EPA/625/5-87/022
September 1987

User's Guide

Emission Control Technologies and Emission Factors for Unpaved Road Fugitive Emissions

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Acknowledgments

This handbook is primarily a summary of the results of two independent studies, one conducted by Midwest Research Institute (MRI), Kansas City, Missouri, and the other by Southern Research Institute (SORI), Birmingham, Alabama. The MRI Report, *Identification, Assessment and Control of Fugitive Particulate Emissions* was written by Chatten Cowherd Jr., John S. Kinsey and Dennis Wallace; Dale Harmon of EPA's Air and Energy Engineering Research Laboratory was project officer. The SORI report, *Critical Review of Open Source Particulate Measurement, Part II – Field Comparison*, was written by Bobby E. Pyle and Joseph McCain; Robert McCrillis of EPA's Air and Energy Engineering Research Laboratory was project officer.

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If you wish to obtain the more detailed reports, they are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161; (703) 487-4650. The order numbers are:

MRI Report; PB 86-230083; EPA-600/8-86-023
SORI Report; PB 86-239787; EPA-600/2-86-072

Notice

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Appendix D – Control Efficiency Decay Curves: figures depicting control efficiency decay curves.

1.3 References

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At a minimum, the wind direction and speed must be recorded on-site.

2.1.2 The Exposure Profiling Method

This method uses the profiling concept that is the basis for conventional (ducted) source testing. The difference is that in the case of exposure profiling, the ambient wind directs the plume to the sampling array. The passage of airborne particulate matter immediately downwind of the source is measured directly by means of simultaneous multi-point sampling of particulate concentration and wind velocity over the effective cross section of the fugitive emissions plume. For measurement of fugitive emissions, profiling sampling heads are distributed over a vertical network positioned just downwind (usually about 5 m) from the source. Particulate sampling heads should be symmetrically distributed over the concentrated portion of the plume containing about 90% of the total mass flux (exposure). A vertical line grid of at least three samplers is sufficient for measuring emissions from line or moving point sources. At least one upwind sampler must be operated to measure background concentration, and wind speed must be measured concurrently on-site. Figure 2-2 illustrates the exposure profiling method.

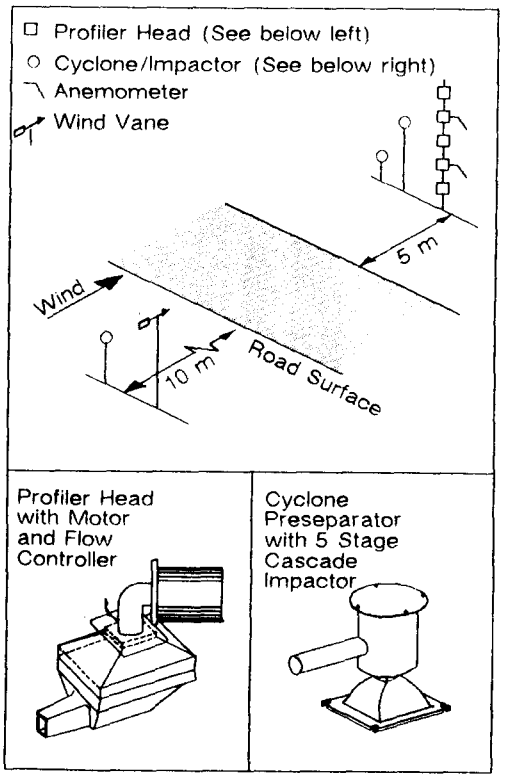
Unlike the upwind/downwind method, exposure profiling uses a mass-balance calculation scheme rather than requiring indirect calculation through the application of a generalized atmospheric dispersion model. The mass of airborne particulate matter emitted by the source is obtained by spatial integration of distributed measurements of particulate flux, after subtracting the background contribution. The exposure is the point value of the flux (concentration of airborne particulate accumulated over the time of measurement).

2.1.3 Recommended Sampling Procedures

The method of choice in measuring fugitive emissions from unpaved roads is the exposure profiling method. [4,5]. Measurement results of a line source (such as unpaved road) obtained using the exposure profiling method are more accurate than those obtained by the upwind/downwind method. [5] The exposure/profiling method is source-specific, and its increased accuracy over the upwind/downwind method is a result of the fact that emission factor calculation is based on direct measurement of the emission rate. [5]

Maximum exposure values from unpaved roads usually occur at a height of 1.5 to 2.0 meters above ground level. However, there may be significant

Figure 2-2. Illustration of exposure profiling sampling method. [3]



dust exposures at heights up to at least 9 meters. The exposure profile method provides better characterization of the plume generated by vehicular traffic on an unpaved road because emissions are measured at multiple heights in the dust plume.

The ideal exposure profiling system to characterize unpaved road mass emissions would have mass samplers situated at 1.5, 2.5, 4.0, 6.0, 7.5 and 10 meters above the road surface. Each sampling head would contain a horizontally mounted high-volume filter and an inlet nozzle below the filter. It is possible to sample isokinetically at each mass sampler on the profiler tower if each sampler is equipped with a servo system and individual velocity sensors. This sampling set-up provides continuous adjustment of the flow rate based on wind velocity at each elevation on the profiler tower.

2.2 Particle Sizing Methods

Three fundamentally different methods are commonly used to perform particle size measurements on open dust emission sources — cyclone/impactors, stacked filters, and scanning electron microscopy. These measurement techniques will be discussed in the following sections. For particle size analysis of fugitive road dust emissions, sampling is generally done in conjunction with total particulate

Chapter 2
Overview of Source Testing Methods

Testing verifies the rates of uncontrolled emissions from the most significant sources and establishes the relative importance of each of those sources. In addition, source testing provides valuable data on the emission characteristics of each source, which in turn aids considerably in selecting the most suitable control method for each source. This chapter presents an overview of the testing methods used to sample emissions from unpaved roads.

Fugitive particulate emission rates and particle size distributions are difficult to quantify because of the diffuse and variable nature of fugitive emission sources, and the wide range of particle sizes involved (including particles which deposit immediately adjacent to the source). Standard source testing methods, which are designed for testing confined flows under steady-state, forced-flow conditions, are not suitable for measurement of fugitive emissions.

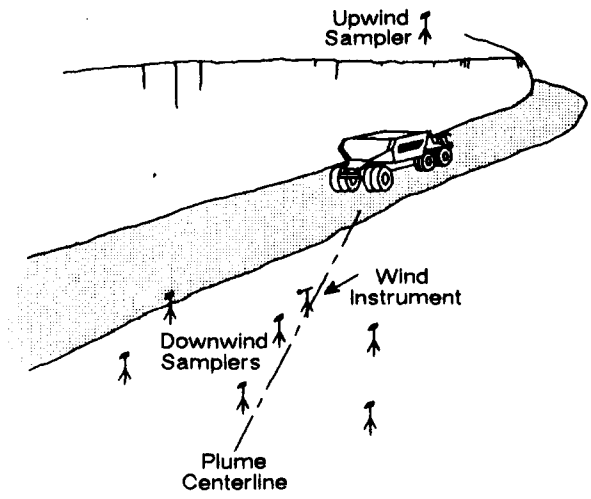
2.1 Mass Emissions Measurements

Field measurement of fugitive mass emissions from unpaved roads is usually conducted using either the upwind/downwind method or the exposure profiling method. The former involves measurement of upwind and downwind particulate concentrations, utilizing ground-based samplers under known meteorological conditions, followed by calculation of source strength (mass emission rate) with atmospheric dispersion equations. The exposure profiling method involves simultaneous, multi-point measurements of particulate concentration and wind speed over the effective cross-section of the plume, followed by calculation of net particulate mass flux through integration of the plume profiles.

2.1.1 The Upwind/Downwind Method

The basic procedure of the upwind/downwind method, shown schematically in Figure 2-1, is to measure particulate concentrations both upwind and downwind of the pollutant source using ground level samplers. The required number of upwind sampling instruments depends on how well the source operation can be isolated (i.e., the absence of interferences from other sources upwind). At least five downwind particulate samplers must be operating during a test; increasing the number of downwind instruments will improve the reliability in determining the emission rate by providing better plume definition. [1]

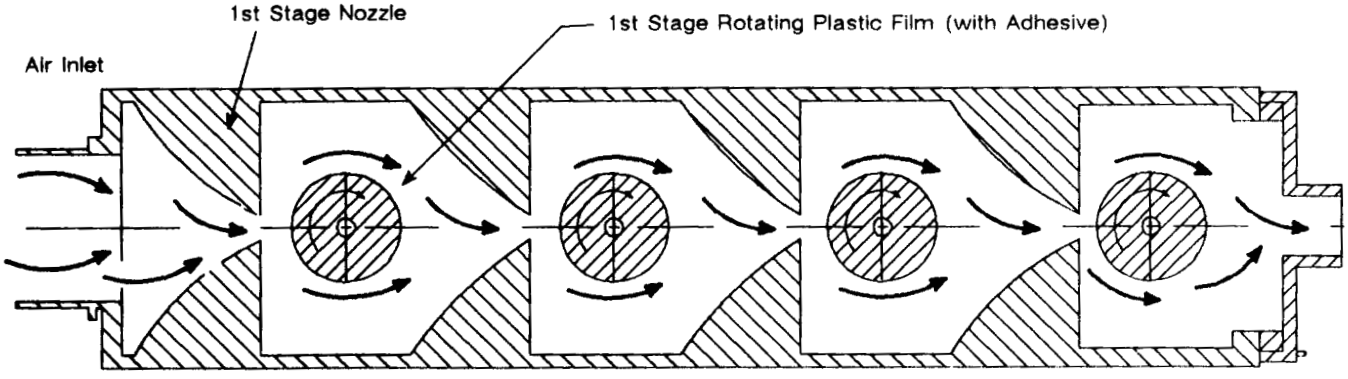
Figure 2-1. Illustration of upwind/downwind sampling method.[a]



[a] A modified drawing from reference 2.

After the concentrations measured upwind are subtracted from the downwind concentrations, the net downwind concentrations are input to dispersion equations (normally of the Gaussian type). The dispersion equations are used to back-calculate the particulate emission rate required to generate the pattern of downwind concentrations. (See Appendix C for a brief discussion of Gaussian air quality models and the parameters used in the models). A number of meteorological parameters must be concurrently recorded for input to this dispersion equation.

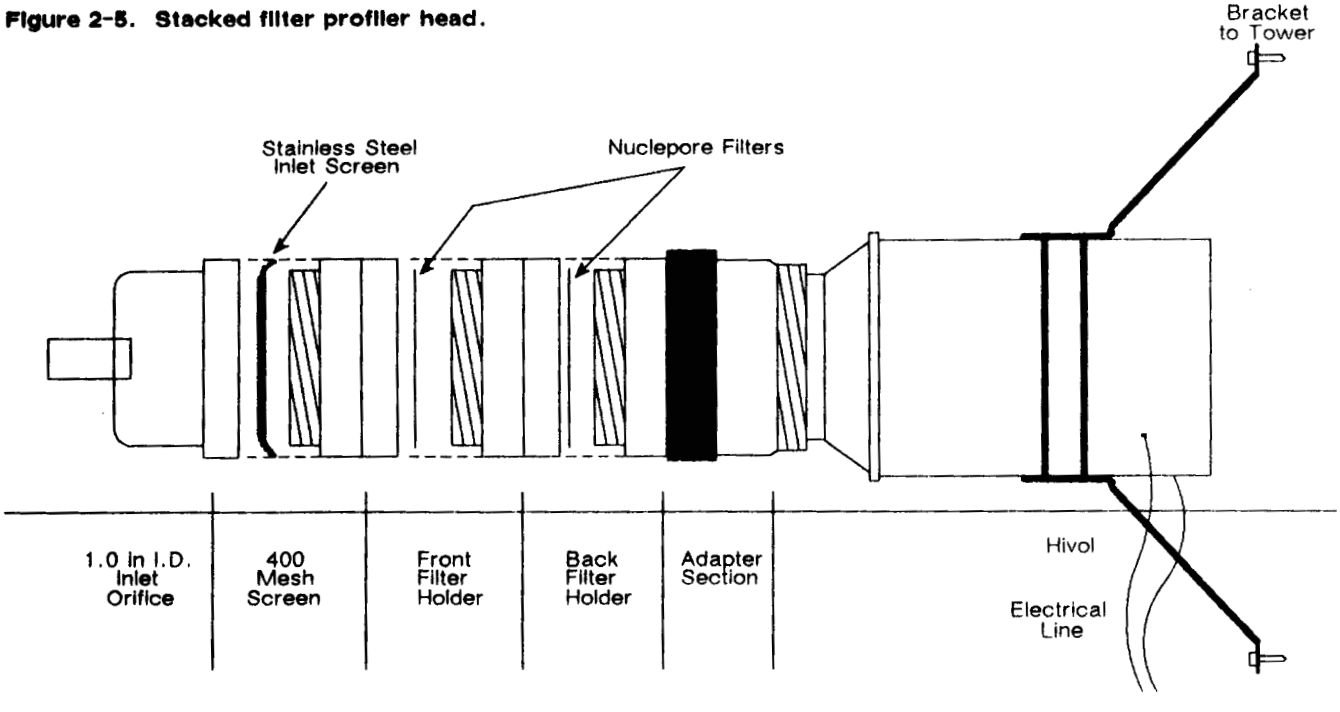
Figure 2-4. Lundgren cascade impactor.



redeposited specimen after mounting on SEM sample stubs.

Of the many techniques available to size particles by their physical dimensions as observed through the microscope, the most common approach is the projected area technique. Particle volumes are estimated by categorizing the particle shapes and estimating overall dimensions based on the measurements and assigned shape category. X-ray fluorescence emissions are used to assign a probable composition class to each particle. A density is then assigned to the particle. After measuring approximately 700 to 4,500 particles and assigning estimated volumes and densities, a physical diameter-weight distribution curve is constructed. Aerodynamic diameters are also estimated for each particle based on the assigned category, the measured dimensions, and aerodynamic shape factors. The choice of particle measuring technique and the method for deciding that a sufficient number of particles have been measured varies among firms performing the analysis.

Figure 2-5. Stacked filter profiler head.



Because this work requires several tedious hours to perform manually, automated processes have arisen. An example is the use of automatic image analysis for optical computer controlled scanning electron microscopy (CCSEM).

2.2.4 Comparison of Particle Sizing Methods

There are advantages and disadvantages with each of the particle sizing techniques described in the previous section.

Particle sizing is performed at only two stages with the stacked filter technique (2.5 and 30 μm), which means that all other particle sizes (such as the common 10 μm size) are inferred based on the two sizing points. Another problem with this method is that the 30 μm screen, the first sizing cutpoint in the sampler, becomes effectively smaller during sampling due to impaction and interception of smaller particles on the screen. This reduces the effective cutoff diameter of the screen to a value smaller than 30 μm, which could cause systematically low results for all particle sizes.

The procedures used to prepare samples for SEM analysis could cause bias among both the large and small particles. The filter retention screens used in transferring the sample from the profiler filter (the original collection medium) to the Nuclepore material will themselves act as filters and bias the sample taken from the profiler filter by suppressing the transfer of large particles. At the other end of the size spectrum, it is unlikely that the techniques used to remove particles from the profiler filters would be effective in removing smaller particles. Thus the bulk of the small particles removed would be in the form of agglomerates which would be counted as larger particles. In order to properly characterize the size distribution, measurements of about 4,500 particles are needed to obtain a statistically valid sample; this is generally larger than the number of particles currently counted for SEM analysis. There are also inherent difficulties in estimating particle volumes and assigning aerodynamic diameters to the irregular, nonhomogeneous particles encountered in fugitive road dust.

The cyclone/impactor method obtains data directly on an aerodynamic basis at five to seven cutpoints. One problem with the technique is potential particle bounce in the sampler. Particle bounce can be overcome by sampling at a reduced flow rate (15 cfm) or by using adhesive coated substrates at the current 20 cfm[a] flow rate. A second potential problem is errors resulting from the possible transfer of material from the outlet of the cyclone tube to the first stage of the impactor.

