EPA-450/2-77-029
October 1977
(OAQPS No. 1.2-071)

GUIDELINE SERIES

GUIDELINE FOR DEVELOPMENT OF CONTROL STRATEGIES IN AREAS WITH FUGITIVE DUST PROBLEMS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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Monitoring and Data Analysis Division

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OAQPS GUIDELINE SERIES

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Publication No. EPA-450/2-77-029
(OAQPS Guideline No. 1.2-071)

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

1.0 INTRODUCTION

The purpose of this document is to outline a methodology for development of control strategies for areas experiencing nonattainment problems due to fugitive dust emissions. Historically, relatively little attention has been focused on control of fugitive dust sources. Awareness of the nature and extent of these sources has been very limited, and potential dust control measures have not been generally implemented. As the extent of the fugitive dust problem has become evident, more effort is now being applied to characterize dust sources and to develop methods for their control. This document synthesizes the results of these recent efforts and establishes an overall procedural method for the development of air programs to control high TSP levels caused by fugitive dust. However, this document does not address the various policy issues associated with fugitive dust control such as definition of those areas where control plans should be developed or new source review as outlined in the Fugitive Dust Policy Paper dated August 1, 1977.

Many states are now facing the problem of controlling fugitive dust. Previously, it was routinely believed that fugitive dust emissions were unavoidable. However, recent studies show that while some fugitive dust emissions are mainly a result of natural phenomena, most frequently fugitive dust sources result directly from or during human activity. In this sense, most fugitive dust sources are controllable although the extent of control required for attainment of the National Ambient Air Quality Standards (NAAQS) may impose unreasonable demands.

Before control strategies can be systematically formulated and evaluated, essential and basic technical analyses must be performed. Chapters 2, 3, and 4 summarize the analytical foundation for the strategy development process.

Subjects discussed in these chapters include: (1) representativeness of monitoring sites and characterization of air quality levels; (2) compilation of particulate emission inventories for the base year and projected inventories for future years*; (3) formulation of a model to translate emission levels into suspended particle concentrations. The final chapters contain a procedure for formulation and evaluation of an appropriate control strategy, including the consideration of emission control effectiveness, air quality impact, costs and implementation problems.

1.1 BASIC DEFINITIONS

Fugitive Dust - A type of particulate emission made airborne by forces of wind, man's activity, or both, such as unpaved roads, construction sites, tilled land or windstorms. A summary of the various significant categories of fugitive dust sources is listed in Table 1-1. Two major categories are identified: anthropogenic sources (those which result directly from and during human activities) and wind erosion sources (those resulting from erosion of soil by wind). Fugitive dust is distinguished from fugitive (industrial process) emissions as defined below:

Fugitive Emissions - Particles which are generated by industrial or other activities and which escape to the atmosphere not through primary exhaust systems, but through openings such as windows, vents or doors, ill-fitting oven closures, or poorly maintained equipment. Aggregate storage operations and active tailing piles are included in this category of sources.

*Refer to EPA's maintenance regulation in Subpart D, 40 CFR 51.

TABLE 1-1. FUGITIVE DUST SOURCES CATEGORIES

Anthropogenic Fugitive Dust Sources

. Unpaved Roads

. Agricultural Tilling

. Construction Activities

. Street Dust

. Off-Road Motor Vehicles

. Inactive Tailing Piles

Wind Erosion Fugitive Dust Sources

. Unpaved Roads

. Agricultural Fields

. Disturbed Soil Surfaces

Baseyear and Baseline - In assessing the impact of proposed emission control strategies, it is necessary to characterize the extent and nature of the existing and anticipated conditions related to the air pollution problem. These "nominal" conditions are referred to as the baseline. Important baseline information concerns: (1) baseline emissions; (2) baseline air quality; (3) baseline control policies; and, (4) baseline meteorology. For the purposes of this document, the baseline consists of the baseyear, and projections for future years*. The baseyear is selected as the current or recent year, depending on the availability of information to characterize the air pollution problem suitably.

In formulating control plans, it is necessary to distinguish between control measures and control strategies. A control measure refers to a specific emission reduction method applied to a certain source category. A control strategy consists of a collection of various control measures to be implemented jointly.

1.2 SUMMARY OF PROCEDURES FOR DEVELOPMENT OF CONTROL STRATEGIES FOR FUGITIVE DUST

Scope and Objectives

The development of an air pollution control strategy designed to attain and maintain the National Ambient Air Quality Standards (NAAQS) requires an analysis of current and possible future air quality problems. It is the objective of this Section to briefly present the quantitative and qualitative procedures used in developing an acceptable plan for the

*Refer to EPA's maintenance regulation in Subpart D, 40 CFR 51.

control of fugitive dust. The amount of work involved in each step will vary from area-to-area depending on available data, magnitude of the particulate problem, types of emissions sources, etc.. These steps can be summarized as follows:

Step 1. Review air quality monitoring data to characterize nature and extent of suspended particulate problem.

a. Assess representativeness of monitor sites. Characterize the general area and the site-specific area around the monitor. Identify local factors which exert influence on TSP measured at each site. Establish history of these local influences and anticipated status in near future. Evaluate if TSP levels at the various sites are representative of (1) the general area surrounding the monitor, or (2) only the specific area near the monitor. Assess the implications of representativeness of station measurements for the utility of the particulate air quality data. If local sources contribute substantially to the problem, this may indicate that local sources need to be controlled, whereas if analyses indicate areawide sources contribute to the monitor, then areawide controls should be considered.

b. Analyze patterns of the air quality data to characterize the suspended particulate problem. Various analytical procedures may be employed to develop insights into the origin and factors affecting the particulate problem. The most significant of these analyses concerns the apparent relationship between meteorology and TSP levels. Evaluate measured data to determine seasonal patterns of TSP and associated meteorology affecting these levels. Analyze daily meteorlogy and TSP data to determine apparent effect of meteorology on TSP. Analyze meteorological circumstances associated with particulate problem: TSP trends at various sites may be examined, statistical correlations between TSP levels at various sites can be developed, and the geographic distribution of TSP levels may reveal significant spatial patterns in the air quality and the nonattainment problems. Several of these potential analysis methods are described in reference 1. Here again, this analysis may show if local or specific sources contribute substantially to the problem, thus indicating the type of sources that need to be controlled.

Step 2. Develop the baseline particulate emissions inventory for sources significantly affecting the problem area.

a. Identify particulate sources which may exert significant effect on the area experiencing the nonattainment problem. Such sources may be located both within the urban areas and in the surrounding rural areas several miles from the urban centers. Determine the geographic area to be included in the analysis based on the relative significance and proximity of rural sources compared to other urban sources.

b. Select a baseyear and estimate the emission levels for conventional sources including fugitive emission and fugitive dust sources in that year. If seasonal levels vary distinctly, estimate emission levels by season as well. Document the emission inventory in terms of an emissions grid network.

c. Project the baseyear emissions inventory to future years* by considering projected growth predictions related to the various emission sources. Predict probable emission levels and spatial distribution of these levels, and express in terms of emissions grid network.

Step 3. Formulate an emissions/air quality relationship.

Evaluate alternative source-receptor models and select an appropriate relationship. No single model is presently available for application to all areas where substantial impact of the particulate emissions arises from larger particles originating from the fugitive dust source types. In lieu of a complete theoretical model which is capable of accounting for deposition of particles, there are several approaches that have been utilized in previous studies (Section 4). It is believed that these techniques do have application in those arid western areas with fugitive dust problems. Continued use of AQDM[2] and CDM[3] appears to be most reasonable approach for those areas where particles less than 10 micrometers predominate.

Step 4. Characterize alternative control measures for application to significant fugitive dust sources. Identify control

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* Refer to EPA's maintenance regulations in Subpart D, 40 CFR 51.

methods available for mitigation of the area's most significant dust sources. Determine probable effectiveness of these methods in the subject area. Consult with local agencies to derive estimates of cost for the candidate control measures. Calculate expected cost effectiveness of the various measures, and compare results.

Step 5. Select a control strategy and evaluate the impact of the strategy on air quality.

a. Select a control measure for application to each of the major source categories and specific geographic areas which are the cause of high TSP levels in the nonattainment area. The control measure selected should reflect the technical feasibility and reasonableness of the control, and will usually vary from region-to-region due to several general factors. These factors should be considered before final selection of the optimum control measures. Because of the many candidate controls for fugitive dust sources, selection of the overall control strategy may typically be an iterative process accomplished by means of successive alternative trials.

b. Evaluate the proposed strategy in terms of its impact on emission levels and TSP levels, and adjust the strategy to meet the primary air quality standards. Control effectiveness data are used to estimate emission levels resulting from the strategy, and the air quality model is employed to estimate resulting air quality. To obtain this objective, degree of control, geographic area of control, type of control, and timetable of the control are manipulated iteratively until the strategy achieves the primary standard.

c. Estimate the cost of the proposed strategy, and assess the problems associated with its implementation. Political, legal, and socioeconomic obstacles should be assessed, and consideration should be given to alleviating problems arising from strict regulatory approaches by adoption of an alternative approach providing for integration of the dust control measures into ongoing governmental agency programs. A demonstration strategy can be considered as the first step in the development of the total strategy which can reflect phased development.

SUMMARY

The remaining sections of the text provide detailed information regarding how to consider fugitive dust in the State Implementation Plans (SIP's).

2.0 ANALYSIS OF AIR MONITORING DATA

In conducting preliminary analyses required for the technical base of the control strategy formulation, existing air monitoring data must be analyzed to characterize the nature and extent of the suspended particulate problem. This characterization establishes the overall scope of the problem and aids in identifying origins of the particulate problem. This chapter outlines the procedures which may be employed to analyze the air monitoring data including monitoring site surveys, statistical analysis of air quality data, identification of relationships between TSP levels and meteorology, and relationships between TSP levels and nearby sources.

2.1 MONITOR SITE SURVEYS

Many decisions concerning air program planning are dependent upon the placement of the sensors used to measure air quality. Because ambient pollutant levels often vary substantially throughout a planning area, it is evident that contrasting siting procedures can result in totally different air quality characterizations. These differences have important implications on the nature of planning decisions for air quality standards and implementation programs.

Ultimately, a monitoring network cannot possibly satisfy all siting criteria. However, the network can still be very useful. This utility can be assured when an understanding of the representativeness of the monitors, and the relative levels of air quality measured there to other unmeasured areas in the study area, is fully developed. One means of developing this understanding is the site survey.

In conducting the site surveys, the geographic range of representativeness of the monitor is estimated by observation of local sources and topography surrounding the monitor. Figures 2-1 through 2-3 illustrate some potential source orientations with respect to monitor stations. In Figure 2-1, the monitor is located in a rather homogeneous field of sources, and the measurements should be representative of the general area. In Figure 2-2, the monitor is source oriented in an uneven field of sources, and measurements there may only be representative of a very limited space around the sensor. In Figure 2-3, the monitor is representative of the shaded region of area source emissions.

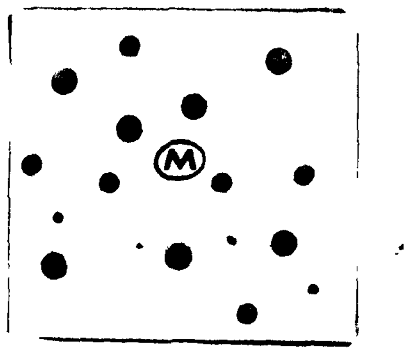


Figure 2-1. Monitor in Homogeneous Field of Point Sources. Representation of General Area.

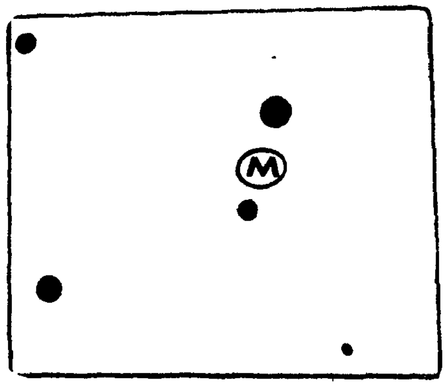


Figure 2-2. Monitor in Inhomogeneous Field of Point Sources. Site-Specific Representativeness.

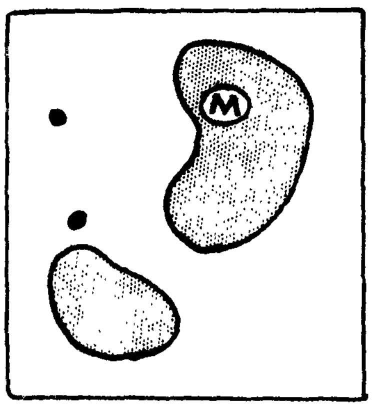


Figure 2-3. Monitor in Field of Area Sources (shaded). Site-Specific Representativeness.

A major issue in the representativeness of any monitor (such as that in the example above) concerns the placement of the sensor with respect to sources and topography immediately adjacent to the site. If the sensor is placed directly in an emissions plume, the measurements derived from the sensor will be dominated by this local source. If the source is well described and can be quantitatively assessed, the domination of measurements may also be assessed and the readings recorded by the monitor may serve as indicators for air quality nearby. However, it is more desirable that the sensor be placed in areas where source emissions are relatively mixed and spatial variations in concentrations are less dramatic. This is particularly the case when the local influences next to the monitor are not easily described, and their accountability in the measurements is indeterminant. A sensor located next to physical obstructions (i.e., too close to ground, near a wall) can fail to sense the desired pollutant concentrations because ambient air streamlines are directed away from the site.

In summary, the air quality measured at a given monitor may be representative of either a broad or confined area. In either case, if the relationship of air quality at the sensor site to air quality at other nearby points can be understood, the monitor is representative in a useful way. If it is not possible to estimate or assume this relationship with some certainty, the measurements obtained at the monitor are of limited utility. However, the data could be used to estimate the degree of control needed for the impacting sources to achieve National Ambient Air Quality Standards. Site surveys can provide the information necessary for these appraisals.

Site Review Procedure

Figure 2-4 illustrates a proposed scheme for evaluating the representativeness of air quality measured by the existing monitoring network. The

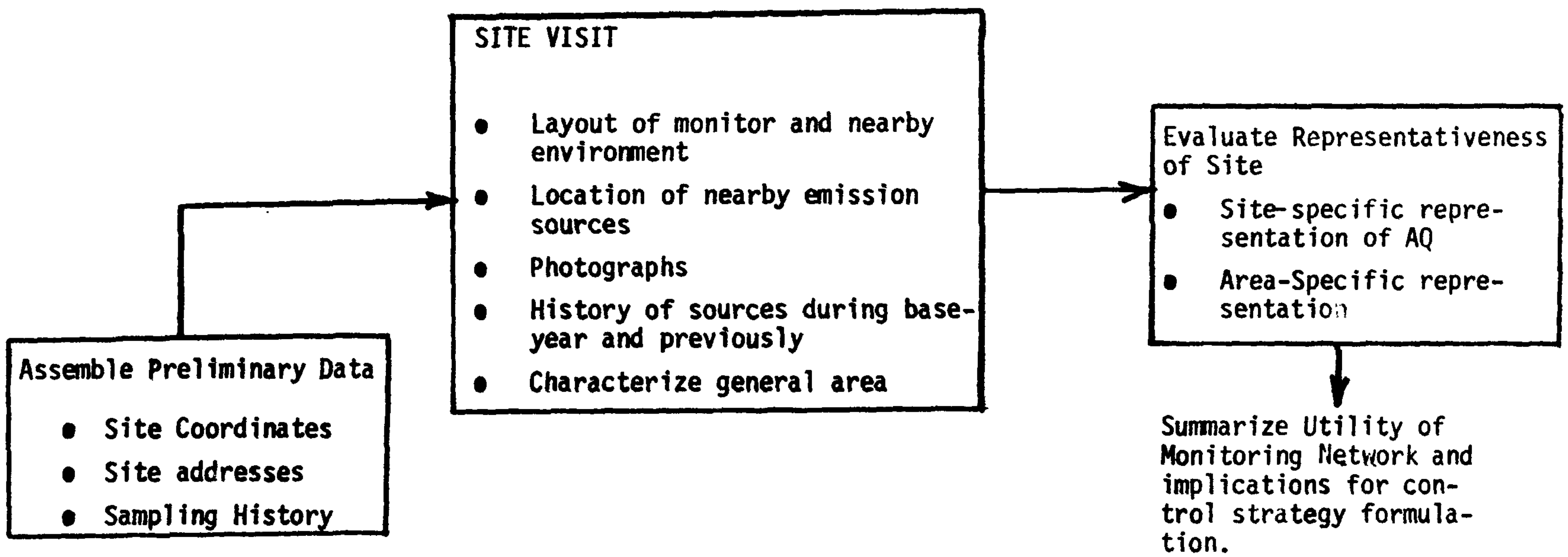


FIGURE 2-4. RECOMMENDED PROCEDURE FOR EVALUATING REPRESENTATIVENESS OF MONITOR SITE DATA BY MEANS OF SITE REVIEW

first step in the process involves a compilation of preliminary data preparatory to the site characterizations. Frequently, significant changes in the surrounding environment have affected air quality levels and representativeness of air quality at the monitor site. These changes should be documented based on records of the local monitoring agency, and the actual site visits later.

Each of the monitor sites should be visited, and photographs and plot layout diagrams should be performed to characterize the site environment and the placement and location of the monitor.

Both the general area surrounding the site (immediate vicinity in all directions) and the specific area at the site should be observed and characterized. Potential significant sources of particulate emissions should be noted and described. These sources include soil dust surfaces subject to suspension influences such as vacant lots, open fields, unpaved road shoulders, residence yards, unpaved roads and parking lots, excavated areas, and agricultural lands. Observations of the general area can be greatly aided by the use of aerial photographs if available. Brief interviews with local residents or employers may be conducted to establish changes which have occurred, or are expected to occur, in the monitor environment. The historical changes should be documented so that it may be known what the measurements were representing at any given time of reference (i.e., the baseyear).

Based on the characterization of the general and specific areas surrounding the monitor site, the representativeness of the monitor in expressing TSP levels of the local area should be assessed. For sites whose air quality is typical of that of the general area, the measurements there have direct utility in representing ambient TSP exposure levels.

For other sites where the significance of factors affecting the representativeness is uncertain, potential bias should be identified, and awareness of this bias should be maintained throughout the subsequent analysis of the source-receptor model and control strategy formulation.

No precise formula may be outlined for conducting site reviews. Obviously, the procedures will vary greatly depending on budget, the monitoring network, and the requirements of the control objectives. The basic elements comprising the review are illustrated in the case example (Figure 2-5) provided on the following page. In this example, the characterization of the general area and the specific environment around the site were found to contrast. Sources were prevalent adjacent to the site, which were not typical in the general environment. Accordingly, TSP levels at the site environment were judged to be representative in a site-specific manner only.

CHARACTERIZATION OF SITE SPECIFIC ENVIRONMENT

The plot description of Figure 2-6 provides an orientation for structures, objects, and emission sources in the immediate vicinity of the hi-vol at the St. Johns site. The hi-Vols is located on the rooftop of the St. Johns Indian School administration building. The roof is approximately 15 feet above ground level, and the sampler is mounted on a conventional stand 1-1/2 feet above the flat tarpaper rooftop. The sampler has adequate vertical clearance with all nearby objects to the east, north and northwest, but there are potentially significant vertical barriers to wind movement from south of the hi-Vol, and rises at its peak to an elevation of 20 feet about the hi-Vol sampler. A small rooftop room rises 8 feet above the hi-Vol sampler only 12 feet to the southwest. Air movement from the west is obstructed by a school building which rises 8 feet above the sampler. A thick hedge of trees rises 4 feet above the hi-Vol to the northeast. These obstacles, in addition to the high elevation of the sampler above ground, are apt to prevent dust levels experienced at ground level from being measured by the rooftop sampler.

The most significant local source of particulates consists of fugitive dust. The suspension of this dust is related to vehicle activity and other activities which disturb the ground surface sufficiently to permit suspension of soil by wind. Almost all activity in the immediate vicinity of the St. Johns School occurs on soil surfaces. Parking lots and roadways are unpaved. Most walkways are unpaved and most yards (residential and school) consist of dirt fields. The composition of the roadways parking lots, and open fields is generally hardpack with a fine dust powder cover. Except for tall groups of trees, there is very little vegetation in the area During the day of the survey site visit, a slight 5 to 10 mph breeze from the northwest was blowing loose paper and occasionally dust clouds off of vehicle parking lots and open ground and yard areas. Dust clouds were frequently observed in the parking lot surrounding the entrance side (northeast) of the school administration building. This parking lot merges with the main school entrances, and is used intermittently throughout the day. The dust clouds arising from the adjacent parking lot and roadway, both from vehicle activity and wind erosion, are apt to affect measurements of the hi-Vol monitor significantly, especially when prevailing winds are northerly.

Local sources other than fugitive dust probably have minor effect on the hi-Vol measurements. Bus and automobile exhausts are emitted in the parking lot adjacent and below the monitor. No commercial activities are conducted in the area. The numerous fireplace vents which exit on the roof where the hi-Vol is located have not been used for several years (since the school was equipped with gas and electric heating). A stove vent exits at the southeast end of the roof, but only limited breakfast cooking for a few persons is conducted over this vent.

There have been very few changes in the environment of the hi-Vol site which would have significantly affected air quality measurements. No development has occurred near the monitor site for more than 15 years. However, a new single level school building is presently being erected approximately 700 feet east of the site. The parking area near the monitor is gravelled annually to reduce dust levels and to prevent erosion. No deliberate efforts are implemented (i.e., surface wetting) to diminish dust levels on a continual basis.

REPRESENTATIVENESS OF MONITOR

Based on the review of sources at the site and in the general area, the monitor siting is probably generally representative of air quality at the community of the Gila River Indian Reservation near the school, but not representative of the general area. The small community surrounding the school is a hot-spot for fugitive dust source activity, and the monitor is centered in this activity. The rural area outside the small community is characterized by vast expanses of undisturbed desert terrain and less traffic activity.

Definite representativeness of the monitor site is limited by two principal factors. First, the monitor is sheltered by obstructions to the south, so that particulate levels measured under prevailing southerly winds may tend to be slightly lower than levels at most points within the community. Second, the elevation of the sampler is inappropriate to represent typical ground level exposures. These factors will be considered in subsequent considerations of the air quality data preceding the diffusion modeling calibration task.

The effect of historical changes in the monitor environment (i.e , source activity, new structures, new or deleted sources) and on the representativeness of the air quality measurements may be considered negligible. There is no immediate plan which would affect significant environmental changes to alter this situation in the future (1980 and 1985).

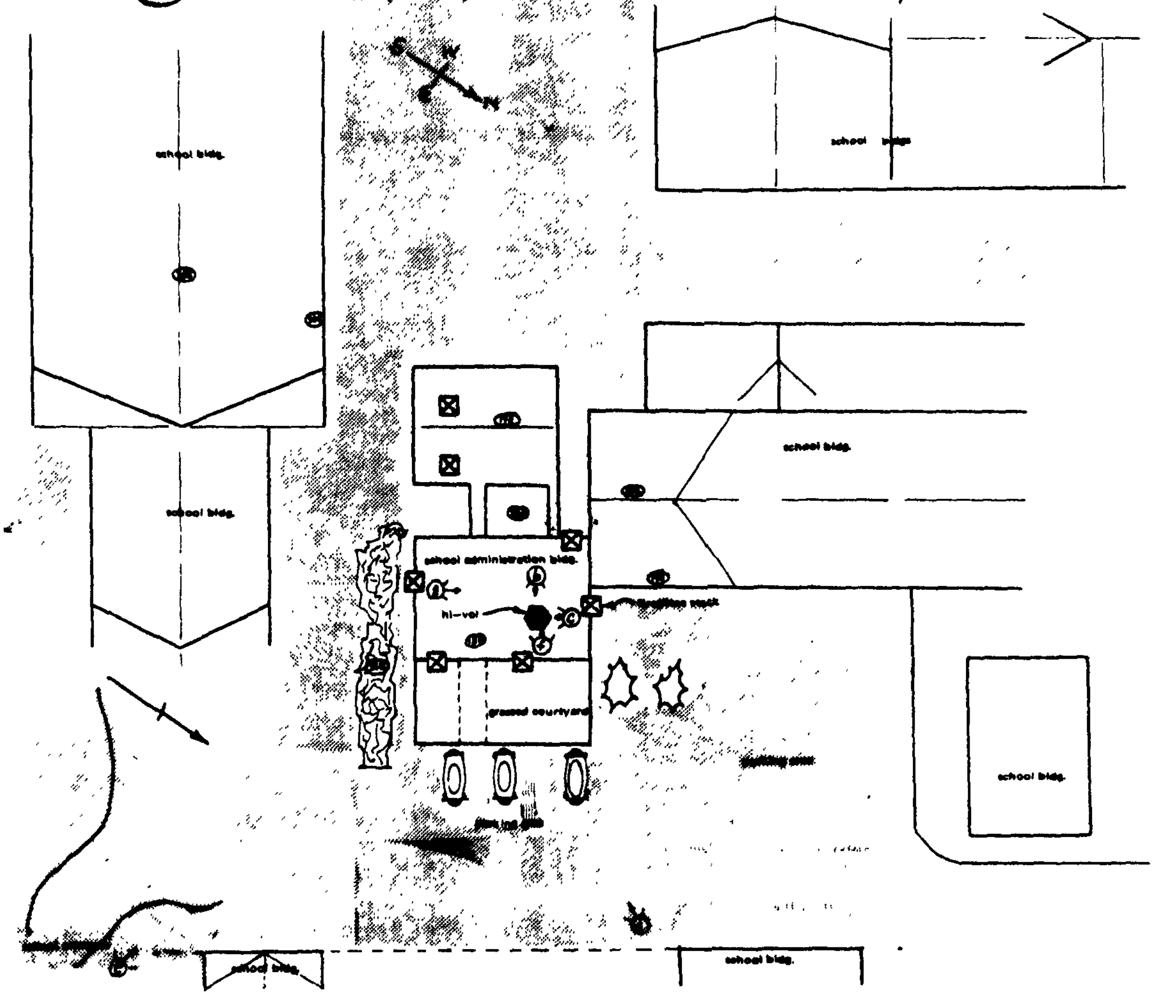
Figure 2-5. Case Example of Monitor Site Review: St. Johns Monitor in Phoenix Area

LEGEND:

Designates Location and Orientation for Photographs

Soil Surface

Elevation (i.e., 12 Feet Above Ground Level)



Plot Schematic of Environment in Immediate Vicinity of Hi-Vol Monitor Site

Figure 2-6 St. Johns Hi-Vol Monitor Site

2.2 Nature and Extent of the TSP Problem

The air quality data should be analyzed to assess the nature of TSP problem. In assessing the origin of TSP levels and the factors affecting these levels, it may be useful to analyze the apparent relationship between meteorology and TSP. The effect of meteorology on TSP levels will provide indications of the TSP origins, that is, whether the sources are predominantly anthropogenic fugitive dust, wind-blown dust, or conventional sources. The TSP/meteorology relationship may be demonstrated by: (1) evaluating seasonal patterns of particulate levels and the associated meteorology affecting the levels; (2) analyzing daily meteorology and air quality data to isolate effects of single meteorology parameters on air quality; and (3) investigating the meteorological circumstances associated with particulate episodes and other days of interest.

