EPA/600/8-85/002
February 1985

RAPID ASSESSMENT OF EXPOSURE TO PARTICULATE EMISSIONS FROM SURFACE CONTAMINATION SITES

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FOREWORD

The Exposure Assessment Group (EAG) of EPA's Office of Research and Development has three main functions: (1) to conduct exposure assessments; (2) to review assessments and related documents; and (3) to develop guidelines for Agency exposure assessments. The activities under each of these functions are supported by and respond to the needs of the various EPA program offices. In relation to the third function, EAG sponsors projects aimed at developing or refining techniques used in exposure assessments. This study is one of these projects and was done for the Office of Emergency and Remedial Response.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 established a national fund for the purpose of cleaning up spills and abandoned sites containing hazardous substances. When these sites are discovered EPA must decide quickly if an urgent threat exists requiring immediate action. This project is intended to aid the Agency in making these decisions by providing a method for rapidly evaluating the human health and environmental threat caused by particulate emissions from land contamination sites.

Spills, waste disposal, and various waste industrial operations can result in the contamination of land surfaces with toxic chemicals. Soil particles from these areas can be entrained into the air, transported off-site via the wind, and result in human exposure by direct inhalation. Indirect exposure could result if particulates are deposited in agricultural fields, pastures, or waterways and enter the human food chain. This exposure route is enhanced by the facts that many of the environmentally troublesome compounds are tightly bound to particles and that many surface contaminated sites have conditions favoring wind erosion, such as sparse vegetation cover and high levels of activity which disturb the surface.

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ABSTRACT

Emergency response actions at chemical spills and abandoned hazardous waste sites often require rapid assessment of (a) the potential for atmospheric contamination by the chemical or waste compound and (b) the inhalation exposure of people living in the vicinity of a surface contamination site. This manual provides a methodology for rapid assessment of inhalation exposure to respirable particulate emissions from surface contamination sites. Respirable particulate matter is defined as airborne particles equal to or smaller than 10 μm aerodynamic diameter. The methodology consists of a site survey procedure, particulate emission factor equations for wind and mechanical entrainment processes, procedures for mapping atmospheric contaminant concentration distributions by scaling the output of pre-solved computer models of regional atmospheric dispersion, and an equation for calculation of inhalation exposure. In addition to the components of the methodology, this manual discusses critical contaminant and site characteristics, describes assumptions and limitations of the procedures, and presents example applications.

The quantitative procedures for estimating atmospheric contaminant concentrations are based on a number of simplifying assumptions related to the contaminated surface and the atmospheric environment, to conform to the data, time, and resource limitations expected during an emergency response. Consequently, the assessment methodology provides order-of-magnitude estimates of atmospheric contaminant concentrations as a function of averaging time and downwind location. The user should carefully review all the assumptions and limitations, and make specific judgments as to their validity for the specific site, contaminant(s), and emergency situation being analyzed. Familiarity and prior training in the use of this manual is highly recommended for efficient use during an emergency response situation.

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ACKNOWLEDGEMENTS

A number of organizations and individuals contributed to the preparation of this document. Financial support was provided by the EPA Office of Emergency and Remedial Response through a prime contract with Anderson-Nichols and Company, Inc. Mr. Anthony S. Donigian, Jr., was the Project Officer for Anderson-Nichols and Mr. John Schaum (Exposure Assessment Group) was the EPA Technical Project Monitor. These individuals provided valuable technical guidance to Midwest Research Institute.

Midwest Research Institute was assisted in the area of wind erosion emission assessment by Dr. Dale A. Gillette of the NOAA Environmental Research Laboratories. In addition, technical review comments were provided by the following individuals: Mr. Rodger K. Woodruff, Dr. G. A. Sehmel, and Dr. T. W. Horst of Battelle Pacific Northwest Laboratories; Dr. H. E. Cramer of H. E. Cramer Company, Inc.; Mr. David Lincoln of CH_2M Hill; and Ms. Geraldine K. Cox of the Chemical Manufacturers Association.

Among the authors, Dr. Chatten Cowherd was the program manager for Midwest Research Institute. Dr. Gregory Muleski developed the dispersion modeling approach and the output format. Mr. Phillip Englehart provided expertise in meteorology and climatology related to the estimation of parameters for emissions and dispersion models. Dr. Cowherd and Dr. Gillette collaborated on developing the emission models and the field survey procedure.

SECTION 1

INTRODUCTION

The purpose of this manual is to provide a rapid assessment methodology for estimating potential atmospheric contamination and resulting inhalation exposure of people living in areas surrounding an abandoned hazardous waste or toxic chemical spill site. Only respirable particulate emissions, defined as particles equal to or smaller than 10 μm aerodynamic diameter (denoted by the symbol PM_{10}) are considered in this assessment methodology. PM_{10} is the anticipated size fraction for the impending revision to the primary (health-related) national ambient air quality standard (Federal Register, 1984).

Specifically, this manual is designed for use by field personnel to quickly estimate how breathing-height concentrations of contaminated respirable particulate matter might change with distance and direction from an emergency response site, under annual average and worst-case 24-hr conditions. The procedures include evaluation of critical contaminant and site characteristics as input to an assessment methodology for analyzing the entrainment and atmospheric dispersion of chemicals or contaminated surface material. A modeling technique has been developed for determining the spatial distribution of atmospheric contaminant concentration resulting from wind and/or mechanical entrainment processes, taking into account regional differences in meteorology. Guidelines for evaluating critical contaminant and site characteristics are provided to allow estimation of needed input parameters.

1.1 SCOPE AND LIMITATIONS OF THIS MANUAL

The phrase EMERGENCY RESPONSE is emphasized throughout this manual because it has been the overriding criterion (and constraint) for selection, evaluation, and development of pollutant transport assessment methods and parameter evaluation techniques included herein. Emergency response situations require assessments of potential atmospheric contamination to be completed in less than 24 hr. Consequently, extensive field sampling, laboratory analyses, data search and collection, and sophisticated computer analyses are generally impractical during this limited time frame. Although these extensive sampling and analysis activities may be initiated during the emergency response period, the results cannot be expected to be available for use in an emergency assessment. The assessment procedures in this manual are designed to allow emergency response personnel to make a first-cut, order-of-magnitude estimate of the potential extent of atmospheric contamination and exposure resulting from a waste site or chemical spill, within the 24-hr emergency response time frame.

The primary goal of this manual is to provide the basis for determining the need for emergency actions, such as emergency sampling, containment/stabilization or removal, in order to minimize human exposure to atmospheric contamination by respirable particulate matter in the vicinity of an emergency response site. Two specific emergency response situations are envisioned where the assessment procedures in this manual would be applied:

1. Discovery of an abandoned hazardous waste site where an assessment of the potential extent of the atmospheric contamination is needed within the emergency response time frame.

2. Spill (or leakage) of a toxic waste or chemical where the potential for atmospheric contamination and/or the extent of contamination must be assessed within the emergency response time frame.

Time and resource limitations expected during an emergency response have required a number of simplifying assumptions in the assessment procedures; additional simplifications may be needed by the user due to limited data and information available at a particular emergency response site. The most fundamental assumptions incorporated into the assessment procedures in this manual are as follows:

1. Uniform contamination of a symmetrical land area is assumed, with the concentration in respirable particulate emissions matching the bulk contaminant concentration in the surface material.

2. Emission rates associated with wind and mechanical entrainment processes are modeled as continuous and steady.

A variety of other assumptions and limitations in the procedures are further discussed in Section 4.4. The user should carefully review all the assumptions and limitations, and make specific judgments as to their validity for the specific site, contaminant(s), and emergency situation being analyzed.

Perhaps the most critical aspect of an emergency response situation will be the ability of the user to adequately characterize, within the 24-hr time frame, the surface media (e.g., erodibility, suspendible particle content, level and extent of surface contamination) from which the contaminants are emitted. Consequently, access to and/or availability of data, expertise, and familiarity with local, site-specific surface conditions is critical to the successful application of the assessment procedures in this manual. If the emergency response situation consists of a long-term surface contamination problem with no apparent change in intensity, it may be reasonable to extend the response time frame beyond 24 hr.

1.2 REQUIRED USER BACKGROUND, TRAINING, AND PREPARATION

Effective use of this manual requires a general understanding of a mix of disciplines, such as climatology, soil science, chemistry, on the part of the intended user, and sufficient familiarity or training with the techniques, procedures, and auxiliary sources of information described herein.

This manual is not intended to be a primer on pollutant release and transport through the atmosphere; a variety of excellent introductory textbooks and reports in these areas are available to the potential user to provide the needed background.

Ideally, advanced academic training in physical science supplemented with pertinent work experience and job training, (e.g., short course attendance) provides a profile of the recommended background for a user. Alternatively, an engineering or science undergraduate degree with appropriate training is acceptable as long as a basic understanding in the following areas is included:

1. The mechanisms of wind and mechanical entrainment of surface particulate matter.

2. Meteorological concepts, processes, and terminology related to atmospheric transport.

3. Soil science concepts related to surface soil processes.

4. Chemical processes, parameters, and terminology.

5. Mathematical capabilities and skills in the use of scientific hand calculators.

6. Map reading techniques.

In many emergency response situations, the user will have access to experts in the above disciplines to provide guidance in parameter evaluation. Thus, it is important that the user comprehend the fundamental concepts of each discipline in order to take full advantage of available expertise.

User training and preparation is needed to develop familiarity with the assessment procedures described in this manual. Training and/or familiarity with the specific procedures described herein is absolutely essential to effectively use this manual. Without prior study, users cannot expect to use this manual for assessing potential atmospheric contamination within a 24-hr period. Every effort has been made to simplify the procedures and parameter evaluation guidelines; however prior study is needed to become familiar with the assumptions/limitations, the step-by-step calculations, the application of the graphs, the parameter evaluation guidelines, and the auxiliary sources of information.

Since site characterization may require the greatest effort during an emergency assessment, preparation of a regional or local data base on meteorology, soils properties, and local experts (i.e., contacts and phone numbers) could considerably shorten the time needed to obtain data and improve the resulting parameter estimates. A similar, regional data base for the characteristics of wastes and chemicals produced in, or transported through, the region would be extremely valuable. Recommendations for the contents and format of such a regional data base have been developed for EPA (Battelle PNL, 1982).

1.3 FORMAT OF THE MANUAL

The format of this manual is similar to that used in the companion manual on the rapid assessment of potential groundwater contamination. (Donigian et al., 1983). In this section as well as Section 2, much of the wording was taken directly from the companion manual whenever the subject matter was common to both manuals.

Section 2 describes the types of hazardous waste and spill situations for which the assessment procedures are designed, and provides a methodology flowchart to guide an application. An overview of critical compound and site characteristics is provided along with a discussion of recommended sources of information. Section 3 provides technical guidelines for conducting a contamination site survey.

Section 4 provides a detailed description of the assessment methodology, making use of information gathered from the site. Guidelines are presented for estimating the other input parameters for the assessment. Emphasis is placed on obtaining local site and contaminant specific data in order to obtain realistic parameter estimates. Section 4 also discusses the assumptions and limitations of the assessment procedures; these should be carefully reviewed and understood by the user.