2.2.5 Recommended Particle Sizing Method

There are long recognized problems in reconstituting size distributions of airborne particles from resuspensions of bulk material. For fugitive emission sampling of unpaved roads the sizing should take place prior to collection (or concurrent with collection as in cyclones and impactors). The recommended procedure for measuring the particle size distribution is the cyclone/impactor technique. [4]

The ideal particle sizing sampling technique for fugitive road dust emissions is composed of profiler towers (upwind and downwind), with cyclone/impactors placed at 1.5, 4.5, and 7.0 meters above the road surface on the tower. Sizing is conducted using a cyclone for the removal of large particles followed by a high-volume cascade impactor for size distribution measurement. The size distribution measurements are made separately from the exposure measurement.

With regard to field operations, reduction in the sampling flow rate from the commonly used 20 cfm to 15 cfm would help minimize errors from particle bounce. Alternatively, adhesive coated substrates could be used at the current 20 cfm flow rate. Errors resulting from the possible transfer of material from the outlet tube of the cyclone to the first stage of the impactor can be avoided by counting only the material collected in the body of the cyclone as its catch. The outlet tube catch would then be combined with that of the first impactor stage.

With respect to particle sizing data analysis, the technique commonly used in reducing impactor data from industrial sources is appropriate. [9,10,11] A spline fit is made to the cyclone/impactor data in the cumulative percentage form of the distribution. The fit is made in a manner that requires continuity in the slope of the curve, and the solution is forced to be asymptotic to 100% at a diameter equal to the maximum diameter present in the sample. The fitted curve is then used to interpolate or extrapolate as needed to obtain the mass fractions in the selected size intervals. This technique avoids the assumption of a functional form for the distribution and makes

[a] 20 cfm is a specific sampling flow rate used by Sierra high volume cascade impactors (Model No. 230) designed to sample fugitive road dust. Theoretically, sampling flow rates can vary by manufacturer, although there are no other known manufacturers of cascade impactors used in this application.

use of the complete data set rather than just two of the data points.

2.3 References

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11. TRS-80 Cascade Impactor Data Reduction System. Denver Research Institute, P.O. Box 10127, Denver, CO 80208.

Chapter 3
Uncontrolled Fugitive Road Dust Emission Factors

The large number of individual sources and the diversity of source types make impractical the field measurement of emissions at each point of release. In most cases the only feasible method for determining source-by-source emissions is to estimate the typical emission rate for each type of source and to adjust each estimate for the size or activity of the specific source and the level of control. Emission rates can be estimated using published emission factors (AP-42) or emission factors developed during in-house sampling. An emission factor is an estimate of the quantity of emissions released to the atmosphere relative to appropriate units of weight, volume, distance or duration of the activity that emits the pollutant. For unpaved roads, emission factors are expressed in pounds per vehicle mile traveled (or kilograms per vehicle kilometer traveled).

3.1 Published Emission Factors

The document *Compilation of Air Pollutant Emission Factors* (commonly called AP-42), published by the EPA since 1972, is a compilation of emission factor reports for the most significant emission source categories. Data obtained from source tests, material balance studies, and engineering estimates are used to calculate the emission factors in AP-42.

The predictive equation for unpaved road emissions described in AP-42, expressed in pounds of particulate per vehicle mile traveled (lb/VMT) or kilograms per vehicle kilometer traveled (kg/VKT), is as follows:[a]

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

(for lb/VMT)

(3-1a)

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

(for kg/VKT)

(3-1b)

where

- E = emission factor, lb/VMT (kg/VKT)
- k = particle size multiplier, dimensionless
- s = silt content of road surface material, % passing a 200 mesh (75 μm) screen
- S = mean vehicle speed, mph (km/hr)
- W = mean vehicle weight, tons (Mg, metric tons)
- w = mean number of wheels, dimensionless
- p = number of days with at least 0.01 in. (0.254 mm) of precipitation per year, dimensionless.

The particle size multiplier, k, varies with the aerodynamic particle size range. The values for the particle size multiplier k, as listed in the AP-42 document, are: 0.80 (<30 μm), 0.50 (<15 μm), 0.36 (<10 μm), 0.20 (<5 μm), and 0.095 (<2.5 μm).

The silt content of the road surface material, s, varies on a site-by-site basis. Silt content is determined using the ASTM-C-136 method; however, the information on Table 3-1 can be used to approximate the silt content for unpaved roads.

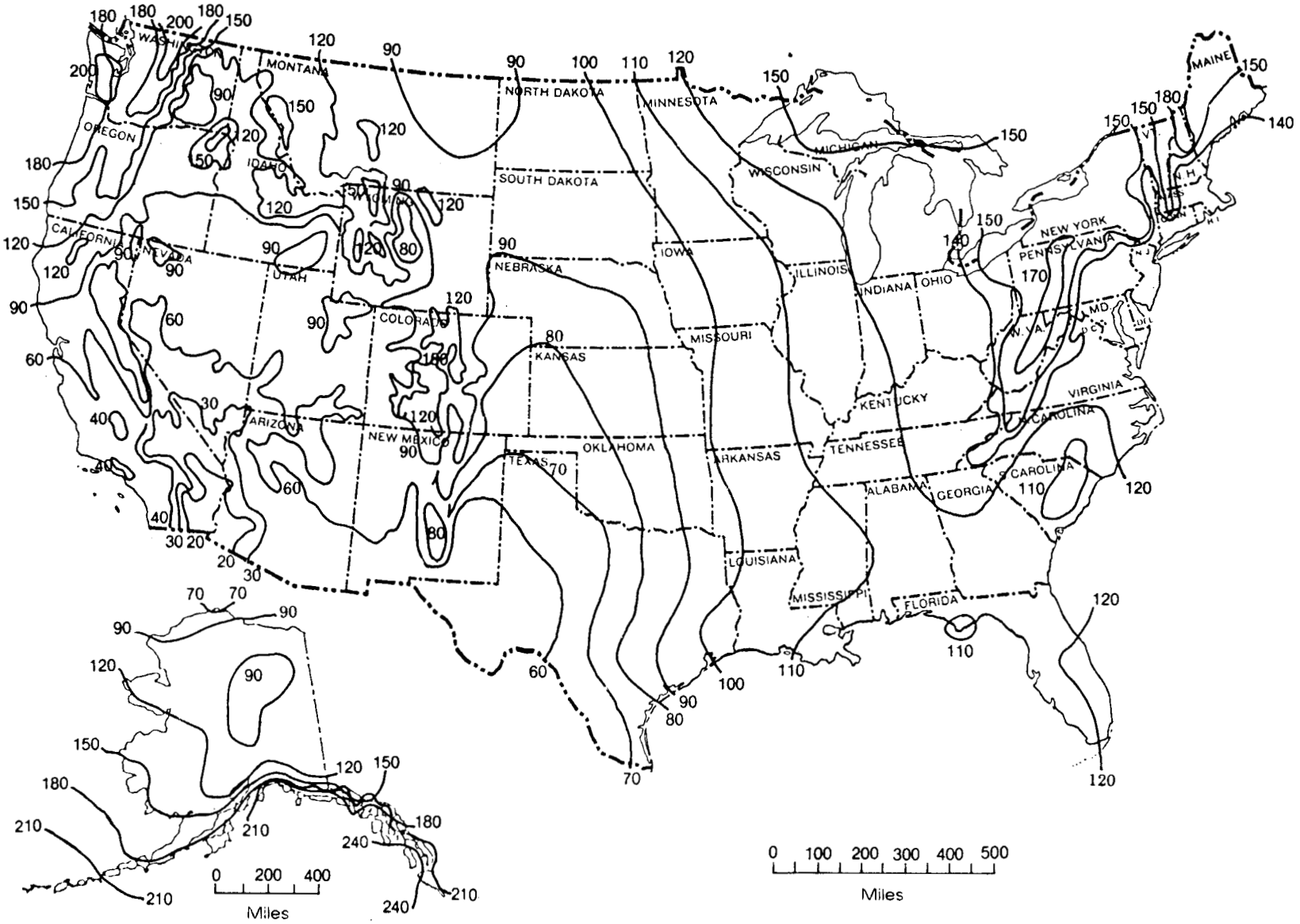
Figure 3-1 shows the mean number of days with at least 0.01 inches (0.254 mm) of precipitation per year, which is p in equations 3-1a and b.

3.2 Quality Rating System for AP-42 Emission Factors

Data used to calculate AP-42 emission factors are obtained from a variety of sources, including published technical papers and reports, documented emission testing results, and personal communications. Some data sources provide complete details

[a] All abbreviations used in this report are defined in Appendix B as well as in the text where the abbreviation first appears.

Figure 3-1. Mean number of days with greater than or equal to 0.01 in. of precipitation. [1]



about their collection and analysis procedures, whereas others provide only sketchy information. A rating system for AP-42 emission factors was developed by the U.S. EPA, Office of Air Quality Planning and Standards to help users assess the reliability and accuracy of emission factors. The system entails 1) rating individual test data sets for accuracy and reliability and 2) calculating an overall rating for the emission factor based on ratings assigned to individual data sets.

Several subjective schemes have been used to assign emission factor ratings. Because of the subjective nature of the rating system, a rating should only be considered an indicator of the accuracy and precision of a given factor.

The AP-42 rating system is briefly discussed in this section because the system is used to rate test data presented in Chapter 5. For a more detailed description of the AP-42 rating system and how it relates to unpaved road emission factors, other references are available. [1,2,3]

The rating system for an emission factor test data set, as it relates to unpaved roads, is based on the following data standards:

- A – Tests performed by a sound methodology and reported in enough detail for adequate validation. These tests are not necessarily EPA reference method tests, although such reference methods are certainly to be used as a guide.
- B – Tests that are performed by a generally sound methodology but lack enough detail for adequate validation.
- C – Tests that are based on an untested or new methodology or that lack a significant amount of background data.
- D – Tests that are based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

In the ideal situation, a large number of A-rated source test data sets representing a cross section of the industry are reduced to a single value for each individual source by computing the arithmetic mean of each test set. The emission factor is then computed by calculating the arithmetic mean of the individual source values. Alternatively, regression analysis is used to derive a predictive emission factor equation for the entire A-rated test set. No B-, C-, or D-rated test sets are used in the calculation of the emission factor because the number of A-rated tests is sufficient. This ideal method of calculating an emission factor is not always possible because of a lack of A-rated data.

If the number of A-rated tests is so limited that inclusion of B-rated tests would improve the emission factor, then B-rated test data are included in the compilation of the arithmetic mean. No C- or D-rated test data are averaged with A- or B-rated test data. The rationale for inclusion of any B-rated test data is in the background information document.

If no A- or B-rated test series are available, the emission factor is the arithmetic mean of the C- and D-rated test data. The C- and D-rated test data are used only as a last resort, to provide an order-of-magnitude value.

In AP-42, the reliability of these emission factors is indicated by an overall Emission Factor Rating ranging from A (excellent) to E (poor). These ratings

Table 3-1. Typical Silt Contents for Unpaved Road Surface Materials[a]

Industry	Road Use or Surface Material	Plant Sites	Test Samples	Silt (%)[b] Range	Silt (%)[b] 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 - 18.0	8.4
	Scraper road	3	10	7.2 - 25.0	17.0
	Haul road (freshly graded)	2	5	18.0 - 29.0	24.0
Rural roads	Gravel	1	1	NA	5.0
	Dirt	2	5	5.8 - 68.0	28.5
	Crushed limestone	2	8	7.7 - 13.0	9.6

[a]Reference 1.
[b]Expressed on a weight per weight basis.

take into account the type and amount of data from which the factors were calculated, as follows:

- A – Excellent. Developed only from A-rated 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 data from a reasonable number of facilities. Although no specific bias is evident, the facilities may not 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, the facilities tested may not 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. Developed only from A- and B-rated data from a small number of facilities, and these facilities may 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 should be footnoted.
- E – Poor. Developed from C- and D-rated data, and the facilities tested may 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.

The equations listed in AP-42 (equations 3-1a and b discussed previously) to calculate an emission factor for unpaved roads have an Emission Factor Rating of A. The A rating for size-specific emission factors is based on two criteria. First, the test data were developed using well documented and sound methodologies. Second, a total of at least six tests were performed at two or more plant sites. [3]

However, the A Emission Factor Rating is only applicable with all the following conditions:

- Road surface silt content between 4.3 and 20%
- Mean vehicle weight between 3 and 157 tons (2.7–147 Mg)
- Mean vehicle speed between 13 and 40 mph (21–64 km/hr)
- Mean number of wheels between 4 and 13.

Also, the A rating only applies if site specific data (such as silt content) is available. The rating is lowered to a B if assumptions are made for site-specific data.

The rating system discussed in this section will be used to rate test data presented in Chapter 5 of this report.

3.3 Other Types of Emission Factors

The most reliable emission factors are based on field tests of representative sources using a sound test methodology reported in enough detail for adequate validation. Usually the emission factor for a given source operation, as presented in a test report, is derived simply as the arithmetic average of the individual emission factors calculated from each test of that source. Frequently the range of individual emission factor values is also presented.

As an alternative to the presentation of an emission factor as a single-value arithmetic mean, an emission factor may be presented in the form of a predictive equation derived by linear regression analysis of test data. The predictive emission factor equation mathematically relates emissions to parameters which characterize source conditions. An emission factor equation is useful if it is successful in explaining much of the observed variance in emission factor values on the basis of corresponding variances in specific source parameters. This enables more reliable estimates of source emissions on a site-specific basis by allowing for correction of the emission factor to specific source conditions.

Examples of site-specific predictive emission factor equations developed using linear regression techniques are as follows:

$$E = k\,(W)^{a}\,(m)^{b} \qquad (3\text{–}2)$$

where

E	=	emission factor, lb/VMT (kg/VKT)
m	=	road surface moisture content, %
W	=	mean vehicle weight, tons (Mg)
k,a,b	=	constants dependent upon the size fraction of the particulate being considered

and

$$E = k(s)^{0.139}(R)^{-0.203}(w)^{0.267}(W)^{0.395} \quad (3\text{–}3)$$

where

E = emission factor, lb/VMT (kg/VKT)

R = ambient relative humididty, %

W = mean vehicle weight, tons (Mg)

w = mean number of wheels, dimensionless

s = silt content of road surface material

k = particle size multiplier, dimensionless

Equations 3–2 and 3–3 are provided only as samples of equations developed using linear regression techniques. The equations were derived from a set of data from a specific site and the equations are, most likely, only applicable for the specific site. Also note that the equations do not take into account the amount of rainfall.

3.4 Recommendations for Use of Emission Factors

The utility of an emission factor predictive equation is that of predicting the emissions from a particular site in lieu of actual measurements. In order that the equation be applicable over a wide range of site locations and conditions, it should include as many of the relevant parameters describing the site as possible. This requires that the predictive equation be developed from as large a data base as possible. The equation currently described in the AP–42 manual was developed from a fairly broad data base using multiple linear regression techniques. The AP–42 emission factor equation is probably the most reliable predictor of unpaved road emissions currently available.

The high emission factor rating for the AP–42 equation for calculating emissions from unpaved roads is only applicable within specific limits of road surface silt content and mean vehicle speed, weight, and number of wheels (see Section 3.2). If actual plant conditions stray outside the limits of the AP–42 equation, it may be necessary to conduct mass or particle size testing to determine emission rates.

AP–42 emission factors are useful for estimating emissions from an air pollutant source. However, the factors are averages obtained from a wide range of data with varying degrees of accuracy. Emissions calculated using AP–42 emission factors are likely to be different from a facility's actual emissions. For the most accurate estimate of emissions, site–specific data should be obtained whenever possible.

3.5 References

1. U.S. Environmental Protection Agency. Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources. Fourth Edition, Supplement A, AP–42, Office of Air Quality Planning and Standards, Research Triangle Park, NC, October, 1986.

2. Cowherd, C., Jr. and B. Peterman. AP–42 Update, Section 11.2, Fugitive Dust Sources. EPA–450/4–83–010, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1983.