Examples of procedures which may be used in demonstrating the TSP/meteorology relationship are described in the Phoenix Study.[1] In that study, analysis of particulate episodes revealed clear patterns between meteorology and high TSP levels. Table 2-1 illustrates the two distinct patterns occurring in the Phoenix area. These patterns are typical of areas where high levels of TSP are caused mainly by fugitive dust. In the wintertime, when low wind speeds and low mixing heights limit dispersion of particulate emissions, high ambient concentrations generate consistently at the city monitoring sites (Categories 1 and 2). Particulate levels also increase at other stations throughout the entire region, but generally to a lesser degree. For the episodes associated with strong wind gusts, particulate concentrations are highest in the rural and suburban residential areas (Categories 3 and 4). This behavior is consistent with known facts regarding the particulate sources:

TABLE 2-1. PARTICULATE EPISODES IN PHOENIX AREA, 1973-1975.

STATION CATEGORY	DATE & STATIONS	CONCENTRATION µg/m³	MIXING HEIGHT (Meters)	NO.OF DAYS SINCE RAIN	AVERAGE WIND SPEED (MPH)	RESULTANT WIND DIR. AND MAGNITUDE.	TEMP.	GENERAL COMMENTS ON WEATHER
	November 12, 1973							
1	Downtown Phoenix	513	253	120	6.0	5.1	70	haze most of day. Maximum wind speed 13 mph.
3	Paradise Valley	439						
2	West Phoenix	364						
4	Chandler	355						
	November 18, 1973							
1	Downtown Phoenix	458	394	126	9.8	3.9	63	Partly cloudy & thunderstorms and wind gusts to 36mph beginning at night.
4	North Phoenix	439						
2	West Phoenix	389						
2	Central Phoenix	337						
	January 17, 1974							
1	Downtown Phoenix	480	108	9	4.3	4.1	58	Haze much of day. Maximum wind speed 13 mph.
3	Paradise Valley	351						
2	West Phoenix	279						
4	Chandler	261						
	June 16, 1974							
4	Chandler	372	3888	75	10.9	6.1	98	Clear. Wind gusts from SE at 43 mph.
4	Mesa	330						
2	Central Phoenix	322						
1	Downtown Phoenix	239						
	November 13, 1974							
1	Downtown Phoenix	454	352	11	3.7	1.9	64	Cloudy much of day. Maximum wind speed 13 mph.
3	Paradise Valley	255						
1	South Phoenix	252						
2	Central Phoenix	234						
	December 19, 1974							
2	Arizona State	460	261	14	5.3	2.2	54	Clear. Maximum wind speed 12 mph.
1	Downtown Pheonix	353						
3	Paradise Valley	260						
2	Central Phoenix	234						
	March 25, 1975							
3	Paradise Valley	842	NA	11	12.2	4.6	66	Partly cloudy. Wind gusts from west at 35 mph.
3	Litchfield	379						
3	St Johns	346						
3	N Scotts/Paradise	295						
	June 17, 1975							
3	N Scotts/Paradise	1083	NA	69	11.4	4.8	88	Clear. Wind gusts from West at 35 mph.
3	St Johns	798						
3	Litchfield	519						
4	North Phoenix	248						
	August 10, 1975							
3	St Johns	456	NA	25	12.4	6.3	96	Partly Cloudy. Wind gusts from SE at 47 mph.
4	North Phoenix	343						
2	Central Phoenix	287						
5	Glendale	262						

NA = not available

* Station Category:
1 = Central City/residential commercial surrounded by fugitive sources.
2 = Central City/residential, no source in immediate surroundings.
3 = Rural/residential, surrounded by fugitive sources.
4 Surburban/residential, surrounded by fugitive sources.
5 Rural/residential, no sources immediately nearby.
6 Remote

- Human activity, which is most densely focused in the city area, is responsible for suspension of substantial fugitive dust emissions. These emissions are of higher density than those released at the rural sites, and this is reflected by the higher concentrations produced during the stable atmospheric conditions of winter.
- Because vast expanses of agricultural land, unpaved roads, and unimproved (but disturbed) soil surfaces surround the rural sites, suspension of dust by soil wind erosion is very likely a dominant factor affecting high particulate levels during gusty winds in the rural areas. Soil erosion by wind is of less consequence in the more developed areas.

Various additional analyses of the data may be performed to characterize the particulate problem. Examination of TSP trends, statistical correlations between TSP levels, interpretations of pollution roses, and inspection of geographic distributions of TSP levels are a few examples of the analyses which may be performed.

2.3 Air Quality Data Analysis

Two methods have been suggested to determine to what extent a given site is responding to areawide emission patterns or one or two dominant nearby sources. The first of these is the pollution rose. This is simply a graphical presentation of the average concentration associated with each wind direction.[4] Such a display requires only daily resultant or 3-hour average wind data along with TSP concentrations. The calculation is relatively simple. It is useful to review the pattern for each individual site to determine if a particular or general wind direction is associated with high TSP levels.

Particular directions with higher concentrations may indicate a particular source or small cluster of sources; higher concentrations in a general wind direction may indicate an industrial area or a weather pattern where rains and cleaner air are associated with one wind direction and stagnant conditions with another. Reviewing several sites in the same urban area may indicate which is the case.[5,6]

A second indication of local influence may be formed by comparing the consistency by which concentrations are similar or dissimilar at neighboring sites on the same day. Various statistical analysis (e.g., such as a multiple correlation analysis or use of a chi-square test on the data among all sites for several years of data has been used to indicate the level of correlation between neighboring sites).[4] Either calculation may be used to indicate which group of sites tend to have generally similar levels. Similar levels between sites may indicate that the sites are influenced by areawide pollutant concentrations or meteorological patterns and strongly dissimilar levels may indicate an influence by a nearby source that does not strictly adhere to the general emission patterns of the urban area.

The multiple correlation analysis may be extended to include meteorological variables. Data such as wind speed or rainfall may indicate which sites are affected by wind-blown dust storms or fugitive dust from dry conditions. A recent study used average annual values of rainfall to indicate that changes in annual rainfall did influence TSP concentrations.[7]

A multiple regression analysis of 5-year data sets from 10 cities showed that a 1-inch decrease in precipitation is associated with an increase in annual TSP levels of 4 $\mu g/m^3$. Such techniques must be viewed with caution because the relationship may not be precisely linear as implied by the regression. Non-linear transformations of the data are recommended where appropriate.

The effect of long-range transport on TSP levels may be indicated by the calculation of the path of the air parcel as it moves across the U.S.. Such calculations have been made by computer aided analysis using a model developed by NOAA, Air Resources Laboratory.[7] Such analysis may be used to indicate the general geographical sources of exceptionally high TSP or sulfate levels.

Several other methods have been used to provide gross estimates of the sources of TSP. One such method is summarized in a National TSP problem assessment study.[7] This study indicates that there is a relatively constant average contribution from general urban activity from city-to-city. Using this empirical value, known values of non-urban background and secondary TSP, it is possible to determine iteratively which sites have major influence from local sources and the approximate level of impact of industrial particulates on TSP levels. Another method to indicate, in a very general way, the relative contributions due to traffic and industry is to calculate changes in weekend and weekday concentrations. To do this, the daily variations in both industrial emissions and average daily traffic should be known.

Another aspect of data analysis is the examination of the hi-vol filter to determine the components of the aerosol on the filter. The most straight-forward approach is polarized light microscopy. This technique can yield a semi-quantitative assessment of the generic type of particulate. Such an examination should be undertaken only in conjunction with a quality control program to ensure the consistency and replicability of the results.[8]

More sophisticated techniques for the identification of individual particles are available, but resource limitations usually preclude their widespread application. Such techniques include scanning electron microscopy, Ramon spectroscopy, Electron Scanning for Chemical Analysis (ESCA) and electron microprobe.

SUMMARY

In general, the site reviews and data analysis performed in the preceding Sections provide a useful tool for assessing whether local or specific sources contribute substantially to the problem, thus indicating the type of sources that need to be controlled. Also, this qualitative assessment can be employed to indicate areas where the results of modeling analysis (discussed in Section 4.0) should be used with reservations as to their representativeness.

3.0 EMISSION INVENTORIES AND PROJECTIONS

The development of air pollution control strategies depends on a detailed knowledge of the quantity and character of pollutant emissions in the region. Appreciable concern has been devoted to the characterization of conventional sources, and various data sources (i.e. NEDS) are available for the rapid assembling of regional and area-specific emissions. With the realization that fugitive dust emissions also exert a substantial impact on air quality nonattainment problems, efforts are now being increased to develop detailed characterizations of the various fugitive dust sources. Such efforts have recently been employed to develop a fugitive dust emissions inventory for the Phoenix area.[9] The procedures employed during the Phoenix Study are generally applicable for characterizing fugitive dust emission in other regions as well, and are summarized herein. This chapter provides an outline of recommended procedures, including numerous examples of applications as applied to the Phoenix Study. Section 3.1 concerns the estimation of emissions for anthropogenic fugitive dust sources and Section 3.2 involves estimation of fugitive dust emissions resulting from wind erosion. Section 3.3 describes the general considerations associated with forecasts for emission levels in future years.

The procedures for compilation of conventional sources emissions are not repeated here. They have been in use for some time and are documented in the literature.[10,11] The emission factors given herein are compatible with AP-42, "Compilation of Air Pollutant Emission Factors" or will be reflected in future updates to AP-42. As improvements in these factors are made, they will also be reflected in AP-42; therefore, the user should assure that the latest information is used.

For potential utility in air quality impact analysis, estimates of both fugitive and conventional emissions should be organized and spatially disaggregated for description in a point source and grid network of the study area. Each emissions category should be adequately described and reflected in the grid network. Area source emissions should be tabulated for each of the grid squares for modeling purposes. The grid boundaries are defined by considering all sources which might significantly affect air quality in the target control area as well as any model constraints that exist. For areas characterized by numerous fugitive dust sources, relatively small grid squares, but not less than a kilometer on a side, should be considered to permit analysis of the impact of these sources on a local scale. When practical, emission sources should be spatially resolved to a greater level of discrimination immediately around the monitor sites. The gridding procedures have been in use for some time and are well documented in the literature.[11] One of the modeling approaches discussed in Section 4 uses particle size ranges for describing the air quality/emissions level relationship. This disaggregation by particle size range is based on particle size information contained within this section.

Emission inventory grid systems may be developed after, or before, the emissions are calculated. For inventories involving extensive evaluation of small scale or localized problems where it is critical that emissions be located fairly precisely, it is usually necessary to use preliminary inventory results and knowledge to develop the grid system in advance of locating and quantifying all the sources. If the alternate approach of developing the grid system after calculations are complete is used, then many area source emissions will have to be re-apportioned from aggregate totals to various grids by approximate and locally customized apportioning factors. The former procedure is usually preferable for fugitive dust considerations.

3.1 ESTIMATION OF BASEYEAR ANTHROPOGENIC FUGITIVE DUST EMISSIONS

For the context of this document, anthropogenic fugitive dust sources are considered to be those resulting directly from, and during, human-related activities. These include motor vehicles on unpaved and paved roads, off-road motor vehicle activity, construction activities, etc.. Section 3.1.1 through 3.1.7 outline general procedures for estimating emissions levels from several of these sources.

3.1.1 Motor Vehicles on Unpaved Roads

The basis for estimating fugitive dust emissions (± 20%) arising from motor vehicles traveling on unpaved roads as derived from AP-42 is:

$$e = .81s\left(\frac{S}{30}\right)\left(\frac{365-W}{365}\right)$$

where e = emission rate (lb/vehicle-mile)

s = silt content of road surface (percentage by weight of particles smaller than 75 micron diameter)

S = average vehicle speed (mph) (valid between 30-50 mph)

W = number of days with 0.01 in. or more rainfall

It is reasonable to adjust the above by a multiplier factor of $\left(\frac{N}{4}\right)$ applied to vehicles with more than four wheels where N = number of wheels on vehicle. Also, if local conditions in the area and time period under consideration warrant, "W" should be modified by a multiplier equal to the average number of days required for the road surface to return to the dry state.

Dust emissions from unpaved roads generally exhibit the following particle size distribution (from AP-42):

PARTICULATE DIAMETER	WEIGHT PERCENT*
$< 30\ \mu$	60
$> 30\ \mu$	40

The data base required for estimation of dust emissions from unpaved roads in a given study area will include: 1) mileages and distribution of unpaved roads, 2) vehicle speed, 3) average daily traffic, 4) silt content of road surfaces, 5) number of days of rainfall $>$0.01 inches, 6) average number of days required for road surfaces to return to the dry state and, if significant, the average number of wheels per vehicle.

The spatial resolution of unpaved road mileages should be accomplished in cooperation with the local transportation department. In one applicable approach, a grid is imposed on a department road map

*Note: One of the modeling approaches discussed in Section 4 uses particle size ranges for describing the air quality/emissions level relationship.

showing the various road classes (dirt, gravel, paved). The mileages of each road class are scaled and recorded for each of the grid squares of the network. In another alternative approach, road mileages and classifications are related to road maintenance activities in fixed maintenance districts. Computer based summaries of the maintenance activities in each district may be available and will facilitate the determination of road surface type and mileage in each such district. If a single transportation department is not responsible for all roads within a study area, it will be necessary to consult other appropriate local departments (e.g., county, the major cities, unincorporated cities, private organizations).

Average vehicle speed and average daily traffic (ADT) on unpaved roads are frequently difficult to determine since there is generally little incentive to study traffic behavior on roads carrying limited traffic. Speed and ADT estimates then must often be based on rough approximations from interviews with local transportation department personnel and/or by limited traffic studies conducted for representative road types. Expected vehicle speeds for unpaved roads in areas studied have been between 30 to 40 mph,[12] but local data should be used if available. The equation above has been developed using speeds between 30 and 50 mph. Speeds in excess of 50 mph are not likely. If speeds below 30 mph are encountered, however, caution and engineering judgement should be employed in extrapolations. ADT is typically less than 100 vehicles per day on most unpaved roads. Table 3-1 shows some typical values of ADT for various unpaved road types in the Phoenix Area. Always use locally developed data if available and reliable.

TABLE 3-1. AVERAGE DAILY TRAFFIC VOLUMES ON UNPAVED ROADS IN THE PHOENIX AREA

TYPE OF ROAD			AVERAGE DAILY VEHICLE COUNT URBAN	RURAL
County:	dirt	- county maintenance	75	40
		- no county maintenance	15	10
	gravel	- county maintenance	100	60
City :	dirt		75	40
	gravel		100	60

The results of a field sampling test[9] in Phoenix indicate that the silt content of soils on unpaved road surfaces reaches an equilibrium value substantially less than that of the native soil. Fines are readily removed from the road surface by vehicle traffic, and equilibrium of the particle sizes is attained with a higher percentage of coarse particles than are observed in the native soil. Based on the modest tests performed by TRW, any relationships formulated between native soil characteristics and road surface particle distributions are highly questionable. Until indices of road silt levels are available, site-specific field data is needed to insure suitable parameterization of the AP-42 emission estimate equation.*

The spatial variation of road surface silt levels throughout a study region should be documented by relating general soil maps to the field test results. Accordingly, road surface sampling sites should be selected in areas that are representative of the major unpaved road surface types, as determined by preliminary assessment of the soils maps.

*Note: AP-42 is being revised to include this.

Rainfall effectively reduces emissions of road dust to near zero during the period the surface is wet. The drying effects of traffic, wind, low humidity, and solar radiation will usually return the surface to its equilibrium state in one to three days, depending upon the extent of the rainfall. One day may be assumed as a default average, but local experience should be utilized for the particular soil, season and other conditions experienced during the period of interest for the area involved. The "W" factor in the equation should be adjusted to reflect this local experience (i.e., "2W" for two days drying time).

The emission rates may be affected by large numbers of heavy vehicles having more than four wheels. While there is speculation that vehicle weight is the governing factor, larger and heavier vehicles have more wheels to carry and distribute their loads. Therefore, if the proportion of such heavy vehicles is significant, it may be necessary to utilize the "N" factor multiplier for the emissions equation.

Once the various influence parameters have been quantified within the grid network, dust emissions for unpaved roads are calculated using the equation. For example, a one-mile length of unpaved roadway with surface silt content of 20%, carrying 100 light duty vehicles per day at an average speed of 35 mph, will emit:

$$e = 0.81(20)(35/30)(100)(1) = 189 \text{ pounds}$$

of suspendable dust per day (assuming no rainfall and all four-wheeled vehicles).

In developing the complete unpaved road emissions inventory, the calculation is performed for each of the various road links within the grid network. In the limit, when the data base is complete, this process involves a separate calculation for each identifiable link. Generally, the available data base for unpaved roads provides less discrimination, permitting the aggregation of road links of a given "average" description. It may be useful and efficient to computerize the emissions modeling effort, both for actual calculations as well as for display of results. This decision will be dependent upon local capabilities and resources.

3.1.2 Entrainment of Street Dust

Vehicles traveling on paved roads and streets are likely to be a major source of fugitive dust emissions. Based on two separate studies of re-entrained street dust[13-14], an average dust emission rate of .012 lb/vehicle mile has been established [as shown in Table 3-2 soon to be published in AP-42, Supplement 8].

Table 3-2

Measured Emission Factors for Dust Entrainment from Paved Roadways

Study	Emission Factors (Range and Average)			
	g/vehicle-km		lb/vehicle-mile	
	Range	Average	Range	Average
Reference 13	2.8-5.6	4.3	0.01-0.02	0.015
Reference 14	0.26-10.4	2.6	0.0009-0.037	0.0009
Average (overall)	3.5		0.012	

The utility of the above emission factor depends essentially on the ability to quantify the vehicle miles traveled (VMT) on paved roads or streets during the base year or of other years of interest. The information necessariy for this characterization can usually be obtained from internal documentation available within various State and local agencies.

Dust emissions from paved roads generally exhibit the following particle size distribution.[14]

Particle Size	Weight Percent
Greater than 30 μm	10
Less than 30 μm	90
Less than 5 μm	50

3.1.3 Construction Activities

Construction activities inevitably result in the exposure and disturbance of soil. Fugitive dust is emitted both during the activities (i.e., excavation, vehicle traffic, human activity), and as a result of wind erosion over the exposed earth surfaces. The major construction of interest is typically occurring in "heavy" construction activities, such as roadway construction and residential/commercial/industrial building which involves disturbance of significant quantities of soil surface area.

Based on field tests conducted at construction sites,[15] an average dust emission rate of 1.2 tons/acre/month for active construction has been established. The test results do not include an analysis of the expected particle size distribution of emissions. Until further study results are available to characterize construction emissions, the particle size distribution may be assumed to approximate that of the lower ranges (less than about 100 microns) of the parent soil. Parent soil distributions may be obtained from published USDA soil surveys.

The utility of the above emission factor depends essentially on the ability to quantify the acreage of soil which is disturbed during the various construction projects occurring in the baseyear or of other years of interest. The information necessary for this characterization must usually be obtained from internal documentation available within various local agencies.

Roadway Construction

Roadway construction activities and associated mileages may be obtained and characterized by consultation with state, county, and city transportation departments. Table 3-3 illustrates the tabulation of this type of data obtained for the Phoenix area.[9] The data are approximate, but based on the uncertainty associated with universal application of the average emission factor, more precise survey efforts are unwarranted. Based on average roadway clearing widths used in construction, the average area of exposed surface may be calculated. Significant borrow pits outside the roadway may be important in areas requiring extensive cut and fill such as will exist in hilly or mountainous terrain. The duration of active construction, during which the road bed is exposed soil is typically about 6 months for a major road job of one mile length and 80 feet width, and about 2 months for each half a mile of local streets 33 feet wide.[15] Various widths of right of way disturbance may also be involved and should be considered. Local regulations and practice are giving more and more attention to reducing this exposure time by temporary seeding or other stabilization, and should be considered in this analysis. Based on an average emission rate of 1.2 tons/acre/month, the dust emissions arising from road construction are calculated by multiplying the average emission rate of 1.2 tons/acre/month by two terms: 1) acres of soil exposed in road construction, and 2) the average duration of the soil disturbance. Because of the variable location and relatively minor effect of roadway construction emissions, efforts to resolve these sources spatially on the grid network should usually be limited. It is normally adequate, for example, to allocate construction dust emissions equally to all grids on the emissions grid network that are within the entire city boundaries, and to allocate road construction dust for the county and State Highway Department equally to the grids in the county portion of the study area network.

Residential/Commercial/Industrial Construction

The most significant source of construction dust typically arises during the building of residential/commercial/industrial structures. Residential housing usually comprises the major portion of the activity in this construction category. Housing construction can generally be

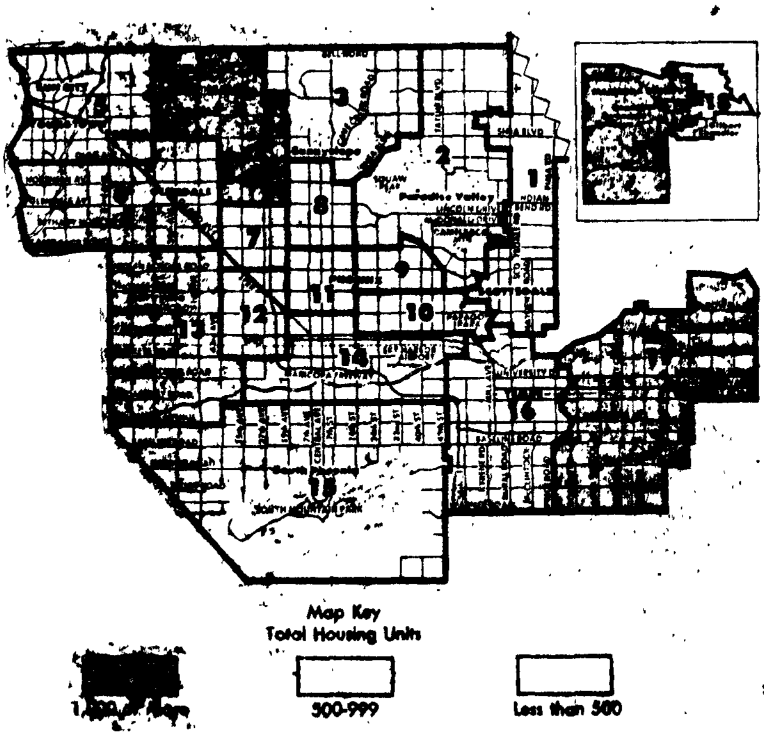
TABLE 3-3. SUMMARY OF ROAD CONSTRUCTION ACTIVITY IN PHOENIX AREA, 1975[9]

RESPONSIBLE AGENCY	IMPROVEMENTS (MAJOR & LOCAL ROADS)	SUBDIVISION (PRIVATE CONSTRUCTION)	FEDERAL AID SYSTEM	CITY OR COUNTY	TOTALS
	MILES OF ROADWAY				
County	20.0	56.0	15.8	128.7	
Phoenix	26.4	58.7	3.6	1.4	
Glendale	0	14.7	0	0	
Paradise Valley	1.5	2.8	0	.6	
Peoria	0	0	0	2.1	
Mesa	0	32.7	0	0	
Tempe	0	10.3	0	0	
State Highway Dept.	0	0	36.8	0	
	47.9[c]	175.2[b]	56.2[a]	132.8[b]	

a. Of those roads financed by federal aid, 18.9 miles are 4 lane highways 80' wide, and 37.3 miles are 2 land highways 48 ft. wide.

b. Average width of these roads is 33 feet.

c. Average width of local and major roadways is 55 feet.



District	Single	Townhouse	Multiple	Total Units
1	319	43	13	375
2	953	5	9	967
3	548	—	17	565
4	552	8	440	1,00[illegible]
5	127	7	—	134
6	744	—	10	754
7	52	—	152	204
8	37	12	20	69
9	7	—	15	22
10	9	—	95	104
11	6	—	2	8
12	39	—	—	39
13	734	—	—	734
14	16	—	21	37
15	211	—	—	211
16	513	104	14	631
17	1,184	32	5	1,221
18	808	22	30	850
19	1,846	176	2	2,0[illegible]
Total Metro Phoenix 1975	8,705	409	845	9,959
Total Metro Phoenix 1974	11,280	2,354	6,073	19,[illegible]07
Per Cent Change 1974-1975	-22.8%	-82.6%	-86.1%	-49.5%

Source: Maricopa County Housing Study Committee, M. R. West Marketing Research, Inc.