Section 5 presents example applications for the assessment. Section 6 includes cited references. Appendix A contains photographs of ground surfaces of varying erodibility. Appendix B describes the evaluation of the integral needed for calculation of wind erosion emission rates. Appendix C presents a general discussion of atmospheric dispersion models and their applicability to the assessment; Appendix C also describes the process by which meteorological input to the assessment procedures was developed. Appendix D provides the tabulated dispersion modeling output needed for implementation of the assessment procedure. Appendix E provides particulate emission factors for several mechanical entrainment processes other than vehicle traffic. Appendix F is a glossary of terms. Finally, Appendix G contains graphics needed to create the map overlays for use in the assessment process.

1.4 CAVEAT

Although all efforts have been made to insure the accuracy and reliability of the methods and data included in this manual, the ultimate responsibility for accuracy of the final predictions must rest with the user. Since parameter estimates can range within wide limits, especially under the resource and time constraints of an emergency response, the user should assess the effect of methodology assumptions and parameter variability on predicted concentrations for the specific site. The methodology predictions must be evaluated with common sense, engineering judgment, and fundamental principles of soil science, meteorology, and chemistry. Accordingly, neither the authors nor Midwest Research Institute (MRI) assume liability from use of the methods and/or data described in this manual.

SECTION 2

OVERVIEW OF RAPID ASSESSMENT METHODOLOGY

An emergency response to releases of hazardous substances is generally comprised of three steps--characterization, assessment, mitigation--defined as follows (Battelle PNL, 1982):

- Characterization - The acquisition, compilation, and processing of data to describe the scene so that a valid assessment of alternative actions can be made.

- Assessment - An analysis of the severity of an incident; the evaluation of possible response actions for effectiveness and environmental impact.

- Mitigation - The implementation of the best response action and followup activities.

This manual addresses the first and second steps relative to potential for atmospheric contamination and resulting exposure.

The assessment procedures for potential atmospheric contamination in this manual draw upon data and information developed in the characterization phase in order to provide a tool for performing parts of the assessment phase when atmospheric contamination is suspect. The EPA Field Guide for Scientific Support Activities Associated with Superfund Emergency Response (Battelle PNL, 1982) provides an excellent framework within which to view these procedures as part of the arsenal of the emergency response team for assessments of hazardous substance releases. This field guide identifies the calculation of transport rates of hazardous materials as an important element in the assessment phase. When entrainment and atmospheric transport of hazardous substances is important at an emergency response site, these calculations can be made with the procedures described herein based on the methodology assumptions and data expected to be available within the emergency response time frame.

2.1 APPLICATION SCENARIOS

Surface contamination by hazardous materials may result from surface spills; seepage from waste injection operations, waste storage/burial sites; and upward migration from leaks in underground containers (i.e., waste or storage) or pipelines. The rapid assessment procedures are designed for application in two typical scenarios, or cases, based on the temporal nature of the release:

- A typical hazardous waste site or chemical/waste storage facility where the depth of surface contamination provides a relatively continuous and constant potential for emissions over an extended period of time (e.g., years).

- A typical spill incident where the contaminant is highly exposed in a relatively thin surface layer such that emissions can be expected to decay significantly over a relatively short period of time (e.g., weeks or months).

The assumption of a constant release either on a continuous or intermittent basis is necessary for the analytical solutions which have been developed for application within the emergency response time frame. Consequently, although actual releases may be time decaying, the user will need to approximate the actual release as a constant over a given exposure period. However, the constant can be adjusted to reflect the decrease in release rate as the surface contamination is depleted.

Superimposed on the temporal nature of the release is the averaging time of concern for the assessment of resulting atmospheric contamination. The averaging time may represent either long-term (monthly, annual) conditions or short-term (24-hr) "worst-case" conditions. Thus, the time period of concern and the temporal nature of the release jointly determine the appropriate type of analysis (i.e., annual average versus worst-case) and parameter estimates for the driving force behind contaminant transport.

2.2 METHODOLOGY FLOWCHART

The overall flowchart for the rapid assessment methdology is shown in Figure 2-1. Prior to initiating application of these procedures, the On-Scene Coordinator (OSC) at the emergency response site must determine that (a) the potential for atmospheric contamination exists, and (b) an assessment of the potential or current extent of contamination must be made within the 24-hr emergency response time frame. These decisions will be based on the results of the characterization phase of the emergency response effort and will depend on current conditions (e.g., extent of contamination of surface material, weather forecasts), contaminant characteristics (e.g., toxicity, solubility, sorption, volatility), and site characteristics (e.g., soil characteristics, distance to populated areas). If no emergency assessment is deemed necessary, the procedures in this manual should not be used, except as preliminary guidance for subsequent detailed sampling, analysis, and investigations. If an emergency assessment is deemed necessary, the steps in Figure 2-1 should be followed.

The rapid assessment methodology is directed to estimation of respirable particulate inhalation exposure of people living in the vicinity of a surface contamination site. The assessment methodology consists of three sequential estimating procedures as described in the following subsections.

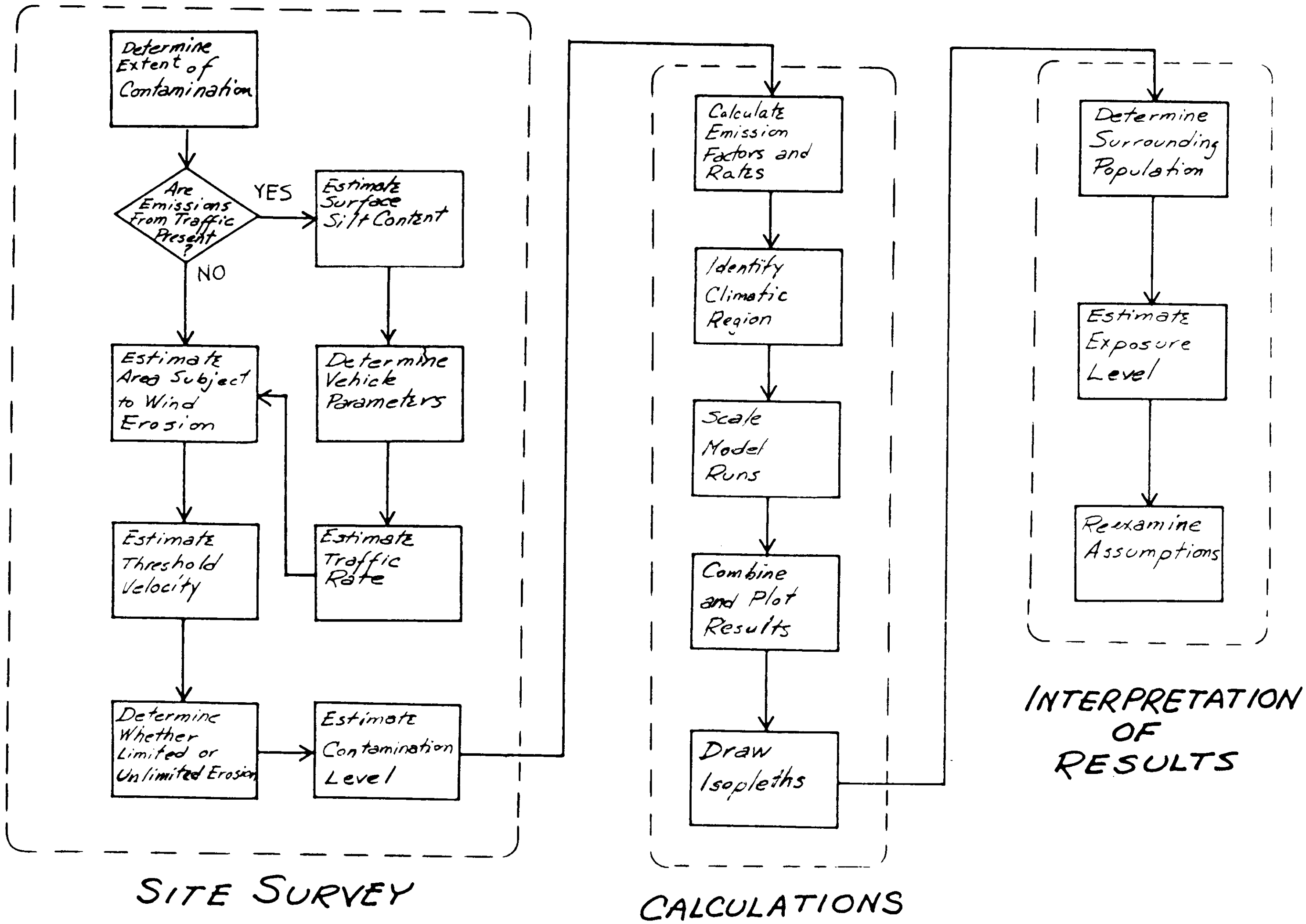


Figure 2-1. Diagram of Assessment Procedure

Step 1 - Estimation of Emissions

The technical approach for estimating respirable (PM_{10}) emissions from surface contamination sites is consistent with the technique used in air pollution assessments. It is based on the following equation:

$$R_{10} = \alpha E_{10} A \tag{2-1}$$

where R_{10} = emission rate of contaminant as PM_{10} (mass/time)

α = fraction of contaminant in PM_{10} emissions (mass/mass)

E_{10} = PM_{10} emission factor (mass/source extent)

A = source extent (source-dependent units)

The emission factor is simply the ratio of uncontrolled emissions per unit of source extent. For wind erosion, the source extent is the area of erodible surface. In the case of emissions generated by mechanical disturbance, source extent is also the area (or volume) of the material from which the emissions emanate. Normally, the "uncontrolled" emission factor incorporates the effects of natural mitigation (e.g., rainfall). If anthropogenic control measures (e.g., treating the surface with a chemical binder which forms an artificial crust) are applied to the source, the uncontrolled emission factor must be reduced to reflect the resulting fractional control.

The first step in the estimation of atmospheric particulate emissions from a surface contamination site is to decide whether potential emissions are limited to those generated by wind erosion. If traffic over the site occurs, it is likely that the traffic emissions (or emissions from other forms of mechanical disturbance) substantially exceed emissions from wind erosion. This is because, for most parts of the country, vehicle traffic is an intensive entrainment mechanism in comparison with wind erosion.

For estimation of emissions from traffic on unpaved surfaces, a predictive emission factor equation is recommended in Section 4. This equation, developed from regression analysis of field test data, explains much of the observed variance in road dust emission factor values on the basis of variances in specific road surface and traffic parameters. Thus it provides more reliable estimates of source emissions on a site specific basis than does a single-valued average emission factor. The appropriate measure of source extent for this emission factor is obtained by converting traffic counts and road segment lengths into the total vehicle-distance traveled; in effect this represents the cumulative road surface area from which the emissions are released.

For estimating emissions from wind erosion, either of two emission factor equations are recommended in Section 4 depending on the erodibility of the surface material. In both cases, the appropriate measure of source extent is the contaminated area of the site. The contaminated surface must be placed in one of two erodibility classes described below. The division between these classes is best defined in terms of the threshold wind speed for the onset of wind erosion.

Nonhomogeneous surfaces impregnated with nonerodible elements (stones, clumps of vegetation, etc.) are characterized by the finite availability ("limited reservoir") of erodible material. Such surfaces have high threshold wind speeds for wind erosion, and particulate emission rates tend to decay rapidly during an erosion event. An emission factor equation developed from wind tunnel data on coarse textured aggregate materials is suitable for this application. It relates the rapidly occurring fine particle loss from the surface to wind speed maxima during periods between mechanical disturbance of the surface.