3. Cowherd, C., Jr. and P.J. Englehart. Size Specific Particulate Emission Factors for Industrial and Rural Roads -- Source Category Report. EPA–600/7–85–051, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1985.

Chapter 4
Control Alternatives

There are several options for control of fugitive particulate emissions from unpaved roads. Emission reduction may be achieved by reducing the source extent (the level of the source activity) or by using measures to prevent or reduce emission generation.

Although the reduction of source extent results in a highly predictable reduction in the uncontrolled emission rate, such an approach 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.

Wet suppression, chemical stabilization, and physical stabilization are feasible control techniques for unpaved road fugitive particulate emissions. This chapter describes the basic characteristics of each control technique and briefly discusses cost effectiveness.

In selecting or evaluating a control alternative, it is important to keep in mind the overall environmental impact of the control alternative. For example, a chemical suppressant used to stabilize the road surface could cause ground water or surface water problems if the chemical is improperly applied. In other words, to reduce an air pollution problem, a water pollution problem was created.

4.1 Wet Suppression

Wet suppression systems for unpaved roads apply either water or a water solution of a chemical agent to the surface of the road. Application of chemical agents in a water solution will be addressed in the next section of this chapter. Wet suppression prevents or suppresses the fine particles contained in that material from leaving the surface and becoming airborne. The suppressant agglomerates and binds the fines to the aggregate surface, thus eliminating or reducing its emissions potential.

Plain water has been used as a wet suppression system for many years on such sources as crushing, screening, and materials transfer operations as well as unpaved roads. Water is generally applied to the surface of unpaved roads by a truck or some other vehicle using either a pressurized or a gravity flow system. Watering unpaved roads is only a temporary measure and must be repeated at regular intervals.

Wet suppression with plain water can cause freezing problems in the winter. In the arid West, wet suppression is not always practical due to inadequate water supplies.

To improve the overall control efficiency of wet dust suppression systems, wetting agents can be added to the water to reduce the surface tension. The additives allow particles to more easily penetrate the water droplet and increase the number of droplets, thus increasing the surface area and contact potential.

4.2 Chemical Stabilization

Particulate release from unpaved surfaces can be reduced or prevented by stabilizing those surfaces. The use of chemical dust suppressants for stabilization has received much attention in the past several years. Chemical suppressants can be classified into six generic categories: salts (i.e., $CaCl_2$ and $MgCl_2$), lignin sulfonate, wetting agents, latexes, plastics, and petroleum derivatives.

Salts, which are usually obtained from natural brine deposits, control dust by absorbing and retaining moisture in the surface material. Wetting agents lower the surface tension of water, thereby causing more rapid penetration into the surface material. The remaining dust suppressants, both natural and synthetic, bind the fines to larger aggregates in the surface material.

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, dilution ratio, and frequency (number of applications/unit time) of the chemical applied to the surface. Control depends on the type and number of vehicles using the road.

4.3 Physical Stabilization

Physical stabilization techniques can also be used for the control of fugitive emissions from unpaved road surfaces. Physical stabilization includes any measure, such as compaction of fill material at construction sites, which physically reduces the emissions potential of a source from either mechanical disturbance or wind erosion.

The most notable form of physical stabilization of current interest involves the use of civil engineering fabrics or "road carpet" for unpaved roads. In practice, the road carpet fabric is laid on top of a properly prepared road base just below a layer of coarse aggregate (ballast). The fabric sets up a physical barrier that prevents the fines (particles less than 75 μm in diameter) from contaminating the ballast layer. These smaller particles are now no longer available for resuspension and saltation resulting from the separation of the fines from the ballast. The fabric is also effective in distributing the concentrated stress from heavy-wheeled traffic over a wider area. Currently, this application has limited actual use; therefore detailed information on the effectiveness of this technique is not yet available.

4.4 Other Unpaved Road Control Techniques

Other practices may be used to reduce fugitive particulate emissions from an open dust source. Work practices focus on transport equipment operation. For an unpaved travel surface, emissions can be reduced by decreasing vehicle speed and weight.

Housekeeping practices generally refer to the periodic removal of exposed dust-producing materials to reduce the potential for dust generation through wind or machinery action. Examples of housekeeping measures that may be used to reduce unpaved road emissions include clean-up of spillage on travel surfaces or elimination of mud/dirt carryout onto roads at construction and demolition sites. Any such housekeeping method can be employed depending on the source, its operation, and the type of dust-producing material involved.

A recent study indicates that paved road cleaning techniques (such as flushing and vacuuming) may be used to increase the control efficiency of chemically treated unpaved roads.[1] This preliminary conclusion was drawn based on one test series conducted on an unpaved road in an iron and steel plant.

4.5 Estimation of Cost-Effectiveness of Control Options

Development and evaluation of particulate fugitive emissions control strategies require analysis of the relative costs of alternative control options. The primary goal of any cost analysis is to provide a consistent comparison of the real costs of alternative control measures.

The general approach for cost analysis is to calculate the cost-effectiveness for each proposed control alternative. Cost-effectiveness is the ratio of the annualized cost of the emissions control to the amount of emissions reduction achieved.

Calculation of cost-effectiveness for comparison of control measures or strategies can be accomplished in four steps. First, the alternative control/cost scenarios are selected. Second, the capital costs of each scenario are calculated. Third, the annualized costs for each of the alternatives are developed. Finally, the cost-effectiveness is calculated as a ratio, taking into consideration the level of emissions reduction.

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 major cost elements. For unpaved road control techniques these major cost 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.

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 4-1.

The second step is to calculate capital costs for each scenario. 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 control 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

Table 4-1. Implementation Alternatives for Stabilization of an Unpaved Road

Cost Elements	Implementation Alternatives
Purchase and ship chemical	Ship in railcar tanker (11,000-22,000 gal/tanker)
	Ship in truck tanker (4,000-6,000 gal/tanker)
	Ship in drums via truck (55 gal/drum)
Store chemical	*Store on plant property*
	—In new storage tank
	—In existing storage tank
	Needs refurbishing
	Needs no refurbishing
	—In railcar tanker
	Own railcar
	Pay demurrage
	—In truck tanker
	Own truck
	Pay demurrage
	—In drums
	Store in contractor tanks
Prepare road	Use plant-owned grader to minimize ruts and low spots
	Rent contractor grader
	Perform no road preparation
Mix chemical and water in application truck	Put chemical in spray truck
	—Pump chemical from storage tank or drums into application truck
	—Pour chemical from drums into application truck, generally using forklift
	Put water in application truck
	—Pump from river or lake
	—Take from city water line
Apply chemical solution via surface spraying	Use plant-owned application truck
	Rent contractor application truck

incurred by the system but not directly attributable to specific equipment items. Indirect costs include engineering/design, construction/field expenses, contractor's fee, shakedown/startup and contingency costs.

The third step in calculating cost–effectiveness is to calculate annualized costs for the control scenario. 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 annualized costs of control equipment can be calculated from:

$$C_a = CRF\ (C_p) + C_o + 0.5\ C_o \qquad (4\text{–}1)$$

where:

C_a = annualized costs of control equipment ($/year)

CRF = Capital Recovery Factor

C_p = installed capital costs ($)

C_o = direct operating costs ($/year)

0.5 = plant overhead factor

The capital recovery factor (CRF) 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:

$$CRF = \frac{I\,(1 + i)^n}{(1 + i)^n - 1} \qquad (4\text{–}2)$$

where:

I = interest rate (annual % as a fraction)

n = economic life of the control system (years)

The final step in calculating cost–effectiveness is to calculate the actual cost–effectiveness ratio. This ratio is defined as:

$$C^* = \frac{C_a}{\Delta R} \qquad (4\text{–}3)$$

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 annual reduction in particulate emissions can be calculated from the following equation:

$$\Delta R = M\,E\,c \qquad (4\text{–}4)$$

where:

M = annual source extent (i.e., measure of source size or level of activity -- such as vehicle miles traveled per year)

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

c = average control efficiency expressed as a fraction

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. Published sources of cost data for fugitive emission control systems are included in references 2 through 7. References 2 through 4 relate primarily to open dust control systems while references 5 through 7 can be used to estimate component costs for both open dust and process fugitive emissions control systems.

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 typically 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.

4.6 References

1. Muleski, G.E. and C. Cowherd, Jr. Evaluation of the Effectiveness of Chemical Dust Suppressants on Unpaved Roads. U.S. Environmental Protection Agency, Research Triangle Park, NC, Draft Final Report, May 1986.

2. Cuscino, T., 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, IL, April 1984.

3. Cuscino, T., Jr., G. E. Muleski, and C. Cowherd, Jr. 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.

4. Muleski, G. E., T. Cuscino, Jr., and C. Cowherd, Jr. Extended Evaluation of Unpaved Road Dust Suppressants in the Iron and Steel Industry. EPA-600/2-84-027 (NTIS PB 84-110568), U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1984.

5. Neveril, R.V. Capital and Operating Costs of Selected Air Pollution Control Systems. EPA-450/5-80-002 (NTIS PB 84-154350). GARD, Inc., December 1978.

6. Richardson Engineering Services, Inc. The Richardson Rapid Construction Cost Estimating System: Volume I - Process Plant Construction Estimating Standards. 1983-84 Edition.

7. Robert Snow Means Company, Inc. Building Construction Cost Data. 1979.

Chapter 5
Estimation Of Control System Performance

The principal control measures for unpaved roads are wet suppression, chemical stabilization, and paving. This chapter will discuss available performance data and design considerations for each of these control measures. Other control approaches, such as physical stabilization, will be discussed briefly. Work practices, such as speed control on unpaved travel surfaces, will not be discussed.

Performance capabilities of unpaved road dust controls can be affected by four categories of variables: a) control application parameters; b) vehicle characteristics; c) properties of the surface to be treated; and d) climatic factors. Furthermore, because of site-to-site differences in most of these parameters, the performance of a given control system can be expected to vary significantly from one application to another. Therefore, in using the control efficiency data presented in this section, care must be taken to document the source and control parameters tied to each control efficiency data set. The selection of a control technique involves the evaluation of both performance characteristics and cost considerations. No individual table or figure can provide all the required information.

Most of the control techniques involve periodic rather than continuous control application, for example, watering unpaved travel surfaces. The control efficiency is cyclic, peaking immediately after application, then eroding with time. Because of the finite durability of these control techniques, ranging from hours to months, it is essential to relate an average efficiency value to a frequency of application. For measures of extended durability such as paving, the application program required to sustain control effectiveness should be indicated. One common pitfall to be avoided is using field data collected soon after control measure application to represent the average control efficiency over the lifetime of the measure.

For a periodically applied control measure, the most representative value of control efficiency is the time average, given by:

$$C(T) = \frac{1}{T} \int_0^T c(t)\, dt \qquad (5\text{–}1)$$

where:

$C(T)$ = average control efficiency during period of T days between application (%)

$c(t)$ = instantaneous control efficiency at t days after application (%), where $t \leq T$

It must be emphasized that the rate of control efficiency decay is heavily dependent upon the source and control variables discussed in the following sections.

5.1 Wet Suppression

This section will discuss the use of water as a road dust suppressant. The addition of surfactants or other chemical agents to the water to improve control efficiencies will be discussed in the chemical stabilization section of this chapter.

An empirical model for the performance of watering as a control technique has been developed. [1] The supporting data base consists of 14 tests performed in four states during five different summer and fall months. [2–4] The model is:

$$c = 100 - \frac{0.8\ pdt}{i} \qquad (5\text{–}2)$$

where:

c = average control efficiency, %

p = potential average hourly daytime evaporation rate mm/hr (Reference 5 has this information on an annual basis. The National Climatic Data Center in Asheville, NC maintains computer files of this information on a daily basis.)

d = average hourly daytime traffic rate, hr^{-1}

i = application intensity, l/m^2

t = time between applications, hr

The data to support this empirically based mathematical model are shown in Table 5–1 along with additional results from testing of unpaved haul roads with water control. No significant difference in the average control efficiency of watering as a function of particle size has been established to date. As with all empirical models, equation 5–2 should not be applied beyond the ranges of independent variable values tested.

5.2 Chemical Stabilization

5.2.1 Design Considerations

The control application parameters affecting control performance of chemical dust suppressants are: a) application intensity; b) application frequency; c) dilution ratio; and d) application procedure. Application intensity is the volume of diluted solution applied per unit area of surface (for example, l/m^2 or gal/yd^2). The higher the intensity, the higher the anticipated control efficiency. However, this relationship applies only to a point, because too intense an application will begin to run off the surface.

Application frequency is the number of applications per unit of time. The dilution ratio is the volume of chemical concentrate to the volume of water (for example, a 1:7 dilution ratio = 1 part chemical to 7 parts water).

The decay in control efficiency of a chemical dust suppressant occurs largely because vehicles traveling over the road surface impart energy to the treated surface which breaks the adhesive bonds that keep fine particles on the surface from becoming airborne. An increase in vehicle weight and speed accelerates the decay in efficiency for chemical treatment of unpaved roads.

Any action which contributes to the breaking of a surface crust will adversely affect the control efficiency. For example, the structural characteristics of an unpaved road affect the performance of chemical controls. These characteristics are: a) combined subgrade and base bearing strength, as measured by the California Bearing Ratio (CBR); b) amount of fine material (silt and clay) on the surface of the road; and c) the friability of the road surface material. Low bearing strength causes the road to flex and rut in spots with the passage of heavy trucks; this destroys the compacted surface enhanced by the chemical treatment. A minimum amount of fine material in the wearing surface is needed to provide the chemical binder with the particle surface area necessary for effective interparticle bonding. Finally, the larger particles of a friable wearing surface material simply break up under the weight of the vehicles and cover the treated road with layer of untreated dust.

Adverse weather usually accelerates the decay of control performance. For example, freeze–thaw cycles break up the crust formed by chemical binding agents; heavy precipitation washes away water–soluble chemical treatments like lignin sulfonates; and intense solar radiation dries out watered surfaces. On the other hand, light precipitation might improve the efficiency of water extenders and hygroscopic chemicals like calcium chloride.

Table 5-1. Field Data on Watering Control Efficiency

Location	Reference(s)	No. of Tests	Month	Application Intensity (L/m^2)	Average Time Between Applications (hr)	Average Traffic Rate (hr^{-1})	Average Potential Evaporation (mm/hr)	Average Control Efficiency (%)[a]
N. Dakota	2-4	4	October	0.2	1.8	40	0.084	59[b]
New Mexico	2-4	5	July/Aug.	0.2	2.0	23	0.23	69[b]
Ohio	2-4	3	November	0.6	4.5	98	0.042	77[b]
Missouri	2-4	2	September	1.9	2.8	72	0.26	88[b]
Mine 1	7	–	–	–	2.0	32	–	TSP: 16 FP: 29
Mine 1	7	–	–	–	1.0	24	–	TSP: 37 FP: 40
Mine 1	7	–	–	–	0.5	28	–	TSP: 51 FP: 43
Mine 2	7	–	–	–	1.0	65	–	TSP: 41 FP: 26
Mine 2	7	–	–	–	0.5	78	–	TSP: 59 FP: 47

[a]TSP = total suspended particulate; FP = fine particulate.

[b]No significant difference in control efficiency as a function of particle size was observed.

5.2.2 Performance Data

The control of dust emissions from unpaved roads has received the widest attention in the literature (see Table 5–2). Exposure profiling and upwind/downwind sampling have been used to measure control efficiencies for watering and for a range of chemicals which bind the surface material or increase its capacity for moisture retention. Tables 5–3 and 5–4 summarize the measured performance data for chemical dust suppressants.

The observed control efficiency decay functions for several dust suppressants are shown in a series of nine figures contained in Appendix D (Figures D–1 through D–9). Most of the data on the figures are expressed in terms of vehicle passes rather than time because vehicle traffic is the primary cause of the loss of control effectiveness. The control efficiency decay functions can be used to derive the critical relationships between average control efficiency and application frequency. Assuming, as a first approximation, that control efficiency decays linearly from an initial value of 100%, the average control efficiency for a given frequency of application is twice the value at the end of the decay cycle.