FIGURE 3-2. NEW HOUSING UNITS IN MARICOPA COUNTY, 1975[16]
(Based on Building Permits issued January through December, 1975)

characterized from data available from local building and safety departments, but often this data is assembled in summary form and published by various local service organizations. Figure 3-2 illustrates a typical format for presentation of building permit data to describe new housing unit starts. Average unit land utilization for various housing classes may be determined from sources such as local planning departments, building and safety departments, and local service organizations. This determination may involve a synthesis of several input data items,[9] such as land use ratios, average occupancy rates by dwelling and housing unit inventories and should consider the portion of the land area disturbed by typical construction practices utilized locally. Average land utilization rates are then combined with new housing start data to calculate disturbed soil area associated with housing construction in the various districts.

Disturbed soil acreage occurring from land use development other than housing may be determined by employing calculation procedures similar to that described above for housing construction. If data are not readily available to characterize commercial, industrial, and public construction projects, historical land use ratios between the various land use types may be applied to construction acreage totals for these land use categories. Estimates of dust emissions arising from all categories of construction activities are then generated by applying the general emission factor of 1.2 tons/acre/month to the number of acres disturbed by construction in each definable district or sector. The building construction emission levels are then assigned to the emission grid network by any suitable allocation procedure (i.e., a grid network overlay may be used to accomplish the appropriate allocations).

3.1.4 Agricultural Tilling Operations

Based on field measurements[17] of suspended particulates arising from tilling operations, the equation as given in AP-42 for estimating tilling emissions is given as:

$$e = \frac{1.4s}{\left(\frac{PE}{50}\right)^2}$$

where e = emission rate (lb/acre),

s = silt content of soil surface (percent), and

PE = Thornthwaite's precipitation - evaporation index with implement speed being typical (5-7 mph).

Two general assumptions apply to the estimation equation involves the type of implement. The field tests reflect utilization of one-way disk and sweep-type plows. In practice, a wide variety of implements are employed, ranging from disk plows to moldboard plows to listers. It is assumed that emissions do not differ greatly from one implement type to another. It is also presumed that no irrigation is conducted before plowing. In areas where irrigation is employed, fields may be flooded with water to leach out salts from the previous season, but this occurs after plowing.

Test results indicate that, on the average, dust emissions from agricultural tilling have the following particle size distribution but may vary according to the local soil characteristics.

Particle Diameter	Weight Percent
< 2 μ	35
2-30 μ	45
> 30 μ	20

The data base required for estimation of dust emissions from tilling of agricultural fields includes: 1) silt content of the soil, 2) implement speed, 3) distribution of agricultural acreage, 4) temporal distribution of tilling activities, and 5) the Thornthwaite precipitation-evaporation index.

Soil Silt Content

U.S. Department of Agriculture Soil Sample Analyses are published and made available for use in potential farmland areas throughout the country. These analyses typically include a detailed particle size distribution for case samples from various representative sites in a given area. The data may be used to estimate the silt content as defined by the emissions equation (the percent by weight of the top four inches of soil having particle diameter from 2 to 50 microns). The soil silt measurements may be related to soil types identified on general soil maps, and agricultural regions may then be located on the soil maps with the use of aerial photographs or some other suitable procedure. An average silt level is estimated for cropland within each grid square (or some other suitable geographic jurisdiction such as a township) by weighting cropland acreage with corresponding soil silt levels.

Distribution of Croplands

The spatial distribution of croplands may be determined from aerial photographs of the study area. Potential cropland, which was fallow at the time the photo was taken, may also be identified, and confirmed, with photos corresponding to another growing period. By scaling of the photos and the suitable use of grid overlays, crop acreage in each of the grid squares may be quickly estimated. Frequently, such estimates are already available (by some alternate grid system) in documents published by state or local agricultural agencies. A check should be made to compare the total compiled agricultural acreage with alternative sources of published cropland totals. When patterns of crop types are available, acreage in each grid square by crop type may be documented.

Implement Speed

Limited data are available to characterize typical speeds of tillage implements[17] Investigation during the Phoenix Study[9] confirmed previous findings that a speed of 5-1/2 mph is generally representative of most tillage operations[18].

Since agricultural tillage occurs seasonally based on crop type, the resulting emissions from this activity should be expressed by season. To permit discrimination of emission by season, it is necessary to characterize 1) the tillage period for each crop type, and

2) the acreage of each crop type. Moreover, if this seasonal discrimination is to be made on a grid basis, the spatial distribution of the different crop types must be determined. The latter determination is often non-productive in areas where use of agricultural lands is unpredictable, or is constantly changing. In these cases, a constant distribution of crop type may be assigned throughout the study area. However, if specific geographic patterns for cropland use can be identified, these data may be used to establish a varying spatial distribution for agricultural acreage by crop type.

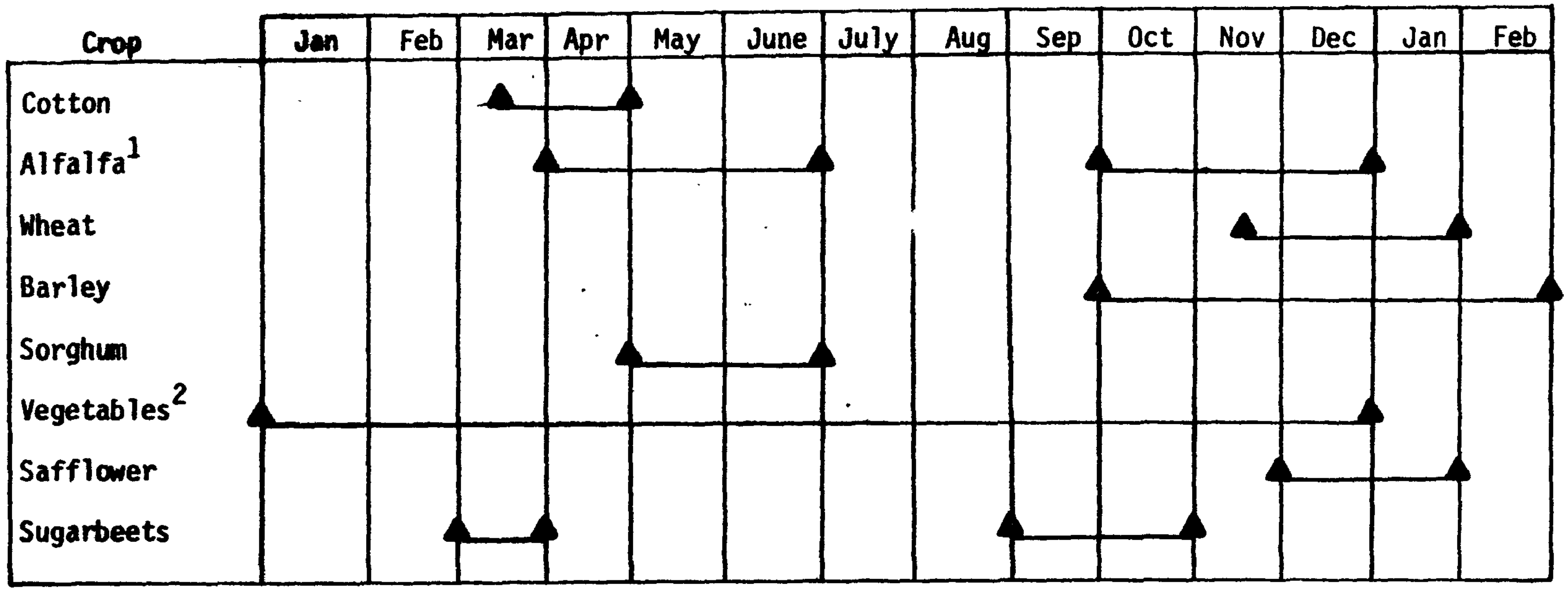
The tillage periods for various crop types depends on regional considerations and may be identified by consulting with local agricultural agencies. Figure 3-3 illustrates the planting period for major crops in the Phoenix area, obtained from local publications of the Arizona Crop and Livestock Reporting Service.[18] Tillage is assumed to be distributed over the planting period.

Thornthwaite Precipitation-Evaporation Index

The Thornthwaite Precipitation - evaporation index is used to reflect moisture exchange between soil and atmosphere. The use of this expression is an attempt to quantify the suppression or encouragement of emissions by the presence of moisture in the soil. The use of index for a specific area and baseyear is discussed in Section 3.2.1.

Calculation of Emissions

Once the various model parameters have been characterized for the grid network, dust emissions from tillage operations are calculated



Source: Reference[19]

[1]Alfalfa is planted and then cut for three years. Planting is usually during fall and spring.

[2]Vegetables include broccoli, cabbage, carrots, cauliflower, lettuce and onions. The [illegible] are planted at different times during the year (i.e. cabbage from Aug. 1–March [illegible], [illegible] from Oct. [illegible]–Dec. 5) but span the entire year. For the purposes of this study, vegetables are assumed to be planted all-year around.

Figure 3-3. Usual Planting Periods in Arizona[19] using the emission equation. For example, consider a grid square in which 100 acres of cotton were grown in the baseyear. If the silt content of the soil was 50%, the tilling implement was run at a typical speed of 5-1/2 mph, the PE index was 50, and the tilling season was from March through April, the dust emissions resulting from the tilling are:

$$e = \frac{1.4\ (50)}{\left(\frac{50}{50}\right)^2} = 70 \text{ lbs/acre}$$

or the total daily emissions from the grid square during the tilling period is:

$$\frac{e\ (100 \text{ acres})}{(61 \text{ days})} = 115 \text{ lbs/day}$$

Emission estimates should be located and described on the emission grid.

3.1.5 Off-Road Motor Vehicles

Recreational vehicles traveling off-road on native soil surfaces may generate significant dust emissions in some locales, particularly during weekend periods. While the impact of non-construction off-road vehicle emissions is minimal in most metropolitan areas, air quality near the areas of greatest activity may be sufficiently affected to require consideration.

Because documentation of off-road vehicle activities is very limited, only crude emission approximations are possible at this time. Based on the emission factor for motor vehicles on unpaved roads (Section 3.1.1), the rate of dust emissions arising from off-road vehicle activity would be:

$$e = .81s \left(\frac{S}{30}\right) \left(\frac{N}{4}\right)$$

where N = 2 for motor bikes and 4 for 4-wheeled vehicles.

The size distribution of particles emitted from off-road vehicle activity is assumed to be the same as that emitted by motor vehicles on unpaved roads.

The location, operational characteristics and activity levels for off-road vehicle recreation may typically be best determined by consultation with local motorcycle associations, city parks and recreation departments, the Forest Service, the Bureau of Land Management, etc. Based on discussions with cognizant organizations in the Phoenix area,[20, 21, 22, 23, 24, 25] a typical motorbike rider was assumed to travel about 45 miles per outing at an average rate of 15 miles per hour. The average trip length for a four-wheel vehicle was assumed to be 150 miles at an average speed of 30 miles per hour. Vehicle activity levels are generally several times greater for week-end days as compared to weekdays.

Silt content of areas used for off-road travel may be determined by combining information from general soils maps and the results of soils surveys available from the local branch of the U.S. Department of Agriculture Soil Conservation Service.

In documenting emissions estimates, a distinction should be made between weekend-day levels and weekday levels. The weighted daily average should be computed for consideration in air quality modeling of annual TSP averages (Section 4).

3.1.6 Unpaved Parking Lots and Truck Stops

The dust emission rate for vehicles travelling in unpaved parking lots or truck stops is assumed to be the same as that for vehicles on unpaved roads. Based on an exponential increase in the emission rate[26, 27] for vehicle speed from 0 to 30 miles per hour, the emission factor for a typical parking lot surface of 24% silt level would be 2.2 pounds/vehicle (4-wheel) mile at an average vehicle speed of 10 miles per hour. For a gravel surface, the silt level is about 12%, and the parking lot dust emission rate is about 1.1 pounds/vehicle mile at a speed of 10 miles per hour.

Total parking lot dust emissions are estimated by (1) determining the average number of vehicles using the lot each day and the average distance traveled by each of the vehicles, and (2) by calculating total vehicle miles traveled daily and multiplying this rate by the emission factors discussed above. In an alternative approach, average vehicle miles traveled may be related to parking lot size. For example, in one recent study to characterize factors influencing fugitive dust emissions,[4] it has been assumed there are 190 VMT/year per 10,000 square feet of parking lot. Based on this assumption, unpaved parking lot emission rates may be summarized as follows:

$e = .21\ (N/4)$ ton/yr. per 10,000 sq. ft. for parking lots with surface silt content of 24%.

$e = .10\ (N/4)$ ton/yr. per 10,000 sq. ft. for parking lots with surface silt content of 12% (gravel surface).

Where N = average number of wheels for vehicles traveling in parking lot.

The particle size distribution of the parking lot emissions is assumed to be equivalent to that emitted off unpaved roads (see Section 3.1.1).

3.1.7 Aggregate Storage Piles

Based on field measurements[17] of suspended dust arising from aggregate storage operations, average emission factors for three categories of process activity (active, inactive, and normal mix) are as shown in Table 3-4. Sources of the aggregate process include loading and unloading to the storage piles, traffic movement among the storage piles, and wind erosion. The factors shown are representative for storage piles in areas with climatic conditions similar to Cincinnati; however, the values may be adjusted by applying the

TABLE 3-4 EMISSION FACTORS FOR AGGREGATE STORAGE PILES [17]

Aggregate Storage Operation

Pile Status	Emissions: Lbs/acre/day	-or- Lbs/ton placed in storage
Daily Activity[a]	13.2	0.42
Inactive (wind-blown emissions only)	3.5	0.11
Normal activity mix [b,c]	10.4	0.33
Composition:		
Loading onto piles		0.04
Vehicular traffic		0.13
Wind erosion		0.11
Loadout from piles		0.05
	total	0.33

[a] 8-12 hour activity/24 hour day

[b,c] 5 active days/week

A correction factor of $1 / \left(\frac{PE}{100}\right)^2$ should be applied to account for effect of regional climate.

correction factor $1/(\frac{PE}{100})^2$ to the total storage process emission factor, where PE is the area-specific Thornwaite Precipitation-Evaporation Index.

Field tests that have been conducted[17] have revealed the particle size distribution for one of the representative operations (aggregate loadout) to be as follows:

Particle Size	Weight Percent
<1 μ	30
1-2 μ	46
2-3 μ	16
3-4 μ	6
>4 μ	4

Estimation of total dust emissions resulting from aggregate storage operations should be conducted using an appropriate emission rate selected from Table 3-4. Activity of the storage operation is generally documented through the permit system of the local air pollution control agencies. Dust emissions are then calculated by combining the appropriate data and emission rate selected from Table 3-4. For example, consider an aggregate operation with a storage of 10 acres and a normal mix activity, located in an area with a PE Index of 50. The rate of dust emissions arising from this enterprise would be:

$$e = \frac{10.4}{(\frac{50}{100})^2} = 41.6 \text{ lbs/day/acre of storage}$$

or 416 lbs/day total emissions from the entire aggregate storage operation.

3.2 ESTIMATION OF BASEYEAR WIND EROSION EMISSIONS

This section includes procedures which may be used to estimate fugitive dust emissions resulting from wind erosion of soil. Section 3.2.1 describes the general emissions model and the data base required for calculation of wind erosion emissions. Section 3.2.2 outlines specific considerations involved when applying the emissions equation to various source categories.

3.2.1 General Methodology

The exact mechanisms causing entrainment of the soils are not yet fully understood. The quantification of these mechanisms for application in air pollution studies will not be available in the short term. Presently it appears the most plausible approach for estimation of wind-blown dust, is to assign a suspension rate to the horizontal soil movement as determined by the established wind erosion equation[28]. This approach has been used recently in studies concerning control of fugitive dust emissions.

A simplified version[17] of the basic wind erosion equation is given by

$$E_s = AIKCL'V'$$

where E_s = suspended particulate fraction of wind erosion losses of tilled fields, tons/acre/year

A = portion of total wind erosion losses that would be measured as suspended particulate

I = soil erodibility, tons/acre/year

K = surface roughness factor, dimensionless

C = climatic factor, dimensionless

L' = unsheltered field width factor, dimensionless

V' = vegetative cover factor, dimensionless.

The variable of greatest uncertainty in the adopted wind erosion relationship is the suspension factor A. Only limited test data is available to establish the relationship of the suspension ratio of eroded soil with wind speed and soil type. A review of this data[9] has been conducted to establish best estimates of suspension ratios.

These estimates are listed in Table 3-5 for the major source categories. The values serve as the current preferred basis for emissions compilation, but should be considered tentative and subject to adjustment in the future.

TABLE 3-5. FRACTION OF TOTAL WIND EROSION LOSSES WHICH ARE SUSPENDED (DUST SUSPENSION FACTORS)[9,15]

Exposed Soil Surface Category	Dust Suspension Factor (Dimensionless)
Croplands	0.025
Unpaved dirt roads	0.38
Disturbed native soil (parking lots, residence yards, excavation clearings)	0.38

The remaining terms of the wind erosion equation reflect parameters of the basic wind erosion equation as a result of 30 years of research to determine the primary factors that influence erosion of soil by wind. The data base used to assemble representative values of the erosion equation parameters is discussed in Appendix A. When all terms of the erosion model are quantified to reflect area-specific conditions, the rate of soil erosion emissions is calculated for each definable region of the emissions grid network. This rate is then applied to the number of acres of soil subjected to erosion in each of the definable regions.

3.2.2 Soil Erosion Emissions From Specific Source Categories

The major sources of wind-blown soil dust are unpaved roads and parking areas, agricultural fields, undisturbed desert, tailings piles, and disturbed soil surfaces. Specific aspects concerning the estimation of these wind-blown soil sources are discussed briefly below.

Unpaved Roads

The erodibility (I) of soil surface of unpaved roads may be related directly to the silt content of the road surface (Figure A-1). The silt content of unpaved roads is determined by field tests (Section 3.1.1) or by adjusting native silt content data available from USDA soil survey results.

The surface roughness factor (K) for dirt roads was assumed to be 1.0. It is not expected that the limited number of ridges worn in dirt roads would affect this overall estimate significantly.

The climatic factor (C) is calculated to reflect seasonal variations in temperature, precipitation, and average wind speeds for the specific study area. Table 3-6 is an example illustrating the significant seasonal variation of the climatic factor associated with long-term historical and 1975 meteorology for the Phoenix area. These differences are due to the transient moisture content of the soil and the changing magnitude of wind speed. The Thornthwaite Precipitation-Evaporation Index (PE Index) was formulated to express the net moisture exchange between soil and atmosphere. The index is a measure of cumulative moisture balance over the past 12-month period (See Table 3-6).

The unsheltered distance factor (L'), for a given road surface in the prevailing wind direction varies continually. To assess an average effective distance factor, it may be assumed that in the long-term, wind direction is equally distributed for all roads. Any error attributed

TABLE 3-6 SEASONAL CLIMATIC FACTOR, C, IN PHOENIX AREA FOR 1975 AND HISTORICAL LONG-TERM AVERAGES.[9]

Period	Quarterly PE* Average	Average Wind Speed, w	$C = .345 \frac{w^3}{(PE)^2}$
1975			
1st qtr.	8.8	7.2	1.7
2nd qtr.	8.8	8.4	2.6
3rd qtr.	7.7	8.3	3.4
4th qtr.	5.3	7.3	4.8
Historical Averages			
1st qtr.	9.4	5.6	0.7
2nd qtr.	9.4	6.7	1.2
3rd qtr.	9.4	6.5	1.1
4th qtr.	9.4	5.2	0.6

* PE = Thornthwaite's Precipitation Evaporation Index.

$$PE = 10 \sum_{n=1}^{12} \left(\frac{p}{e}\right)_n$$

where $\frac{p}{e} = 11.5\left(\frac{p}{T-10}\right)^{\frac{10}{9}}$ = precipitation-evaporation ratio for month n

and
p = monthly rainfall (inches)
e = evaporation (inches)
T = average monthly temperature (^oF)
n = month under consideration

to this assumption would be minimized by the more probable assumption that unpaved dirt roads are equally distributed in terms of direction. For example, when the prevailing wind traverses north-south roadways at a 10° angle, the net effect is to balance the various cases of wind direction oblique to the road. Figure 3-4 shows the effect of wind direction to unsheltered road distance for a typical unpaved road of 25 foot width. Figure A-2 relates the unsheltered distances to the unsheltered distance factor L'.

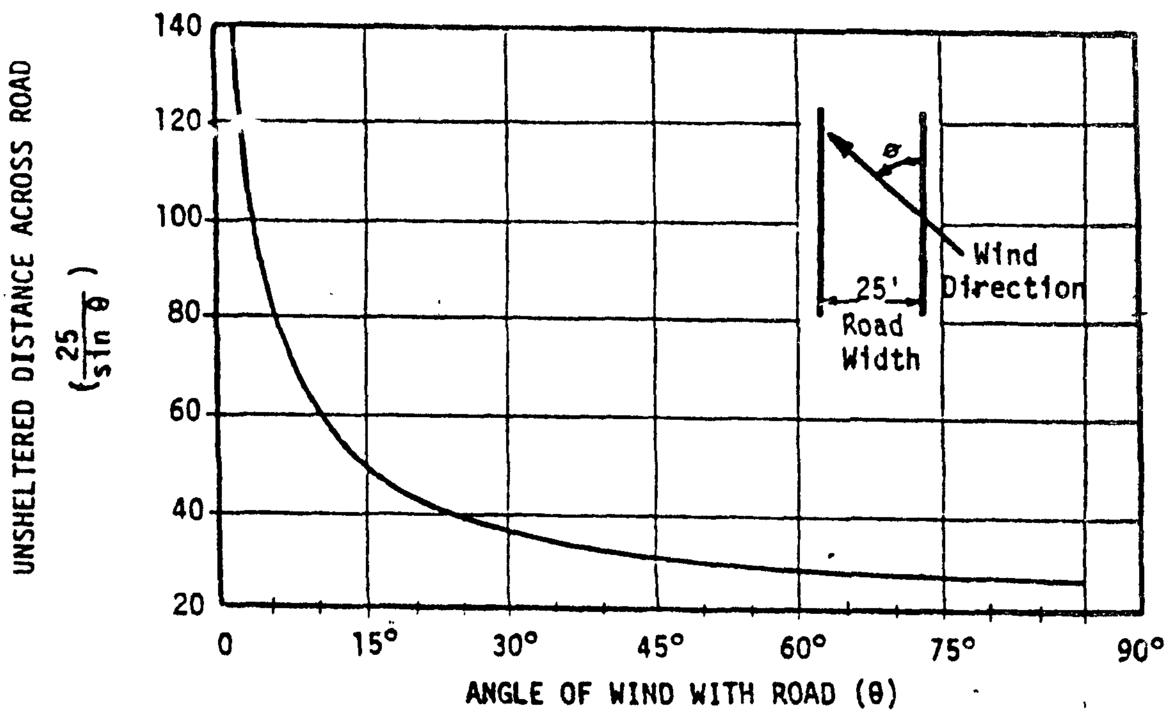


Figure 3-4. Effect of Wind Direction on Unsheltered Road Distance[9]

L' is related to the distance in which maximum soil movement is reached, and varies with soil erodibility. The average value of L' for road surfaces of specified erodibility IK, is shown in Table 3-7. It is evident that L' varies only slightly for a relatively wide range of soil characteristics. It should also be noted that L' approaches zero from road silt levels less than 40%.

TABLE 3-7 UNSHELTERED ROAD DISTANCE FACTOR L'

IK	L' AT Different Prevailing Wind Directions				Average L'
	θ = 90°	θ = 60°	θ = 30°	θ = 0°	
40	0.05	0.06	0.07	1.00	0.29
60	0.08	0.09	0.10	1.00	0.32
80	0.11	0.12	0.14	1.00	0.34

A suspension factor of 0.038 is applied to approximate the suspended portion of the wind erosion soil losses. Table 3-8 summarizes the overall computation procedure. Emission rates of suspended dust arising from wind over unpaved dirt roads are calculated by assigning specific values, as discussed previously, to the parameters of the wind erosion equation. These rates are combined with the total acres of unpaved roads in each district or grid square to calculate emission totals by grid. The emissions are computed on a seasonal basis to reflect the significance of differences in the climate.

Agricultural Fields

Wind-blown dust emissions from agricultural fields are estimated by assigning area-specific values to the variables of the wind erosion equation (Section 3.2.1). Except for the potential soil erodibility (I), the emission determinants depend on crop type. In the process of the development of the wind erosion equation, the U. S. Department of Agriculture has assembled sufficient data to parameterize soil surface preparations and agricultural practices for various crops. These data should be employed to estimate crop-specific soil losses in each identifiable district or grid square of the study area.

TABLE 3-8. CALCULATION SCHEME FOR WIND-BLOWN FUGITIVE DUST EMISSIONS OFF UNPAVED ROADS

SPECIFIC DISTRICT OR GRID SQUARE	D, MILES OF DIRT ROADS	BASIC ERODIBILITY, I, OF SOIL, (ton/acre/year)	UNSHELTERED DISTRICT FACTOR, L'	EMISSIONS = AIKCL'V'(D) (.00828) Tons/day			
				1st QUARTER	2nd QUARTER	3rd QUARTER	4th QUARTER
-	a	b	c	d	d	d	d

a See discussion of Section 3.1.1.

b Derived from soil silt content and Figure A-1.

c Determined from Table 3-7.

d Computed from the wind erosion equation and the suspension factor .038. k = 1, V' = 1, and the climatic factor C is calculated from each season.