Bare surfaces of finely divided material such as sandy agricultural soil are characterized by a large number ("unlimited reservoir") of erodible particles. Such surfaces have low threshold wind speeds for wind erosion, and particulate emission rates are relatively time independent at a given wind speed. An emission factor equation based on fine particle emission measurements performed during agricultural wind erosion events is suitable for this application. For either class of erodible surface, the source extent is simply the area contaminated.

As noted in Eq. (2-1), estimation of contaminant emissions requires knowledge of the contaminant levels in the erodible surface material. It is presumed that the surface contamination data which triggered the emergency response will be available. In the case of spills, the estimated level of contamination can be based on the amount of material spilled and the volume of receiving material penetrated by the spill.

Contaminants in particulate form may be present either as discrete solid particles or adsorbed onto soil or other surface aggregate materials. This depends on the physical and chemical interaction between the contaminant species and the surface aggregate. For adsorbed contaminants, there is usually an enrichment of contamination in the finer particle sizes because of larger surface-to-volume ratio. However, in the absence of data on the contamination level of PM_{10} particles in the surface material, it will be assumed that the level of contamination (denoted throughout by the symbol α) in the respirable particulate emissions matches that measured in the bulk surface material.

Step 2 - Estimation of Ambient Concentrations

The primary purpose of this assessment is to provide the user with first-order estimates of atmospheric concentrations and exposures caused by respirable particulate emissions from a surface contamination site. Using the emissions estimates developed in Step 1, the assessment procedure employs atmospheric dispersion models to estimate pollutant transport and dilution under annual average and worst-case 24 hour meteorological conditions. An introduction to air quality dispersion models and the rationale for selection of specific models for this assessment are provided as Appendix C.

Numerous "off-the-shelf" computer models for atmospheric dispersion have been developed in the past. The most common air quality models are contained in the EPA's User's Network for Applied Modeling of Air Pollution (UNAMAP). The applicability of such models within the emergency response time frame, however, is severely constrained by the amount of time required to collect and prepare input data in a suitable format and by the constraint of having immediate access to an implemented model.

It is also possible to develop hand calculation algorithms for use in the assessment process (Versar, 1983; Dynamac, 1983; EPA, 1981). However, this approach requires either restrictive assumptions about the site's meteorology or excessive time to extract information from wind data (which may not be available for the site). Other complications in these hand calculation schemes would involve using a point to represent a source with a definite non-zero areal extent and assuming that the directional distribution of the high-speed winds is identical to that observed over all wind speeds. Both of these complications would result in distortion of the concentration field.

Thus, although computerized models are capable of modeling area sources with emission rates that are functions of wind speed, their direct use is limited by time constraints and accessibility. Hand calculation algorithms are readily implemented but either require restrictive simplification or become unwieldly in terms of application.

The approach adopted in this manual attempts to combine the best features of both options. The manual user scales tabulated output from two relatively sophisticated UNAMAP computer models as a basis for assessing the impact of the site in question. This approach allows the analyst to obtain concentration estimates of a quality comparable to that for computer models while performing calculations that are algebraically simpler than those required for the hand calculation algorithms.

Step 3 - Estimation of Exposure

Human exposure resulting from the air transport of particulate emissions from surface contamination sites is the final aspect of the emergency response assessment procedure. The primary interest of this manual is direct exposure due to inhalation of the airborne contaminant. Although not addressed in this manual, the assessment of acute risk focuses on the worst-case 24-hr exposure, while chronic risk is associated with annual average exposure levels.

When the dispersion modeling is completed, the user will have maps showing the spatial variation of atmospheric contaminant concentrations at breathing height. These maps are overlaid onto a map of the site and surrounding area, and the number of people residing within areas bounded by certain respirable particulate concentration isopleths is then estimated. Thus, the analyst is presented with information about the number of people exposed to specified levels of respirable concentrations of the contaminant.

Indirect exposure resulting from spreading of the surface contamination is also possible. Spreading of the surface contamination can be attributed to settling of airborne emissions from the original site. Such surface spreading can constitute an exposure risk, especially to field workers or children at play. In addition, particulate settling may result in contamination entering the food chain. The treatment of indirect exposure, however, is beyond the scope of this manual.

2.3 CRITICAL CONTAMINANT AND SITE CHARACTERISTICS

The EPA has compiled a list of 271 hazardous chemicals that are abundant and dangerous enough to be singled out for special attention (Federal Register, 1981). This list provides a good starting point for considering the properties such as solubility, physical state, viscosity, size distribution, chemical reactivity, etc., which allows one to divide the chemicals into groups for which similar fates in the soil would be expected. For example, a study by Wentsel et al. (1981) on land restoration recommends physical removal for 98 of the 271 hazardous chemicals. Of these 98 chemicals, 18 are insoluble (Table 2-1) and may offer a long-term air pollution hazard because they will not be removed from the soil surface by rainfall. Thus, transport by wind to populations vulnerable to the chemical contaminant exposure may be possible for long periods following the contamination.

TABLE 2-1. EXAMPLE INSOLUBLE HAZARDOUS CHEMICALS FOR THE RECOMMENDED CLEANUP PROCEDURE IS PHYSICAL REMOVAL

Common name	Synonyms
Aldrin	Octalene, HHDN
Arsenic trioxide	Arsenious acid, arsenious oxides, white arsenic
Arsenic trisulfide	Arsenious sulfide, yellow arsenic sulfide
Calcium arsenate	Tricalcium orthoarsenate
Chlordane	Toxichlor, chlorodan
Dichlone	Phygon, dichoronaphtoquinone
Dieldrin	Alvit
Diuron	DCMU, DMU
Endosultan	Thiodan
Endrin	Mendrin, Compound 269
Kelthane	Di(p-chlorophenyl)-trichloromethycarbonol, DTMC, dicofol
Lead arsenate	
Lead sulfate	
Lead sulfide	Galena
Lindane	Gamma-BHC, Gamma-benzene hexachloride
Polychlorinated biphenyls	PCB, Arochor, polychlorinated diphenyls
Tetraethyl lead	Lead tetraethyl, TEL
Toxaphene	Camphechlor

The extent of contaminant transport following releases to the land surface and subsequent entrainment to the atmosphere depends upon a variety of critical contaminant and site characteristics. This section briefly describes the important contaminant and site characteristics. It provides the user with an understanding of the types of information needed to perform a valid assessment. Guidelines for translating these characteristics into required specific parameter values required by the assessment procedures are provided in Section 4.

2.3.1 Critical Contaminant Characteristics

To assess the potential for atmospheric contamination in an emergency response situation, several properties of the compound or waste must first be determined, especially in the case of chemical spills. Much of this information may be difficult to accurately quantify within a 24-hr time frame, but it is likely that an applicable range of values will be estimated. Some properties are used directly in the assessment or to estimate parameters, while others are needed to interpret the results. Those characteristics deemed crucial to an informed assessment are discussed below:

1. Contaminant identity - The identities of the contaminants must be known to determine those physical/chemical properties necessary for assessing pollutant fate and migration. The physical state of the contaminant (liquid or solid) should be assessed as part of the identification process. Within the emergency response time frame, it may be possible to identify only general classes of chemicals rather than specific compounds. In such instances, parameter estimation will be especially difficult.

2. Extent of the contamination - The extent of the surface contamination must be defined to determine the source term used in estimating transport into the atmosphere. This assessment should provide an estimate of the mass fraction of the contaminant in the surface material. Ideally, the level of contamination in the PM_{10} fraction of the surface material is needed. In addition, the total ground area contaminated by the spill or the disposal operation should be ascertained. In the case of a spill it is necessary to account for contaminant losses by volatilization into the air, runoff, and containment or removal measures on the land surface in estimating the extent of residual contamination. Information on the volatility and reactivity of the waste may be required in making this assessment.

3. Volatility - The volatility of an organic liquid affects its loss to the atmosphere as a vapor. This is especially important in the case of spills where a high degree of atmosphere exposure is typical. As with most other critical contaminant properties, volatility is strongly temperature dependent.

4. Solubility - The solubility of a compound affects its mobility in the soil. The spreading of the contaminant from a surface spill is usually controlled by its tendency to dissolve in the water moving through the soil.

A material's solubility may also affect the ease with which it can adsorb on soil particles, with less soluble wastes being more easily adsorbed. The existence of solvents other than water should also be determined since it can affect the compound's miscibility with soil water.

5. Adsorption - Adsorption can be a significant means of retarding contaminant movement through the soil. It is a property dependent upon both the nature of the compound and the soil. Adsorption capabilities for organic, nonionic compounds are often described in terms of adsorption (or partition) coefficients for a particular compound/soil combination. These coefficients are often estimated from the organic carbon (or organic matter) content of the soil and the organic carbon partition coefficient (which in turn can be estimated from compound characteristics such as the octanol/water partition coefficient). Adsorption of ionic compounds is also a function of ion exchange capacities and clay type and content. This is especially important for soils or media with low organic matter.

6. Degradation - Degradation by both chemical and biological mechanisms is important because it can reduce levels of contaminants in the surface material. Common degradation mechanisms in the environment are hydrolysis, photolysis, biodegradation, chemical oxidation, and radioactive decay. Hydrolysis and chemical oxidation are important primarily for contaminants in soils. Photolysis can occur only on the surface of the soil. Biodegradation is most important in the top few feet of soil where bacterial concentrations are high. Radioactive decay occurs in all environments under all conditions.

6. Toxicity - To assess the hazard of any predicted or observed atmospheric contamination, the toxicity of the pollutants must be determined. Since nearly all chemicals are toxic at very high concentrations, the concern in this assessment is for materials that are moderately to severely toxic or are carcinogenic, mutagenic, or teratogenic to humans and other organisms.

7. Density, viscosity and surface tension - These compound parameters are important in evaluating the penetration characteristics of the contaminant into the soil and the potential for particle reentrainment into the atmosphere.

2.3.2 Critical Site Characteristics

To assess potential atmospheric contamination at a hazardous waste or spill site, a number of site characteristics are important in addition to the contaminant characteristics discussed above. The discussions below are intended to provide an overview of the information needed to characterize an emergency response site in appropriate detail to estimate contaminant release to and transport in the air environment; specific guidelines on parameter estimation are presented in Sections 3 and 4.

Emissions from open dust sources associated with contaminated land areas exhibit a high degree of variability from one site to another, and emissions at any one site tend to fluctuate widely. The site characteristics which cause these variations may be grouped into two categories: measures of energy expended by wind or machinery interacting with the contaminated surface (for example, the wind speed or the speed of a vehicle traveling over the surface); and properties of the contaminated surface material (for example, the content of suspendable fines in the surface material and its moisture content or, for a crusted surface, the strength of the crust).

1. Surface material texture - The dry particle size distribution of the exposed soil or surface material determines its susceptibiliy to wind erosion and mechanical entrainment. Wind forces move soil by three transport modes: saltation, surface creep, and suspension. Saltation describes particles, ranging in diameter from about 75 to 500 μm that jump or bounce within a layer close to the air-surface interface. Particles transported by surface creep range in diameter from about 500 to 1,000 μm. These surface creep particles move very close to the ground propelled by wind stress and the impact of smaller particles transported in saltation. Particles smaller than about 75 μm in diameter move by suspension and tend to follow air motions. The upper size limit of silt particles (75 μm in diameter) is roughly the smallest particle size for which size analysis by dry sieving is practical, and this particle size is also a reasonable upper limit for particulates which can become suspended. The threshold wind speed for the onset of saltation, which drives the wind erosion process, is also dependent on soil texture, with 100 to 150 μm particles having the lowest threshold speed.