The quality rating of control performance data for a periodically applied control measure must address the reliability of the average control efficiency for the particular application frequency tested. Obviously, a spread in the measured values of instantaneous control efficiency is expected as the efficiency decays. The quality rating must be based on how well the instantaneous values fit a decay function. At the time of this writing, mathematically derived decay functions were available for only a few of the control measures. Therefore, no quality ratings were assigned to the control efficiency data presented.

In most of the extended tests of control performance, efficiency values were found to decay with vehicle passes (and time) after application. In Figures D–1 through D–3 and D–9, the best-fit linear decay functions determined by least-squares analysis are shown. In Figures D–4 through D–8, the data points are connected by line segments.

Apparent increases in control efficiency with vehicle passes were observed in several test series from Reference 7. This behavior is thought to be the result of moisture effects on the uncontrolled emission rate, which was measured simultaneously with each controlled emission rate. In other words the efficiency values were not always referenced to a dry uncontrolled emission rate.

Table 5-2. Classification of Tested Chemical Road Dust Suppressants

Dust Suppressant Category	Trade Name	Number of Valid Controlled Tests[a]	Reference Numbers
Petroleum-based	Petro Tac®	13	2-4,6
	Coherex®	130	2-4,6,8-10
	Arco 2200®	20	7
	Arco 2400®	91	11
	Generic 2 (QS)[b]	8	6
Lignosulfonates	Lignosite	73	11
	Trex®	3	12
Salts	Peladow®	1	13
	LiquiDow®	34	7
	Dustgard®	11 (17)	11
	Oil Well Brine	4	8
Polymers	Soil Sement®	32	6,7
Surfactants	Biocat®	3	7
Mixtures	Arcote 220® / Flambinder®	4	8

[a]Numbers without parentheses represent total suspended particulate (TSP) and numbers in parentheses represent respirable particulate (RP).

[b]This is a petroleum resin product developed at the Mellon Institute for the American Iron and Steel Institute.

5.3 Paving

The control efficiencies afforded by paving unpaved road segments can be estimated by comparing the AP–42 emission factors for the unpaved and paved road conditions. The emission factor for the paved road condition requires an estimated silt loading on the paved surface. An urban street dust loading model[14] can be used to estimate silt loadings as a function of traffic volume. The model is expressed as follows:

$$sL = 21.3\ (ADT)^{-0.41} \qquad (5\text{–}3)$$

where:

sL = silt loading, oz/yd² (g/m²)

ADT = average daily traffic, vehicles/day

This urban model was developed from silt loading measurements in five urban areas (Baltimore; Buffalo; Granite City, IL; Kansas City; and St. Louis). All of the streets were paved edge to edge and had curbs and gutters. The calculated control efficiencies for paving are usually on the order of 90%.

5.4 Other Control Alternatives

A number of open source control techniques have not yet been quantitatively evaluated for control effi-

Table 5-3. Summary of Major Unpaved Road Dust Suppressant Control Efficiency Tests

Ref. No.	Dust Suppressant Tested	No. of Valid Controlled Tests	Test Site	Measurement Method[a]	Days After Application	Application Intensity (gal sol/ yd^2)	Dilution Ratio (gal chem: gal H_2O)	Average Vehicle Weight (ST)	Control Efficiency[b] (%)
2-4	Coherex®	2	Steel plant	P	< 7	Unknown	1:9	3	91[c]
	Coherex®	4	Steel plant	P	1-2	0.19	1:6	50	TP: 92-98 TSP: 91-96 FP: 90-97
	Coherex®	5	Steel plant	P	1-2	0.19	1:6	3	TP: 94-100 TSP: 91-99 FP: 92-97
9-10	Coherex®	4	Steel plant	P	Unknown	Unknown	Unknown	4-19	TP: 81
	Coherex®	2	Steel plant	P	14-15	Unknown[d]	1:4-1:7	26	TP: 99
11	Coherex®	91	Public road	U/D	30-270	1.5[e]/0.33[f]	1:5[e]/1:9[f]	4	TSP: 53 RP: 64
	Arco 2400®	91	Public road	U/D	30-270	3.5	1:0	4	TSP: 96 RP: 57
	Lignosite (50% solids)	73	Public road	U/D	30-270	0.125[e]/0.25[f]	1:1[e]/1:1[f]	4	TSP: 46 RP: 42
	Dustgard®	11 (17)[g]	Public road	U/D	3-60	0.5	1:0[h]	4	TSP: 48 RP: 24
	Peladow®	1	Surface coal mine	P	90	0.6	1:2	3	TSP: 95 RP: 95 FP: 88
12	Trex® (ammonium lignin sulfonate)	3	Taconite mine	P	< 7	0.08	1:4	110-127	TSP: 88

[a]P = profiling; U/D = upwind/downwind.
[b]TP = total particulate; TSP = total suspended particulate; RP = respirable particulate; FP = fine particulate.
[c]Particles of less than 30μm stokes diameter (47μm aerodynamic diameter).
[d]Four applications; testing began 2 weeks after fourth application.
[e]Initial application.
[f]Repeat application.
[g]Eleven TSP tests and 17 RP tests conducted.
[h]Dilution as shipped unknown; no further dilution.

ciency. These methods include physical stabilization of unpaved surfaces, mud/dirt carryout control, and vegetative stabilization. Vegetative stabilization can be used only when the material to be stabilized is inactive and will remain so for an extended time period; therefore, the technique has limited, if any, application to controlling unpaved road emissions. References which describe these control alternative methods in further detail are available in the literature. [15–20]

5.5 Calculation of Controlled Emission Rate

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

$$R = M\,E\,(1 - c) \qquad (5\text{–}4)$$

where:

R = estimated controlled mass emission rate

M = source extent

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

c = fractional efficiency of control

The source extent is the appropriate measure of source size or level of activity which is used to scale the uncontrolled emission factor to the particular source in question. For unpaved roads, the source extent is reported in vehicle miles traveled per year (VMT/yr) or vehicle kilometers traveled per year (VKT/yr). Source extent is calculated by multiplying the average daily traffic count (ADT) by the length of

Table 5-4. **Summary of Major Unpaved Road Dust Suppressant Control Efficiency Decay Function Tests**

Ref. No.	Dust Suppressant Tested	No. of Valid Controlled Tests	Test Site	Measurement Method[a]	Days After Application	Application Intensity (gal sol/ yd^2)	Dilution Ratio (gal chem: gal H_2O)	Average Vehicle Weight (ST)	Efficiency Decay Function Figure[b]
2-4	Petro Tac®	8	Steel plant	P	2-116	0.70	1:4	23-34	D-1
	Coherex®	8	Steel plant	P	7-41	0.83[c]	1:4[c]	27-50	D-2
	Coherex®	4	Steel plant	P	4-35	1.0[d,e]	1:8[d,e]	31-56	D-3
8	Coherex®	5	Steel plant	U/D	17-35	1.5	1:4	3	D-4
	Oil well brine	5	Steel plant	U/D	17-35	3.8	Neat	3	D-4
	Arcote 220® / Flam-binder® Mixture	5	Steel plant	U/D	17-35	1.9	1:4	3	D-4
7	LiquiDow®	8	Surface coal mine 1	P	14-49	0.27-0.6	1:1.6	28-66[f]	D-5
		18	Surface coal mine 2	P	7-28	0.27-0.6	1:1.6	44-83[f]	D-5
		8	Surface coal mine 3	P	14-21	0.3-0.6	1:1.9	70-276[f]	D-5
	Soil Sement®	12	Surface coal mine 1	P	21-42	1.9-3.0	1:8.3	22-89[f]	D-6
		12	Surface coal mine 2	P	7-35	1.0	1:6.4	38-82[f]	D-6
	Biocat®	3	Surface coal mine 3	P	7-14	2.0	1:20,000	70-276[f]	D-6
	Flambinder®	4	Surface coal mine 1	P	14	0.5-2.1	1:4.6	16-65[f]	D-7
		16	Surface coal mine 2	P	7-28	0.5-2.0	1:4.6	51-69[f]	D-7
		8	Surface coal mine 3	P	7-21	1.8	1:4.6	70-276[f]	D-7
	Arco 2200®	16	Surface coal mine 2	P	7-28	0.9-2.8	1:7	18-80[f]	D-8
		4	Surface coal mine 3	P	7	1.1-2.3	1:6.1	70-276[f]	D-8
6	Petro Tac®	5	Steel plant	P	13-30[g]	0.21[h]/0.35[i]	5:1	9.7-24	D-9
	Coherex®	6	Steel Plant	P	13-30[g]	0.21[h]/0.36[i]	5:1	9.6-24	D-9
	Generic 2 (QS)	8	Steel Plant	P	13-30[g]	0.14[h]/0.46[i]	5:1	9.3-24	D-9
	Soil Sement®	8	Steel Plant	P	13-30[g]	0.16[h]/0.44[i]	5:1	9.6-24	D-9

[a]P = profiling; U/D = upwind/downwind.
[b]Figures are contained in Appendix D.
[c]Initial application.
[d]Repeat application.
[e]Retreated 44 days after the initial application.
[f]Values represent range of haul truck weights from empty to loaded vehicles. Haul truck has 10 wheels at mines 1 and 2 and six wheels at mine 3.
[g]Days after second application.
[h]First application.
[i]Second application, 40 days after first application.

the unpaved road. Each vehicle has a disturbance width equal to the width of a traffic lane.

The uncontrolled emission factor is calculated by using predictive equations (see Chapter 3) or measured using either the upwind/downwind or exposure profiling methods (see Chapter 2). Normally, the uncontrolled emission factor incorporates the effects of natural mitigation (such as rainfall), although emission factors developed as a result of testing under specific conditions may or may not account for natural mitigation.

Fractional control efficiency can be determined through a testing program (before and after testing of the application of the treatment scheme) or through estimates available in the literature based on tests performed under similar conditions (see Figures D–1 through D–9 in Appendix D and Tables 5–1 through 5–4). There is also a simple model discussed in this chapter (see equation 5–2) which can be used to estimate control efficiency for water suppression.

The equation to estimate controlled mass emission rate is a fairly simple mathematical expression. The emission rate is dependent on only three variables — the source extent, the uncontrolled emission factor, and the fractional control efficiency. Care should be used in selection or estimation of these three data variables. A high or low estimate of any of the variables could yield a misrepresentative value for the estimated controlled mass emission rate. For example, an inflated uncontrolled emission factor and an unusually high fractional control efficiency could show a greater improvement in ambient air quality than actually will be realized. As with any mathematical expression, the final result is only as good as the data used in the equation.

5.6 Alternate Indicators of Control Performance

Actual field measurement of controlled and uncontrolled emissions from unpaved roads is expensive and time consuming. Studies have been conducted in an attempt to develop an alternate method to monitor the effectiveness of dust control programs. Early preliminary studies showed a strong correlation between the efficiency of a control technique and the silt content of surface material. [2,6,21] Later long-term studies indicated no significant correlation between silt content and control performance. [3,6] The studies completed to date used various types of chemical dust suppressants to control emissions.

Another recent study indicates that the AP-42 emission factor equation for industrial paved road emissions can be used to conservatively overestimate unpaved road emissions controlled by chemical dust suppressants. [6] The paved road emission factor equation tends to overestimate emissions by a factor of 1.5 to 2 when applied to situations of typical chemical suppressant application intensities over the first 30 days. [6] The emission factor equation for industrial paved roads is discussed in detail in reference 22.

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Chapter 6
Fugitive Emissions Control Strategy Development

Developing a fugitive emissions control strategy for an industrial facility can be accomplished through a five step process:

Step 1: Identify and classify all fugitive sources.

Step 2: Prepare an emissions inventory.

Step 3: Identify control alternatives.

Step 4: Estimate control system performance.

Step 5: Estimate control costs and cost-effectiveness.

This section will illustrate these five steps for a hypothetical rock crushing plant with a rated capacity of 300 ton/hr and an actual operating rate of 150 ton/hr. As shown in Figure 6-1, the facility includes a primary, secondary, and tertiary crusher; associated materials sizing, handling, and storage facilities; a paved road; and an unpaved haul road. The following subsections describe the control strategy evaluation for this facility. Emphasis will be placed on calculating emissions, developing a control scheme, and calculating control costs for unpaved roads, as this is the primary thrust of this report.

6.1 Identifying/Classifying Fugitive Emission Sources

The fugitive particulate emission sources for this facility, identified schematically in Figure 6-1, include:

- A primary crusher
- A secondary crusher
- A tertiary crusher
- Two screens
- A truck dump station
- Six conveyor transfer points
- Vehicular traffic on unpaved haul road between the quarry and the plant
- Windblown emissions from product storage
- A front-end loader for loadout of customer trucks
- Vehicular traffic on a paved road between the loadout area and the property line.

6.2 Preparing an Emissions Inventory

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

$$R = M E (1 - c) \tag{6-1}$$

where

R = estimated mass emission rate

M = source extent

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

c = fractional efficiency of control

For this plant we assume that the initial control efficiency for all sources is 0%. The uncontrolled emission factors for the five open dust sources, the 11 process sources, and the source extents are shown in Table 6-1.

Plant and process data for the hypothetical crushing plant used to calculate the emission factors are shown in Table 6-2.

The uncontrolled emission factor for unpaved roads as presented in Reference 1 is:

$$E = k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \tag{6-2}$$

where

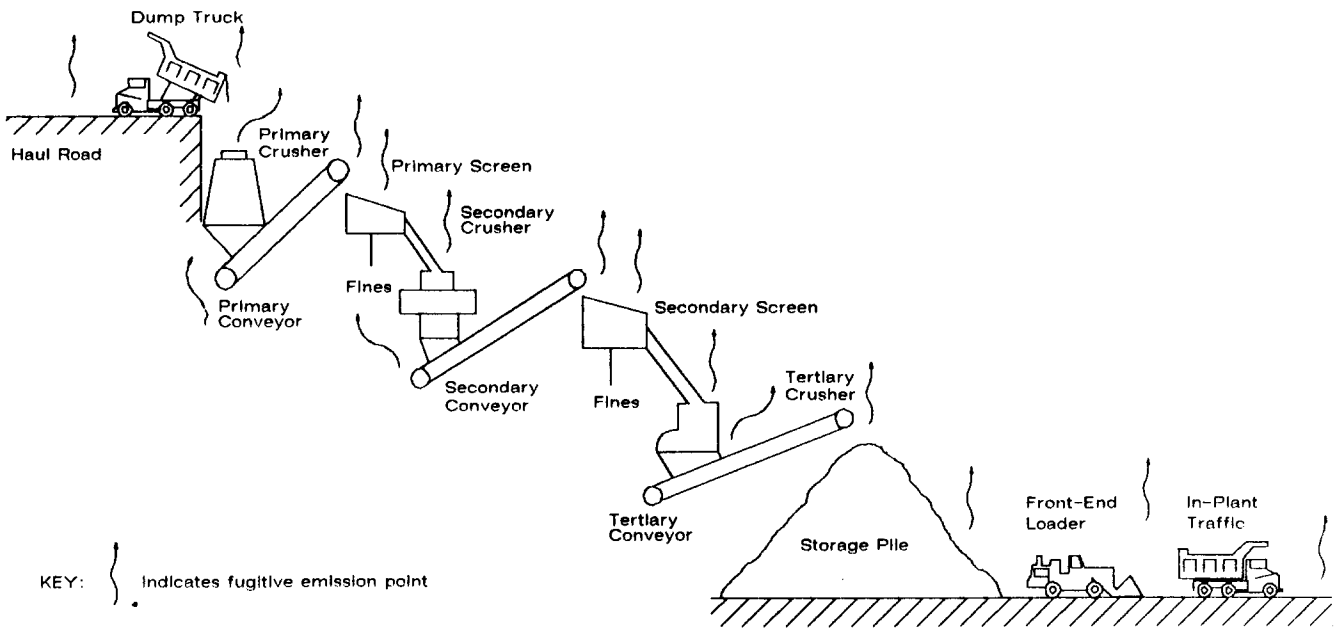
E = emission factor, lb/VMT

k = particle size multiplier (dimensionless)

s = silt content of road surface material (%)

S = mean vehicle speed (mph)

Figure 6-1. Process flow diagram of hypothetical rock crushing plant.