An overall value for the soil erodibility (I), is determined for the agricultural area of each township (or other convenient units of area) of the study area. Soil silt measurements conducted by the U. S. Department of Agriculture may be related to soil types identified on general soil maps. Agricultural regions are then located on the soil maps with the use of aerial photographs. An average silt content is estimated for cropland within each geographical jurisdiction inventoried by weighting cropland acreage and corresponding soil silt levels. Average erodibility of the croplands is then determined by the silt content/erodibility relationship shown in Appendix Figure A-1. This procedure may be simplified substantially if preliminary analysis shows the study area is homogeneous in soil silt level.

Values for the soil surface roughness factor (K), the unsheltered field length (L), and the vegetative cover, are relatively uniform for a specific crop. The surface roughness factor accounts for resistance to wind erosion due to ridges or clods in the field. An optimal ratio of ridge heights to ridge spacing will reduce soil erosion by a factor of 0.5. Table A-1 shows typical roughness factors associated with soil preparation for various crops.

Average field sizes for relatively flat terrain devoid of tall natural vegetation have been established for various crops as shown in Table A-1. Soil losses from wind erosion across a field vary from the windward edge of the field and increase proportionately with length until a terminal rate of soil movement is attained. The distance required before attaining maximum erosion rate is influenced by the potential erodibility (I) and roughness (K) of the soil. The relationship between the unsheltered field length (L), the surface erosion potential (IK), and the field length factor (L') is shown in Figure A-2.

The amount of vegetative cover residue left on a field after the growing season varies appreciably by crop (Table A-1). Cover residue reduces soil wind erosion losses by the factor V' as shown in Figure A-3. The degree of reduction attainable with the crop residue is related to the surface erosion (IKCL').

The climatic factor (C), is calculated to reflect seasonal variations in temperature, soil moisture (including precipitation and irrigation effects) and average wind speeds for the study area in the baseyear. Calculations of C were illustrated in Table 3-6. Regional values of C must be adjusted for cropland soils to reflect additional soil moisture provided by crop irrigation. Periodic irrigation during the growing season maintains soil moisture and aggregated state of the soil. The effects of the irrigation are significant in the off-growing season, when disconsolidation of the soil and exposure to winds would reduce resistance to soil erosion.

Based on area-specific irrigation schedules obtained from local agricultural agencies for the major crops in the area along with monthly precipitation and temperature data, a PE index is calculated for each crop. (Irrigation water is treated as equivalent to rainfall.) The PE values are then combined with baseyear monthly average wind speeds to calculate climatic factors corresponding to the non-growing or erosion-susceptible period (obtained from local agricultural organizations). An example of the results of these calculations for a study of the Phoenix area is shown in Table 3-9.

Table 3-9. CROP-SPECIFIC CLIMATIC FACTORS IN PHOENIX AREA[9]

CROP	PE INDEX	NON-GROWING OR EROSION SUSCEPTIBLE PERIOD	AVERAGE CLIMATIC FACTOR (FOR PERIOD OF VULNERABILITY) $C = .345 \frac{W^3}{(PE)^2}$
Cotton	58.0	All Year	.05
Alfalfa	113.0	None	-
Barley	52.8	May - December	.06
Sorghum	40.2	November - July	.10
Wheat	54.9	May - December	.06

Estimates of suspended dust arising from soil wind erosion losses are calculated based on assignment of wind erosion equation parameters as specified above. A suspension factor of 0.025 is employed to approximate the suspended portion of the soil losses. Table 3-10. summarizes the overall computation procedure for a series of five example crops. The calculations should be computerized for convenience in dealing with areas having numerous townships containing agricultural fields. Values of the erodibility index I, the unsheltered field length factor L', and the vegetative factor V' may be extracted from the curves of Figures A-1, A-2, and A-3.

TABLE 3-10. ESTIMATION OF FUGITIVE DUST EMISSIONS FROM WIND EROSION OF CROPLANDS IN FIRST QUARTER

$$E = .025\ GIKC_1L'V'f$$

TOWNSHIP	CROP TYPE	G ACRES OF CROPLAND	I SOIL ERODIBILITY (tons/acre-yr)	K SURFACE ROUGHNESS FACTOR	C_1 AVERAGE FACTOR	L UNSHELTERED LENGTH (ft)	L' LENGTH FACTOR	V VEGETATIVE RESIDUE (lb/acre)	V' VEGETATIVE FACTOR	f FRACTION OF YEAR FOR WHICH SOIL IS EXPOSED IN QUARTER[d]	TOTAL EMISSIONS Tons/Quarter
-	Cotton	-	a.	.5	.05	2000	b.	250	c.	3/12	-
	Barley	-	↓	.6	.06	2000	↓	1100	↓	0	-
	Sorghum	-	↓	.5	.10	2000	↓	900	↓	3/12	-
	Alfalfa	-	↓	1.0	-	1000	↓	3000	↓	1/12	-
	Wheat	-	↓	.6	.06	2000	↓	1350	↓	0	-

a. Values of I are determined from silt content and Figure A-1.

b. L' is determined from IK and Figure A-2.

c. V' is determined from IKCL' and Figure A-3.

d. f is equivalent to fraction of year which is the nongrowing or erosion susceptible season of crop

1. Assuming continuous cropping of same crop.

Disturbed Soil Surfaces

Estimation of wind erosion emissions from vacant and cleared property is conducted by assigning area specific values to the terms of the equation. Area-specific values of the disturbed soil properties are likely to vary substantially from district-to-district, or from lot-to-lot. A survey of vacant lots, parking lots, and dirt residence yards may be required to establish representative characterizations of these sources in the various identifiable geographic areas. This survey may be accomplished by field visits, use of aerial photos, or special summary data available from local planning agencies or service organizations. The level of effort associated with acquiring a representative data base should be dependent on the apparent impact of the sources on air quality in the area.

Tailing Piles

Tailing piles consist of deposits of earth removed during mining operations. For large mines, the tailing piles may expand over several thousand acres. Generally the piles are composed of substantial proportions of fines and are relatively susceptible to significant wind erosion losses.

Only limited information is available concerning soil emissions from tailings piles. Recently, PEDCo[15] has developed an emission factor for this fugitive source by employing the wind erosion equation. No field testing was performed in the PEDCo analysis. Representative characteristics were identified for tailings for use in the wind erosion equation. The piles were described as being composed of sand and loamy sand soils with possible fines for surface cementation (I = 130). They are characterized by a smooth, unridged surface (K = 1) and no vegetative cover (V' = 1). Wind fetch over the piles is approximately 2000 feet. Ten percent of the soil loss estimated by the wind erosion equation is assumed to become suspended. The emissions are seasonally related to the climatic factor, which may vary substantially during the year. The effect of climate on the emission rate is illustrated in Table 3-11. Total emissions are calculated by applying the emission factor to the number of acres of tailings piles.

Soil erodibility, vegetative cover, roughness factor, and wind fetch may be adjusted to reflect tailings piles of various characteristics. However, typically it is difficult to obtain detailed information to characterize the piles. It is anticipated that a survey of individual mines will be required to obtain the needed data. This effort may be allocated according to the apparent significance of the tailings piles in TSP levels.

TABLE 3-11. EMISSION FACTORS FOR TAILINGS PILES (NO VEGETATIVE COVER)

Climatic Factor	Emissions tons/acre/year
.30	4.0
.40	5.3
.50	6.6
.60	8.0
.70	9.5
.80	10.5
.90	12.2
1.00	13.3
1.20	16.0

It is assumed that the particles size distribution of tailings piles emissions is equivalent to that of emissions from aggregate loadout operations.

Particle Size (μ)	Weight Percent
<1	30
1-2	46
2-3	16
3-4	6
<4	4

3.3 PROJECTION OF FUGITIVE DUST EMISSIONS

The extent and nature of fugitive dust emissions depends on the human activities which create or influence these sources. As the community experiences development and reshaping, sources of fugitive dust are being altered in magnitude, location, and type. If control strategies are to be devised to correct air pollution problems, it is essential that these air pollution problems be characterized to reflect the future environment, when strategies would be implemented. Therefore, to accurately assess the impact of prospective control strategies, projections of baseline emissions should be developed. It is useful to display the projected inventory spatially in a graphical manner such as on a grid overlay of the local map. This will permit a comparison of projected versus baseyear emissions for each of the various sectors of the study area. Because fugitive dust controls are by nature relatively long-term in execution, the forecasts should be conducted only for years after these controls are expected to become effective and should coincide with other emission projection years used in the area.

The general considerations associated with forecasting emissions (extent and distribution) of various fugitive dust source categories is described below.

3.3.1 Anthropogenic Sources

This section discusses considerations involved in projecting emissions from vehicles on unpaved roads, agricultural tilling, aggregate storage piles, off-road motor vehicles and the resuspension of fugitive dust from motor vehicles on unpaved roads.

Since the specific data base encountered for anv study area will vary significantly, the forecast indices which may be used to determine projected emission levels will also vary.

<u>Unpaved Roads</u>

The parameters needed to calculate dust emissions off unpaved roads are discussed in Section 3.1.1. Two of these parameters may change significantly in future years. They are 1) mileages and distributions of unpaved roads, and 2) average daily traffic.

The changing mileages of unpaved roads in various sectors of study area may be indicated by identifying trends in the historical data. Additionally, plan forecasts and future objectives of the local transportation department should be obtained. Road improvement programs will have significant impact on the status of unpaved road mileages in many cities. Generally the target areas and schedules for such improvement programs are outlined in detail, and can be employed directly to adjust the baseyear parameters used in estimating the baseyear emissions (see Section 3.1.1).

For many cities, improvements in county and city roads may be occurring with some uncertainty, depending on the annual budget and most pressing maintenance or new development requirements. In this instance, average budget trends may be assumed to approximate the expected extent of roadway paving, each year, and location of these improvements may be approximatea by assuming tneir occurrence witnin anticipated growth areas specified on city and county planning maps. Distribution of the expected mileage of road paving throughout the growth belt areas may be expediently tabulated with the use of isoline overlays depicting incrementally expanded development areas for the period from the present to the years of interest. A detailed explanation of this overall approach is documented in reference [9].

While road improvements may reduce dust emissions on unpaved roads, increasing traffic in future years will tend to offset this benefit. The projected ADT for unpaved roads may be assumed to be directly related to expected population growth for the area.

Agricultural Tilling

The most suitable index of agricultural growth is reflected by the historical trend of cropland acreage. When agriculture exerts a major impact on the economy of an area, the trend rate will probably remain fairly constant in the near term. Inspection of previous and future land use maps for the area will indicate the changing location of croplands. Projections are made by comparing the present location of croplands with the future expected locations on the land use maps.

If appropriate, available historical agricultural data may be evaluated to identify apparent trends in crop types. Changes in crop type will affect the tillage season and would impact the temporal distribution of emission levels from croplands. Local USDA officials may be able to provide an assessment of any changes in projected crop types.

4.0 EMISSIONS/AIR QUALITY RELATIONSHIP

This section provides an outline of general procedures which may be used as a guideline in formulating an appropriate source-receptor relationship for areas where fugitive dust sources are prevalent. The procedures presented here should be considered tentative and should not inhibit incorporation of modifications and improvements. Section 4.1 concerns some important considerations affecting the choice of the source-receptor relationship. Section 4.2 discusses several air quality models that have been used for fugitive dust modeling and others that could be adapted for use.

4.1 SOME FACTORS AFFECTING SELECTION OF THE SOURCE-RECEPTOR RELATIONSHIP

The evaluation of air pollution control strategies requires a detailed understanding of the relationship between emissions and ambient air quality. This subsection considers the importance of averaging time and source configuration for selection of models applicable to fugitive dust.

4.1.1 Averaging Time

An essential aspect in selecting a source-receptor relationship concerns the averaging time of the air quality predictions. There is reasonable cause to restrict the analysis to only the long-term averages. First, greater control is typically required to attain the primary annual standard than to attain the 24-hour standard (provided episodes due to dust storms and accidental industrial emissions are excluded from consideration, as allowed by SIP regulations). A second reason for restricting the scope of the model to long-term considerations concerns the uncertainties associated with the data base. Uncertainties are introduced at several stages of the air monitoring measurements, the emissions inventory compilation, and model formulation. The analytical limitations associated with the detailed documentation of short-term particulate origins and their relationship to air quality levels would increase the uncertainties greatly, making the substantial additional effort needed for this task impractical and unwarranted at this time.

4.1.2 Source Configuration

The nature of the source is an important criterion to be considered in the selection of a source-receptor relationship. For conventional well-controlled particulate emission sources, where most of the particulates emitted are typically smaller than 10µm in diameter, the source-receptor relationship may be established through the standard equations for atmospheric transport and dispersion.

However, the application of currently available models to the fugitive dust problem is further complicated by the ill-defined nature of the sources themselves. It is often difficult to characterize the sources in the traditional classifications as: point, area or line. Also, certain commonly used emission terms such as exit velocity and effluent temperature may become inappropriate parameters in this context. These potential ambiguities, of source type and emission characteristics, are inherent to the application of any currently available model. They must be dealt with, by the user, on a case-by-case basis.

Unfortunately, typical Gaussian-type dispersion models may not properly consider the physical characteristics or the emissions of unpaved roads, storage piles, resuspended street dust or other fugitive dust

3.3.2 Wind Erosion Sources

The major sources of fugitive dust which are suspended by wind are agricultural fields, unpaved roads, undisturbed desert, tailings piles, and disturbed soil surfaces.

Unpaved Roads

The procedure for estimation of projected wind erosion emissions from unpaved roads is the same as that outlined in Section 3.2.2. The adjustments which must be applied to the baseyear parameters used in the wind erosion equation include: 1) the miles of unpaved roadways in the various grid sectors, and 2) the climatic factor. The former item is obtained by the considerations outlined in Section 3.3.1. The climatic factor is calculated to reflect representative meteorology for the area, based on historical data for temperature, precipitation, and mean wind speed obtained from the National Climatic Service.

Agricultural Fields

Due to changes in location, acreage, crop types, and climate, the estimates of agricultural wind erosion emissions performed for the baseyear (Section 3.3.3) should be repeated for the selected future years. The considerations outlined in Section 3.3.1 are applicable to the issue here: crop type by grid sector, and acreage by grid sector must be determined. These inputs are utilized to derive appropriate values for the terms of the wind erosion equation. The climatic factor is adjusted to a representative historical value for the area if necessary.

Disturbed Soil Surfaces

The major consideration associated with the projection of emission loadings from each of these sources involves changes in spatial distribution and total source area. Projected development reflected by the general plan will indicate acreage changes and location for undisturbed desert areas and disturbed soil surfaces. Potential procedures for approximating these changes are similar to those discussed under construction (Section 3.3.1) emissions estimation.

Construction Activities

Forecasted construction activities should be based on the general future land use plan for the study area. Land areas involved in construction for projected years are assumed to be consistent with the forecasts of the county general plan. Based on the annual area of new urbanization development, and an assumed duration for active construction on this area, a total dust loading may be estimated for future years of interest. The location of the development will proceed according to the scheme shown in the general plan. A geometric mapping procedure may be used to estimate the projected location of the construction activity. Isolines reflecting the constant rate of expanding development may be constructed for specific future years by interpolating between the boundaries of the existing developed area and that developed area forecasted by the Future General Land Use Plan. The differential development in the years projected for example may then assume to occur within a growth belt representing the expanded urbanization over the specified 5-year period. The forecasted dust emissions loadings are apportioned according to the relative area of the growth belt in each of the grid squares of the emissions grid network.

Aggregate Storage Piles

Historical employment trends in the mineral industry are a relatively accurate index of increasing area of aggregate storage piles. These employment data are available from state economic organizations. Frequently, the compilations are presented with projections which can be used directly in adjusting the baseyear emissions levels to those forecasted for future years. Potential relocation or new storage operations may be identified by consultation with cognizant local agencies such as the zoning and planning department, the construction industry, or the mineral industry itself.

Entrained Street Dust

Roadway improvements, expected to be implemented over the next ten years, will have significant impact on street dust loadings. Improvements consist of upgrading currently paved streets, paving of dirt roads, new road construction (both paved and unpaved), and curbing and sidewalk construction. While all of these improvements will result in lower dust loads on existing streets, the identifiable change which will most affect street dust loadings from existing roads concerns the decrease in number of miles of uncurbed roads. (The street dust loading for roads with uncurbed road shoulders is four times less than that observed for curbed streets.)

Projections of vehicle miles traveled (VMT) for future specific years are assumed to be directly related to population projections. These projections are used to adjust the VMT for the existing traffic network to future year levels. The adjusted emission factor reflecting newly curbed streets is calculated by weighting the emission factors for uncurbed streets and curbed streets relative to the proportion of each of these street configurations in those future years.

sources. Nor do they normally consider gravitational settling or dry and wet deposition of particulate matter; pollutants are typically treated as though they were unreactive gases. Gravit·.tional settling and dry deposition become increasinqly important as the diameter of the particles exceeds about 10 μm. Available data indicate that fugitive dust emissions in some areas (for example, the ari·· southwest) may have a large proportion of mass in the range of 20-70+ μm. Therefore, application of conventional Gaussian plume models may be inadequate for air quality evaluation where fugitive dust sources predominate and where particle sizes are generally large. These caveats notwithstanding, the following subsection outlines some modeling techniques that should prove to be useful in assessing the fugitive dust problem.

4.2 DESCRIPTIONS OF SUGGESTED AIR QUALITY MODELS

The discussion in this section focuses on several models that have been used or that may be adopted to evaluate the impact of fugitive dust sources.

4.2.1 AQDM and CDM

Two models that are applicable and available for estimating the annual impact of conventional sources on the ambient air quality are the Air Quality Display Model (AQDM) and the Climatological Dispersion Model (CDM). (The format of the required input parameters and the necessary data base are documented in the AQDM[2] and CDM[3] User's Guides).

These models have been used for a number of years to relate particle emissions to ambient TSP concentrations. For the most part, because of the lack of basic emission data with respect to fugitive dust sources, such sources were not directly considered in these models. Such sources have been considered in an indirect manner through the regression analysis of observed and model-predicted concentrations. The Y-intercept resulting from that analysis has generally been assumed to be the contribution of those sources not directly input into the model, plus background. In urban areas where smaller sized particles predominate, (e.g., Chicago, Philadelphia), AQDM and CDM may still represent the best approach (at the present time) for developing a source-receptor relationship.

In those areas where fugitive dust sources predominate, such as in the west and the arid southwest (e.g., Phoenix, Las Vegas, etc.) AQDM and CDM are of limited value; other models outlined in following discussion may be adapted for these cases.

4.2.2 The Atmospheric Transport and Diffusion Model (ATM)[29]

The ATM is a receptor-oriented, micro-mesoscale (100m - 50km), climatological, flat terrain, Gaussian plume model with a particle deposition option. The dispersion coefficients are calculated from Pasquill-Gifford[30] stability parameters or Hosker's[31] formulation of Briggs[32] - Smith[33] dispersion parameters using surface roughness. Plume rise is calculated using Briggs'[34] formula. At a given receptor, the model computes the contribution, for time periods of one month or longer, from each source (point, area and line) to the ambient air concentration ($\mu g/m^3$). Also included in the output are the dry deposition rate and the wet deposition rate ($g/m^2/s$) for each source at each receptor. The wet deposition rate is a function of the rainfall rate and frequency of occurrence. The dry deposition is computed by assuming fractional, rather than complete, plume reflection at the surface; the percent reflection depends on the type of ground cover. The gravitational settling of the particulates is accounted for by lowering the effective height of emission, "tilting the plume", based on the distance to the receptor, the mean wind speed and the terminal velocity of the particle.

The meteorological input to the model consists of the usual stability-wind rose frequency data, fraction of the time during the period of record that precipitation occurred and average rate of precipitation (in hundredths of an inch per hour).

The point source data must include emission rates for all sources in g/s, stack heights, exit gas temperatures, volume flow rate (or stack diameters and exit velocity), and source locations in UTM coordinates.

Line source data consists only of the emission rate in g/m/s, height of the line source, and the UTM coordinates of the line end points. Receptor locations, likewise, are specified in UTM coordinates.

Modeling of gaseous pollutants requires that the boundary layer thickness and gas diffusivity be specified while modeling of particulates requires specification of particle diameters and densities. This imposes a potential limitation on the application of this model because reliable particle size and particle density data are generally limited. The fact that the model considers particle size and particle deposition makes the model appealing for use in areas with sources that emit larger-sized dust particles. However, at the present time, severe restrictions over and above the basic data input limitation previously described exist which limit the general usefulness of this technique to the fugitive dust problem. First, the model does not have the capability to handle a large number of sources or receptors, and hence, would be severely limited as a regional scale model unless significant revisions were made. Second, if the detailed particle density and particle size spectra are not available, the deposition and gravitational settling modes of the model cannot be used. Finally, in its current form the model is of limited use for establishing control strategies because of the output format and lack of source contribution tables.

4.2.3 Hanna-Gifford Model

The Hanna-Gifford model is an area source model that accepts a gridded emissions inventory. The elements of the emission grid must be square and they must be of uniform size; however, the specific size is variable (a typical example would be a 2 km x 2 km grid). It is possible to incorporate physical removal mechanisms (deposition) with minor modifications (see Appendix B for a detailed discussion of the model). In those regions where conventional well-controlled point sources are present, the Hanna-Gifford model must be supplemented by one of the models described in 4.2.1 or 4.2.2 and the results superimposed.

The basic model has been used in several case studies [35, 36, 37, 38] in which the comparison of modeled and predicted concentrations has been examined in detail.

4.2.4 Modified CDM/Rollback Model

A necessary but not sufficient feature of a fugitive dust model is the requirement that it accommodate a range of particle sizes. TRW [39] developed a modeling procedure that uses the CDM to model that portion of the emissions comprised of particles smaller than 20 μm and uses a proportional (rollback) analysis to represent the contribution of the larger particles. The rationale being that the CDM is a suitable model for describing the dispersion of particles smaller than about 10 μm diameter. However, the CDM is presently unable to account satisfactorily for the dispersion-deposition behavior of larger particles characteristic of fugitive dust sources because it does not contain techniques such as those developed by Van der Hoven [40] and Dumbauld, et al. [41] or procedures such as those incorporated in the Atmospheric Transport Model.

In order to facilitate this modified modeling approach (see Appendix C for model description and Appendix D for model input requirements), the gridded emissions inventory is prepared for four particle diameter ranges reflecting the cut-off points in dispersive behavior;

0 - 10 μm

10 - 20 μm

20 - 70 μm

greater than 70 μm.

The CDM may be applied directly to the first two ranges since diffusion and atmospheric turbulence effects play a major role in the movement of these particles. However, for the 10-20 μm size range, the effect of gravitational settling is approximated with the assignment of a decay constant in the CDM. The explanation of the derivation of the decay constant is given in Appendix D.

The emissions of particles greater than 70 μm in size are ignored in the air quality model. The fate of these particles will be determined almost exclusively by gravity effects. The range of horizontal travel of these particles is only a few meters, generally not enough to impact the air quality monitors, except for those cases where the local source is very near the monitor.

This technique appears useful because it applies an atmospheric transport and dispersion model to that portion of the fugitive dust emissions that can be so treated and because it provides a technique for approximating the impact of the emissions of larger particles. The technique has not been widely applied and should be used with caution. Appendix E provides a sample application of the CDM/Rollback Model.

4.3 SUMMARY

At the present time, the consideration of fugitive dust sources in diffusion models is limited. Continued use of AQDM and CDM appears to be the most reasonable approach for those areas where particles less than 10 micrometers predominate. Other techniques may be more useful in those areas where larger sized particles are common (e.g., west and arid southwest). The procedures included herein should not be considered inclusive and should not inhibit the development and incorporation of various modifications and improvements.

5.0 ALTERNATIVE CONTROL MEASURES

In areas where fugitive dust is the cause of high levels of TSP, the major sources are typically unpaved roads, construction activities, re-entrained street dust, and suspended soil eroded by wind off vacant lots and disturbed soil surfaces. While the impact of these sources is generally localized in nature, they are typically found throughout a given area and therefore may create widespread problems of high TSP concentrations. However, several other sources of fugitive dust (i.e., tailing piles) are generally less widespread and create more of a truly localized limited impact for a specific area.

In order to determine the impact of the sources most responsible for the high TSP levels at various monitoring sites for the baseyear and projected years, it is necessary to review the emission inventory and modeling results which have been previously discussed in Sections 3.0 and 4.0. A review of these results will establish the significant sources for which alternative control options should be investigated. The control options for various fugitive dust source categories are outlined below.

5.1 Control of Dust from Unpaved Roads

Control methods to reduce dust emissions from unpaved roads consist of (1) paving roads, (2) application of chemical stabilizers, (3) watering, and (4) traffic-related controls. Some communities have experimented with these alternatives and may be considering the implementation of these measures in the general plan for the area. Relevant county and city departments should be consulted to identify prospective planning efforts with potential air quality impacts, and to obtain data which would help characterize dust control applications for unpaved roads in the study area.

A study[42] was recently completed in which various chemical stabilizers were tested for dust control on unpaved roads. The stabilizers were applied to sections of an unpaved road with an average daily traffic (ADT) of 140 vehicles and a surface soil silt content of 28%. Some of the chemicals were applied by spray, while others were mixed to a three-inch depth after ripping the roadbed surface. Hi-vol and dust collector measurements were utilized to evaluate the dust-supressing ability of the stabilizers with the road subject to normal traffic conditions. The performance of the stabilizer products is shown in Tables 5-1 and 5-2.*

As a spray treatment, dust control oil demonstrated the highest degree of dust control on the road surface after both the 5-month and 14-month observation periods. This palliative also was superior in terms of least cost. As a stablizer which is mixed into the roadbed, the Redicote E52 Asphalt Stabilizer Emulsion provides superior dust control, especially for the longer observation period. The stabilizer exhibiting the best performance for dust control also performed significantly better in terms of road surface preservation. The palliatives tested are available commerically and can be applied at costs ranging from $4,370 to $1[illegible],300 per mile of 2-lane roadway. Since these palliatives must generally be applied once annually (for roads carrying 150 ADT), it is clear that the substantial annual cost of this measure should be carefully evaluated against alternatives before it is applied.