2. Surface material moisture - Dust emissions are known to be strongly dependent on the moisture level of the emitting material. Water acts as a dust suppressant by forming cohesive moisture films among the discrete grains of surface material. In turn, the moisture level depends on the moisture added by natural precipitation and on the moisture removed by evaporation and moisture movement beneath the surface. The evaporation rate depends on the degree of air movement over the surface soil texture, clay minerology and crust presence. The moisture holding capacity of the air is also important, and it correlates strongly with the surface temperature. Vehicle traffic intensifies the drying process primarily by increasing air movement over the surface.

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

4. Crust formation - Following the wetting of a soil or other surface material, fine particles will move to form a surface crust. The surface crust acts to hold in soil moisture and resist erosion. The degree of protection that is afforded by a soil crust to the underlying soil may be measured by the modulus of rupture and thickness of the crust. This modulus

of rupture is roughly a measure of hardness of the crust. A soil which lacks a surface crust (for example a disturbed soil or a very sandy soil) is much more susceptible to wind erosion.

5. Frequency of mechanical disturbance - Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface. A disturbance is defined as an action which results in the exposure of fresh surface material. This would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present. Each time that a surface is disturbed, its erosion potential is increased by destroying the mitigative effects of crusts, vegetation and friable non-erodible elements and by exposing new surface fines. Although vehicular traffic alters the surface by pulverizing surface material, this effect probably does not restore the full erosion potential, except for surfaces that crust before substanital wind erosion occurs. In that case, breaking of the crust over the area of the tire/surface contact once again exposes the erodible material beneath.

6. Wind speed - Agricultural scientists have established that total soil loss by continuous wind erosion is dependent on the cube of wind speed. More recent work has shown that the loss of particles in suspension mode follows the same dependence. Soils protected by non-erodible elements or crusts exhibit a weaker dependence of suspended particulate emissions on wind speed. In fact, mean atmospheric wind speeds in many areas of the country are not sufficient to initiate wind erosion from "limited reservoir" surfaces. However, wind gusts may quickly deplete a substantial portion of the erosion potential of surfaces having a "limited reservoir" of erodible particles. In addition, because erosion potential (mass of particles constituting the "limited reservior") increases rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. The quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 1-2 min (for fastest miles of 30-60 mph, respectively), matches well with the half-life (i.e., the time required to remove one-half the erodible particles on the surface) of the erosion process. It should be noted, however, that peak wind speeds can significantly exceed the daily fastest mile.

SECTION 3

SITE SURVEY AND DATA GATHERING

3.1 ASSESSMENT OF EXTENT OF SURFACE CONTAMINATION

As stated in Section 2.1, it is presumed that surface contamination data will be available for the spill site or the abandoned waste disposal site being assessed. Ideally, the surface contaminant levels will have been determined for that fraction of the surface material which has the potential to become airborne, i.e., the silt fraction (defined in this manual as particles passing a 200 mesh screen on dry sieving). In any case, unless data can be obtained on the fine particle enrichment of contamination for classes of compounds which are readily adsorbed onto soil particles, the analyst should assume that the level of contamination in the particulate emissions matches that measured in the bulk surface material.

As an alternative to contamination measurements for chemical spills, it may be possible to estimate the level of contamination based on the amount of material spilled and the volume of receiving material penetrated by the spill. Although the size of the surface affected by the spill may be easily determined, the depth of penetration depends on several factors such as viscosity and surface tension of the chemical and the porosity of the receiving surface. For volatile chemicals, that portion of the spill which evaporates must also be accounted for.

Unless the level of contamination in the surface material is uniform over the full extent of the contaminated area, it is desirable to know the spatial distribution of surface contamination. Also, it is implied that there are well defined boundaries to the contaminated area. Generally, except for spills, such will not be the case because of the spreading of contamination over a period of time by successive entrainment/deposition processes.

If no data are available on the distribution of contamination and its boundaries, the emergency response team must estimate the size of the contaminated area based on historical data on the typical size ranges of contaminated areas of various types. Also, surface features (cover, topography, surface texture, etc.) can be used to delineate site boundaries. A worksheet has been prepared for use in conducting a site survey and is shown in Figure 3-1. An expanded version of the site survey decision flowchart is given in Figure 3-2.

SITE SURVEY WORKSHEET

By ________ Date ________ Reviewed by ______ on ______

I. GENERAL

SITE ________________

LOCATION ________________

LAT/LONG ________________

DATE OF { INCIDENT ________ / DISCOVERY ________ }

COMPOUND ________________

CONTAM. LEVEL (α) ________________ (units)

SKETCH OF SITE (Indicate north, landmarks, approximate dimensions

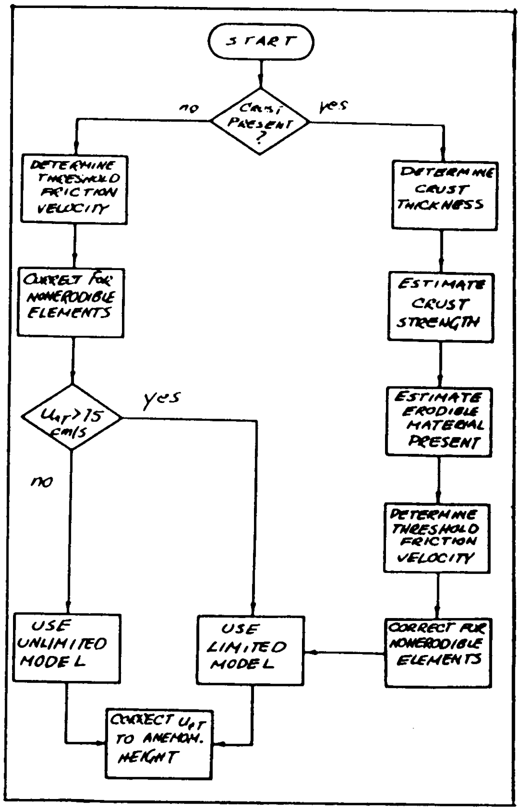
II. MECHANICAL RESUSPENSION (Omit if no evidence of traffic is found)

PARAMETER	VALUE	DATA SOURCE/COMMENTS
SILT	%	
AVG. VEH. SPEED	kph	
AVG. VEH. WEIGHT	Mg	
AVG. NO. WHEELS PER VEHICLE		
AVG. DAILY TRAFFIC	veh/day	
CONTAMINATED TRAVEL LENGTH	km	

Figure 3-1. Site Survey Worksheet

III. WIND EROSION

The site must be classified as either of limited or unlimited erosion potential. To make this decision, first look for evidence of crusting, and then follow the steps in the flowchart to right. Also, refer to Section 3.0 of the manual for guidance in the estimation processes.



COMPLETE APPROPRIATE SECTION BELOW

PARAMETER	VALUE	DATA SOURCE/COMMENTS
LIMITED		
THRESHOLD SPEED	m/s	
FREQ. OF DISTURBANCE	/mo	
FRACTION OF VEGETATIVE COVER		
UNLIMITED:		
THRESHOLD SPEED	m/s	
FRACTION OF VEGETATIVE COVER		

Figure 3-1. (concluded)

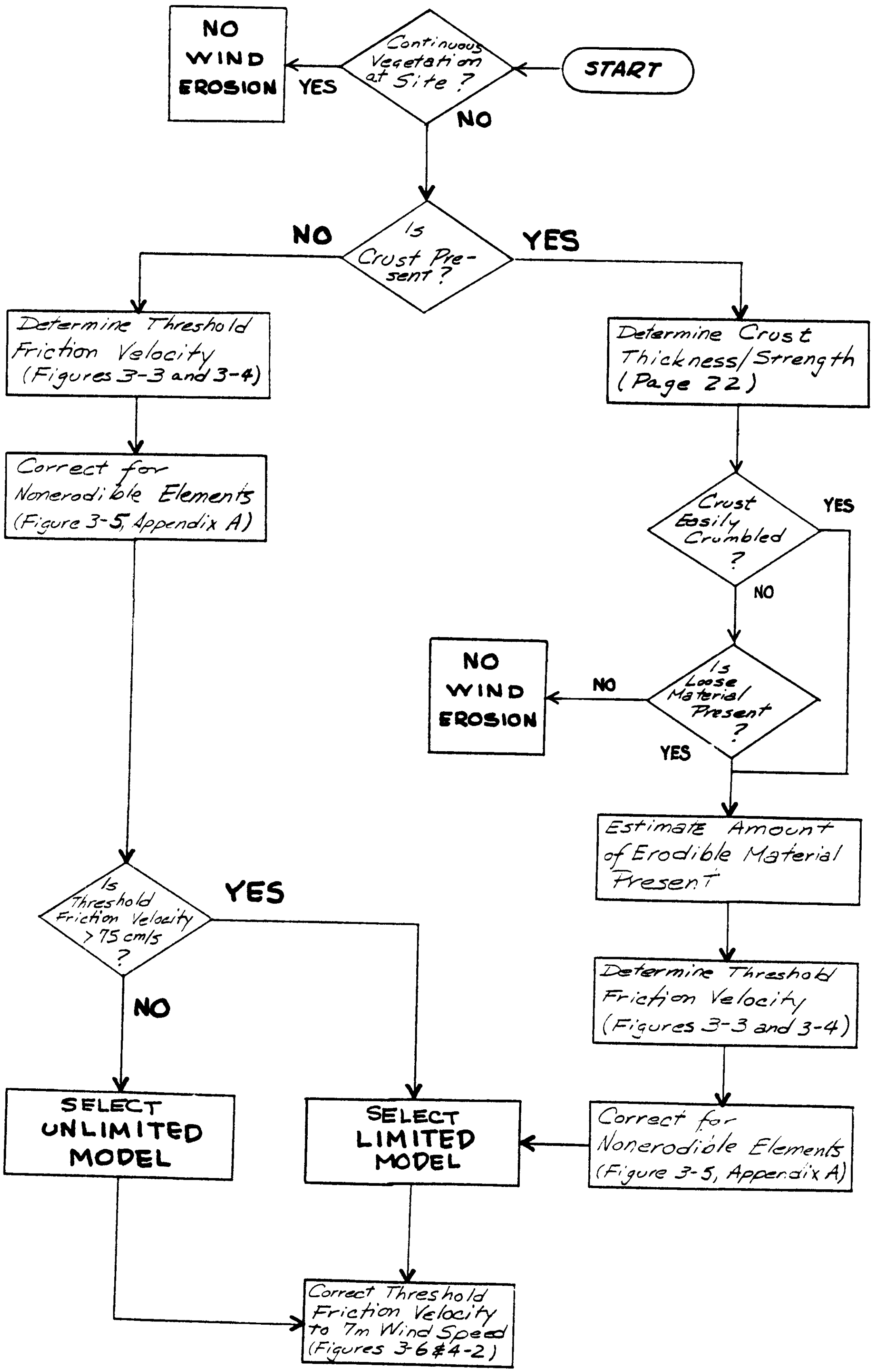


Figure 3-2. Site Survey Decision Flowchart

The second step in the estimation of emissions from an abandoned waste dump or spill site is the determination of the potential for entrainment of contaminated soil by wind or by mechanical disturbance. This determination will be based on a visual site inspection coupled with optional hand sieving of surface material.