W = mean vehicle weight (tons)

w = mean number of wheels

p = number of days with at least 0.01 in. of precipitation per year

Plant data required to calculate the emission factor are silt content, vehicle speed, mean vehicle weight, and mean number of wheels. These are taken from the hypothetical plant data presented in Table 6-2.

Using the particle size multiplier for TSP and precipitation frequency from Reference 1, the resultant emission factor for the haul road is:

$$E = 0.8(5.9)\left(\frac{7.3}{12}\right)\left(\frac{20}{30}\right)\left(\frac{40}{3}\right)^{0.7}\left(\frac{6}{4}\right)^{0.5}\left(\frac{365-140}{365}\right)$$

$$= 8.86 \text{ lb/VMT}$$

where

k = 0.80 for particles $\leq$ 30 μmA (see Reference 1)

s = 7.3% (given in Table 6-2)

S = 20 mph (given in Table 6-2)

W = 40 tons (given in Table 6-2)

w = 6 (given in Table 6-2)

p = 140 (see Reference 1, as applied to lower Great Lakes)

The information in Tables 6-1 and 6-2 can be used to calculate the source extent for the unpaved haul road as follows:

$$M = 240 \frac{\text{days}}{\text{yr}} \times 100 \frac{\text{vehicles}}{\text{day}} \times 6.3 \frac{\text{miles}}{\text{vehicle}}$$

$$= 151{,}200 \text{ VMT/yr}$$

The data on source extent and emission factors can be substituted into equation 6-1 to obtain the following uncontrolled estimated mass emission rate for the unpaved haul road:

$$R = 151{,}200 \frac{\text{VMT}}{\text{yr}} \times \frac{8.86 \text{ lb}}{\text{VMT}} \times \frac{\text{ton}}{2000 \text{ lb}} \times (1-0)$$

$$= 670 \text{ ton/yr}$$

Table 6-3 summarizes source extents and uncontrolled emission rates for the unpaved haul road as well as the other particulate emitting sources for the hypothetical crushing plant.

Table 6-1. **Uncontrolled Emission Factors for Hypothetical Crushing Plant**

Source	Emission Factor Equation[a,b]	Emission Factor
Unpaved haul road	$k(5.9)\left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{W}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)$	8.86 lb/VMT
Truck dump and Front end loader	$k(0.0018)\frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)^{0.33}}$	Dump — 0.00019 lb/ton Loader — 0.000529 lb/ton
Storage pile erosion	$1.7\left(\frac{s}{1.5}\right)\left(\frac{365-p}{235}\right)\left(\frac{f}{15}\right)$	3.2 lb/acre/day
Paved roads	$k\,(0.077)\,I\left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1000}\right)\left(\frac{W}{3}\right)^{0.7}$	0.398 lb/VMT
Primary crushing	—	0.28 lb/ton[a]
Secondary crushing	—	0.28 lb/ton[a]
Tertiary crushing	—	1.85 lb/ton[a]
Screening	—	0.16/ton/screen[a]
Conveyor transfer	—	0.0034 lb/ton/transfer point[a]

[a]Reference 1.

[b]Refer to Table 6-2 for description of variables used in equations.

6.3 Identifying Control Alternatives

Based on the emissions inventory for the hypothetical facility, the primary focus of control should be vehicular traffic on the unpaved haul road with secondary emphasis on certain process fugitive sources (primary, secondary, and tertiary crushing, and screening operations).

Three methods can be used to control emissions from unpaved roads — wet suppression, chemical stabilization, and physical stabilization. For this hypothetical facility, chemical stabilization was selected as the most feasible means. Wet suppression was rejected because of the difficulty in maintaining watering systems over relatively long stretches of roads in rural areas. Chemical rather than physical stabilization was selected because of the temporary nature of the facility.

The two principal means of controlling emissions from crushing and screening operations are wet suppression and capture hoods with an associated air pollution control device. Wet suppression was selected as the preferred control because of difficulties associated with the operation and maintenance of capture/collection systems on mobile crushed stone facilities.

6.4 Estimating Control Efficiencies

A petroleum-based resin, Coherex®, was selected for chemical dust suppression on the unpaved road.[a] The data in Table 5-3 and Appendix D suggest that an average control efficiency of 90% can be achieved for up to about 5,000 vehicle passes.

Only limited test data are available on the effectiveness of wet suppression systems in controlling emissions from minerals processing operations.

Based on these limited data, the control efficiency estimates are: [2,3]

Primary crusher: 80%

Secondary crusher: 65%

Tertiary crusher: 50%

Screens: 50%

6.5 Calculating Cost and Cost Effectiveness

The procedure for calculating the estimated cost and the associated cost effectiveness of controlling vehicular emissions by chemical stabilization of the

[a] Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table 6-2. Plant and Process Data for Hypothetical Facility

Process Operation
Operating rate = 150 ton/hr
Operating hours = 1,920 hr/yr
No. of days with at least 0.01 in. rain (p) = 140[a]

Haul Road
Average daily traffic = 100 vehicles/day[b]
Average vehicle weight (W) = 40 tons[c]
Average number of vehicle wheels (w) = 6
Average capacity = 16 yd^3
Average vehicle speed (S) = 20 mph
Roadway length = 6.3 miles
Roadway width = 30 ft
Roadway silt content (s) = 7.3%
Particle size multipler (k) = 0.8 (for particles $\leq 30\mu mA$)[a]

Truck Dump
Material silt content (s) = 0.5%
Mean wind speed (U) = 5 mph
Drop height (H) = 10 ft
Material moisture content (M) = 2%
Average capacity (Y) = 16 yd^3
Particle size multiplier (k) = 0.73 (for particles $\leq 30\mu mA$)[a]

Storage Piles
Storage pile silt content (s) = 2.2%
Storage pile size = 0.5 acre
% time unobstructed wind speed > 12 mph (f) = 20%

Front End Loader
Aggregate silt content (s) = 1.6%
Mean wind speed (U) = 5 mph
Drop height (H) = 5 ft
Aggregate moisture content (M) = 2%
Loader dumping capacity (Y) = 3 yd^3
Particle size multiplier (k) = 0.73 (for particles $\leq 30\mu mA$)[a]

Customer Traffic
Road augmentation factor (I) = 1[a]
No. of travel lanes (n) = 2
Surface silt content (s) = 6%
Surface dust loading (L) = 1,000 lb/mile
Average vehicle weight (W) = 30 tons[d]
Roadway length = 0.5 miles
Average daily traffic = 120 vehicles/day[e]
Particle size multiplier (k) = 0.86 (for particles $\leq 30\mu mA$)[a]

[a]Reference 1.
[b]50 round trips per day.
[c]Tare + load ÷ 2 = 28 + 24/2 = 40 tons.
[d]Tare + load ÷ 2 = 20 + 20/2 = 30 tons.
[e]60 round trips per day.

unpaved haul road at the hypothetical plant is as follows:

Step 1 – Determine the Times Between Applications and the Application Intensity. The following application parameters are taken from Table 5–4 and Figures D–2 and D–3 in Appendix D.

Initial application intensity = 0.83 gal of 20% solution/yd^2

Table 6-3. Source Extents and Uncontrolled Emission Rates For Hypothetical Crushing Plant

Source	Source Extent	TSP Emissions (ton/year)
Unpaved haul road	151,200 VMT/yr	670
Truck dump	288,000 ton/yr	0.027
Storage pile erosion	182 acre day/yr	0.29
Front end loader	288,000 ton/yr	0.076
Paved roads	14,400 VMT/yr	2.87
Primary crushing	288,000 ton/yr	40
Secondary crushing	288,000 ton/yr	40
Tertiary crushing	288,000 ton/yr	266
Screening	288,000 ton/yr	46
Conveyor transfer points	288,000 ton/yr	3
	Total	1068.3

Reapplication intensity = 1.0 gal of 12% solution/yd^2

Application frequency = once every 44 days

Step 2 – Calculate the Required Number of Annual Applications and Number of Treated Miles.

$$\text{No. of annual applications} = \frac{365 \text{ days/yr}}{44 \text{ days/application}}$$

$$= 8.3 \text{ applications/yr}$$

$$\text{No. of treated miles per year} = 6.3 \frac{\text{miles}}{\text{application}} \times 8.3 \frac{\text{applications}}{\text{yr}}$$

$$= 52 \text{ treated miles/yr}$$

Step 3 – Select the Desired Program Implementation Plan. The decision is made to purchase rather than rent equipment. The implementation plan and associated costs are outlined in Table 6–4, Scenario 2.

Step 4 – Calculate Total Annual Cost. To annualize the capital investment, the capital cost shown in Table 6–4, Scenario 2, is simply multiplied by a capital recovery factor which is calculated as follows:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

i = annual interest rate fraction

n = number of payment years

Assuming i = 0.15 and n = 10 years,

$$CRF = \frac{0.15\,(1.15)^{10}}{(1.15)^{10} - 1} = 0.199252$$

The annual operation and maintenance costs (C_o) are calculated as follows:

$$C_o = \$4{,}785/\text{treated mile} \times 52 \text{ treated miles/yr} + \$630/\text{actual mile} \times 6.3 \frac{\text{actual miles}}{\text{yr}}$$
$$= \$253{,}000/\text{yr}$$

The total annualized cost (C_a) is:

$$C_a = CRF\,(C_p) + C_o + 0.5(C_o)$$
$$= (0.199252)\,(105{,}000) + 253{,}000 + 0.5(253{,}000)$$
$$= \$400{,}000$$

Because the costs in Table 6-4 are based on a road width of 40 ft, it is necessary to scale total cost by actual road width of 30 ft:

$$\text{Actual total annualized cost} = \$400{,}000/\text{yr} \times \frac{30 \text{ ft}}{40 \text{ ft}}$$
$$= \$300{,}000/\text{yr}$$

Step 5 – Calculate Cost–Effectiveness (C).* Cost–effectiveness is defined as:

$$C^* = \frac{C_a}{\Delta R}$$

where

C_a = total cost from Step 4

ΔR = reduction in TSP emissions, i.e. the product of the uncontrolled emission rate and the fractional efficiency of control

$$C^* = \frac{\$300{,}000/\text{yr}}{770 \text{ ton/yr} \times 0.9}$$
$$= \$433/\text{ton of TSP emissions reduced}$$

The above calculations to determine the cost–effectiveness ratio for control scenario 2 show that it will cost approximately $433 to reduce emissions by one ton from this unpaved road. To determine the most cost–effective emissions reduction plan for the facility, a similar series of calculations must be performed for each possible control scenario.

Table 6-4. Cost Comparison for Two Selected Implementation Scenarios[a]

Alternative Approach	Cost: Capital investment ($)	Cost: Unit O&M cost[b] $/Treated mile	Cost: Unit O&M cost[b] $/Actual mile
SCENARIO 1—Rent Where Possible to Minimize Capital Expenditure			
Purchase chemical and ship in truck tanker		4,650	
Store in contractor tank		140	
Rent contractor grader to prepare road			1,200
Take water from city line		20	
Rent contractor truck[c]		500	
	0	5,310	1,200
SCENARIO 2—Buy Equipment Where Possible			
Purchase chemical and ship in truck tanker		4,650	
Store in newly purchased storage tank	30,000		
Prepare road with plant owned grader			630
Pump water from river or lake	5,000	135	
Apply chemical with plant owned application truck[c]	70,000		
	105,000	4,785	630

[a]1983 Dollars.
[b]Plant overhead costs are included.
[c]Includes labor to pump water and chemical and apply solution.

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Appendix A
Glossary Of Terms

Air Quality Model – An equation or series of equations which predict a source impact on air quality.

Annualized Cost – The control technique cost ($/yr) calculated as annual cost over the useful life of the equipment (or application). The annualized cost is a sum of the annualized purchase and installation cost (i.e., capital costs) and the annual maintenance and operating costs.

Application Frequency – Number of applications of a control measure to a specific source per unit time; equivalently, the inverse of time between two applications.

Application Intensity – Volume of water or chemical solution applied per unit area of the treated surface.

Capital Recovery Factor – The factor which is used to annualize capital investment to obtain the annualized capital cost. The capital recovery factor is a function of annual interest rate and the total number of payment years.

Chemical Stabilization – The use of chemical dust suppressants for the control of fugitive particulate emissions from open dust sources or material storage piles.

Control Efficiency – Percent decrease in controlled emissions from the uncontrolled state.

Cost–Effectiveness – The cost of control per unit mass of reduced particulate emissions.

Dilution Ratio – Ratio of the number of parts of chemical to the number of parts of solution, expressed in percent (e.g., one part chemical to four parts water corresponds to a 20% solution).

Dry Sieving – The sieving of oven–dried aggregate by passing it through a series of screens of descending opening size.

Dust Suppressant – Water or chemical solution which, when applied to an aggregate material, binds suspendable particulate to larger particles.

Emission Factor – An estimate of the mass of uncontrolled emissions released to the atmosphere per unit of source extent (e.g., lb/VMT).

Emission Rate – Mass of emissions generated per unit time (e.g., lb/hr).

Emissions Inventory – A listing and classification of all sources of emissions, and the quantity of emissions generated for a specific geographic area or facility.

Erosion Potential – Total quantity of erodible particles, in any size range, present on the surface (per unit area) prior to the onset of erosion.

Exposed Area – Outdoor ground area subject to the action of wind and protected by little or no vegetation.

Exposure Profiling Method – A method for quantifying fugitive emissions which involves the isokinetic measurement of airborne pollutant immediately downwind of the source by means of simultaneous multipoint sampling over the effective plume cross section.

Fine Particulate (FP) – Particulate matter less than or equal to 2.5 μm in aerodynamic diameter.

Fugitive Dust – Solid particles generated by the action of wind or machinery which are not emitted from a stack, duct, or flue.

Fugitive Emissions – Emissions not originating from a stack, duct, or flue.

Inhalable Particulate (IP) – Particulate matter less than or equal to 15 μm aerodynamic diameter.

Materials Handling – The receiving and transport of raw, intermediate and waste materials, including barge/railcar unloading, conveyor transport and associated conveyor transfer and screening stations.

Moisture Content – The mass portion of an aggregate sample consisting of unbound moisture as determined from weight loss in oven drying.

Open Dust Sources – Sources of fugitive emissions that entail generation of particulate matter by the forces of wind or machinery acting on exposed (i.e., open) materials where no physical or chemical change occurs to the particle–generating material.

Particle Diameter, Aerodynamic – The diameter of a hypothetical sphere of unit density (1 $\mu g/cm^3$) hav-

ing the same terminal settling velocity as the particle in question, regardless of its geometric size, shape and true density.

Physical Stabilization – Any measure which physically reduces the emissions potential of a source resulting from either mechanical disturbance or wind erosion.

PM_{10} – Particulate matter less than or equal to 10 μm in aerodynamic diameter.

Preventive Measures – Techniques for controlling fugitive particulate emissions which prevent the creation and/or release of particulate matter(e.g., wet suppression, stabilization of unpaved surfaces, cleaning of paved surfaces).

Process Sources – Sources of fugitive emissions associated with industrial operations that alter the chemical or physical characteristics of a feedmaterial.

Receptor–Oriented Air Quality Model (Receptor Model) – An air quality model which uses chemical analysis at receptors (i.e., ambient monitors) to statistically infer the separate contribution from each of the sources of the emissions.

Respirable Particulate (RP) – Particulate matter less than or equal to about 3.5 μm aerodynamic diameter, as measured with a 10–mm Door–Oliver cyclone precollector.

Road, Paved – A roadway constructed of rigid surface materials such as asphalt, cement, concrete, and brick.

Road, Unpaved – A roadway constructed of nonrigid surface materials such as dirt, gravel (crushed stone or slag), and oil and chip surfaces.