The tests show clearly that chemical soil stabilizers may be used as an effective control for unpaved road surface, resulting in lower road maintenance cost. Of the various chemicals tested, the Dust Control Spray Application is by far the most cost effective in terms of dust control. The most effective performer was the mix-in application of Redicote Asphalt

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* Mention of trade names of commercial products does not constitute endorsement or recommendation for use by U. S. Environmental Protection Agency.

Emulsion, which was controlling dust emissions by 84.4% after a 14-month period. The main drawback to use of the effective stabilizers is cost. Repeated applications of the chemicals, even at reduced rates, impose costs which approach or exceed the annualized cost of a paved road.

Paving of roads clearly offers the most effective long-term dust control. The most widely used low cost pavement is the bituminous asphaltic chip seal over a granular base or a stabilized soil base. Figure 5-1 shows a profile of this chip seal construction. A penetration stabilizer (liquid asphalt MC-250) is applied to the 6- to 8- inch base, followed by a chip seal. Maintenance requirements depend on vehicle traffic and locale, but generally include a second chip seal after one year, followed by another seal in approximately 5 years.

A study conducted by the city of Seattle Engineering Department[26] has shown the most cost effective method of dust control on Seattle roadways is a chip seal when the average daily traffic is over 100 vehicles. This dust control option is also economically beneficial, considering the estimated annual savings of $2,665/yr/mi in maintenance costs resulting from the measure (annual maintenance costs of roadways diminishes appreciably with the quality of the road surface) and numerous other cost benefits, such as reduced sewer costs, higher property values, lower vehicle operating costs, lower health costs, and reduced cleaning costs.

The cost of the various types of road paving and dust palliative alternatives varies from one region to another. Construction, maintenance, and material costs contrast significantly between regions. Typical cost of initial installation and maintenance for various dust control alternatives in Maricopa County (Arizona) is shown in Table 5-3. Actual costs for any given study region should be determined by inquiring with the local transportation departments.

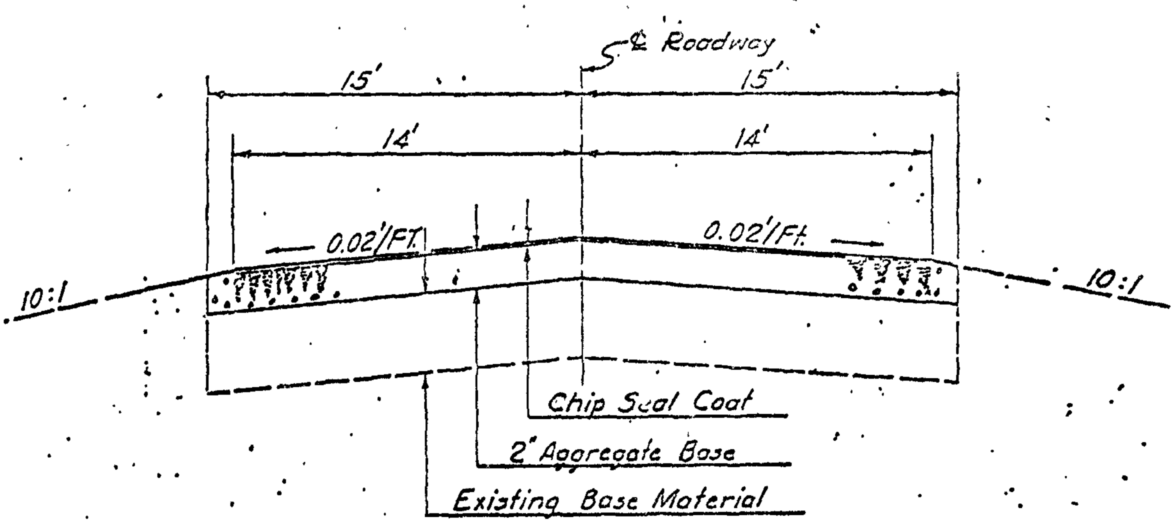


Figure 5-1. Profile of Typical Section for Chip Seal Road Surface Construction

TABLE 5-1. PERFORMANCE RATING AND ROAD CONDITIONS FOR SELECTED ROAD DUST PALLIATIVE, SPRAY ON APPLICATIONS[42]

Chemical	Cost of Chemical & Application[a] $/mi.	After 5 Months: Percentage Control[c]	After 5 Months: Description of Road Condition	After 14 Months and Several Bladings: Percentage Control[c]	After 14 Months and Several Bladings: Description of Road Condition	Cost Effectiveness[b] $/ton of dust Emissions Prevented
Dust Control Oil Mixture of petroleum resin and light hydrocarbon solvent. Applied at .6 gal/yd.[2]	5280	95.2	Black, very hard surface, some potholes near shoulders, minimal loose material, extremely light dust behind traffic.	54.3	Dark brown, hard surface, scattered potholes, moderate loose material but from outside the road, light dust behind traffic.	9.3
Curasol AE A polymer dispersion diluted in water by 6 to 1. Applied in 4 passes at .25 gal/yds[2] each.	8130	86.9	Dark brown, medium hard surface, rutted with few potholes, loose coarse particles on surface, moderate dust behind traffic.	9.4	Brown, several ruts and potholes, large amount of loose particles, very heavy dust behind traffic.	23.8
Aerospray 70 A polyvinyl Acetate resin diluted 6 to 1 with water. Applied using 4 passes at .25 gal/yd each.	8080	82.6	Brown, medium hard surface, medium wear and ruts, few potholes, loose coarse particles on surface, moderate dust behind traffic.	44.3	Lt. Brown several ruts and potholes, large amount of loose particles, heavy dust behind traffic.	18.0
Dust Bond 100 + F-125 Mixture of lignin sulfate and other chemicals. Applied non diluted in first pass at 1 gas/yd[2] then at 1 to 1 dilution plus 2.5% formula 125 on next pass. Surface compacted intermittently for several hours after application	8420	88.0	Brown, medium hard surface, moderate wear, few potholes, smooth surface, slippery when wet, moderate dust behind traffic.	17.6	Lt brown, few patches of treated surface, several ruts, large amount of loose particles, heavy dust behind traffic.	22.4
Foramine 99-194 A urea-formaldehyde resin in water solution. Diluted 1.6 to 1 by water application at 1 gal/yd[2]	10300	46.6	Natural color, worn and rutted surface, large amount of loose particles, poor riding quality, heavy dust behind traffic.	8.9	Natural color, similar to untreated (water) section.	52.2
Water	400	0	Natural color, soft when wet, worn and rutted surface, large amount of loose particles, heavy dust cloud behind traffic.	0	Natural color, worn, numerous ruts and potholes, large amount of loose particles, heavy dust cloud behind traffic.	---

[a] Based on 1975 State cost figures[42] for chemical stabilizers, adjusted 15% upward to reflect current (1976 costs, and another 10 to include cost of surface preparation and applications. Correction for adjustment to current costs is based on personal communication with a principal supplier[45]. Costs include shipping expenses for supplier to Phoenix.

[b] Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content of 28%, and average vehicle speed of 35 mph (see reference [9]). The uncontrolled emissions are 254 tons per mile of road for the 5 month period, and 712 for the 14 month period.

[c] Control effectiveness is based on dustfall measurements conducted at various distances from road.

TABLE 5-2. PERFORMANCE RATINGS AND ROAD CONDITIONS FOR SELECTED ROAD STABILIZERS, MIXED INTO SOIL[a,42]

Chemicals	Cost of Chemical and its application[b] $/mi	After 5 Months: Percent Control	After 5 Months: Description of Road Condition	After 14 Months: Percent Control	After 14 Months: Description of Road Conditions After Several Bladings 9/29/75	Cost effectiveness[c] $/ton of dust emissions Prevented
Redicote E52 Asphalt Emulsion A cationic asphalt emulsion (7.4% in water) applied at 2.4 gal/yd^2.	10810	94.7	Black, very hard, asphalt like surface, little wear, smooth no loose material, no dust behind traffic.	84.4	Black very hard, asphalt like surface, little wear, good riding quality, some loose coarse material, very little dust behind traffic.	17.0
Dust Bond 100 + F-125 A mixture of lignin sulfonate and other chemicals plus formula 125. Applied at 1 gal/yd^2.	8440	86.6	Brown, hard surface, smooth, little wear, some loose material, very light dust behind traffic.	44.7	Brown, few hard spots, numerous ruts and potholes, heavy dust concentration behind traffic.	18.1
Dust Control Oil Mixture of petroleum resin and light hydrocarbon solvent. Applied at .5 gal/yd^2.	4370	80.5	Black, hard at spots, few ruts and potholes, loose course material moderate dust behind traffic	11.5	Dark brown, hard at few spots, numerous ruts and potholes, heavy dust cloud behind traffic.	13.4
Water	690	0	Natural color, rutted, several potholes substantial loose material, heavy dust behind traffic.	0	Natural color, rutted, numerous potholes, substantial loose material, heavy dust cloud behind traffic.	---

a. Mixing of the chemical stabilizer into the road bed is accomplished as follows: 1) the surface is first ripped to a depth of 3 inches; 2) the surface is sprayed with water; 3) the chemical is sprayed on the surface; 4) the chemical is mixed into the soil surface with a series of successive bladings; 5) the road surface is compacted by rolling.

b. Based on state cost figures[42] for chemical stabilizers, adjusted 15% upward to reflect current (1976) costs, and, adjusted another 10% to include cost of surface preparation and chemical application correction to current costs are based on communication with a principal supplier [43]. Costs include shipping expenses from supplier to Phoenix.

c. Cost effectiveness is based on the ratio of the cost and the average emissions reduction attained for the period indicated. This reduction is estimated by applying the control figures above to the uncontrolled dust emissions corresponding to an unpaved road with ADT of 140, soil silt content 28%, and average vehicle speed of 35 mph (see reference [9]). Roadway dust emissions without control are 712 tons for the 14 month period.

d. Control effectiveness is based on dustfall measurements conducted at various distances from road.

TABLE 5-3. INITIAL COST AND MAINTENANCE COST OF ALTERNATIVE ROAD SURFACES APPLIED BY MARICOPA COUNTY HIGHWAY DEPARTMENT[42, 27].

ROAD SURFACE TYPE	INITIAL COST PER MILE	ANNUAL MAINTENANCE
Gravel Road	$ 16,000	$ 600
Oiled surface (low cost Application)	$ 2000-3000	$ 2000-3000
Oiled surface dust control oil	$ 5,300	$ 5,300
Chip seal coat	$ 35,000	$ 800
3" asphalt	$ 55,000-100,000	$ 160

Control efficiency estimates for the various dust measures are tabulated by considering the effect of altering a road which is presently an unpaved dirt surface having a silt content representative of the study area. Cost effectiveness is then estimated by considering the annualized cost of the measure in the given study area and the resulting emissions reduction. Efficiencies and cost effectiveness estimates are shown in Table 5-4. The chip seal surface appears to be somewhat more cost effective than the other road surfacing dust control measures, and of those measures providing the best control, the chip seal is significantly more cost effective. These findings are consistent with the Duwamish Valley Study[26] where it was found that the least cost control was a chip seal surfacing when ADT is 150. However, when ADT decreases to 15, lighter applications of the road dust palliatives may be used to attain a certain level of dust control and cost effectiveness of the palliative in this instance becomes competitive with the chip seal paving approach. It should be noted that the cost figures of Table 5-4 are presented for illustrative purposes, and may vary greatly depending on locale and existing construction and road maintenance practices.

TABLE 5-4. EFFECTIVENESS OF ALTERNATIVE ROAD SURFACES IN REDUCING DUST EMISSIONS FROM AN UNPAVED ROAD IN MARICOPA COUNTY, ARIZONA

ROAD TYPE	EMISSION RATE LB/VEHICLE MI.	ANNUAL EFFICIENCY	COST EFFECTIVENESS[c] $/TON OF DUST
Dirt Surface	22[a]	---	---
Gravel	11[a]	50%	11.0
Oil Surface (Dust Control Oil)	5[f]	75%	19.5
Oiled Surface (Low cost Application)	11[b]	50%	13.5
Chip Seal	0[e]	100%	10.8[d]
Asphalt	0[e]	100%	19.6[d]

a. Based on AP-42 emission factor[44], and road silt content of 24% and average vehicle speed of 35 mph.

b. From reference[15].

c. Computations based on assumption of ADT of 100, maintenance costs of Table 5-3, and annualized cost for indefinite period at 10% interest.

d. These figures do not include the dust reductions attained by inducement of traffic off unpaved roads to the newly paved surface.

e. This emission rate does not include entrainment of dust loadings off the pavement. Entrained dust emissions are discussed in Section 3.1.2.

f. Based on field test conducted by Arizona Department of Transportation[42].

Traffic controls also offer potential for dust emission reductions from unpaved roads. Dust emissions increase exponentially with vehicle speed up to 30 mph[26, 27]. Table 5-5 illustrates the dust emission rate at different speeds for a vehicle travelling over a dirt road. Based on an average speed of 35 mph, the reduction achieved by restricting vehicle speed to 20 mph would be 62 percent.

Restriction in use of unpaved roads may also be employed to reduce dust emissions. Unpaved roads may be closed to travel when alternative paved routes are available. The potential of this dust control measure is not encouraging since almost all roads provide needed access to at least a limited segment of the population, and it is not plausible to restrict traffic to only this limited sector. It should be noted, however, that traffic volume on the remaining interior unpaved roads will be diverted significantly after addition of paved routes to the road network. Such traffic inducement should be considered in assessing the total effectiveness of the road-surfacing measures. For example, a plan to pave half the section line roads in Maricopa County (Arizona) by 1985 would reduce expected traffic on remaining interior unpaved roads by 15 percent[45]. This analysis is made by considering the trip alternatives in a representative section of the road network for the "before and after" paving control measure.

TABLE 5-5. DUST EMISSION RATES AT DIFFERENT VEHICLE SPEEDS

SPEED OF VEHICLE	EMISSION RATE[a]. LB/VEHICLE MI.	DEGREE OF EMISSIONS REDUCTION
35	22.0	---
30	19.0	14%
25	13.0	41%
20	8.5	62%

a. The emission rate is based on the AP-42 emission factor[44] for vehicle speeds of 30 mph and over. For speeds from 0 to 30 mph the emission rate increases exponentially with speed and is calculated as follows: $e = .0211\ S^2$, where e = emission rate (lb/vehicle mi), and S = vehicle speed (mph). The baseline emission rate (35 mph) was calculated assuming a typical dirt road silt level of 24%.

5.2 CONTROL OF ENTRAINED STREET DUST

Various field studies have indicated that dust emissions from paved streets are a major component of material collected by high-volume samplers.[46] Reentrained traffic dust has been found to consist primarily of mineral matter similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicles, but also including engine exhaust, from wear of bearing and brake linings, and from abrasion. These forms of dust may settle to the street surface and become subsequently reentrained. The patterns of material deposition on the street suggest the control of entrained street dust by two principal methods: 1) control of the street dust origins, and 2) street cleaning.

Control of the Dust Origins

One obvious means of reducing street dust loadings is by controlling its origins. Significant origins consist of carryout of dust from dirt surfaces by motor vehicles, atmospheric fallout of airborne particulates, and transport from adjacent exposed land areas. In areas experiencing arid climates, the major sources of street dust originate from transport of exposed soil from areas near the streets (i.e., unpaved road shoulders). Dust from the exposed road shoulders is transported to the street surface by turbulence from passing vehicles, wind erosion, tracking by pedestrians and vehicles, and water runoff. Soil carryout by motor vehciles is also a significant cause of street dust, particularly in areas with abundant rainfall.

In many areas, roadway improvements anticipated in the next several years will result in significant impacts on street dust loadings. These improvements are important because dust loadings for streets with uncurbed shoulders are estimated to be four times greater than that observed for curbed streets[47]. The substantial portion of curbing and gutter improvements will occur in the cities. Since the major portion of vehicle miles traveled in any area are concentrated within the cities, the urban street improvements will have far greater impact on TSP levels than would similar improvements implemented in county road networks. Accordingly, intensification of the street improvement plans should be considered as a potential control for street dust emissions.

To increase the effectiveness of street curbings as a dust control measure, the adjacent soil should be stabilized or covered to prevent wind erosion or tracking of this soil onto the street. Clearly, the most effective means of soil protection at the curb is a sidewalk. A typical and desirable city policy is to include sidewalks whenever curbs are constructed on major streets. The effectiveness of this measure has not been quantified, but it is expected that transfer of exposed soil to adjacent road surfaces will be decreased significantly.

Typical city construction costs for street curbs are currently about $5 per curb foot. The cost of sidewalk construction is $6 per running foot of a standard 5 foot wide sidewalk[48].

In cities where sanding is used on streets for snow and ice control, modifications can be made in the sanding operations to reduce air quality impact without increasing the hazard of vehicle accidents. Some of these modifications are:

- replace the sand with salt or a salt/sand mix;
- plow streets instead of sanding;
- clear the sanding material from street as soon as possible after each storm;
- apply material only at intersections and on hills and curves (reduce the amount applied);
- use sand that has been washed and sized.

It is not possible to quantify the air quality impact of each of these changes or their combinations, but the simple assumption could be made that the impact from sanding would be reduced proportionately to any reduction in the amount of sand used on a street in a given area.

Street Cleaning

There are three main types of machine street sweepers currently in use. Broom sweepers utilize a rotating gutter broom to sweep material from the gutter into the main pickup broom which rotates to carry the material into the truck hoppers. The broom sweeper is by far the most commonly used class of sweeper. A second type of sweeper, called the regenerative air sweeper, uses an air blast to direct material into a collection hopper. A third type of sweeper utilizes a broom and vacuum system to collect material. Each of the sweepers employs a water spray to control dust emissions during sweeping. In addition to machine street sweepers, various cities use flushers which use a jet of water to move material to the gutter rather than actual material pickup.

Broom sweeping has two operational characteristics that make its use alone of doubtful value---it moves material from the gutter back into the street for pickup and it is not efficient in removing fine particles that are most susceptible to re-entrainment. Flushing probably shows the most promise with regenerative air and vacuum sweeper somewhere in between for reducing re-entrained dust. It wets the street, causing dust suppression until the surface is completely dry, and moves material out of the traffic lanes to the gutters. The only practical limitation on the use of flushers is in areas where water availability is restricted. Flushers use 3,000 to 4,000 gallons of water per mile of street, or up to 70,000 gal/day. Therefore, street flushing could easily constitute 1 to 2 percent of a city's total water consumption.

In a recent field study performed by PEDCo[14] for EPA in Kansas City and Cincinnati, air quality impacts were measured using alternative street cleaning techniques. In Kansas City, data indicated that air quality improved 8 to 18 $\mu g/m^3$ with flushing, whereas broom cleaning showed no improvement.

For Cincinnati, the air quality impacts from flushing and broom sweeping showed the reverse from that in Kansas City. Also, in Cincinnati where vacuum sweeping was tested, it was not shown to be effective in reducing particulate concentrations. This finding was unexpected considering the demonstrated efficiency of the vacuum units in removing small size particles from street surfaces and their overall street cleaning efficiency. These cleaning efficiencies were determined from street loading measurements taken before and after each cleaning operation.

Also, in the PEDCo study, particulate air quality were obtained or results were summarized from studies in five cities in which potential control measures had been implemented (i.e., some type of street cleaning program). These cities or studies are: New York - New Jersey; Kansas City, Kansas; Charlotte, North Carolina; Chicago, Illinois; and Twin Falls, Idaho. The air quality data was reviewed to determine whether the programs had a discernible effect on particulate concentrations. The findings were inconclusive with regard to the effectiveness of improved street cleaning as shown in Table 5-5.

Table 5-5

Cleaning method	Studies in which method was effective	Studies in which method was ineffective
Broom sweeping	1	2
Vacuum sweeping	0	2
Regenerative air sweeping	0	1
Flushing	2	2
Sweeping and flushing	0	1

Intuitively, street cleaning as a control measure should reduce re-entrained dust, but is still unproven as an effective method for reducing ambient TSP concentrations, therefore, caution is advised in undertaking control programs involving street cleaning. It is entirely possible that changes in operating procedures (e.g., more frequent, better operator training) or better designed equipment with environmental concern in mind or other improvements in street cleaning methods would reduce ambient concentrations. However, prior to any full scale modification of a city's street cleaning program, a pilot study incorporating a sweeping project is recommended at least until more data on the effectiveness of improved street cleaning methods become available. The interest and support of the public works department are necessary in order for the measure to be successful. If the changes are not supported or measured as important, an expanded or improved cleaning program will probably not translate into an air quality improvement.

Another reason for testing street cleaning modifications on a smaller scale is that study data from one city may not be applicable in another due to great difference in street systems (storm drainage, curbs and gutters, age and type of surface, etc.) and capabilities of street departments.*

*Refer to EPA-907/9-77-007 document, Control of Re-entrained Dust From Paved Streets for more detailed information on street cleaning, construction site control, and associated cost. Additional guidance is currently being prepared for pilot street cleaning studies. This is expected by November, 1977.

5.3 CONTROL OF DUST EMISSIONS FROM CONSTRUCTION AND DEMOLITION ACTIVITIES

Construction activities are temporary and variable in nature. Fugitive dust is emitted both during the activities (e.g., excavation, vehicle operation, equipment operations) and as a result of wind erosion over the exposed earth surfaces. Earth moving activities comprise the major source of construction dust emissions, but traffic and general disturbance of the soil also generate significant dust emissions.

Wetting the surfaces of unpaved access trails for construction vehicles and trucks is an effective control for dust emissions provided the surface is maintained wet. In arid regions this generally requires an appreciable amount of water. A study on the effect of watering on construction sites indicates that extensive wetting of the soil may reduce emissions from existing construction operations up to 60 to 70 percent[15]. The study suggested that wetting of access roads twice a day with an application of .5 gal of water per square yard will suppress dust emissions from existing baseline construction practices by 50 percent. It was assumed that a certain degree of dust control is currently achieved at most construction sites, due to typical local regulations requiring reasonable precautions be exercised in these dust emissions.

A negative tradeoff associated with watering controls at construction sites concerns the carryout of mud onto adjacent streets. The carried out mud later becomes dust again and is susceptible to suspension by passing vehicles. If the construction site is frequented by an appreciable amount of traffic and watering controls are amply employed, mud carryout will be significant and should be controlled. A practical means of removing the mud is cleaning the streets in the vicinity of the construction site. Cleaning could be employed daily to clean those paved roads within the proximity of the site and which are used by vehicles exiting off the site. The sweeping program could be conducted in cooperation with the City Maintenance Department. It is not possible to generalize an effectiveness for this action.

An additional dust source at construction sites consists of exposed earth which is susceptible to wind erosion, and to dust emissions from infrequent traffic disturbance. While the suspended dust from this source is generally insignificant, there are brief periods (i.e., during wind gusts or traffic bursts) when the resulting dust levels may create a nuisance to nearby inhabitants. Dust emissions from these sources may be reduced by combining two control actions. First, a soil stabilizer, such as a chemical palliative or vegetation cover may be applied. A second control action would involve a stipulation that cleared earth be exposed for a limited period before subsequent operations on this land commence. This would prevent the frequent practice of clearance of vast plots of land where subsequent construction operations are not scheduled to begin for several months. Clearance would be permitted only if accompanied by soil stabilization measures within a certain period of the clearing. The method is quite effective in minimizing the wind erosion impact of construction activities. However, there is little definite information to quantify the impact from an overall % control efficiency. However, one can apply the wind erosion equation to the conditions before and after control and obtain the % reduction in suspended soil. This technique is outlined in Reference[15].

Cost estimates of the alternative dust control measures for construction site emissions in the Phoenix area are shown in Table 5-6 for illustrative purposes. These control costs will vary from region-to-region due to differences in water availability, street sweeping costs, and cost of dust palliatives and their application. A region-specific study is needed to determine the actual cost of the candidate measures in the region targeted for controls.

Dust emissions at demolition sites derive from essentially the same source as those found on construction sites. These sources involve earth-moving activities, and general disturbance of the soil. The control methods available for these sources are the same as that employed at construction sites (e.g., wetting of access roads). A significant portion of dust associated with demolition activities may also be generated by falling walls, and an additional significant emission hazard concerns the release of asbestos particles when demolition involves friable asbestos materials. The latter hazard has resulted in the promulgation of demolition and renovation standards[49] for institutional, industrial, and commercial buildings containing a specified amount of friable asbestos materials. These standards require that asbestos materials must be removed prior to wrecking activities by specified handling procedures, and that these materials be wetted prior to removal and handling. The dust created by falling walls of brick, plaster or concrete may be mitigated by spraying walls with water before teardown and immediately after the fall. This control method may reduce emissions from masonry demolition by 10 to 20%[50].

TABLE 5-6. COST OF ALTERNATIVE DUST CONTROL MEASURES FOR CONSTRUCTION EMISSIONS IN PHOENIX AREA.

Description of Measure	Control Efficiency	Cost
1. Wetting of Site Access Roads twice/day at .5 gal/yd^2, and strict enforcement by Building Dept. and County Health Department	30%	$6/acre[a]/day
2. Daily street sweeping of roads used by construction-related vehicles for 1/2 mile from site	indeterminate	$5/day[b]/site
3. Stabilization of all exposed earth on the construction site wherever operations cease on that land for more than 2 months	indeterminate	$200-300/acre[c]

a Based on 3 hours labor and equipment cost. Unlimited water is provided from irrigation canals to contracting for a single annual permit cost.

b Based on City cost for single pass of street sweeper on 1 mile of road ($4.50/curb-mile[51].

c Based on cost of Dust Control Oil Application as reported by State[42] and supplier[45].