3.2 CHARACTERIZATION OF WIND EROSION POTENTIAL

With regard to estimating particulate emissions from wind erosion of contaminated surface material, site inspection can be used to determine the potential for continuous wind erosion. The two basic requirements for wind erosion are that the surface be dry and exposed to the wind. For example, if the contaminated site lies in a swampy area or is covered by unbroken grass, the potential for wind erosion is virtually nil. The same would be true if a substance spilled or otherwise applied to the surface solidifies and acts as impervious binder. If, on the other hand, the vegetative cover is not continuous over the contaminated surface, then the plants are considered to be nonerodible elements which absorb a fraction of the wind stress that otherwise acts to suspend the intervening contaminated soil.

For estimating emissions from wind erosion, either of two emission factor equations are recommended (Section 4) depending on the erodibility of the surface material. Based on the site survey, the contaminated surface must be placed in one of two erodibility classes described below. The division between these classes is best defined in terms of the threshold wind speed for the onset of wind erosion.

Nonhomogeneous surfaces impregnated with nonerodible elements (stones, clumps of vegetation, etc.) are characterized by the finite availability ("limited reservoir") of erodible material. Such surfaces have high threshold wind speeds for wind erosion, and particulate emission rates tend to decay rapidly during an erosion event. On the other hand, bare surfaces of finely divided material such as sandy agricultural soil are characterized by an "unlimited reservoir" of erodible particles. Such surfaces have low threshold wind speeds for wind erosion, and particulate emission rates are relatively time independent at a given wind speed.

For surface areas not covered by continuous vegetation the classification of surface material as either having a "limited reservoir" or an "unlimited reservoir" of erodible surface particles is determined by estimating the threshold friction velocity. Based on the authors' analysis of wind erosion research, the dividing line for the two erodibility classes is a threshold friction velocity of about 75 cm/sec. This somewhat arbitrary division is based on the observation that highly erodible surfaces, usually corresponding to sandy surface soils that are fairly deep, have threshold friction velocities below 75 cm/sec. Surfaces with friction velocities larger than 75 cm/sec tend to be composed of aggregates too large to be eroded mixed in with a small amount of erodible material or of crusts that are resistent to erosion (Gillette et al., 1982).

The cutoff friction velocity of 75 cm/sec corresponds to an ambient wind speed of about 10 m/sec (22 mph), measured at a height of about 7 m.

In turn, a specific value of threshold friction velocity for the erodible surface is needed for either wind erosion emission factor equation (model).

Crusted surfaces are regarded as having a "limited reservoir" of erodible particles. Crust thickness and strength should be examined during the site inspection, by testing with a pocket knife. If the crust is more than 0.6 cm thick and not easily crumbled between the fingers (modulus of rupture > 1 bar), then the soil may be considered nonerodible. If the crust thickness is less than 0.6 cm or is easily crumbled, then the surface should be treated as having a limited reservoir of erodible particles. If a crust is found beneath a loose deposit, the amount of this loose deposit, which constitutes the limited erosion reservoir, should be carefully estimated.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil is highly desirable to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure specified in Figure 3-3. The threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution, following a relationship derived by Gillette (1980) as shown in Figure 3-4.

A more approximate basis for determining threshold friction velocity would be based on hand sieving with just one sieve, but otherwise follows the procedure specified in Figure 3-3. Based on the relationship developed by Bisal and Ferguson (1970), if more than 60% of the soil passes a 1-mm sieve, the "unlimited reservoir" model will apply; if not, the "limited reservoir" model will apply. This relationship has been verified by Gillette (1980) on desert soils.

If the soil contains nonerodible elements which are too large to include in the sieving (i.e., greater than about 1 cm in diameter), the effect of these elements must be taken into account by increasing the threshold friction velocity. Marshall (1971) has employed wind tunnel studies to quantify the increase in the threshold velocity for differing kinds of nonerodible elements. His results are depicted in terms of a graph of the rate of corrected to uncorrected friction velocity versus L_c (Figure 3-5), where L_c is the ratio of the silhouette area of the roughness elements to the total area of the bare loose soil. The silhouette area of a nonerodible element is the projected frontal area normal to the wind direction.

A value for L_c is obtained by marking off a 1 m x 1 m surface area and determining the fraction of area, as viewed from directly overhead, that is occupied by non-erodible elements. Then the overhead area should be corrected to the equivalent frontal area; for example, if a spherical nonerodible element is half imbedded in the surface, the frontal area is one-half of the overhead area. Although it is difficult to estimate L_c for values below 0.05, the correction to friction velocity becomes less sensitive to the estimated value of L_c.

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY*

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

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

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

4. Rotate the covered sieve/pan unit by hand using broad sweeping arm motions in the horizontal plane. Complete 20 rotations at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.

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

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* Adapted from a laboratory procedure published by W. S. Chepil (1952).

Figure 3-3.

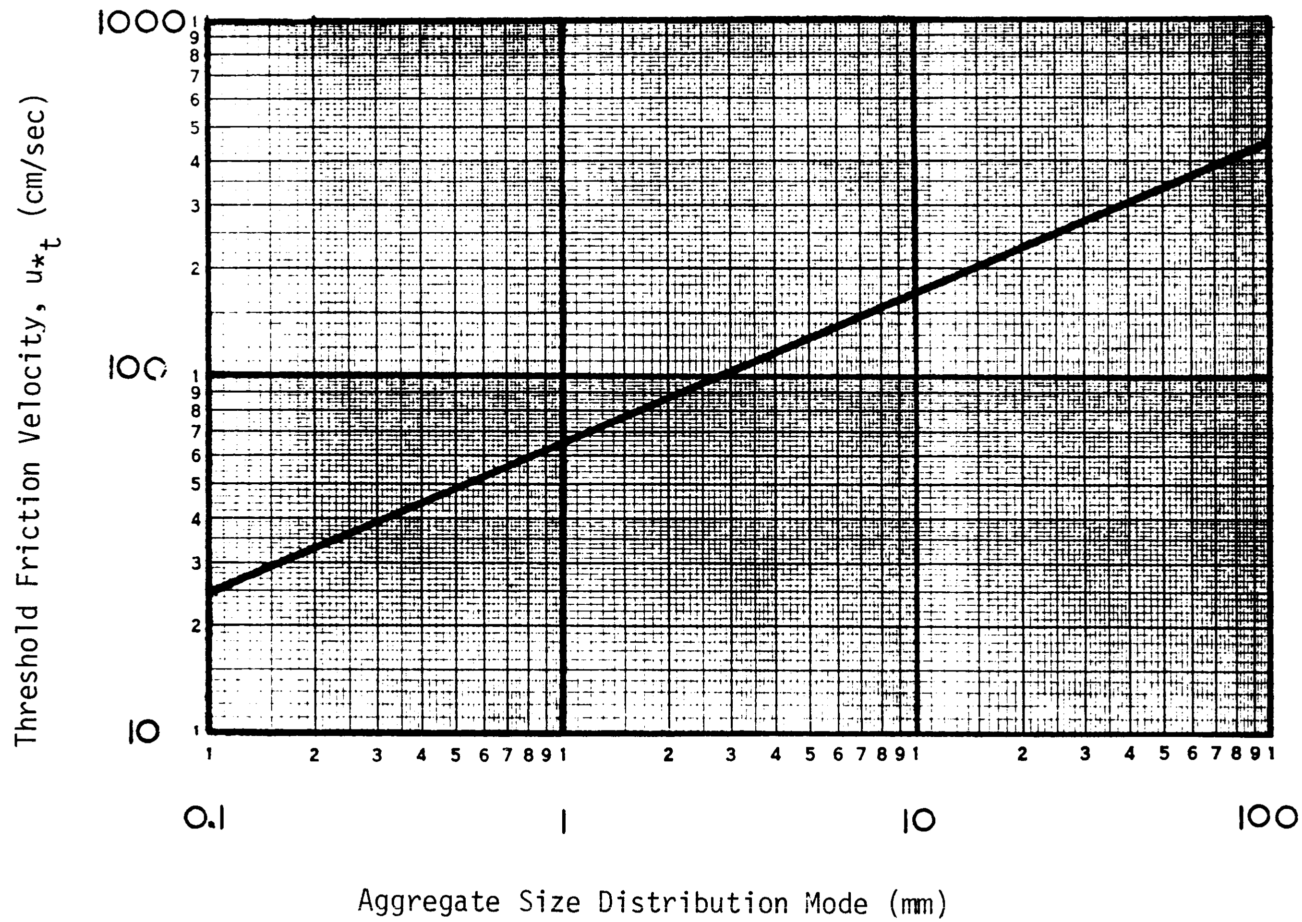

Figure 3-4. Relationship of Threshold Friction Velocity to Size Distribution Mode

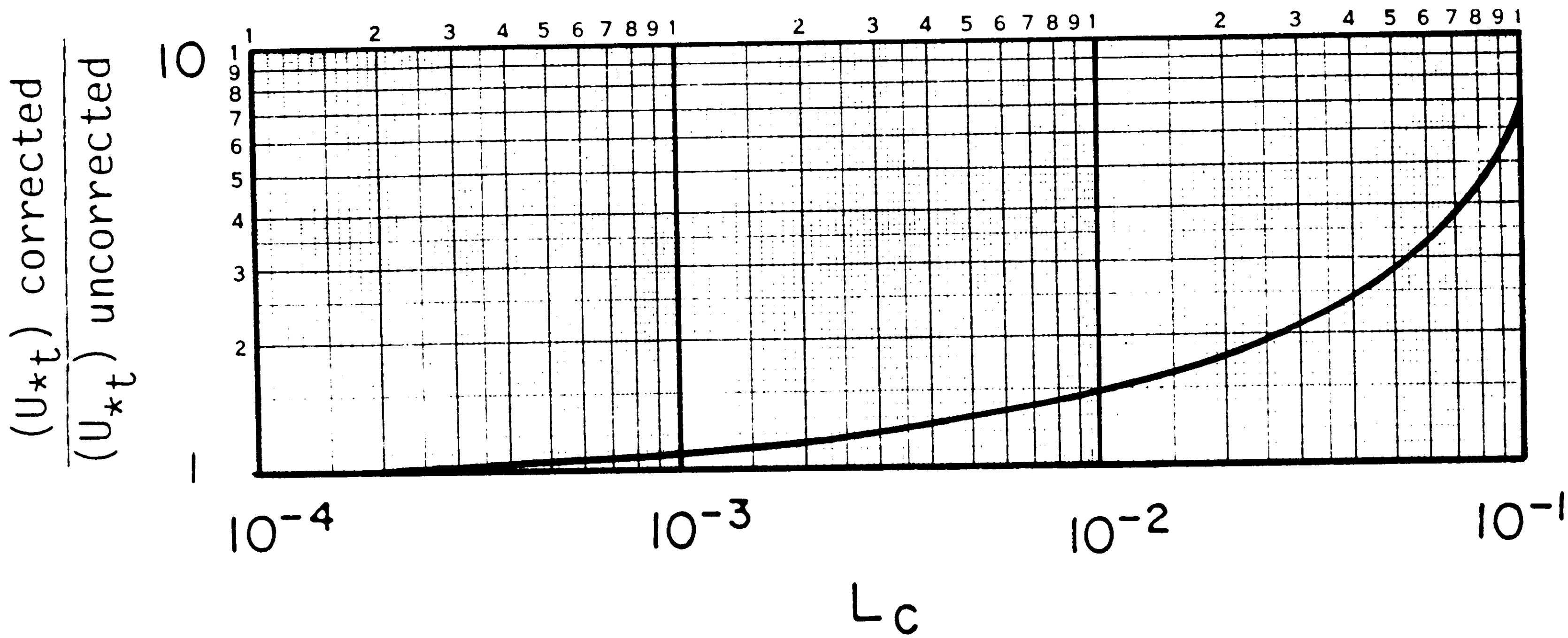

Figure 3-5. Increase in Threshold Friction Velocity with L_c

The difficulty in estimating L_c also increases for small non-erodible elements. However, because small non-erodible elements are more likely to be evenly distributed over the surface, it is usually acceptable to examine a smaller surface area, e.g., 30 cm x 30 cm. The photographs of various non-erodible element distributions presented in Appendix A can be used as an aid in estimating L_c for surfaces with small non-erodible elements. These photographs illustrate the physical appearance corresponding to various values of L_c.