Road Surface Dust Loading – The mass of loose surface dust on a paved roadway, per length of roadway, as determined by dry vacuuming.

Road Surface Material – Loose material present on the surface of an unpaved road.

Silt Content – The mass portion of an aggregate sample smaller than 75 μm in diameter as determined by dry sieving.

Source Extent – The measure of the level of source activity. For roads, the source extent is in vehicle miles traveled (VMT) per year.

Source–Oriented Air Quality Models (Dispersion Models) – An air quality model which predicts a source's impact on air quality by using a series of predictive equations to model the dispersion of the plume from the source.

Total Particulate (TP) – Particulate matter of all sizes as collected by isokinetic sampling.

Total Suspended Particulate (TSP) – Particulate matter measured by a high volume sampler with an inlet 50% cutoff 30–50 μm in aerodynamic diameter.

Upwind/Downwind Method – A method of quantifying fugitive emissions which involves the measurement of air quality upwind and downwind of the source under known meteorological conditions, followed by "back–calculation" of source emission rates using atmospheric dispersion equations.

Vehicle, Heavy–Duty – A motor vehicle with a gross vehicle traveling weight exceeding 30 tons.

Vehicle, Light–Duty – A motor vehicle with a gross vehicle traveling weight of less than or equal to 3 tons.

Vehicles, Medium–Duty – A motor vehicle with a gross vehicle traveling weight of greater than 3 tons, but less than 30 tons.

VKT – Vehicle kilometers traveled.

VMT – Vehicle miles traveled.

Wet Suppression – The application of water to the surface of the material producing emissions to inhibit the generation of particulate matter emissions.

Appendix B
Abbreviations

a – Constant in equation 3–2

ADT – Average daily traffic

AMS – American Meteorological Society

APCA – Air Pollution Control Association

AP–42 – The following publication: U.S. Environmental Protection Agency. Compilation of Air Pollution Emission Factors, Volume 1: Stationary Point and Area Sources. Fourth Edition. Supplement A, AP–42, Office of Air Quality Planning and Standards, Research Triangle Park, NC, October 1986.

Avg – Average

b – Constant in equation 3–2

c – Fractional control efficiency

C* – Cost–effectiveness

C_a – Annualized costs of control equipment

$CaCl_2$ – Calcium chloride

CBR – California bearing ratio

CCSEM – Computer controlled scanning electron microscopy

cfm – Cubic feet per minute

Chem – Chemical

C_o – Direct operating costs

CO – Colorado

C_p – Installed capital costs

CRF – Capital recovery factor

c(t) – Instantaneous control efficiency at t days after application of dust suppressant

C(T) – Average control efficiency during period of T days between application of dust suppressant

d – Average hourly daytime traffic rate

days/yr – Days per year

dt – Change in time

E – Emission factor

EPA – U.S. Environmental Protection Agency

f – Percent time unobstructed wind speed greater than 12 miles per hour

FP – Fine particulate matter

ft – Feet

gal – Gallons

gal sol/yd² – Gallons of solution per square yard

gal/yd² – Gallons per square yard

g/m² – Grams per square meter

g/m³ – Grams per cubic meter

g/s – Grams per second

H – Drop height except as used in Appendix C

H – Final plume rise in Gaussian equation in Appendix C

H_2O – Water

h_c – Height of convectively mixed layer

hi–vol – High volume

h_m – Height of mechanically mixed layer

hr – Hour

hr^{-1} – Per hour

hr/yr – Hours per year

I – Interest rate except as used in equation 5–2

i – Application intensity in equation 5–2

I – Road augmentation factor

IL – Illinois

in – Inches

IP – Inhalable particulate

k – Particle size multiplier

kg – Kilogram

kg/VKT – Kilogram per vehicle kilometer traveled

km – Kilometer

km/hr – Kilometers per hour

l – Liters

L – Surface dust loading

l/m² – Liters per square meter

lb – Pound

lb/mile – Pounds per mile

lb/VMT – Pounds per vehicle mile traveled

m – Meters except as used in equation 3–2

m – Road surface moisture content only as used in equation 3–2

M – Material moisture content as used on Tables 6–1 and 6–2

M – Annual source extent except as used in Tables 6–1 and 6–2

m^2 – Square meters

m^3 – Cubic meter

m^3/hr – Cubic meters per hour

mg – Megagram

$MgCl_2$ – Magnesium chloride

mm – Millimeter

mm/hr – Millimeters per hour

MN – Minnesota

mph – Miles per hour

MRI – Midwest Research Institute

m/s – Meters per second

n – Number of travel lanes as used in Tables 6–1 and 6–2

n – Economic life of control system except as used in Tables 6–1 and 6–2

NC – North Carolina

NCDC – National Climatic Data Center, Asheville, NC

No. – Number

OH – Ohio

O&M – Operation and maintenance

oz/yd^2 – Ounces per square yard

p – Number of days with at least 0.01 inches of precipitation per year except as used in equation 5–2

p – Potential average hourly daytime evaporation rate in equation 5–2

P – Profiling, used in Table 5–4

PA – Pennsylvania

PM_{10} – Particulate matter consisting of particles less than or equal to 10 μm

Q – Source strength

RP – Respirable particulate matter

s – Silt content of road surface material

S – Mean vehicle speed

SEM – Scanning electron microscope

sL – Silt loading

Sol – Solution

SORI – Southern Research Institute

ST – Short tons

t – Time between applications in equation 5–2

TEM – Transmission electron microscope

ton/yr – Tons per year

TP – Total airborne particulate matter

TSP – Total suspended particulate matter

u – Wind speed as used in Appendix C

U – Mean wind speed except as used in Appendix C

U/D – Upwind/downwind, used in Table 5–4

UNAMAP – User's Network for Applied Modeling of Air Pollution

Veh – Vehicle

VKT – Vehicle kilometer traveled

VMT – Vehicle mile traveled

VMT/yr – Vehicle miles traveled per year

w – Mean number of wheels

W – Mean vehicle weight

X – Pollutant concentrations

y – Lateral distance from plume centerline in Gaussian equation in Appendix C

Y – Average capacity (of dumper or front end loader) except as used in Appendix C

yd^2 – Square yard

yd^3 – Cubic yards

yr – Year

ΔR – Annual reduction in particulate emissions

ΔT – Temperature difference

Θ – Wind direction

g/m^3 – Microgram per cubic meter

μm – Micrometer

μmA – Micrometer (aerodynamic basis)

σ_y – Lateral dispersion parameter

σ_z – Vertical dispersion parameter

Appendix C
Modeling Of Fugitive Emissions

The identification and estimation of air quality impacts from fugitive dust sources typically require the use of air quality models. Traditional regulatory approaches have dictated that source impacts be identified by dispersion (source) modeling. The following discussion is intended to provide a general overview of source-oriented models; for more detailed discussions, the user should consult recent reviews readily available in the scientific literature.[1,2] Source-oriented models assume that mass transported from a source to a receptor is transported with conservation of mass by atmospheric dispersion of the source material.[3] It should also be recognized that the selection of an appropriate model(s) will depend upon the particular program/study objectives and resource constraints (i.e., data, manpower, computing facilities, etc.), as well as the user's knowledge of the model technology.

The Gaussian plume model is more widely used than any other source-oriented model. Stripped to its essentials, the Gaussian model may be represented as follows:

$$X = \left(\frac{Q}{2\pi u \sigma_y \sigma_z}\right)\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\left[\exp\left(\frac{-(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \qquad \text{(C-1)}$$

where the parameters are:

X (g/m³)	=	concentration of pollutant in air
Q (g/s)	=	continuous point source strength
u (m/s)	=	wind speed at height H
σ_y (m)	=	lateral dispersion parameter
σ_z (m)	=	vertical dispersion parameter
y (m)	=	lateral distance from plume center line
z (m)	=	height above ground
H (m)	=	final plume rise of plume above ground

As the name implies, the model predicts concentrations under the assumption that the plume disperses in the horizontal and vertical according to a Gaussian distribution. Other major assumptions include: a) constant and continuous emission rates, b) no variations in meteorology (wind speed, wind direction, and atmospheric stability) between source and receptor, and c) complete reflection of the plume from the ground surface.

The Gaussian plume concept is the basis for nearly all models in the U.S. EPA system of UNAMAP (User's Network for Applied Modeling of Air Pollution) models. The differences between models of the UNAMAP family are mostly due to variations in the treatment of plume rise, pollutant half-life, diffusion limitations due to mixing heights, source configurations, and dispersion coefficients to characterize plume growth. Abstracts which summarize model capabilities of most of the current generation of UNAMAP models may be found elsewhere.[4] Reasonably complete technical descriptions for each model are available in the various users' manuals.

For all but the crudest screening applications, the use of a dispersion model requires appropriate information on source emission rates and study area meteorology. In the case of stationary sources, it is usually a fairly straightforward procedure to develop an adequate emissions inventory. For fugitive (particularly open source) emissions, the measures of source extent (e.g., unvegetated surface area exposed to the wind) are often more difficult to define. The reliability of open source emissions estimates are greatly increased if site-specific information is collected.

In similar fashion, to make the best use of Gaussian modeling, site-specific meteorological measurements need to be made that relate closely to pollutant dispersion.[5] These include, for example, a) continuous measurements of wind speed (u) and direction (Θ) at two heights; b) ambient temperature difference (ΔT) between 2 and 10 m; and c) heights of the convectively mixed layer (h_c) and the mechanically mixed layer (h_m). Very few programs are designed to acquire such detailed information.

Many routine modeling applications rely on data from nearby locations such as airports, National Weather Service stations, and military installations to represent the atmospheric conditions for the area of interest. These observations are intended primarily for aviation needs, and are not particularly well suited to dispersion problems. The primary source for surface and upper air meteorological data is the National Climatic Data Center (NCDC, Asheville, NC). For many long-term or climatological applications, the meteorological conditions of a site are represented by a stability array or "STAR" tabulation. The STAR tabulation summarizes meteorological conditions in terms of joint frequency distributions of wind speed, atmospheric stability class, and wind direction. This information has been developed for many locations in the United States and is also available from NCDC.

The principal advantage of source-oriented (dispersion) models lies in the fact that they can be used to directly predict the impact of either existing or proposed sources. [3] Another advantage of this class of models is that they do not require ambient air quality data, though, if available, air quality data may be used to assign "background" pollutant levels. Additional advantages are that the models are widely available and have been evaluated using many different data sets. [2]

The primary limitations of dispersion models relate not only to deficiencies in the quality of the input data for a particular application, but also to the ability of the Gaussian model to reproduce the important physical/chemical processes affecting transport of pollutants in the atmosphere. The Gaussian model will perform best under the conditions used to form the basis for the current models. These conditions include:

Source: Low-level, continuous, nonbuoyant emissions, in simple terrain.

Meteorology: Near neutral stability, steady, and relatively homogeneous wind field.

Estimate: Local, short-term, concentrations of inert pollutants.

Under those relatively simple conditions, "factor of two" agreement between predicted and observed concentrations is probably realistic. [6]

Addition of complicating features to the simple dispersion case will substantially increase the uncertainties associated with model estimates. Complicating features include:

- Aerodynamic wake flows of all kinds
- Buoyant fluid flows and accidental releases of heavy toxic gases
- Flows over surfaces markedly different from those represented in the basic experiments, e.g., forests, cities, water, complex terrain
- Dispersion in extremely stable and unstable conditions
- Dispersion at great downwind distances (>10 to 20 km)

It is widely recognized that significant improvements in dispersion modeling will require more direct observational knowledge under these conditions. Model users should be aware that the capabilities of the current UNAMAP series to represent these features are based on a few special case studies. [7]

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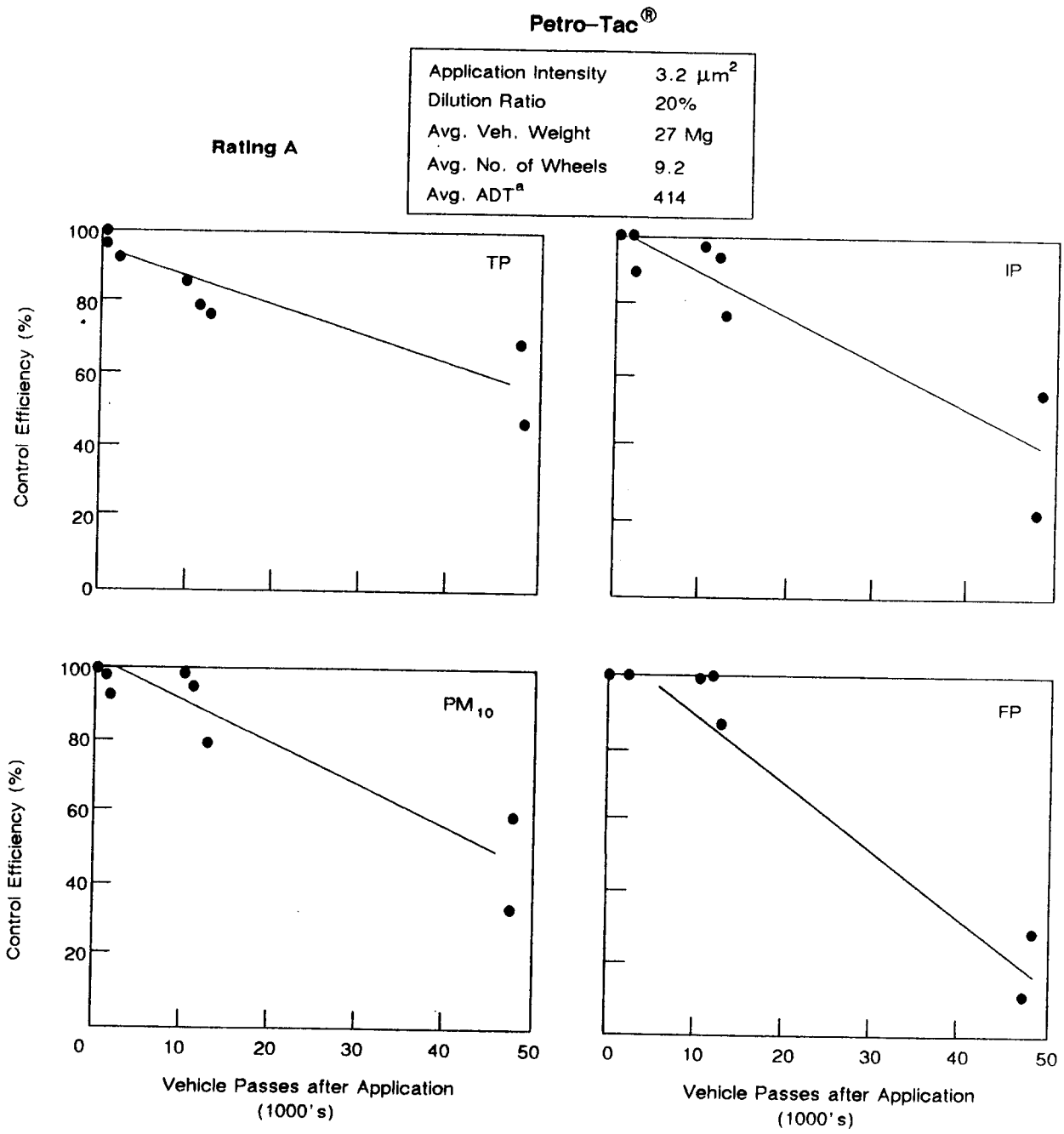
Appendix D
Control Efficiency Decay Curves

Figure D-1. Control efficiency decay for an initial application of Petro Tac® [1-3].



[a]ADT = average daily traffic (vehicles/day)

Figure D-2. Control efficiency decay for an initial application of Coherex® [1-3].