5.4 CONTROLS FOR AGRICULTURAL DUST EMISSIONS

Techniques for controlling fugitive dust from agricultural areas include:

1. Continuous cropping with limited field exposure
2. Crop residue management and modified tilling operations
3. Limited irrigation of fallow fields
4. Windbreaks and stripcropping
5. Chemical soil stabilizers

The effectiveness of each of the alternative control technqiues can be determined by computing the influence of each control on the wind erosion equation (E = AIKCL'V'). Continuous cropping, crop residue and stubble, and stripcropping will effect the vegetative factor (V') of the equation; some aspects of modified tilling will affect the roughness factor (K) and the climatic factor (C); windbreaks will effect the unsheltered field length factor (L'); and chemical soil stabilizers will affect soil erodibility[15, 17].

5.4.1 Continuous Cropping

This technique, which attains maximum productivity from a cropland, is one which also lessens the length of the period of barren field exposure to wind erosion. Continuous cropping may be accomplished by repeated plantings of a single specific crop, or may involve a complex process of rotating various crop types on a given field throughout the year. Some of the important factors which influence the farmers decision to plant a certain type of crop within this rotational scheme are season, water demand, water availability, market demand, and the length of time that is required for the duration of the crop. The key limiting factors to continuous cropping are the lack of rainfall and regulated water allocations to farmlands.

In many agricultural areas, there are periods when fields are fallow while preparations are being made for the next crop as well as periods where fields are barren while in the seedling stage. For example, consider the crops of cotton and sorghum. Assuming that the non-growing, residue period for cotton is three months, and that during this time an alternate crop is planted (such as a fast growing grain which takes about a month to cover the ground, enough to eliminate wind erosion) the annual fugitive emissions off the cotton field that would otherwise lie fallow for three months could be reduced about 67 percent. For sorghum, the non-growing residue period is November to July. Planting of wheat after sorghum harvest in December would leave the sorghum field in residue for only one month, resulting in a 78 percent reduction in annual emissions on fields previously growing only a sorghum crop.

Cost of continuous cropping measures depend on numerous factors such as water availability, additional manpower and equipment requirements, crop resource requirements, and crop market value.

5.4.2 Crop Residue and Modified Tilling Operations

Protection from wind erosion can often be provided by leaving the residue or standing stubble of a crop after it has been harvested. The quantity and quality of stubble mulch which is required to prevent soil blowing varies by crop type, soil characteristics, climate, and whether the residue is standing or flattened. For instance, in a semi-arid area, on a silt loam soil with 25 percent non-erodible fractions, 750 lbs. per acre of one foot standing wheat stubble or 1500 lbs. per acre of one foot flattened wheat residue is required for complete protection against soil erosion, while on a loamy sand, 1750 lbs. per acre of 12" standing stubble or 3500 lbs per acre of 12" flattened residue is required, and, if sorghum is used instead of wheat, twice the weight of sorghum is required[52]. Fine residues provide better protection than short crop residues. Modifying tilling and plowing operations to create the most dust free condition on a given field is a complex issue which depends on the type of crop being harvested, the next crop to be planted, the period between crops, and the manpower, equipment, and time requirements of the farmer.

The length of time that the standing residue of wheat and barley is left unaltered on fields is generally not regulated. Normally, the farmer turns residue under when it is convenient. This might happen very soon before the next planting or as much as a month before the next planting. If tilling is postponed until just before it is necessary to prepare the field for the next crop, wind-blown emissions are reduced by the fraction of total soil exposure time saved by the postponement. The potential emissions reductions which can be achieved for an agricultural region is difficult to determine because the exact chronology of the various farmer's activities are not generally known.

No-tillage farming is currently being used as an advanced farming method to prevent soil erosion, increase cropland production, and to reduce farming costs[53]. Despite the economic benefits of no-tillage farming, there is substantial resistance by farmers to depart from accepted practice. If tilling remains the accepted practice for crop field preparations, and is delayed so that the residue can continue to provide soil erosion control as long as possible, significant additional expense will result from additional manpower and equipment required to carry out tilling operations in a shorter period of time.

Stripcropping consists of the inter-row planting of erosion-resistant crops on fields with other crops which are erosion-susceptible. Small grains which are closely seeded and cover the ground rapidly are erosion-resistant. Cotton, sugar beets, peas, beans, and truck crops are generally erosion-susceptible. The cost of grain stripcropping varies with the grain type and the requirements of that grain and also according to the requirements of the erosion-susceptible crop which is being protected. Modifications in machinery may have to be made in order to tend the crop requirements of a double-cropped field.

Stripcropping may be employed most effectively during the early months of a crop development before foliage is sufficient to provide soil erosion protection. However, the degree of protection provided by this method would be minimal. As the main crop begins to develop, the reduction of soil erosion caused by the accompanying irrigation itself would probably exceed the dust control benefits gained through stripcropping.

5.4.5 Chemical Soil Stabilizers

While a field is in the seedling stage or is barren, wind erosion can be reduced considerably with chemical stabilization. Investigation has shown that the liquid, petroleum resin-in-water emulsion, is the most effective, durable, and economical of the many available varieties of stabilizers for this purpose. Use of herbicides is also required as the stabilizers provide surface layer protection only, and normal weed removal practices would disturb the protective layer[15].

Documentation of the effectiveness of the stabilizers in reducing dust emissions is presently limited. Based on a recent study of soil stabilizers conducted by the State of Arizona Department of Transportation[42], the wind-blown dust emissions from agricultural lands can be reduced by about 90% provided the surface layer remains undisturbed. Cost of applying the various stabilizers varies from about $100 to $650 per acre[15].

5.4.3 Limited Irrigation of Fallow Fields

The periodic irrigation of a barren field will provide control of blowing soil by increasing soil moisture and crusting the soil surface. The impact of irrigation on dust emissions may be estimated by determining the change in climatic factor (C) and soil erodibility (I) due to additional surface crusting. The amount of water and the frequency of each irrigation during fallow to maintain a desired level of control would be a function of the season and of the crusting ability of the soil. The main drawback to irrigation control concerns availability of water, cost of water, and interference with farming activities on the cropland[15].

5.4.4 Windbreaks and Stripcropping

Both windbreaks and stripcropping are intended to reduce wind erosion by reducing the wind velocity over barren soil. The most effective results are obtained when planting (or placement of physical barriers) is done perpendicular to the prevailing wind direction. Windbreaks occur around the field, while stripcropping occurs within the field.

A windbreak provides lateral wind erosion control equal to ten times the barrier height[52]. A barrier 25 feet in height will control erosion over 250 feet. Therefore, on a typical 2000 foot long field, erosion can theoretically be reduced by about 12 percent. The most severe drawback of windbreaks for erosion control is their very high cost. Large scale application of windbreaks for erosion control is generally considered unfeasible, particularly in arid areas where water availability is limited.

Table 5-7 summarizes the range of effectiveness and cost of various control measures for agricultural dust emissions[15].

5.5 Control of Tailing Piles

Control methods for fugitive dust emissions from mineral waste heaps include: (1) physical control; (2) chemical binding; and, (3) vegetative cover. The applicability and cost of these controls varies depending on the type of mineral waste and the region in which it is located. Also, applicability varies with other environmental control objectives, such as aesthetics, water pollution control, land use, etc.

Physical stabilization of tailings with a cover rock or smelter slag can provide complete control of wind-blown emissions. A mixture of soil and rock available from adjacent lands is a more widely used cover material. Soil cover is subject to wind erosion to a lesser degree than the tailings, and permits a habitat for encroachment of local vegetation. The degree of control provided by the soil cover is determined by the difference in erodibility of the soil and the more erodible tailings fines. The primary drawback to physical covers as erosion controls is the high cost of application, particularly when the cover materials are unavailable in the immediate area.

Chemical stabilizers are commercially available and have been employed in numerous applications[15] to create a crusted erosion-resistant layer on mineral waste piles. In applications where the tailings surface is not subject to disturbance, stabilization by crusting attains a control efficiency of about 80%[15]. Since chemical layers create only a thin skin of protection, they offer only temporary protection, and repeated applications are required periodically to maintain the crust. Chemical stabilizers are typically used in combination with vegetation to form long-term erosion-resistant surfaces over tailings piles. The chemicals promote vegetation growth and protect seeds during the germination period. The effectiveness of the vegetation in reducing fugitive dust emissions depends on the density and nature

TABLE 5-7

COST AND CONTROL EFFICIENCIES FOR AGRICULTURAL FUGITIVE DUST CONTROL TECHNIQUES

Control Method	Control Efficiency %	Unit Cost, $/Unit	Cost Reference
Continuous Cropping	25	Dependent on Crop	
Crop Residue	10	---	
Limited Irrigation	20	4-10/acre/year	Salt River Project
Stripcropping	27	Dependent on Crop	
Inter-row Planting	15	No Data	
Windbreaks	6	No Data	
Spray-on Chemical Stabilizer	40	20-50/acre/ application	

of the growth. In areas, and for tailings piles which will support heavy vegetation, wind erosion dust emissions may be virtually eliminated. However, in areas less hospitable to plant growth, such as the arid southwest, only native species may be grown (sagebrush, Indian rice grass, sand dropseed). Assuming a moderate vegetation rate of 500 lbs/acre was attained, fugitive dust emissions from the tailing piles would be reduced approximately 25%. (see Section 3.2.2)[54].

Table 5-8 summarizes the range of effectiveness and cost of the control measures to reduce tailing pile emissions.

5.6 Control of Unpaved Parking Lots and Truck Stops

The alternative controls for mitigating dust emissions from unpaved parking lots are the same as those which may be applied for unpaved roads (see Section 5.1). The traffic surface may be improved by paving, graveling, or applying a dust palliative. Table 5-9 lists the efficiency and cost of controls for parking lot dust emissions. Since no data are available to characterize the effectiveness of the measures specifically for parking lots, the figures of Table 5-9 are based on the assumption the measures are equally effective for parking lots as for unpaved roads. The cost data are the same as cost for applications for road surfacing discussed earlier. Actual costs may vary significantly from region-to-region, and should be determined specifically by inquiry with local transportation departments.

5.7 Control of Emissions from Disturbed Soil Surfaces

Feasible control methods to reduce wind-blown dust emissions from disturbed soil surfaces are similar to those described for tailings piles (Section 5.5) and unpaved parking lots (Section 5.6). Control measures include chemical stabilization, vegetation, and physical covers. For those soil surfaces which receive periodic traffic, such as residence yards, playgrounds, and some vacant lots, application of chemical stabilizers must be intensified similar to that required for control of unpaved road surfaces. Soil covers such as gravel may

TABLE 5-8. EFFECTIVENESS AND COST OF CONTROL MEASURES FOR EMISSIONS FROM TAILINGS PILES

Control Measure	Fractions of Emissions Reduced	Cost of Measure[b] $/acre
Native Soil Cover	$\left(1 - \frac{I_t}{I_n}\right)$ [a]	250 - 600
Rock or Slag Cover	1.00	350 - 450 (available locally) * 950 -1050 (transported)
Chemical stabilization	.80	65 - 650[c]
Vegetation	.25 - 1.00	100 - 450
Chemical stabilization-Vegetation	.85 - 1.00	100 - 150

[a] I_t = erodibility of tailings and I_n = erodibility of native soil cover

[b] Costs based on references[54, 55, 56, 57].

[c] Applications of chemical stabilizers are typically required on annual basis

* plus cost of stabilizing the borrow area. Too often the borrow area is ignored and, subsequently, becomes more of a pollution source than the mineral area.

TABLE 5-9. EFFECTIVENESS AND COST OF ALTERNATIVE MEASURES TO CONTROL DUST EMISSIONS FROM UNPAVED PARKING LOTS OR TRUCK STOPS

Control	Emission rate[f] lb/vehicle mile	Efficiency of Control	Initial Cost of Control[e] $/10,000 ft²	Cost of maintenance[e] $/10,000 ft²
None-dirt parking lot	2.2[a]	--	--	--
Gravel Surface	1.1	50%	1000	37
Oil Surface (Dust Control Oil)	.6	75%[c]	335	335
Oil Surface (Low Cost Application)	1.1	50%[b]	130-190	130-190
Chip Seal Coat	0[d]	100%	2220	51
Asphalt	0[d]	100%	3500-6370	12

a. Based on exponential increase in emissions from 0 to 30 mph The baseline emission rate was calculated using the MRI emission factor[17], surface silt level of 24%, and average vehicle speed in parking lot of 10 mph.

b. Reference[15].

c. Based on field tests conducted by Arizona Department of Transportation[42].

d. This emission rate does not include entrainment of dust loadings off the pavement (entrained dust emissions are discussed in Section 5.2).

e. Costs are based on references[42, 45].

f. Refers to emission rate for normal passenger vehicle. For truck stops, multiply stated emission rate by N/4, where N=number of wheels on trucks[44].

provide varying levels of dust protection depending on the application density. For soil surfaces frequented by minimal traffic, combined vegetation and chemical stabilization generally provide the most cost effective control, particularly in areas where rainfall is sufficient to support vegetation.

6.0 INTEGRATION OF FUGITIVE DUST SOURCE IMPACTS INTO THE STATE IMPLEMENTATION PLANNING PROCESS

6.1 INTRODUCTION

While considerable progress has been made in reducing ambient TSP concentrations in many locations, it is apparent that the primary National Ambient Air Quality Standards (NAAQS) for TSP will not be attained on a nationwide basis under the existing State Implementation Plans (SIPs). In light of this, States are required by Section 172 of the Clean Air Act of 1977 to submit Implementation Plans by January 1, 1979 to attain the NAAQS for TSP as expeditiously as practical, but no later than December 31, 1982. As part of this revision process, the States must seriously evaluate the impact of all particulate matter sources, including fugitive dust sources, and provide a revised SIP to include its control within areas of non-attainment. If needed, strategies for fugitive dust should be developed as a minimum for those areas where the impact of these sources (by themselves or in combination with other particulate matter sources) causes a significant impact upon the health and welfare of the general population. An overall comprehensive control program for fugitive dust may not be realistic for all areas of the country, especially for those areas where natural sources, independent of man's activity are the predominate influencing factors (i.e., isolated rural areas).

All strategies developed with areas significantly impacted by fugitive dust sources should reflect the application of needed reasonable control measures to those fugitive dust sources which are the major contributors to the fugitive dust problem. Such control measures should provide for control of fugitive dust sources as expeditiously as practicable.

6.2 EVALUATION OF CONTROL STRATEGY

6.2.1 Impact of Control Strategy on Emission Levels

The emission levels that will result after various control strategy measures are implemented should be estimated for both the target years of attainment and projected years, considering growth of new emission sources. Control efficiency information for various fugitive dust control measures, (provided in Section 5) in addition to baseline and projected emissions inventories, provide the data base needed for these estimations. The estimated emissions that will result after control regulations are adopted and implemented should be spatially resolved to the same level of detail as the baseline inventory. In making such an analysis, a judgment must be made as to emission reduction impact that will result for compliance with existing emission control regulations (e.g., stationary source as well as fugitive dust control regulations). If the existing regulations are determined to be inadequate for the attainment of the NAAQS, additional emission control measures will be needed.

Once a list of candidate measures has been identified, selection of a control strategy is an iterative process accomplished by means of successive tests of alternatives using a source-receptor model to predict resulting air quality levels (see Section 4.3.2). Through a series of iterative trial judgments, a strategy should be established which attains the air quality standard utilizing the most cost effective combination of control measures available. The impact of controls for individual major source categories should also be investigated as an aid in determining a reasonable mix of the various controls for the overall attainment objective.

The control strategy should be selective for the major sources affecting air quality. The strategy may be widespread and/or site-specific depending on the distribution of the major sources causing high TSP levels. An overall areawide strategy should be proposed to deal with the areawide TSP problem insuring attainment of air quality standards at all points within the area of concern. As various trial alternative strategies are tested, it should become clear which areas in the study region may need local controls. For example, certain controls (such as street sweeping) are more effective within the center city commercial areas, while others (e.g., road paving) are more effective in outlining suburban areas which are still developing.

The overall control strategy developed for fugitive dust sources should reflect the degree of control necessary to attain the NAAQS from both the short-term and annual average aspects. In most cases, the long-term area-wide impact will be the binding constraint; however, in some cases, the short-term or localized impact could be of some significance and it should be evaluated. Once the strategy is finalized, enforceable regulations and compliance test methods must be developed to implement the strategy. The final control strategy should provide for control of fugitive dust sources as expeditiously as practicable. An adequate documentation of the analysis should be prepared for future reference.

6.2.2 Cost of Strategy

The cost of implementing the control measures will vary widely from urban area to urban area. Local cost data should be obtained from those who will be responsible for implementing the measures under consideration. The total cost of instituting the control strategy should be expressed in terms of cost effectiveness and compared to other measures currently being enforced by existing regulations. Control strategy cost should also be compared to overall city and department budgets to assess the economic significance of the proposed measures in comparison to existing expenditures and planned rates of increase.

An important aspect in assessing the cost of the controls concerns the time frame outlined for implementation. A control plan should examine the schedule for implementation to determine if significant cost impacts can be minimized by extending the time frame a year or two to ease the economic burden and allow for a more realistic program that can be implemented to demonstrate marked improvements in air quality.

6.3 GUIDES FOR THE SELECTION OF REASONABLE CONTROL MEASURES

Reasonably available control technology (RACT) defines the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. RACT for source categories with somewhat undefined emission points may represent relatively stringent requirements which in many situations force the application of measures not previously adopted or implemented in a given area. The technological and economic feasibility of various controls will differ depending on several factors indigenous to the area under consideration. General factors affecting the reasonableness of a control measure, and which may vary from area-to-area include:

- o The compatibility of the controls with the overall goals and plans for the area
- o The timetable for implementation
- o The degree of control required
- o The financing mechanisms available for implementation

The extent to which the proposed control measures are compatible with planned development affects the cost and technological feasibility of the measure. For example, the paving of roads for dust control is entirely compatible with long-term city development objectives to improve the transportation network. Similarly, the improvement of road shoulders to reduce street dust loadings and re-entrainment of this dust to the ambient air is completely consistent with city objectives to improve the quality of life in the city. This compatibility lends to greater general technical and economic feasibility for the dust control measures because of the other desirable benefits they provide.

Another consideration in the determination of reasonable measures involves the degree of control which is sought. The ultimate goal of a reasonable control strategy is the achievement of the national ambient air quality standards. The higher the level of control needed for attainment, the greater is the potential for technical and economic demands to be the binding constraint when considering a control strategy to attain the NAAQS.

The economic feasibility of any control alternative is greatly affected by the extent and manner of funding available. Cost required for implementation of different controls can be compared and expressed in terms of the impact per capita. The source and ease of funding should be identified and evaluated. Some controls (such as street sweeping, road surfacing) will be funded by taxes or other governmental money-raising mechanisms, while others will be paid by commercial enterprises.

It is clear that social acceptance is important to the success of the implementation of a control strategy. Consequently, steps should be taken where appropriate to determine the social acceptability of the measures under consideration. A demonstration project, as part of the first phase of implementation, may be used to generate public support when necessary. The elements of the demonstration project, and its implications for resolving implementation difficulties, are considered in Section 6.4.

A measure which is reasonable in one area may be unreasonable in another. In general, most of the measures for control of fugitive dust are reasonable with a few exceptions, the major one being the widespread application of chemical stabilizers to agricultural lands. While this method does have application on a limited basis for dealing with short-term construction projects, its overall environmental impacts are questionable if used without care. This measure may have certain multi-media impacts which have not been fully evaluated to date which may make its widespread application nationwide for agricultural areas unreasonable. However, for the most part, fugitive dust control measures are reasonable from a technical point of view. Selection, therefore, involves a determination of the most cost effective measures which will provide the air quality improvements needed for standards attainment. The timing for the application of control measures is also an important factor when considering the economic feasibility of a certain measure. For example, it may be necessary to pave a large number of unpaved roads to bring about attainment, with any lesser degree being inadequate. However, this may be unreasonable from an economic standpoint unless this paving program is done in phases over the next couple of years. Thus, timing, economics and technical feasibility must be examined in order to develop the types of controls necessary to provide an overall comprehensive achievable strategy.

6.4 IMPLEMENTATION ASPECTS

The difficulty in implementing the strategy depends on technical, political, legal, and socioeconomic considerations associated with the various control measures. The magnitude of these considerations depends on the general implementation approach of the strategy, that is, whether it is to be enforced as a series of air pollution control regulations, or as in-line actions to be taken by various agencies in the performance of related projects. The direct regulatory approach is certainly required for several of the source categories. This will be the only sure way to insure compliance for a number of sources. However, in some cases the direct regulatory approach may pose some difficulties and in fact may be less desirable than binding agreements on the part of certain departments (i.e., public works, etc.) that they will participate in and be responsible for the implementation of a certain portion of the strategy.

This "so-called" alternative to the strict regulatory mechanism is an approach which provides for integration (where possible) of the control measures into the on-line operations of various governmental agencies. This approach generates greater political and social acceptance in that these measures are viewed not only as air pollution controls, but as overall planning and developmental improvements which will yield several tangible benefits in addition to air quality improvement. In view of the types of major fugitive dust emission sources which are typically uncontrolled at present, the integral planning approach is particularly appropriate. Reasonably available controls for unpaved road dust and entrained street dust emissions are entirely consistent with objectives of the local transportation and street maintenance departments and should be incorporated into the overall goals and objectives of these departments.

An example of this inter-governmental cooperation and implementation is found in the current 208 Water Planning process. At the present time, 208 Water Planning agencies are considering various techniques to minimize water runnoff from "non-point sources" which are similar in many cases to fugitive dust sources. Coordination of air management planners with water planners may be mutually beneficial and is certainly encouraged, where appropriate.

The major obstacle confronting implementation of a fugitive dust control strategy, whether utilizing the integral planning approach or the direct regulatory technique, concerns the socioeconomic acceptability of the proposed actions. Appropriations for some major measures by the respective local agencies require financial support of the citizenry, whether by taxes, bonds, or assessment districts. While the funding needed to support implementation of the strategy is generally relatively minimal, there is little chance that the additional expenditures associated with the strategy would be absorbed in the annual budgets without clear justification. Such justification may be facilitated by phasing in the controls with the implementation of a demonstration project as the first phase to validate the benefits of the proposed strategy.

Implementation difficulties anticipated for each of the control measures comprising the strategy should be assessed and ranked to establish the feasibility of successful execution of the proposed program. The assessment should consider the approach in which various departments within the governmental structure of the political jurisdiction are active participants in carrying out the strategy. The assessment may be carried out with or without the benefit of a demonstration project as the first phase of implementing the areawide strategy. Such evaluations are necessarily somewhat speculative, but should be consistent with the economic and technical characterization of the strategy. Overall support for these measures should be generated by providing the overall benefits and objectives of an integrated program to control fugitive dust.

6.4.1 Demonstration Project

In some areas where control may meet with significant implementation obstacles, demonstration projects may be planned as an integral part of the control strategy to generate support and coordinate efforts within various departments. Because the impact of fugitive dust sources is typically very localized, a control demonstration project is particularly appropriate to insure an achievable program in a timely manner. A demonstration strategy is useful in a number of ways. First, the demonstration can be instrumental in generating support for a more rapid implementation of the total strategy. Second, the demonstration would enlist and promote coordination between agencies to achieve the overall objectives in a more complete and comprehensive way. Finally, the demonstration project might be essential as a tool for further pollution control analysis as it will yield useful insights for appropriate adjustments of the regionwide strategy over time. To attain these objectives, the demonstration project should consist of the following elements:

- o Surveys to establish understanding of the overall goals of the long-range plan for the area under consideration.
- o A cooperative task force committee comprised of representatives from the major affected departments. The committee would be responsible for the planning of the strategy and carrying out phase one or the demonstration phase.
- o A field test to demonstrate the effect of the proposed control measures in a limited area. This test would include institution of all controls proposed for the areawide strategy. A comprehensive TSP field monitoring program would be implemented.
- o An economic analysis to evaluate the cost benefits of the proposed control strategy.
- o A public relations program to promote awareness of the benefits of the proposed control plan and to generate support for further funding to implement the measures on a more accelerated scale.

The selection of the specific area for the demonstration would be dependent on several factors. First, receptibility of the various departments and agencies to participate in the overall program should be assured. Second, the area should be representative of major emission sources causing high levels of TSP throughout the problem area. Third, it would be preferable if the selected area included a monitor of the existing air sampling network.

This would facilitate the comparison between before and after control and would place the test program within the context of the data base used to develop the strategy. Fourth, since a key to the utility of the project is its effect on social acceptance, the area selection should reflect a level of social acceptance typical of the characteristic of the entire region which will eventually be affected by the plan. Another, but not necessarily final, consideration in area selection is the planned development for the area. Desirability for selection of the area is increased when scheduled development is compatible with the specific controls comprising the demonstration project under consideration.

6.5 CONCLUSION

States are encouraged to develop comprehensive reasonable control plans to be implemented as expeditiously as practicable. In many areas, demonstration projects will not be necessary, and the program to control fugitive dust can be carried out in a much quicker fashion. In other areas, control efforts have already begun, and further complete enforcement of existing regulations will go a long way in reducing TSP levels due to fugitive dust. An adequate documentation of the analysis of the strategy should be developed to insure completeness. Once the strategy is finalized, enforceable regulations and compliance test methods must be developed to implement the strategy. The plan to control particulate matter should be a comprehensive one which integrates the control of fugitive dust, stack emissions, industrial process fugitive particulate emissions and other area sources into a "well-oiled" program to reduce ambient TSP concentrations as expeditiously as practicable striving for overall acceptance, reasonableness and effectiveness.