The least acceptable technique for classifying the erodibility of the surface material is by visual surface examination and matching with the photographs given in Appendix A. Once again, loose sandy soils fall into the high erodibility ("unlimited reservoir"). These soils do not promote crust formation, and show only a brief effect of moisture addition by rainfall. On the other hand, compacted soils with a tendency for crust formation fall into the low ("limited reservoir") erodibility group. Clay content in soil, which tends to promote crust formation, is evident from crack formation upon drying.

The roughness height, z_o, which is related to the size and spacing of surface roughness elements, is needed to convert the friction velocity to the equivalent wind speed at the typical weather station sensor height of 7 m above the surface. Figure 3-6 depicts the roughness height scale for various conditions of ground cover (Cowherd and Guenther, 1976). The conversion to the 7 m value is discussed in Section 4 (Figure 4-2).

In addition to these surface properties, it is also important that the field personnel note the location and orientation of significant topographic features that are likely to influence the dispersion of contaminated material from the site. Significant topographic features will include not only the terrain of the surrounding area but also the large-scale roughness elements such as trees and buildings that might enhance or obstruct the wind flow for the site in question. A consideration of these features is important in the proper interpretation of the modeling results presented in Section 4.2. In order to ensure the best possible characterization of the local-scale wind flow, it is recommended that the response team contact both the nearest National Weather Service office and an American Meteorological Society (AMS) Certified Consulting Meteorologist[1].

3.3 CHARACTERIZATION OF MECHANICAL RESUSPENSION BY VEHICLE TRAFFIC

The most typical type of intensive mechanical disturbance occurs with vehicle travel over the contaminated surface material. The occurrence of traffic over the site can be determined by inspection of the site for existence of roads. Other less common forms of mechanical disturbance are associated with any operation which moves or turns over surface material (i.e., scraping, grading, tilling, etc.). All of these operations not only release suspended particulate matter into the air, but greatly increase the potential for subsequent wind erosion by destroying protective surface crusts and removing vegetative cover. Because these types of disturbance are rare, the following discussion is limited to vehicle traffic as the typically significant mechanical resuspension process.

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1 A list of Certified Consulting Meteorologists is available from the American Meteorological Society, 45 Beacon Street, Boston, Massachusetts 02108. Telephone: (617) 227-2425

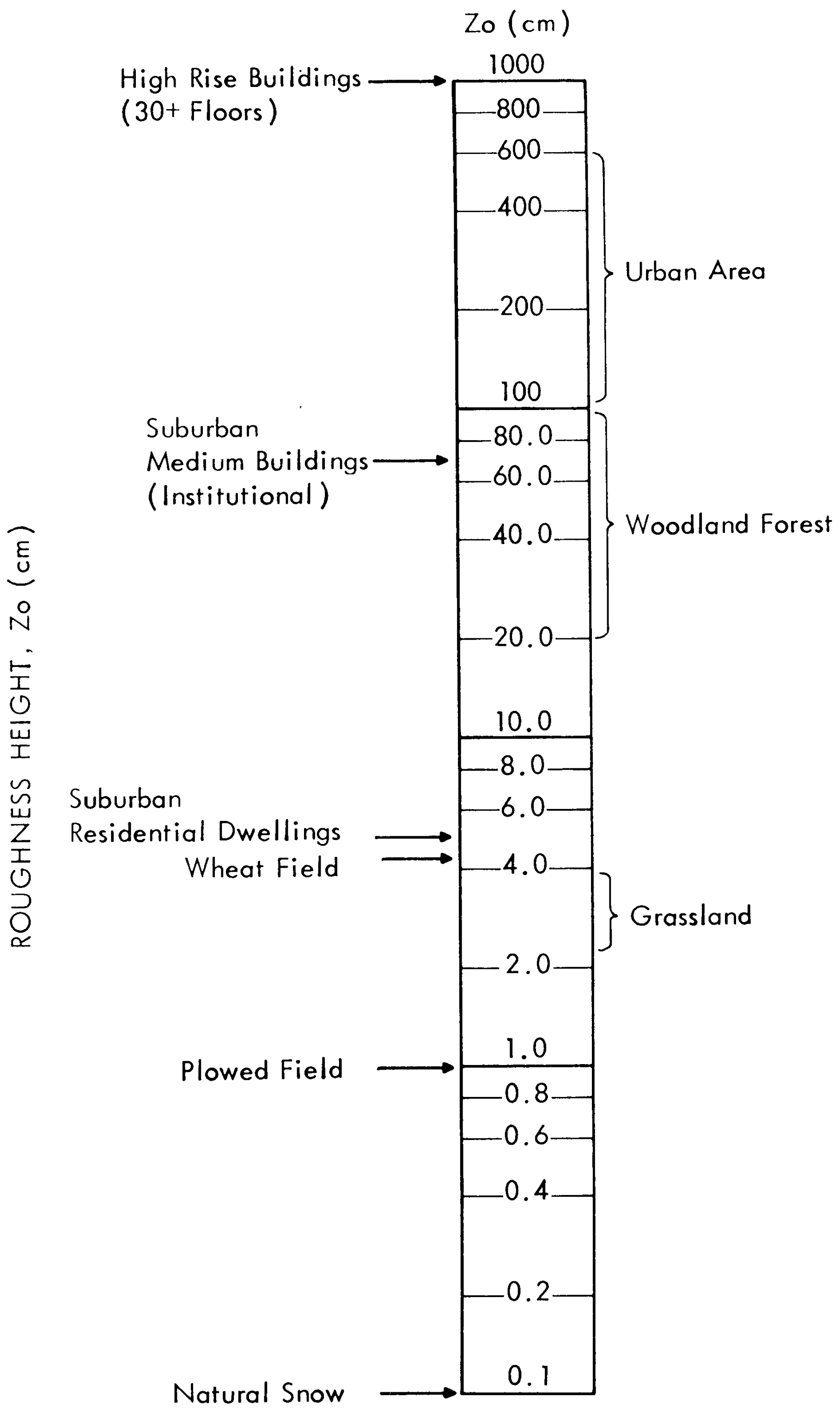

Figure 3-6. Roughness Heights for Various Surfaces (Cowherd and Guenther, 1976)

The emission factor equation for vehicle travel on unpaved surfaces, as presented in Section 4, requires estimates of site-specific traffic and surface parameters. Average vehicle speed and number of wheels can be estimated from direct observation of traffic, site inspection of road condition, and interviews with people living or working near the site. Vehicle weight can be estimated from vehicle type and number of wheels, using a chart presented in Section 4. Default values for road surface silt content are also provided.

SECTION 4

CALCULATIONS AND GATHERING OF RESULTS

The assessment procedure developed in this manual follows a source-oriented approach. It requires the user first to estimate particulate emission rates for the contamination site, and then to link these estimates to the results of a general Gaussian dispersion algorithm in order to estimate ambient concentrations of contaminant in the form of respirable particulate matter. The following sections describe the emission factor models used to estimate contaminant emissions generated by wind erosion and mechanical entrainment, and the procedure for "translating" these results into ambient concentrations and associated exposures.

4.1 CALCULATION OF AVERAGE/WORST-CASE EMISSION RATES

This section describes the emission factor models used to estimate particulate emissions generated by mechanical entrainment and by wind erosion of contaminated surface material. Also this section describes the sources of data and the procedures used to estimate the parameters required for input to the emission models.

In the case of wind erosion emissions, there are no "ready-made" models fully capable of meeting the requirements of rapid assessment. As such, the information presented in Sections 4.1.1 and 4.1.2 provides best estimates for wind generated emissions, based on current knowledge of the suspension of surface material by wind action.

4.1.1 Wind Erosion from Surfaces with Limited Erosion Potential

For estimating respirable particulate emissions from surfaces characterized by a "limited reservoir" of erodible material, a predictive emission factor equation developed by Cowherd (1983) from field measurements using a portable wind tunnel at surface mines is recommended. In relating the annual average rate of respirable particulate emissions to surface and climatic factors, the equation takes the following form:

$$E_{10} = 0.83 \frac{f \, P(u^+) \, (1-V)}{(PE/50)^2} \qquad (4\text{-}1)$$

where: E_{10} = PM_{10} emission factor, i.e., annual average PM_{10} emission rate per unit area of contaminated surface (mg/m^2-hr)

f = frequency of disturbance per month

u^+ = observed (or probable) fastest mile of wind for the period between disturbances (m/s)

$P(u^+)$ = erosion potential, i.e., quantity of erodible particles present on the surface prior to the onset of wind erosion (g/m^2)

V = fraction of contaminated surface area covered by continuous vegetative cover (equals 0 for bare soil)

PE = Thornthwaite's Precipitation Evaporation Index used as a measure of average soil moisture content

Although Equation 4-1 is based primarily on field tests of nonsoil surfaces (e.g., coal with a top size of 3 cm and a silt content exceeding 4%), subsoil and other crustal materials showed similar behavior. The erosion potential (in g/m^2) depends on the fastest mile (in m/s) as follows:

$$P(u^+) = \begin{cases} 6.7\,(u^+ - u_t), & u^+ \geqq u_t \\ 0\quad, & u^+ < u_t \end{cases} \tag{4-2}$$

where u_t is the erosion threshold wind speed (in m/s), measured at a typical weather station sensor height of 7 m.

The threshold friction velocity determined from the site survey is converted to the equivalent wind speed at a height of 7 m using Figure 4-1. This figure assumes a logarithmic velocity profile near the earth's surface:

$$\frac{u(z)}{u_*} = \frac{1}{0.4} \ln (z/zo) \tag{4-3}$$

where:

u = wind speed at height z (m/s)
z = height above surface (cm)
u_* = friction velocity (m/sec)
z_o = roughness height (cm)

Mean annual fastest mile (u^+) values are presented in Table 4-1. The value for the weather station closest to the surface contamination site should be used.