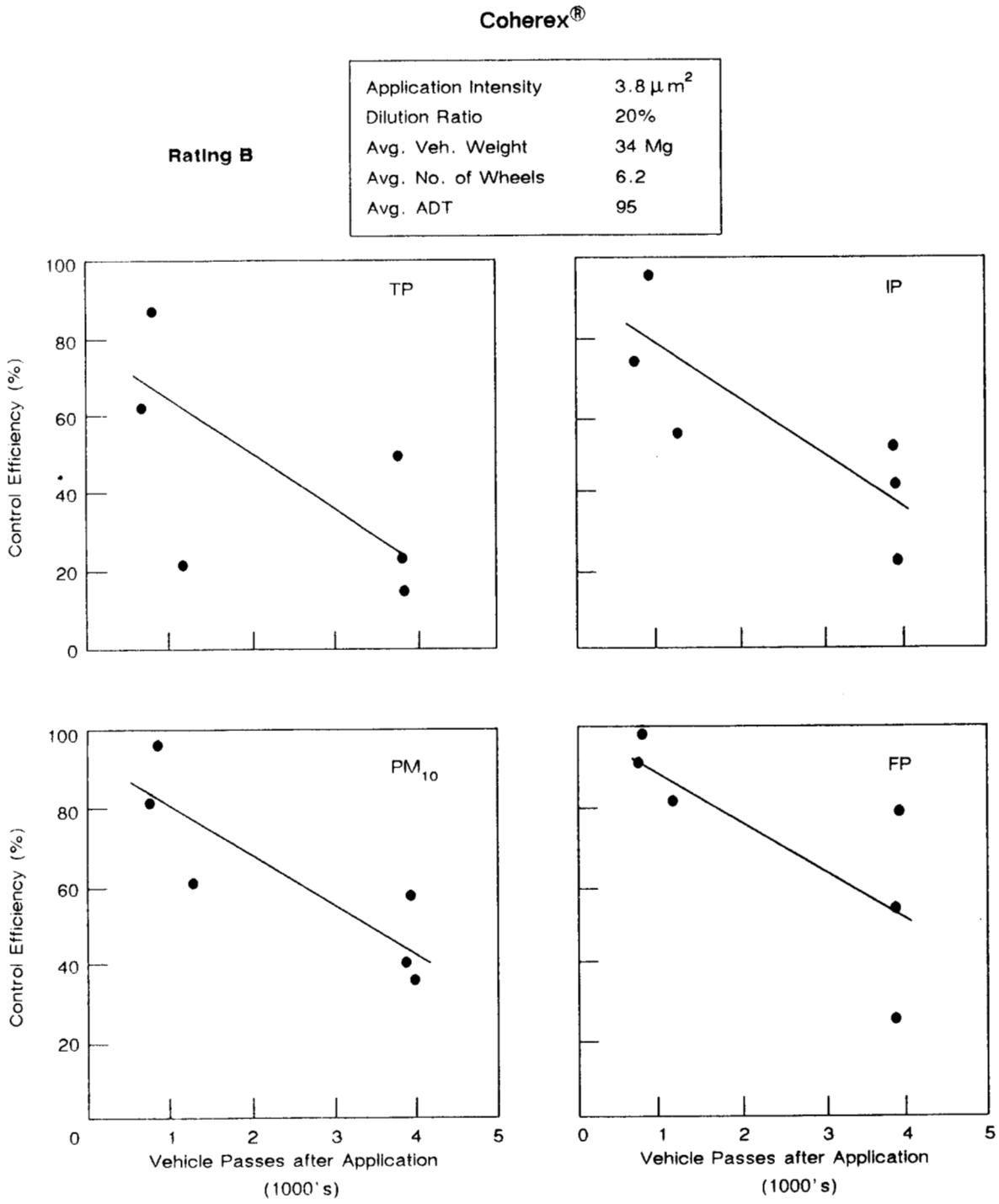


Figure D-3. Control efficiency decay for a reapplication of Coherex® [1-3].

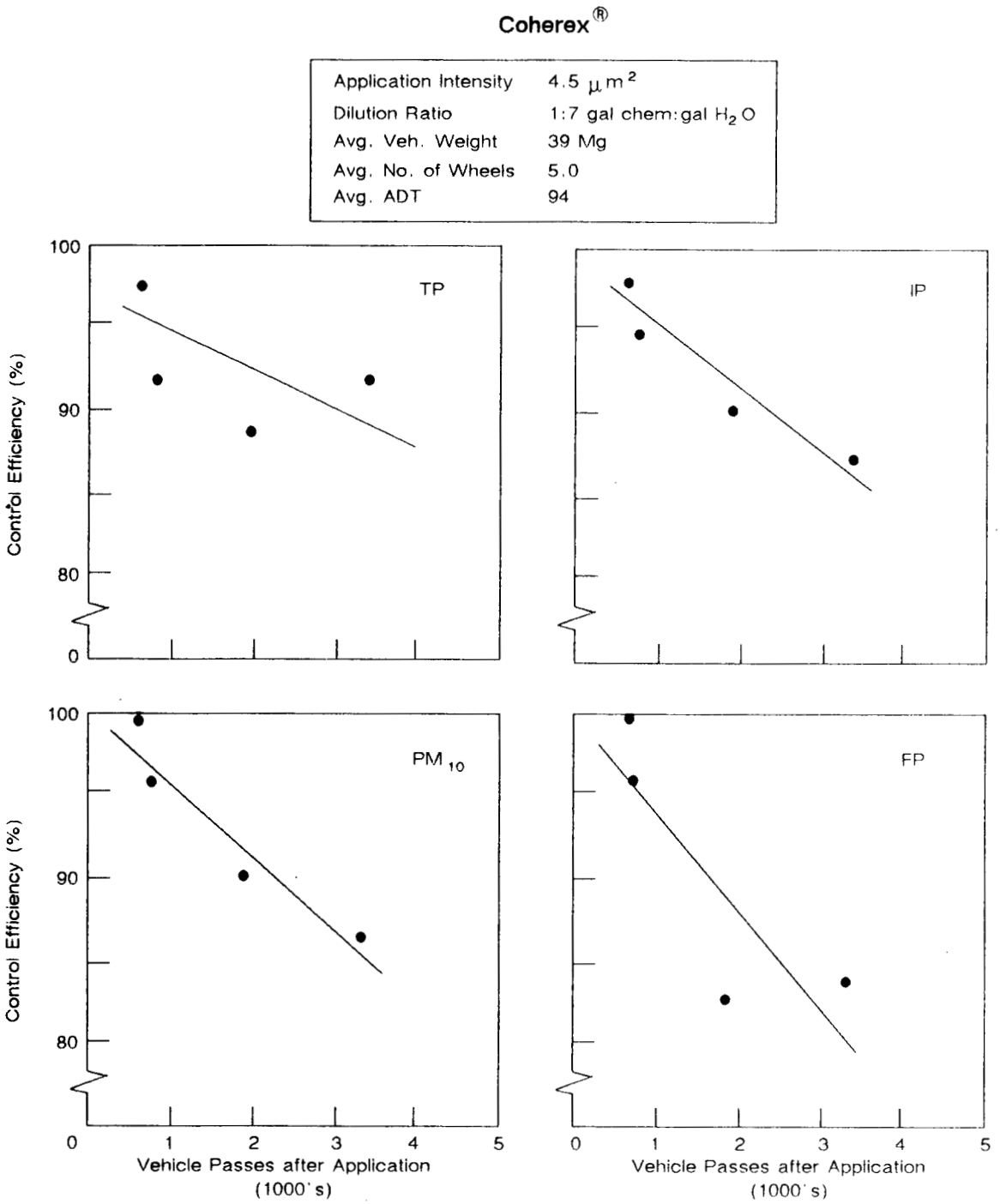


Figure D-4. TSP control efficiency decay for light-duty traffic on unpaved roads [4].

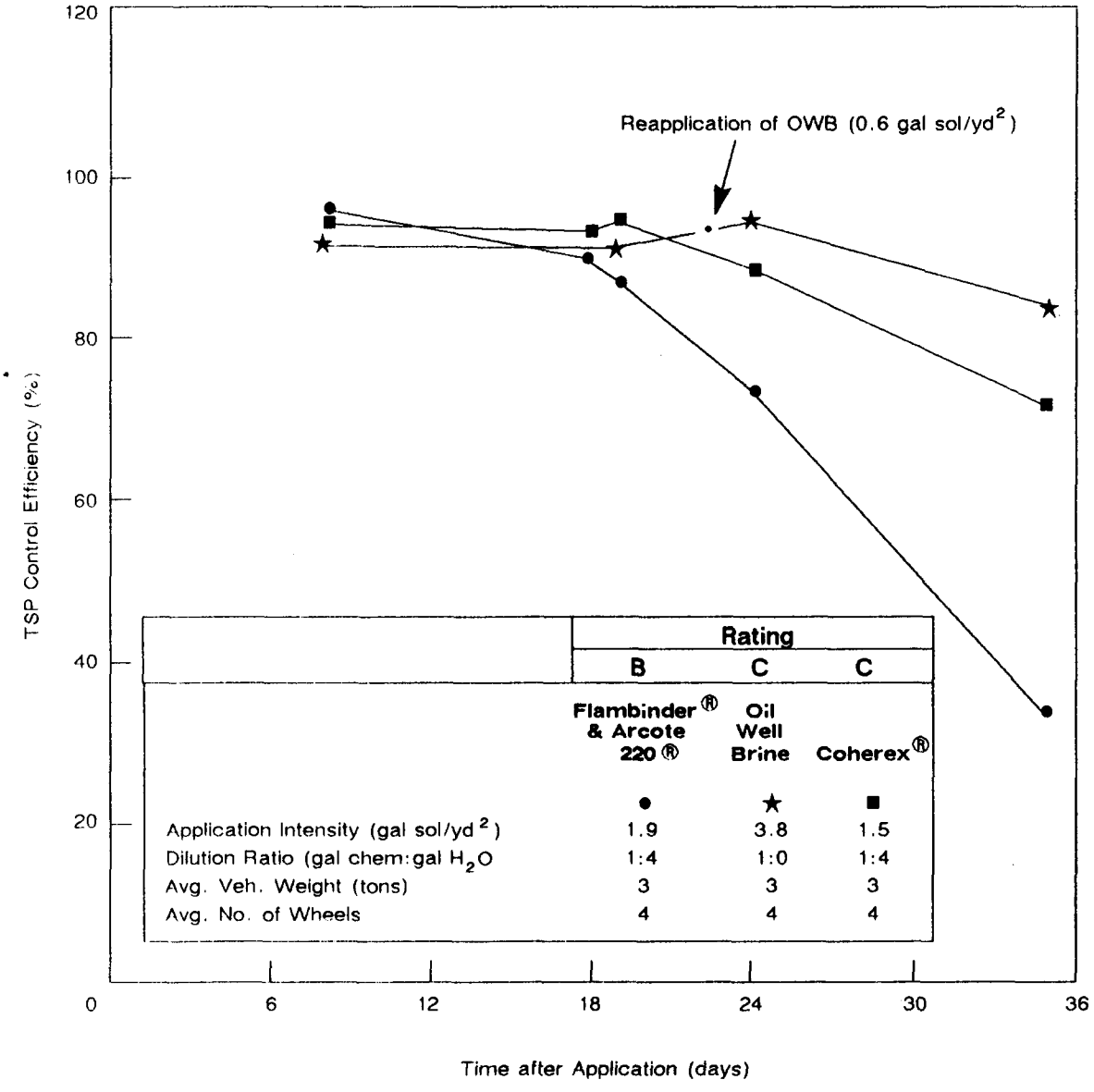


Figure D-5. Control efficiency decay for LiquiDow® applied to haul roads [5].

LiquiDow®

	1 ●—●	2 ■—■	3 ★—★
Application Intensity (gal sol/yd^2)	0.27-0.6	0.27-0.6	0.3-0.6
Dilution Ratio (gal chem:gal H_2O	1:1.6	1:1.6	1:1.9
Avg. Veh. Weight (tons)	28-86	44-83	70-276
Avg. No. of Wheels	10	10	6
Rating	D	D	D

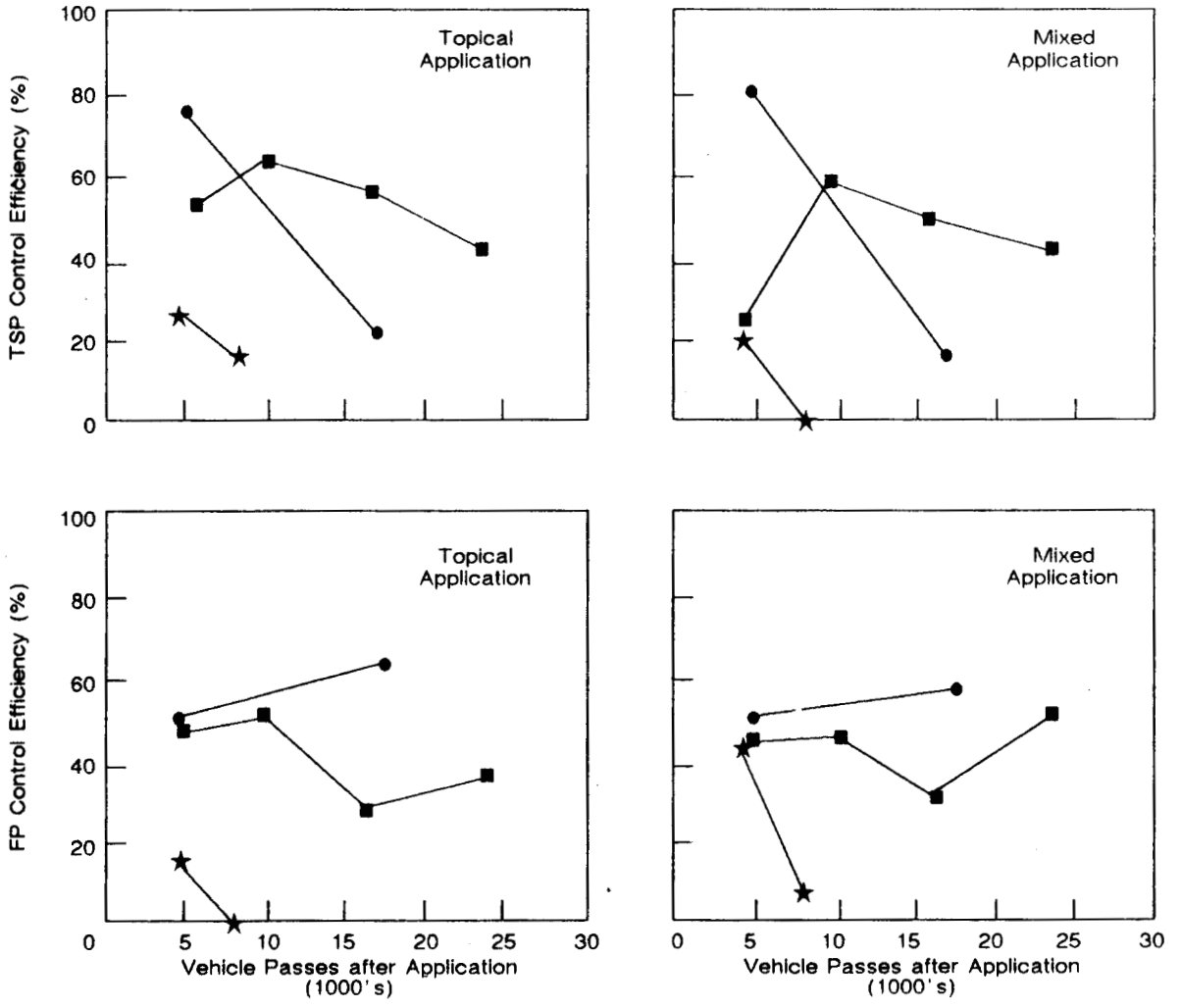


Figure D-6. Control efficiency decay for Soil Sement® and Biocat-Enzyme® applied to haul roads [5].