APPENDIX A

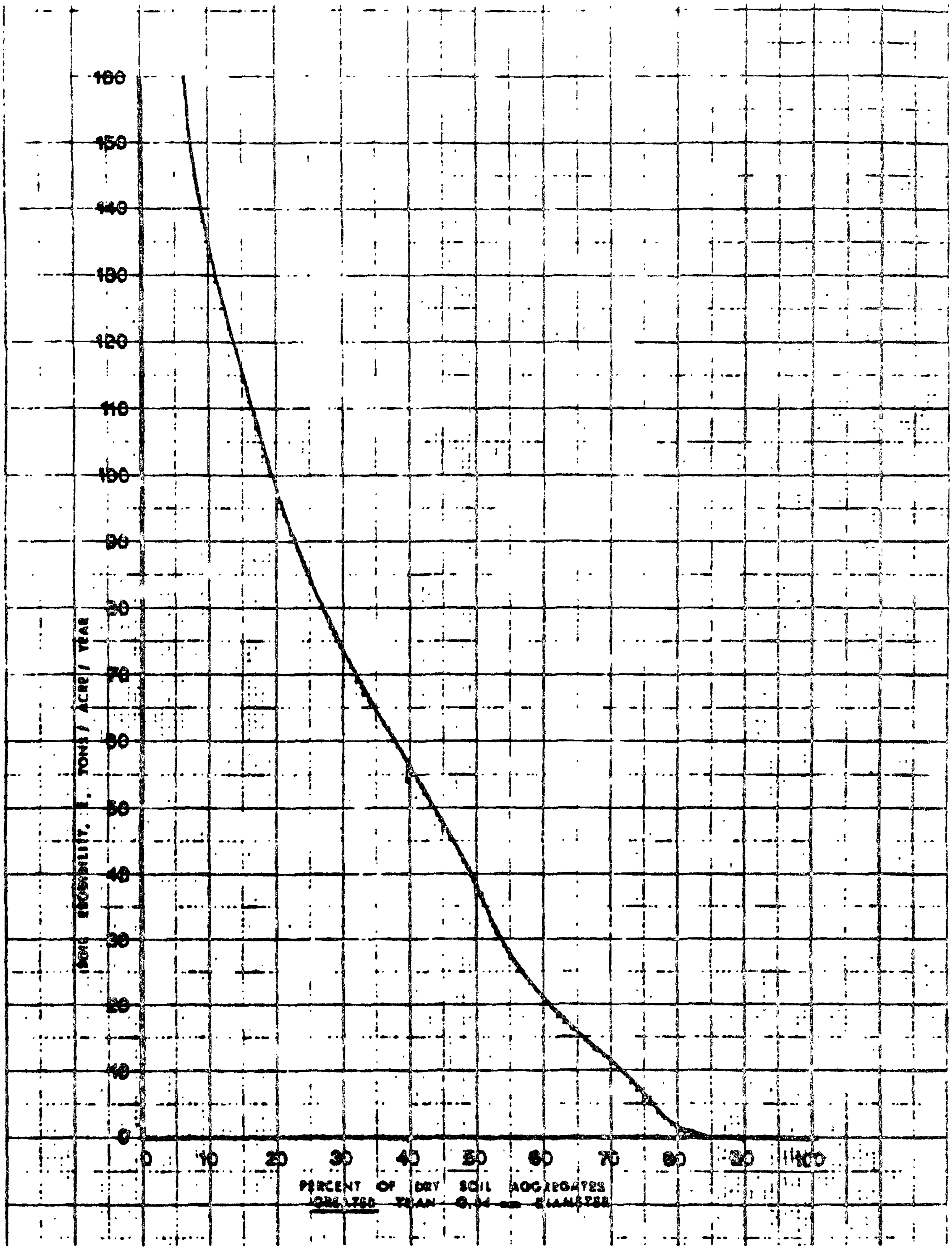


Figure A-1. Soil erodibility as a function of particle size[17].

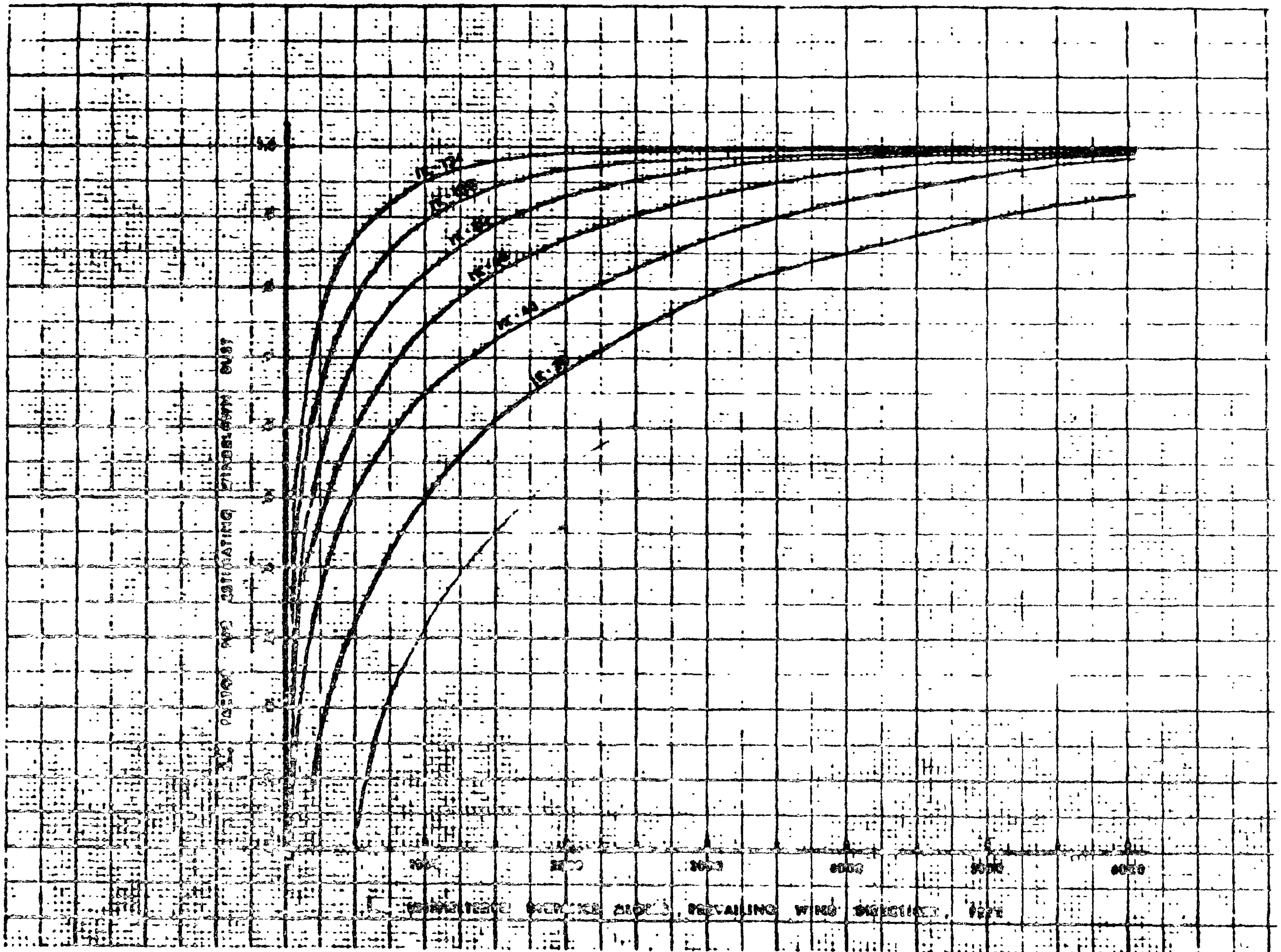


Figure A-2. Effect of field length on relative emission rate[17].

Table A-1. VALUES OF K, L AND V FOR COMMON FIELD CROPS[17].

Crop	K	L,ft.	V,lb/acre
Alfalfa	1.0	1000	3000
Barley	0.6	2000	1100
Beans	0.5	1000	250
Corn	0.6	2000	500
Cotton	0.5	2000	250
Grain Hays	0.8	2000	1250
Oats	0.8	2000	1250
Peanuts	0.6	1000	250
Potatoes	0.8	1000	400
Rice	0.8	1000	1000
Rye	0.6	2000	1250
Safflower	1.0	2000	1500
Sorghum	0.5	2000	900
Soybeans	0.6	2000	250
Sugar Beets	0.6	1000	100
Vegetables	0.6	500	100
Wheat	0.6	2000	1350

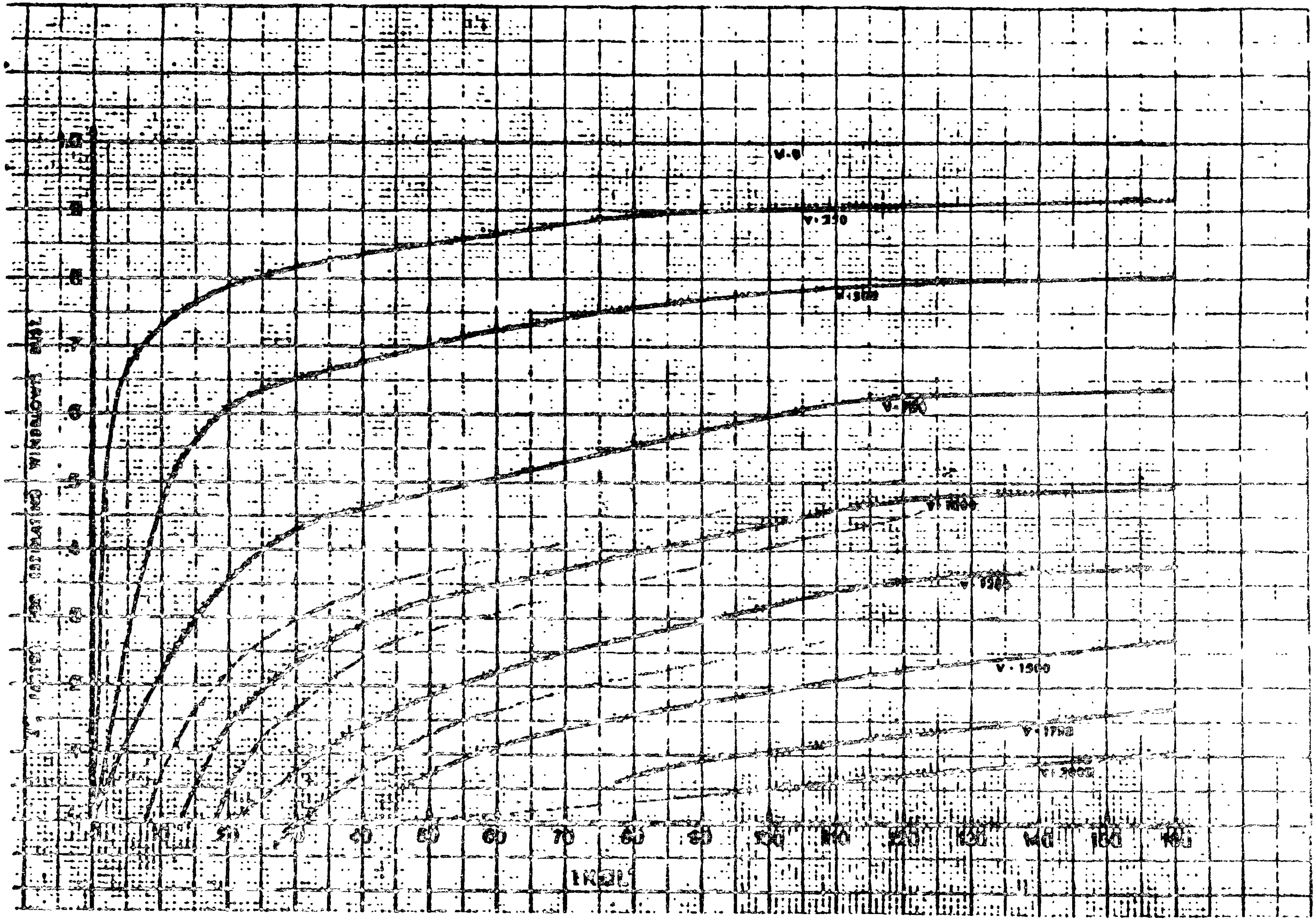


Figure A-3. Effect of vegetative cover on relative emission rate [17].

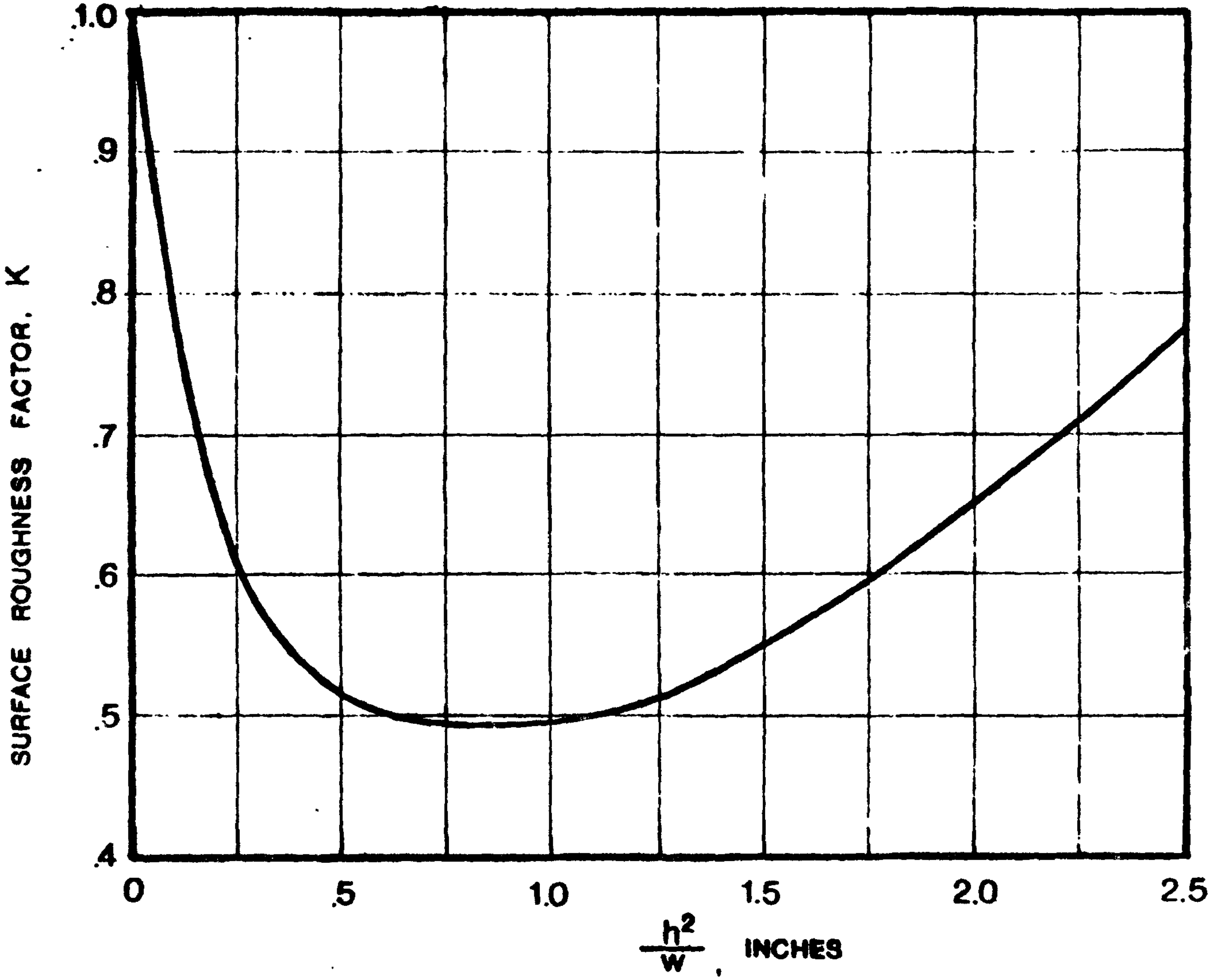


Figure A-4. Determination of surface roughness factor[17].

Appendix B: Detailed Description of the Hanna-Gifford Model

Analytically, this model may be formulated, for cases where emission strength of the receptor grid is much less than that of the neighboring grid squares, as follows:

$$\chi = \left(\frac{2}{\pi}\right)^{1/2} \frac{1}{u} \frac{(\Delta x/2)^{1-b}}{a(1-b)} \left\{ Q_o + \sum_{i=1}^{N} Q_i \left[(2i+1)^{1-b} - (2i-1)^{1-b}\right] \right\} \qquad \text{(B.1)}$$

$$i = 1, 2, 3, \ldots, N$$

or for uniform emissions from all neighboring grid squares as

$$\chi = C\,(Q/u) \qquad \text{(B.2)}$$

where

$C = \left(\frac{2}{\pi}\right)^{1/2} \left(\frac{2N+1}{2}\Delta x\right)^{1-b} \frac{1}{a(1-b)}$,

Q_o = Source strength for the receptor grid ($\mu g/m^2/s$)

Q_i = Source strength for the ith grid square ($\mu g/m^2/s$),

u = Average wind speed (m/s) over the desired averaging time (Greater than 20 minutes),

χ = Average concentration for a suitably defined region ($\mu g/m^3$),

Δx = Grid width (m),

N = Number of grids in any one direction that analysis indicates may have an impact on the receptor (usually limited to 4).

The terms a,b are based on the assumption that the vertical dispersion can be approximated by

$$\sigma_z = ax^b \tag{B.3}$$

where the "a" and "b" can be found in the CDM User's Guide [3].

Physical removal mechanisms can be incorporated into the model through the multiplicative factor

$$1/(1 + C (v_d/u))$$

where v_d is the deposition velocity. As a first approximation to the deposition velocity, the terminal velocity of the particles may be used. The terminal velocity may be found in Meteorology and Atomic Energy [40], if the particle diameter and density are known.

Appendix C: Modified CDM/Rollback Model

The analytical formulation of the CDM/Rollback source-receptor relationship is given by the relation

$$X_i = \alpha_{1i}C_i + \alpha_{2i}E_i + B \qquad (C.1)$$

where

X_i = Total suspended particulate concentraton, observed.

C_i = CDM calculated concentration of 0-10 and 11-20 μm particles.

E_i = Emissions of particles >20 μm in the grid square of the receptor.

B = Background TSP.

α_{1i} = Empirical coefficient to adjust CDM air quality predictions.

α_{2i} = Empirical coefficient relating emissions to air quality for large particles.

i = Denotes the receptor under consideration.

With the magnitude of the assumed background and the particle size distribution on the Hi-Vol filters known, it is a simple task to determine α_{1i} and α_{2i} in the above equation. For example,

let F = Average fraction of particles greater than 20 μm on Hi-Vol filter of monitor i (the larger F is, the greater is the influence of fugitive sources on TSP.

and let F_B = Average fraction of particles greater than 20 μm on Hi-Vol filter of background stations.

Then it follows that

$$FX_i = \alpha_{2i} E_i + F_B B \quad (C.2)$$

$$\text{and } (1-F) X_i = \alpha_{1i} C_i + (1-F_B)B \quad (C.3)$$

Solving for the empirical coefficients,

$$\alpha_{1i} = \frac{(1-F) X_i - (1-F_B)B}{C_i} \quad (C.4)$$

$$\alpha_{2i} = \frac{FX_i - F_B B}{E_i} . \quad (C.5)$$

A sample calculation is presented in Appendix E.

Appendix D: Information Required as Input to the CDM/Rollback Model

The specific format and description of the input procedures relating to the source emissions data, meteorological data and receptor locations are well-documented in the CDM User's Guide and, hence, are not reproduced here. However, for continuity, a brief summary of the required input to the model is given.

Meteorology Data

Meteorology data for the study area are obtained from the National Climatic Center (NCC) in Asheville, North Carolina. The NCC provides both the joint frequency function and mixing height data. The joint frequency function is a combined frequency of occurrence for three meteorological parameters as defined by CDM: six stability classes, six wind speed classes, and sixteen wind directions. The annual mixing height[58] and frequency functions should be obtained for the base year of the study, and an additional distribution should be obtained for a more extended period to reflect annual averages. The annual average will be used to forecast future air quality. Note that the CDM requires a division of D stability into day-night frequencies and that E and F stability frequencies are combined.

Determination of the Decay Constant

The pollutant half-life is required for the estimation of the decay term used in the CDM diffusion model for the 10-20 μm range. Half-life refers to the time elapsed before the ambient concentration of a given size particulate is reduced by one-half due to physical removal mechanisms (e.g., dry deposition and gravitational settling). The following derivation of half-life is based upon the Phoenix study[39]; however, the procedure can be readily applied to other areas. The computational technique is based on Van der Hoven's dry deposition formulation. First, it is assumed that a 15 μm diameter particle is representative of the 10-20 μm range. Then for an average wind speed of 2.41 m/s (mean for Phoenix) and a terminal fall speed of 1.69 cm/s (corresponding to a 15 μm diameter particle), Van der Hoven's expression for reduction of the source strength due to dry deposition may be used to determine the distance at which the effective source strength has been reduced to half its original value due to dry deposition. The time that it takes a parcel of air, embedded in the mean flow, to travel that distance may then be used as the half-life for particles in the 10-20 μm size range. An appropriate half-life value may then be used in the exponential decay term of CDM.

The results of the calculations, using the technique outlined above, are shown in Table D-1.

Because half-life (and the resulting decay term in CDM) varies with both stability and wind speed, the user must decide whether to use separate values for the various wind speed/stability categories of CDM or to use a single composite value. For Phoenix, a single composite value was used on the basis that this is only an approximation technique and that a more complex analysis is not justifiable. The composite value was derived from a weighted average of the half-life times given in Table D-1.

Table D-1. Half Life for Physical Removal Mechanism in the CDM for a 15μm Particle and a Mean Wind Speed of 2.4 m/s.

Stability	Half Life (min.)
A	∞*
B	∞*
C	691.2
D	62.2
E	42.2
F	27.7

*Not calculated, but can graphically be shown to be essentially infinite.

The weights used should be a function of two factors: (1) the percent frequency of each stability and (2) the relative contribution to the predicted concentration given by the model for each stability class. The latter contribution to the weighting term can be approximated from $\chi u/Q$ curves (for example, those given by Turner[59]). Such an analysis for Phoenix, shows that the weighted average only need be representative of D, E and F stability. Based on that calculation[39], the suggested decay time is approximately 40 minutes.

Emissions Parameters

Emissions parameters required as inputs by the air quality model include diurnal assignment of emissions, stack heights of sources, half-life of pollutant and magnitude of emissions by particle size class and grid sector.

The distribution of emissions between day and night is a required input parameter to CDM. To estimate this distribution, the emissions patterns of the major sources should be evaluated.

Physical stack parameters required for model plume rise calculations may be obtained from the National Emissions Data System. The source emission height for the area sources must be assumed (10 m was used in Phoenix).

Particle size distributions of the various emissions source categories should be used to express the gridded emission inventory (Section 3) in terms of the three particle size ranges (Section 4.2). Because of the general lack of information available to characterize the particle size of the various sources, substantial uncertainty is associated with available distribution estimates. Figures D-1 and D-2 summarize the available data for particle size distributions of anthropogenic fugitive dust sources and conventional sources. Distributions for fugitive emissions caused by wind erosion approximate that of the parent soil (Section 3.2.2), and must be determined from soils data for the specific study area.