Emissions generated by wind erosion of "limited reservoir" surfaces are also dependent on the frequency of disturbance (f) of the erodible surface, because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the

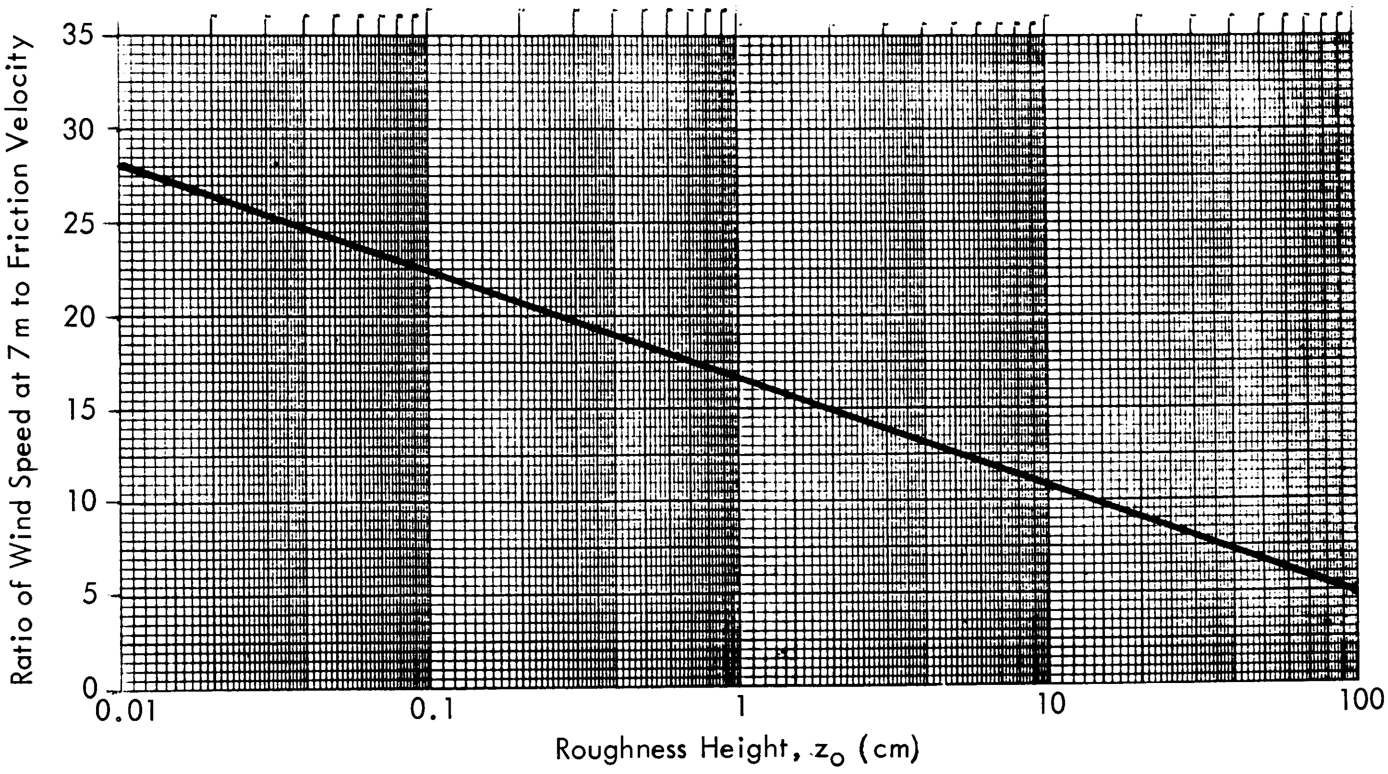

Figure 4-1. Ratio of wind speed at 7 m to friction velocity as a function of roughness height.

TABLE 4-1. FASTEST MILE[a] [u^+] AND MEAN WIND SPEED[b] [u] FOR SELECTED UNITED STATES STATIONS

Station	State	[u^+] (m/s)	[u] (m/s)	Station	State	[u^+] (m/s)	[u] (m/s)
Birmingham	AL	20.8	3.3	Detroit	MI	21.8	4.6
Montgomery	AL	20.2	3.0	Grand Rapids	MI	21.6	4.5
Tucson	AZ	23.0	3.7	Lansing	MI	23.7	4.6
Yuma	AZ	21.8	3.5	Sault St. Marie	MI	21.6	4.3
Fort Smith	AR	20.8	3.4	Duluth	MN	22.8	5.1
Little Rock	AR	20.9	3.6	Minneapolis	MN	22.0	4.7
Fresno	CA	15.4	2.8	Jackson	MS	20.5	3.4
Red Bluff	CA	23.3	3.9	Columbia	MO	22.4	4.4
Sacramento	CA	20.6	3.7	Kansas City	MO	22.6	4.6
San Diego	CA	15.4	3.0	St. Louis	MO	21.2	4.2
Denver	CO	22.0	4.1	Springfield	MO	22.4	5.0
Grand Junction	CO	23.6	3.6	Billings	MT	26.6	5.1
Pueblo	CO	28.1	3.9	Great Falls	MT	26.4	5.9
Hartford	CT	20.2	4.0	Havre	MT	25.9	4.5
Washington	DC	21.6	3.4	Helena	MT	24.7	3.5
Jacksonville	FL	21.7	3.8	Missoula	MT	21.6	2.7
Tampa	FL	22.2	3.9	North Platte	NE	27.7	4.6
Atlanta	GA	21.2	4.1	Omaha	NE	24.6	4.8
Macon	GA	20.1	3.5	Valentine	NE	27.1	4.8
Savannah	GA	21.3	3.6	Ely	NV	23.6	4.7
Boise	ID	21.4	4.0	Las Vegas	NV	24.4	4.0
Pocatello	ID	23.8	4.6	Reno	NV	25.2	2.9
Chicago	IL	21.0	4.6	Winnemucca	NV	22.4	3.5
Moline	IL	24.5	4.4	Concord	NH	19.2	3.0
Peoria	IL	23.2	4.6	Albuquerque	NM	25.6	4.0
Springfield	IL	24.2	5.1	Roswell	NM	26.0	4.1
Evansville	IN	20.9	3.7	Albany	NY	21.4	4.0
Fort Wayne	IN	23.7	4.6	Binghampton	NY	22.0	4.6
Indianapolis	IN	24.8	4.3	Buffalo	NY	24.1	5.5
Burlington	IA	25.0	4.6	New York	NY	22.5	5.5
Des Moines	IA	25.8	5.0	Rochester	NY	23.9	4.3
Sioux City	IA	25.9	4.9	Syracuse	NY	22.5	4.4
Concordia	KS	25.7	5.4	Cape Hatteros	NC	25.9	5.1
Dodge City	KS	27.1	6.3	Charlotte	NC	20.0	3.4
Topeka	KS	24.4	4.6	Greensboro	NC	18.9	3.4
Wichita	KS	26.0	5.6	Wilmington	NC	22.3	4.0
Louisville	KY	22.0	3.8	Bismarck	ND	26.1	4.7
Shreveport	LA	19.9	3.9	Fargo	ND	26.6	5.7
Portland	ME	21.7	3.9	Cleveland	OH	23.6	4.8
Baltimore	MD	25.0	4.2	Columbus	OH	22.1	3.9
Boston	MA	25.2	5.6	Dayton	OH	24.0	4.6

TABLE 4-1 (concluded)

Station	State	$[u^+]$ (m/s)	[u] (m/s)	Station	State	$[u^+]$ (m/s)	[u] (m/s)
Toledo	OH	22.7	4.2	Dallas	TX	21.9	4.9
Oklahoma City	OK	24.1	5.7	El Paso	TX	24.8	4.2
Tulsa	OK	21.4	4.7	Port Arthur	TX	23.7	4.5
Portland	OR	23.5	3.5	San Antonio	TX	21.0	4.2
Harrisburg	PA	20.4	3.4	Salt Lake City	UT	22.6	3.9
Philadelphia	PA	22.1	4.3	Burlington	VT	20.4	3.9
Pittsburgh	PA	21.6	4.2	Lynchburg	VA	18.3	3.5
Scranton	PA	19.9	3.8	Norfolk	VA	21.8	4.7
Huron	SD	27.4	5.3	Richmond	VA	18.9	3.4
Rapid City	SD	27.3	5.0	Quillayute	WA	16.3	3.0
Chattanooga	TN	21.4	2.8	Seattle	WA	18.7	4.1
Knoxville	TN	21.8	3.3	Spokane	WA	21.4	3.9
Memphis	TN	20.3	4.1	Green Bay	WI	25.3	4.6
Nashville	TN	20.9	3.6	Madison	WI	24.9	4.4
Abilene	TX	24.4	5.4	Milwaukee	WI	24.0	5.3
Amarillo	TX	27.3	6.1	Cheyenne	WY	27.0	5.9
Austin	TX	20.2	4.2	Lander	WY	27.4	3.1
Brownsville	TX	19.5	5.3	Sheridan	WY	27.5	3.6
Corpus Christi	TX	24.4	5.4	Elkins	WV	22.8	2.8

[a] Data taken from Extreme Wind Speeds at 129 Stations in the Contiguous United States. Simiu, E., Filliben, J. J., and M. J. Changery. NBS Building Science Series 118. U.S. Department of Commerce, National Bureau of Standards, 1979.

[b] Data taken from Local Climatological Data - Annual Summaries for 1977. U.S. Department of Commerce, National Oceanic and Atmospheric Administration/Environmental Data Service/National Climatic Data Center.

exposure of fresh surface material. This would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

Although vehicular traffic alters the surface by pulverizing surface material, several vehicle passes may be required to restore the full erosion potential, except for surfaces that crust before substantial wind erosion occurs. In that case, breaking of the crust over the area of the tire/surface contact once again exposes the erodible material beneath.

Thornthwaites' P-E (PE) Index is a useful indicator of average surface soil moisture conditions. In the present context, the P-E Index is applied as a correction parameter for wind generated emissions in the limited reservoir case. Figure 4-2 provides a basis for selecting an appropriate P-E value.

The worst-case emission rate is calculated by assuming that a disturbance occurs just prior to the annual fastest mile event, both within the 24-h period of interest. For this calculation, use Equation (4-1) with $f = 30\ mo^{-1}$.

4.1.2 Wind Erosion from Surfaces with Unlimited Erosion Potential

For estimating respirable particulate emissions from wind erosion of surfaces with an "unlimited reservoir" of erodible particles, a predictive emission factor equation developed from Gillette's (1981) field measurements of highly erodible soils is recommended. In relating the annual average rate of respirable particulate emissions (per unit area) to field and climatic factors, the equation takes the following form:

$$E_{10} = 0.036\ (1-V) \left(\frac{[u]}{u_t}\right)^3 F(x) \qquad (4\text{-}4)$$

where:

E_{10} = PM_{10} emission factor, i.e., annual average PM_{10} emission rate per unit area of contaminated surface (g/m^2-hr)

V = fraction of contaminated surface vegetative cover (equals 0 for bare soil)

$[u]$ = mean annual wind speed (m/s), taken from Table 4-1

$x = 0.886\ u_t/[u]$ = dimensionless ratio

$F(x)$ = function plotted in Figure 4-3

u_t = threshold value of wind speed at 7 m (m/s)

This follows from the empirical relationship that the vertical flux of particles smaller than 10 µm diameter is proportional to the cube of wind speed. Because highly erodible soils do not readily retain moisture, no moisture-related parameter is included in the equation.