	Soil Sement ®		Biocat-Enzyme ®
Mine	1	2	3
Application Intensity (gal sol/yd^2)	1.9-3.0	1.0	2.0
Dilution Ratio (gal chem:gal H_2O	1:8.3	1:6.4	1:20.000
Avg. Veh. Weight (tons)	22-89	38-82	70-276
Avg. No. of Wheels	10	10	6
Rating	B	B	D

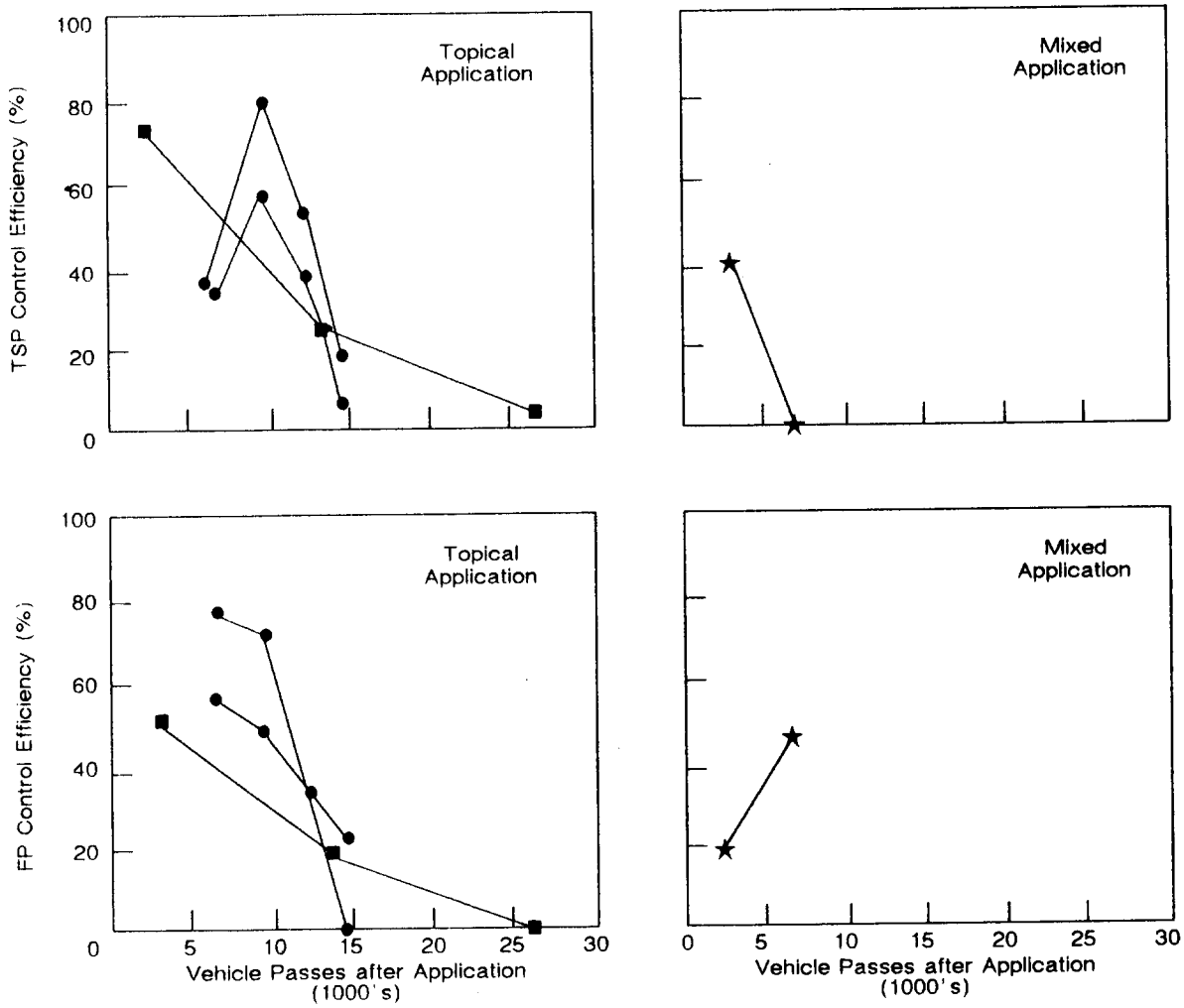


Figure D-7. Control efficiency decay for Flambinder® applied to haul roads [5].

Flambinder®

Mine	1	2	3
Application Intensity (gal sol/yd^2)	0.5-2.1	0.5-2.0	1.8
Dilution Ration (gal chem: gal H_2O	1:4.6	1:4.6	1:4.6
Avg. Veh. Weight (tons)	16-65	51-69	70-276
Avg. No. of Wheels	10	10	6
Rating	E	C	C

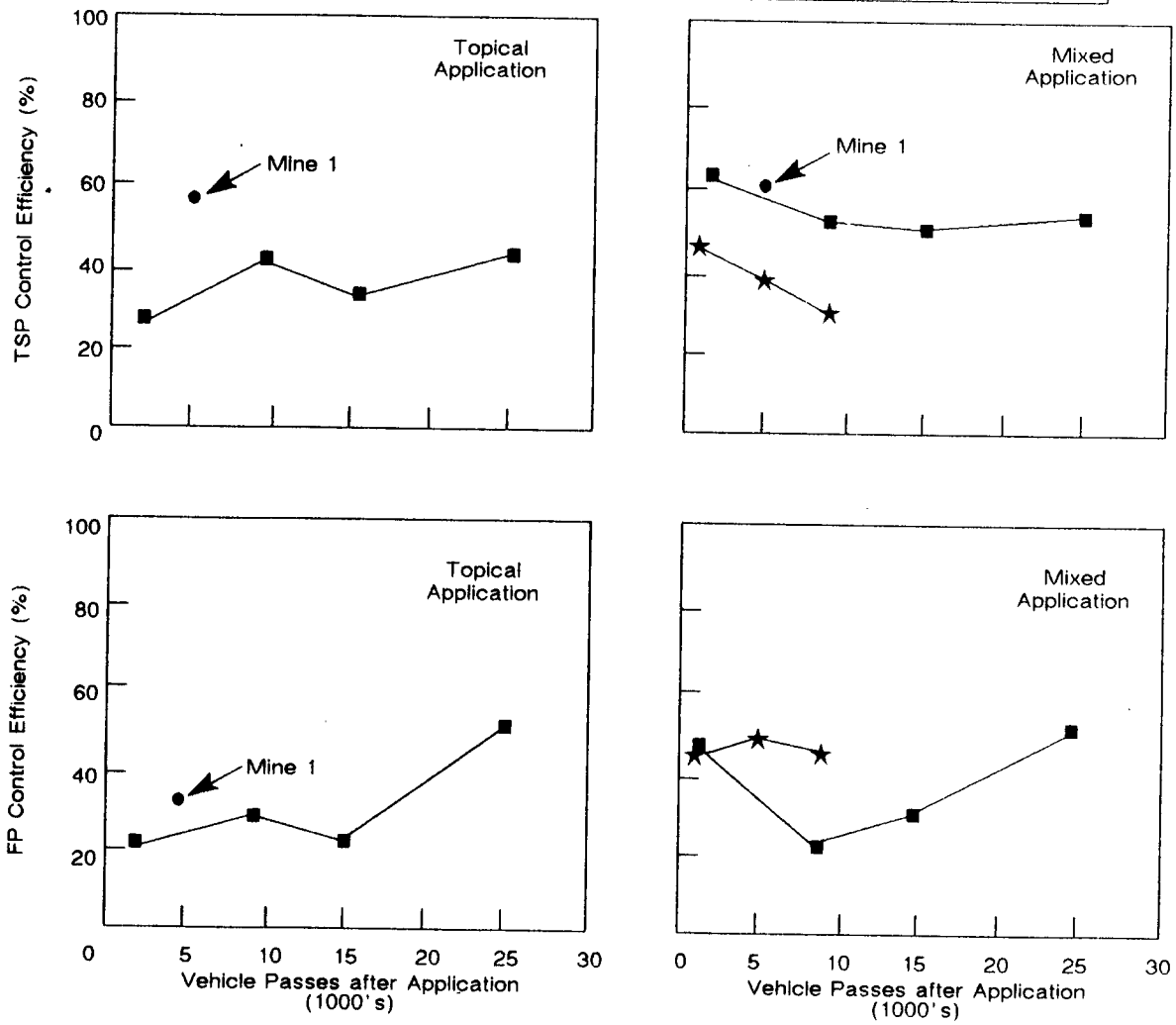


Figure D-8. Control efficiency decay for Arco 2200® applied to haul roads [5].

Arco 2200®

Mine	2 ■—■	3 ★—★
Application Intensity (gal sol/yd^2)	0.9-2.8	1.1-2.3
Dilution Ratio (gal chem:gal H_2O	1:7	1:6.1
Avg. Veh. Weight (tons)	18-80	70-276
Avg. No. of Wheels	10	6
Rating	C	E

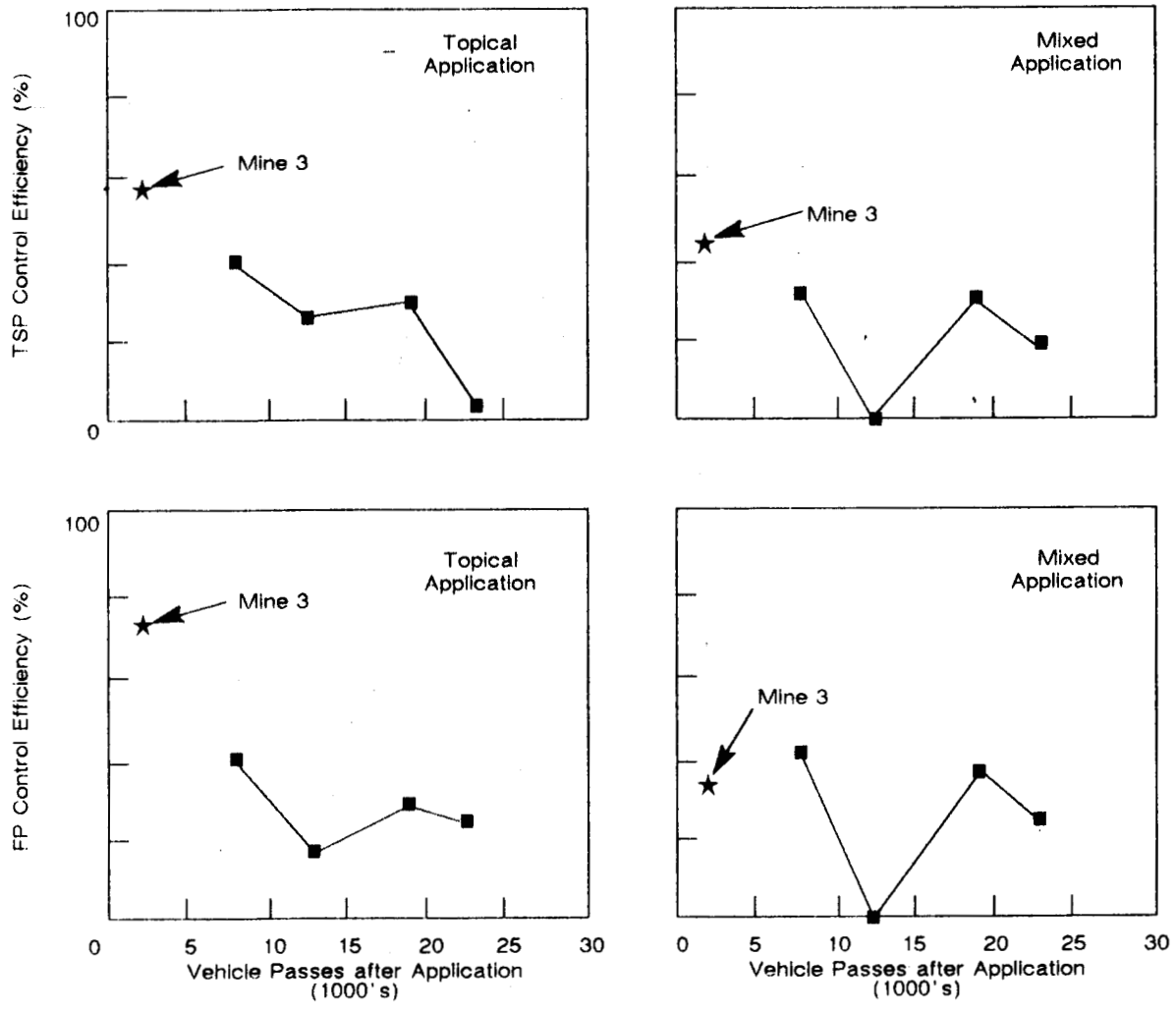
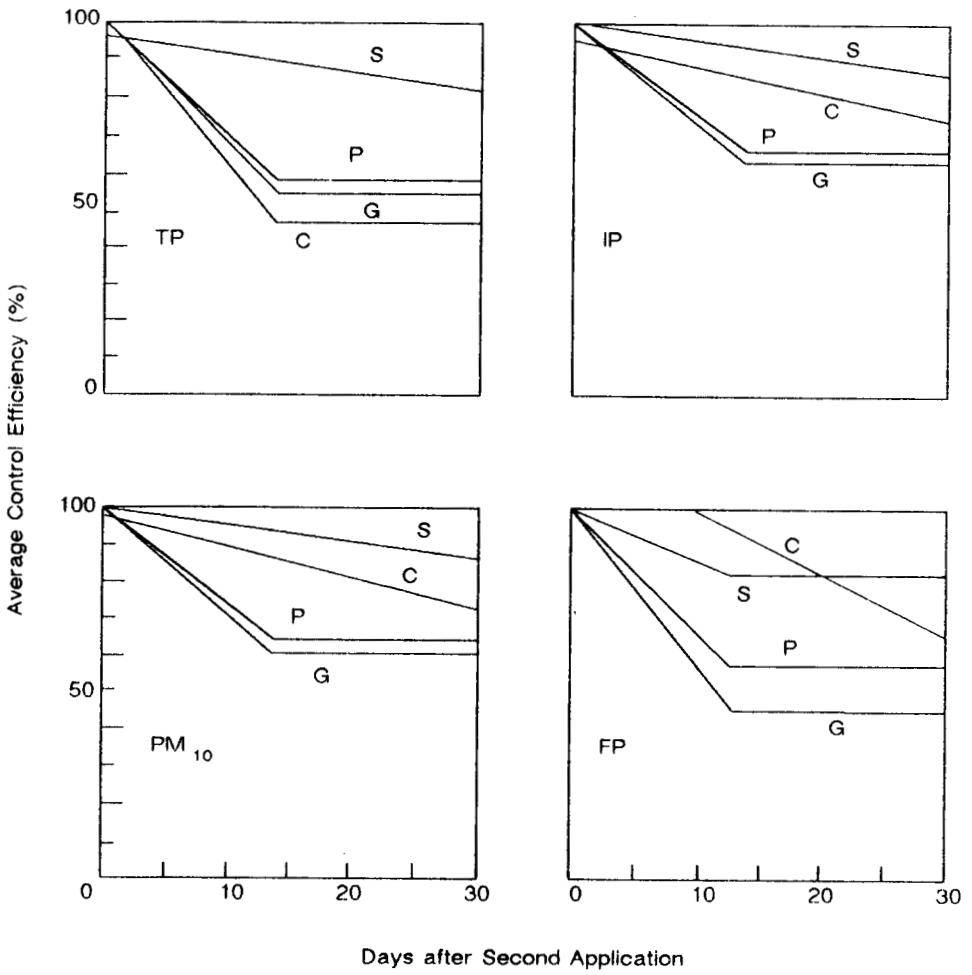


Figure D-9. Control efficiency decay for reapplication of various chemical suppressants [6].

Code Letter	Petro Tac®	Soil Sement®	Coherex®	Generic
	P	S	C	G
Initial Application Intensity (gal/yd^2)	0.21	0.16	0.21	0.14
Second Application Intensity (gal/yd^2)	0.35	0.44	0.36	0.46
Dilution Ration (chem: water)	1:5	1:5	1:5	1:5
Avg. Vehicle Weight (tons)	9.7 - 24	9.6 - 24	9.6 - 24	9.3 - 24
Avg. No. of Wheels	6	6	6	6



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U. S. GOVERNMENT PRINTING OFFICE 1987/748-121/67021