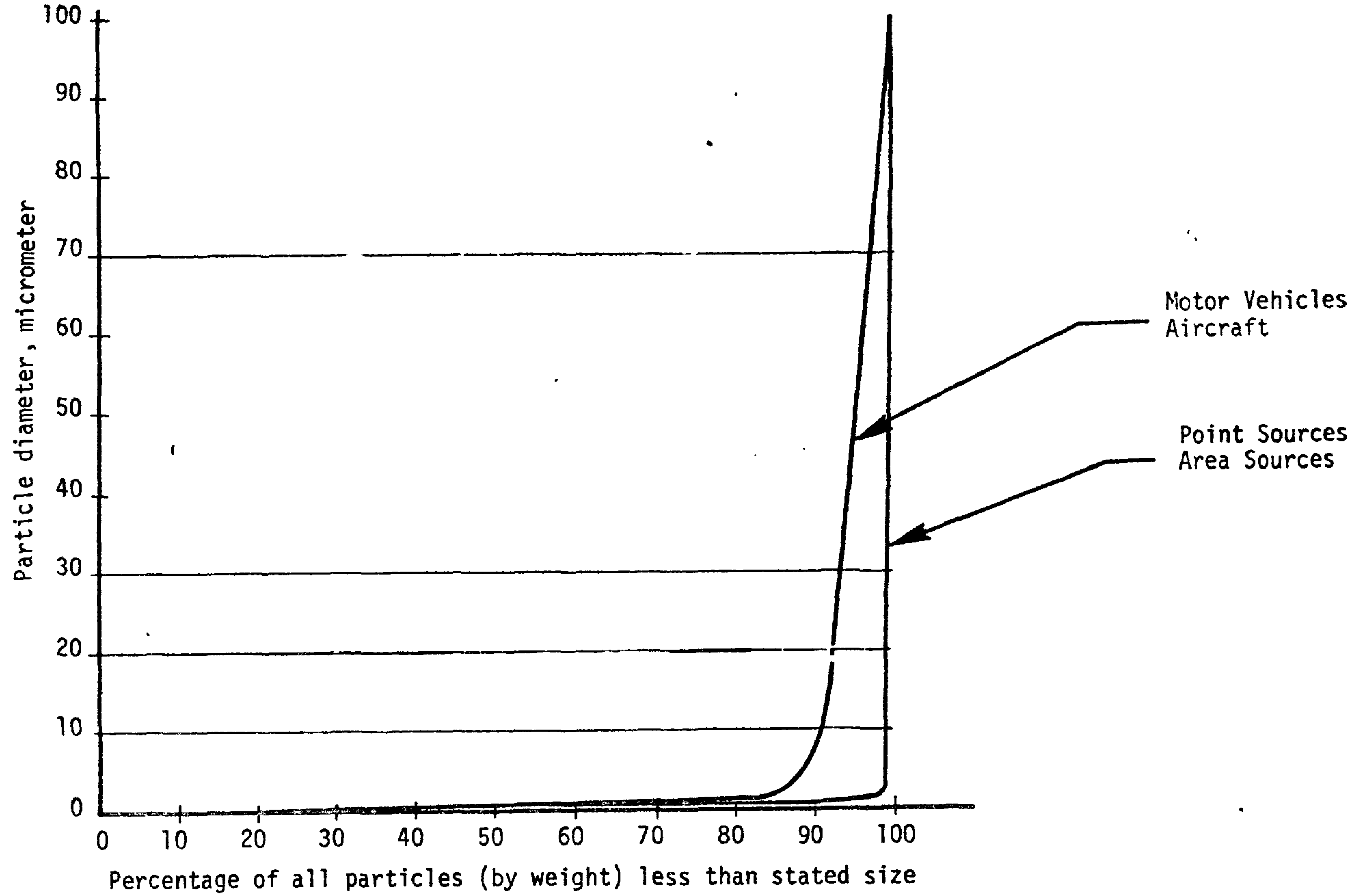


Figure D-1. Particle Size Distribution of Conventional Emission Sources

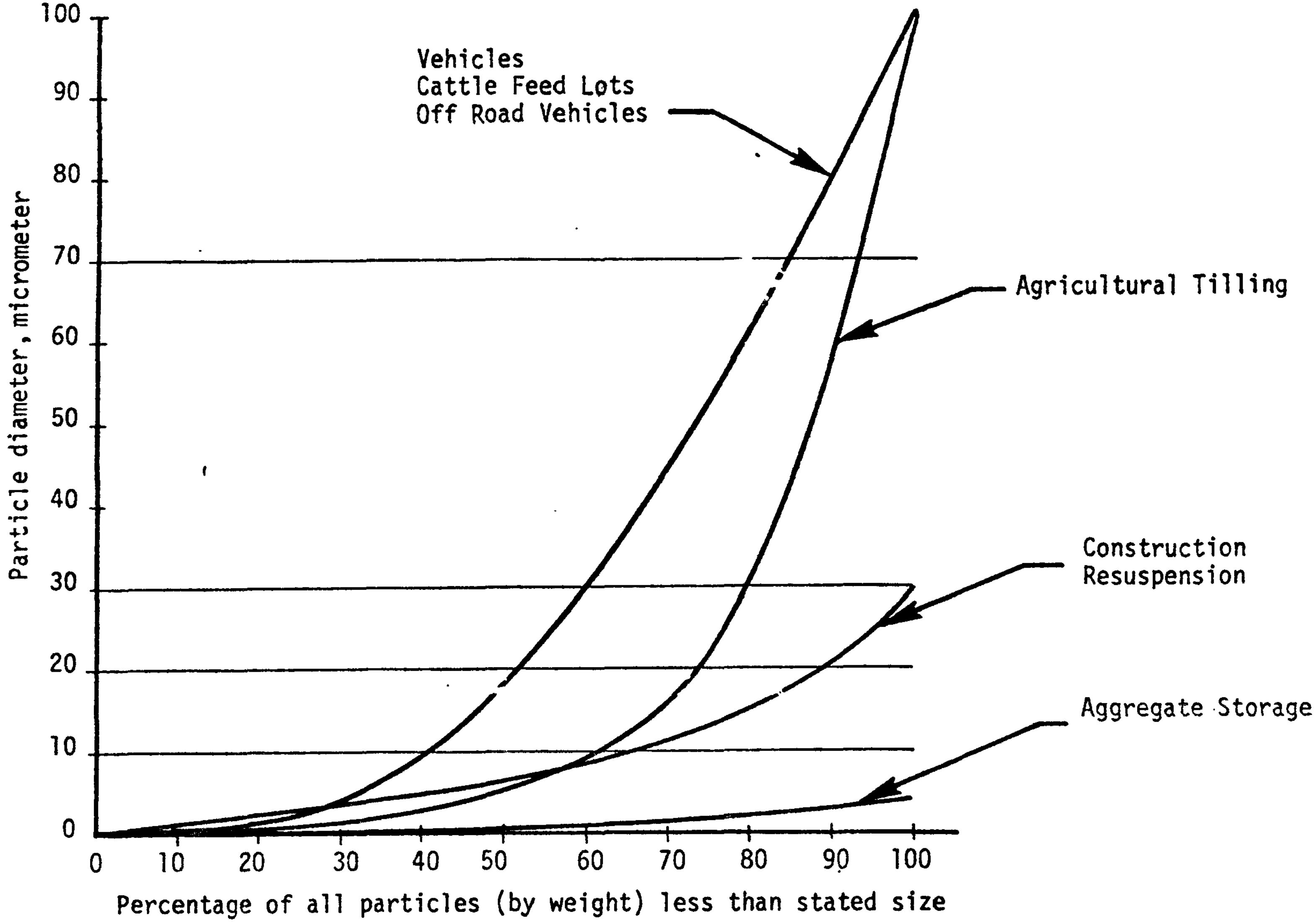


Figure D-2. Particle Size Distribution of Anthropogenic Fugitive Dust Emission Sources

Appendix E: Sample Application of the CDM/Rollback Model

This appendix outlines the procedures which were used to adjust the air quality model estimates and to generate baseline air quality projections for future years.

E.1 Determination of Empirical Coefficients

Figure E-1 is a schematic diagram portraying a single complete run of the CDM/Rollback model. In the first step, the Emissions Simulator Program produces a disaggregated gridded emission inventory. Next, emissions from 0-10 and 11-20 µm ranges are combined with the meteorological data and run through the CDM. The CDM output and the emissions in the 21-70 µm range are input to a parameterization program.[39] This program requires two additional inputs: (1) the average contribution of each of two particle size ranges (0 to 20, and 20-70 µm) to TSP levels at a given receptor, and (2) the background level of TSP in the study area. The source and procedure for tabulating these inputs, plus the actual assignment of empirical coefficients to the model, are discussed below.

Background Levels of TSP

A survey of monitoring sites located remotely from any urban area of the study region should be undertaken to determine typical background levels of TSP affecting the monitor measurements. The background level may be interpreted as an uncontrollable source comprised of particulate

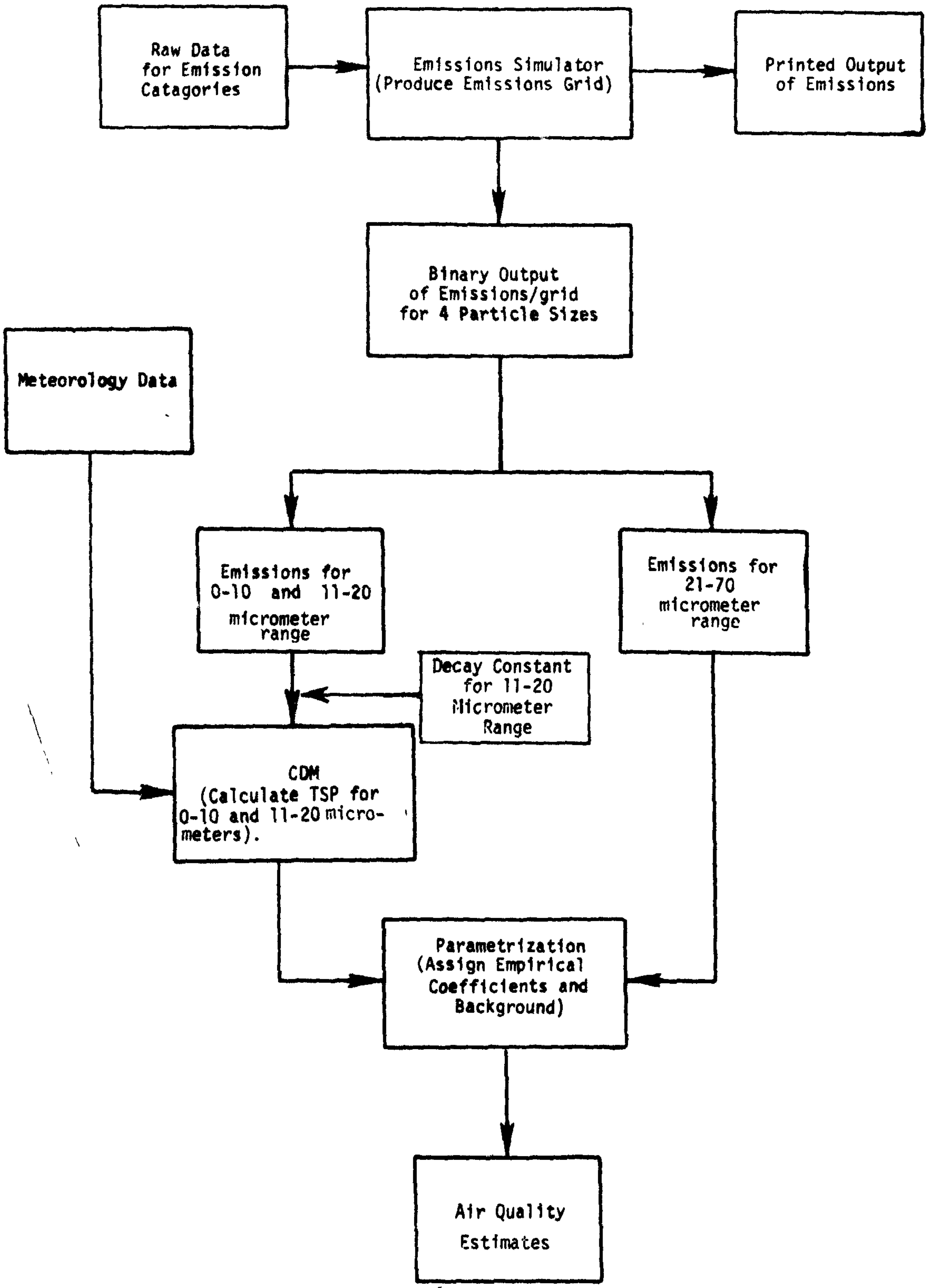


Figure 1: Computer Modeling System

loading and originating from (1) natural sources in the area, and (2) from suspended particulates transported from other areas. Background particulate levels typically vary from 20 to 40 $\mu g/m^3$ throughout the United States[15, 60].

Particulate Size Distribution of Ambient TSP

Mechanical separators (e.g., cascade impactors) or microscopy analyses of hi-vol filters serve as the basis for establishing the average contribution of each particle size class to the TSP levels. In areas with numerous fugitive dust sources, a substantial portion of the particulate mass found in hi-vol monitor filters is comprised of particles greater than 20 μm diameters. Particle size determinations should be obtained for selected days of contrasting meteorology and TSP levels at each of the various monitor sites. Distinguishable patterns in the particle distributions at each of the monitors should be identified, and an average distribution should be estimated over the range of meteorology and TSP levels experienced in the baseyear. In the Phoenix Fugitive Dust Study[39], the resulting particle distributions on the hi-vol filters was relatively invariant for the particle classes considered in the model parameterization. Although sampling was limited, the results showed[61] about 70% of the particle mass to be comprised of particles larger than 20 μm at all monitor sites examined, under both windy and calm conditions. In the Phoenix study, this finding simplified the assignment of empirical constants substantially.

Assignment of Empirical Constants

Recall that the overall air quality model is expressed as:

$$X_i = \alpha_{1i} C_i + \alpha_{2i} E_i + B \qquad (C.1)$$

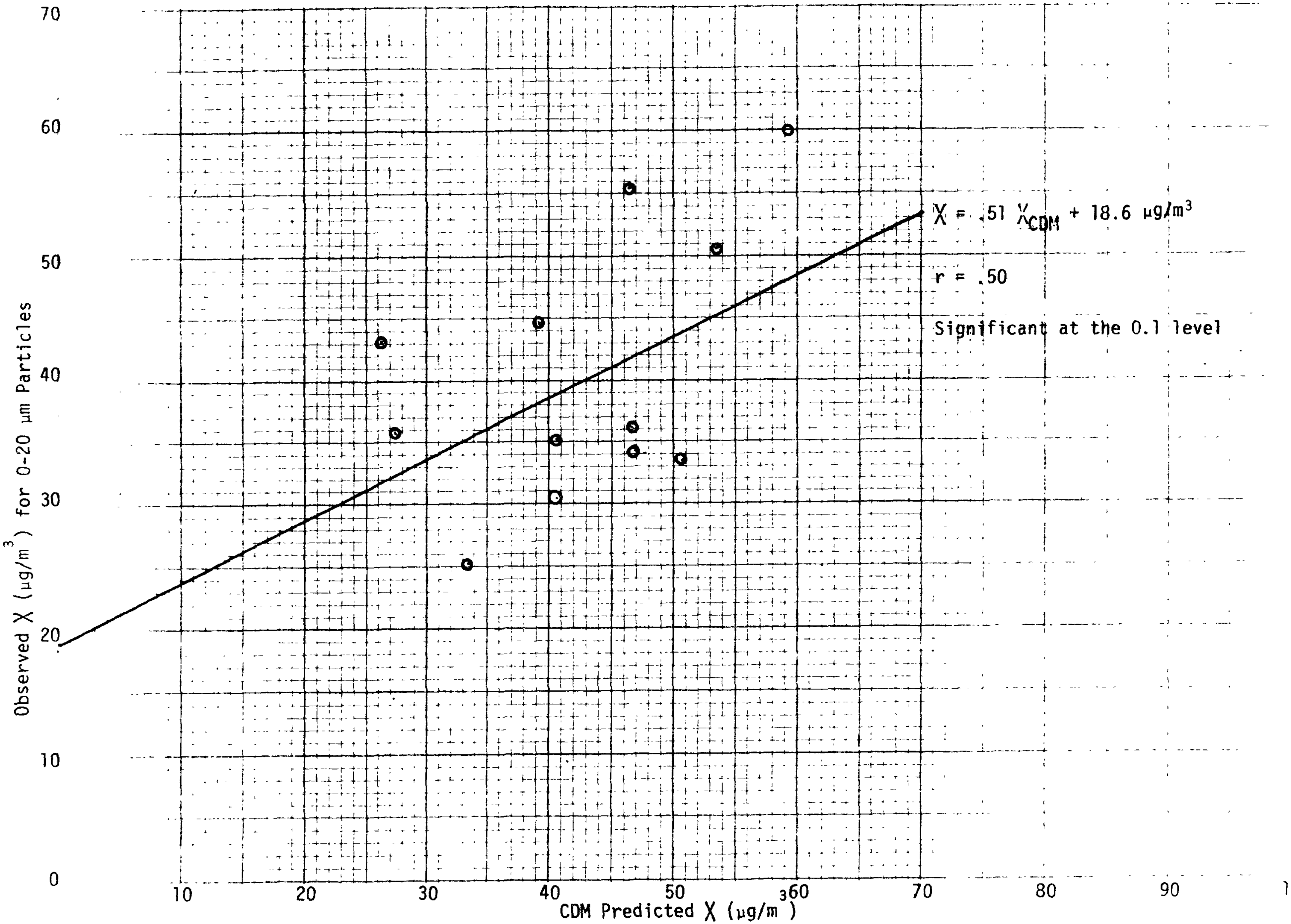
The empirical coefficients are calculated after the CDM has estimated the ambient level of suspended particulates (C_i) in the 0 to 20 μm diameter size range using Equations (5) and (6). Table E-1 illustrates a systematic computation scheme for the empirical coefficients for Phoenix where microscopic analysis gave an F value of 0.7. Column 1, 2, and 3 contain the CDM predictions based on emissions from small particles, column 4 the actual observed air quality, and column 5 the emissions of particle 21-70 μm within the grid square of each receptor. Columns 7 and 9 are the contribution of TSP from particles 0-20 μm in size and from particles 21-70 μm in size, respectively. The coefficients α_{1i} and α_{2i} are shown in columns 6 and 8 and are computed from the equations above. X_i is found in column 11 and C_i and E_i are in columns 3 and 5, respectively.

A brief statistical analysis of the observed and estimated concentrations in columns 3 and 4 can give some indication of the performance of the CDM. Figure E-2 shows the comparison between the CDM model results (for the 0-20 μm particles) and 30% (recall that the microscopic analysis of the Hi-Vol filters indicated that 30% of the weight of the particulates on the filter were 20 μm and smaller) of the observed

TABLE E-1 EMPIRICAL COEFFICIENTS DETERMINED FOR PHOENIX C[illegible]/ROLLBACK MODEL[39]

AIR QUALITY RECEPTORS	1 CDM 0-10μ (μg/m³)	2 CDM 11-20μ (μg/m³)	3 ΣC CDM (μg/m³)	4 OBSERVED AQ (μg/m³)	5 EMISSIONS IN GRID (21-70μ) (tons/day)	6 α_{1i}	7 α_{2i} C_i (μg/m³)	8 α_{2i} $\frac{\mu g/m^3}{T/day}$	9 α_{2i} E_i (μg/m³)	10 B (μg/m³)	11 X_i (μg/m³)
2 C. Phoenix	43.4	6.4	49.8	112	3.69	0.37	18.6	17.18	63.4	30	112
3 S. Phoenix	23.5	2.3	25.8	144	1.73	1.09	28.2	49.60	85.8	30	144
4 Arizona St.	45.3	7.1	52.4	169	4.35	0.68	35.7	23.75	103.3	30	169
5 Glendale	35.1	4.4	39.5	101	2.59	0.39	15.3	21.51	55.7	30	101
7 N. Phoenix	39.5	6.1	45.6	121	3.81	0.47	21.3	18.29	69.7	30	121
8 N. Scott/Par Va.	33.0	5.4	38.4	149	2.97	0.77	29.7	30.07	89.3	30	149
9 Scottsdale	40.3	5.7	46.0	115	3.71	0.42	19.5	17.65	65.5	30	115
10 Mesa	34.6	5.0	39.6	117	3.28	0.51	20.1	20.40	66.9	30	117
11 Downtown	51.0	7.4	58.4	200	4.35	0.77	45.0	28.74	125.0	30	200
12 St. Johns	14.1	1.0	15.1	145	1.66	1.89	28.4	52.11	86.5	30	145
13 Sun City	29.0	3.6	32.6	88	4.74	0.35	11.4	9.83	46.6	30	88
14 Par. Valley	38.8	6.4	45.2	184	3.92	0.89	40.2	29.03	113.8	30	184
15 Carefree	7.7	0.6	8.3	42	0.71	-.29	-2.4	20.28	14.4	30	42
16 Chandler	23.9	3.0	26.9	119	3.75	0177	20.7	18-21	68.3	30	119

Figure E-2 CDM Predicted Concentrations vs. 30% of Observed Concentrations



concentration at each site. Also shown in Figure E-2 is the result of a linear regression analysis of that data. The intercept (18.6 $\mu g/m^3$) is very close to value assumed for background, 15.0 $\mu g/m^3$ for the 0-20 μm range. The slope, 0.51, is a common result for Gaussian models. A prior application of CDM without modification for particle size (not shown here), resulted in essentially no correlation between observed and estimated concentrations. The regression analysis, therefore, gives some indication that the modified CDM substantially improves the treatment of 0-20 μm particles. This is significant since nearly 70% of the emissions are in this size range (for Phoenix).

An explanation that completely accounts for differences between the CDM results estimates the observations is not possible, but the following observations should be considered. First, there is probable bias of the observed values from true representative concentrations due to variations in monitor height, completeness of data, and representativeness of the monitor site environment. Second, there is probable bias in the emissions data base due to numerous uncertainties underlying the development of the fugitive dust emissions inventory. Third, there is the possibility of an inconsistent assumption regarding the particle size distribution in the emissions data and the monitor data. Finally, there are limitations associated with the assumptions of the model itself. While the implications of any one particular limitation on the predictability achieved by the model may be assessed, the simultaneous intervention of many influencing factors known to be affecting the model results make any attempt to explain the variations very difficult. In addition, the explanation is likely to be different for each of the monitor sites.

It must also be recognized that the relationship between local emissions levels and TSP, as reflected in α_{2i}, is distinctly unique for each grid square because of the numerous variations of local source distributions around the monitors. Accordingly, it was considered appropriate to assign a separate empirical factor for application to each of the monitor sites. This, of course, makes the interpretation and application of this model highly site specific. It must be kept in mind that the value of α_{2i} will change according to future development in the grid square and periodic reevaluation is necessary.

E.2 Air Quality Estimates

The base line emissons levels corresponding to the base year and projected years are translated into air quality descriptions using the empirical source receptor relationship discussed previously. The model is used to evaluate contributions of each of the source categories to TSP levels, and the impact of source changes on air quality.

Base Year Estimates

The empirical model should be employed to calculate suspended particulate levels caused by each of the major emission sources suspected to be affecting TSP levels significantly. For areas where TSP levels are dominated by fugitive dust sources, it is likely that nearly all the TSP level (excluding background) will be caused by emissions from unpaved roads, entrained street dust, construction activities, or wind erosion. Sites which are most dramatically affected by wind-erosion emissions tend to be located in the rural areas presently under

TABLE E-2. IMPACT OF MAJOR SOURCES ON TSP LEVELS IN THE PHOENIX AREA[39].

MONITOR SITE	OBSERVED TSP IN 1975 BACKGROUND EXCLUDED	CONTRIBUTION OF SUSPENDED PARTICULATES FROM FOUR MAJOR SOURCES $\mu g/m^3$				PERCENTAGE OF TSP LEVEL CONTRIBUTED FROM FOUR MAJOR SOURCES & BACKGROUND
		UNPAVED ROADS	ENTRAINED DUST	CONSTRUCTION ACTIVITIES	WIND EROSION	
Central Phoenix	82	25	31	4	19	96.3
S. Phoenix	114	75	20	2	15	98.2
Arizona State	139	35	59	7	33	96.4
Glendale	71	30	17	7	15	97.2
N. Phoenix	91	26	28	7	28	97.8
N.Scotts/Para. V.	119	24	8	14	71	98.3
Scottsdale	85	27	33	6	16	96.5
Mesa	87	32	35	8	10	97.7
Downtown	170	42	70	8	40	94.1
St. Johns	115	93	2	0	18	98.3
Sun City	58	15	12	3	2	55.2
Paradise Valley	154	42	14	17	78	98.1
Chandler	89	64	10	7	5	96.6

development. Other sites within cities may also be significantly affected by wind-blown dust emissions. These sites are generally surrounded by numerous vacant lots and/or dirt around residence yards. Entrained street dust tends to impact air quality at sites located in the city areas. Emissions from unpaved roads may contribute significantly to TSP at each of the sites, but are generally particularly dominant in the suburbs areas. Table E-2 illustrates the effect of these major fugitive dust sources in the Phoenix area, as estimated by the source-receptor model.

Projected Base Line TSP Levels

The projected emission levels for future years should be translated into air quality estimates using the source-receptor model developed earlier. These estimates are compared to base year levels for each of the monitoring locations in the study area. Significant changes in air quality are calculated and analysed. In many cases, air quality in areas presently experiencing fugitive dust problems will improve significantly in future years due to base line development planned for the area. This development will change the distribution of emission sources, eliminate local sources near the monitors, and diminish the magnitude of many sources. While total dust emissions from unpaved roads may not decrease, the distribution of these emissions may change substantially owing to city roadway improvement programs. Wind erosion emissions may decrease in future years due to reduction in wind erosion sources (i.e., vacant property), and may increase or decrease based on expectation of typical meteorology in future years. Contributions to TSP from entrainment of street dust are expected to increase with increasing vehicle registration, especially at monitors located within the city areas. Table E-3 is an example format useful for comparison of the base year and projected base line source contributions to air quality.

TABLE E-3 IMPROVEMENT IN TSP LEVELS DUE TO ANTICIPATED DEVELOPMENT IN THE PHOENIX AREA[39]

MONITOR SITE	1975 Observed (TOTAL) µg/m³	1985 Projected (TOTAL) µg/m³	Percentage Reduction in TSP 1975 to 1985 µg/m³	Unpaved Roads 1975 µg/m³	Unpaved Roads 1985 µg/m³	Resuspension 1975 µg/m³	Resuspension 1985 µg/m³	Construction 1975 µg/m³	Construction 1985 µg/m³	Percentage of TSP Contributed by 3 Major Sources Excluding Background 1975	Percentage of TSP Contributed by 3 Major Sources Excluding Background 1985
C. Phoenix	112	87	22.3	25	8	31	37	4	5	73	88
S. Phoenix	144	101	29.8	75	32	20	24	2	9	85	91
Arizona St.	169	132	21.9	35	12	59	68	7	9	73	87
Glendale	101	65	35.6	30	9	17	20	7	2	76	88
N. Phoenix	121	83	30.4	26	8	28	32	7	7	67	89
N. Scott/Paradise	149	101	32.2	24	32	8	9	14	25	39	93
Scottsdale	115	93	19.1	27	10	33	42	6	5	78	90
Mesa	117	95	18.8	32	13	35	45	8	4	86	95
Downtown	200	155	22.5	42	15	70	82	8	10	71	86
St. Johns	145	157	-8.3	93	116	2	0	2	6	84	96
Sun City	88	74	15.9	15	6	12	17	3	16	52	89
Paradise Valley	184	93	49.4	42	14	14	17	17	25	97	89
Chandler	119	160	-34.5	64	91	10	12	7	23	91	97

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The document outlines a methodology for development of control strategies for areas experiencing non-attainment problems due to fugitive dust emissions.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Particulate Matter Total Suspended Particulate Emission Sources Control Methods Fugitive Dust Air Quality Measurement Air Quality Modeling		

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