}{12}\right)^{0.3} \quad \text{(kg/VKT)} \qquad (2)$$

$$E = k(3.5) \left(\frac{sL}{0.35}\right)^{0.3} \quad \text{(lb/VMT)}$$

where: E = emission factor
sL = road surface silt loading, g/m^2 (oz/yd^2)

The particle size multiplier (k) above varies with aerodynamic size range as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 2 (Dimensionless)

≤15 μm	≤10 μm	≤2.5 μm
0.28	0.22	0.081

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation as follows:

silt loading, 2 - 240 g/m^2 (0.06 - 7.1 oz/yd^2)

mean vehicle weight, 6 - 42 Mg (7 - 46 tons)

The following single valued emission factors[6] may be used in lieu of Equation 2 to estimate fine particle emissions generated by light duty vehicles on dry, heavily loaded industrial roads, with a rating of C:

Emission Factors For Light Duty Vehicles On Heavily Loaded Roads

≤15 μm	≤10 μm
0.12 kg/VKT (0.41 lb/VMT)	0.093 kg/VKT (0.33 lb/VMT)

These emission factors retain the assigned quality rating, if applied within the range of source conditions that were tested in developing the factors, as follows:

silt loading, 15 - 400 g/m^2 (0.44 - 12 oz/yd^2)

mean vehicle weight, ≤4 Mg (≤4 tons)

Also, to retain the quality ratings of Equations 1 and 2 when applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and

laboratory procedures for determining surface material silt content and surface dust loading are given in Reference 2. In the event that site specific values for correction parameters cannot be obtained, the appropriate mean values from Table 11.2.6-1 may be used, but the quality ratings of the equations should be reduced by one level.

11.2.6.4 Control Methods

Common control techniques for industrial paved roads are broom sweeping, vacuum sweeping and water flushing, used alone or in combination. All of these techniques work by reducing the silt loading on the traveled portions of the road. As indicated by a comparison of Equations 1 and 2, fine particle emissions are less sensitive than total suspended particulate emissions to the value of silt loading. Consistent with this, control techniques are generally less effective for the finer particle sizes.[4] The exception is water flushing, which appears preferentially to remove (or agglomerate) fine particles from the paved road surface. Broom sweeping is generally regarded as the least effective of the common control techniques, because the mechanical sweeping process is inefficient in removing silt from the road surface.

To achieve control efficiencies on the order of 50 percent on a paved road with moderate traffic (500 vehicles per day) requires cleaning of the surface at least twice per week.[4] This is because of the characteristically rapid buildup of road surface material from spillage and the tracking and deposition of material from adjacent unpaved surfaces, including the shoulders (berms) of the paved road. Because industrial paved roads usually do not have curbs, it is important that the width of the paved road surface be sufficient for vehicles to pass without excursion onto unpaved shoulders. Equation 1 indicates that elimination of vehicle travel on unpaved or untreated shoulders would effect a major reduction in particulate emissions. An even greater effect, by a factor of 7, would result from preventing travel from unpaved roads or parking lots onto the paved road of interest.

References for Section 11.2.6

1. R. Bohn, et al., Fugitive Emissions from Integrated Iron and Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

2. C. Cowherd, Jr., et al., Iron and Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1979.

3. R. Bohn, Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York, U. S. Environmental Protection Agency, New York, NY, March 1979.

4. T. Cuscino, Jr., et al., Iron and Steel Plant Open Source Fugitive Emission Control Evaluation, EPA-600/2-83-110, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1983.

5. J. Patrick Reider, Size Specific Particulate Emission Factors for Uncontrolled Industrial and Rural Roads, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, September 1983.

6. C. Cowherd, Jr. and P. Englehart, Size Specific Particulate Emission Factors For Industrial And Rural Roads, EPA-600/7-85-051, U. S. Environmental Protection Agency, Washington, DC, September 1985.