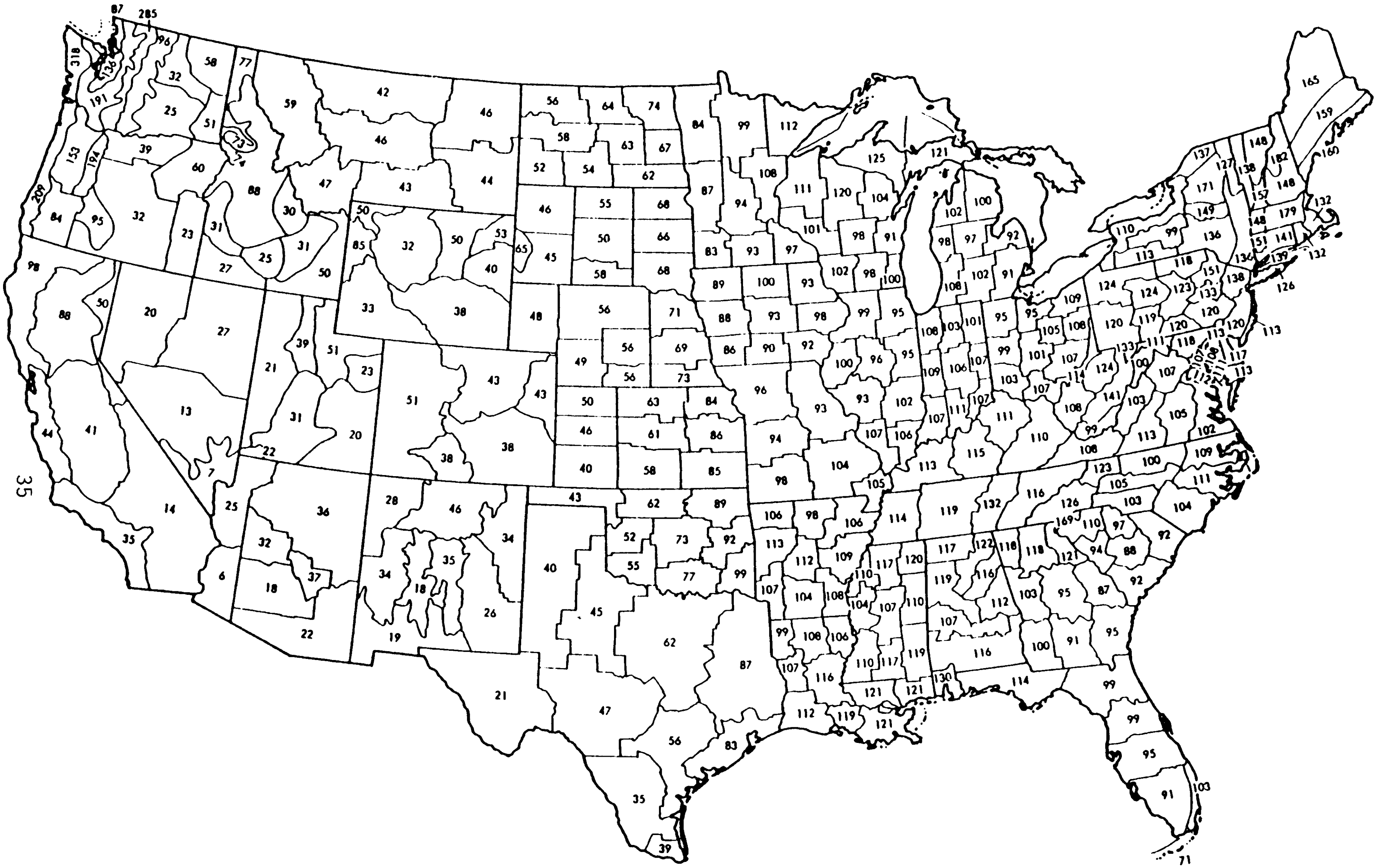

Figure 4-2. Map of P-E Index for State Climatic Divisions

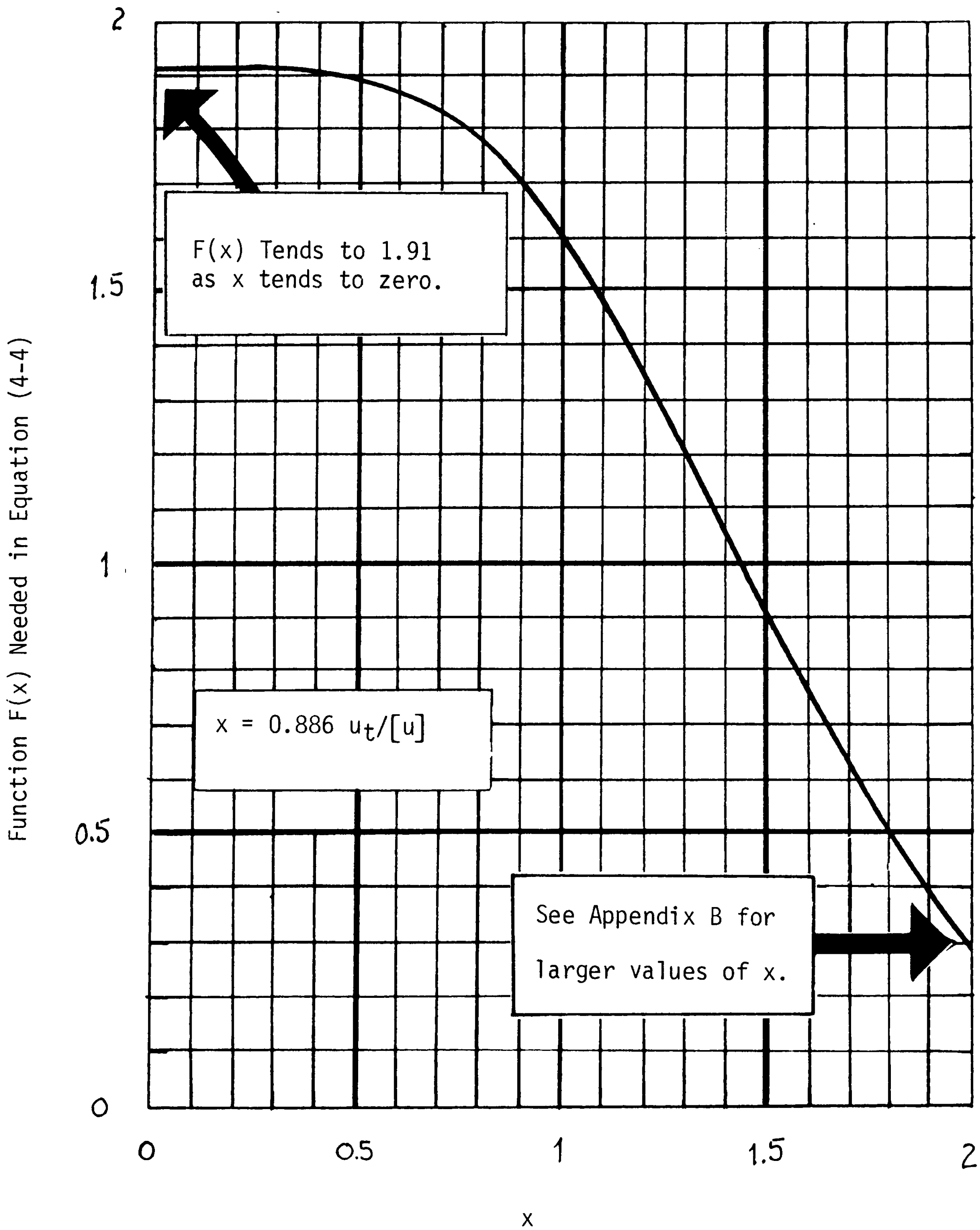

Figure 4-3. Graph of Function F(X) Needed to Estimate Unlimited Erosion

In this assessment process, the mean annual wind speed ([u]) for the weather station nearest the site (Table 4-1) should be used. The threshold wind speed at 7 m (u_t) is found by converting the threshold friction velocity (determined from the site survey) using Figure 4-2. Equation 4-3 is based upon an expected value using an estimated annual wind speed probability distribution as the weighting function. The function F(x) is proportional to this expected value. Details of the integration are presented in Appendix B.

The worst-case emission factor is calculated using a simplified form of Equation (4-3):

$$E_{10} = 0.036\ (1-V)\ [u_{6-hr}]^3 \tag{4-5}$$

where: $[u_{6-hr}]$ = expected maximum 6-hr mean wind speed during the year. From a physical viewpoint, it is apparent that the maximum 6-hr mean wind speed must be somewhat lower than the corresponding annual fastest mile.

In order to roughly account for the influence of increasing averaging time, the following expression should be applied to the $[u^+]$ values in Table 4-1:

$$[u_{6-hr}] = [u^+] - 2\ m/s \tag{4-6}$$

This relationship has been proposed by the World Meteorological Organization (1961) for correction of 1-min to corresponding 1-hr extremes.

4.1.3 Vehicle Traffic

For estimation of PM_{10} emissions from vehicle traffic over unpaved surfaces, the following equation should be used:

$$E_{10} = 0.85 \left(\frac{s}{10}\right) \left(\frac{S}{24}\right)^{0.8} \left(\frac{W}{7}\right)^{0.3} \left(\frac{w}{6}\right)^{1.2} \left(\frac{365-p}{365}\right) \tag{4-7}$$

where: E_{10} = PM_{10} emission factor, i.e., the quantity of PM_{10} emissions from an unpaved road per vehicle-kilometer of travel (kg/VKT)

s = silt content of road surface material (%)

S = mean vehicle speed (km/hr)

W = mean vehicle weight (Mg)

w = mean number of wheels

p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year

Default values for the various parameters in the equation are given in Table 4-2. These should only be applied when site-specific information from local sources is unavailable.

TABLE 4-2. DEFAULT VALUES FOR INDEPENDENT VARIABLES OF EQUATION 4-6[a]

Site	s(%)		S(km/hr)		W(Mg)	w
Rural/Residential	15	(5-68)	48	(40-64)	2	4
Industrial	8	(2-29)	24	(8-32)	3	4
					15	6
					26	10

[a] Numbers in parentheses are ranges of measured values.

Values for p (wet days per year) are obtained from Figure 4-4 or from a local source. Worst-case 24-hr emissions would occur on a dry day (p = 0) with the highest volume of traffic expressed as vehicle-kilometers traveled. If the vehicle mix varies, periods with a greater portion of larger vehicles produce greater emissions.

4.1.4 Determination of Emission Rates

Contaminant emission rates (R_{10}) are determined from the above emission factors (E_{10}) using Equation 2-1:

$$R_{10} = \alpha \ E_{10} \ A \qquad (2\text{-}1)$$

where R_{10} = emission rate of contaminant as PM_{10}

α = mass fraction of contaminant in PM_{10} emissions

A = source extent (for a specified averaging time in the case of mechanical resuspension)

For wind erosion, the source extent is simply the contaminated area. For example, if an area of 2,000 m² is contaminated, the annual emission factor is 0.17 mg/m²-hr and α = 16 ppm, the annual contaminant emission rate is:

$$R_{10} = (16 \cdot 10^{-6})\ (0.17\ \text{mg/m}^2\text{-hr})\ (2{,}000\ \text{m}^2) = 5.4\ \mu\text{g/hr} \qquad (4\text{-}9)$$

In the case of mechanical resuspension in the form of travel on unpaved surfaces, the source extent is found as the product of the contaminated travel length times the daily traffic count. Note that the daily traffic count for a worst-case would be greater than that for annual conditions. An example is provided in Section 5.2.

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF PRECIPITATION, ANNUAL

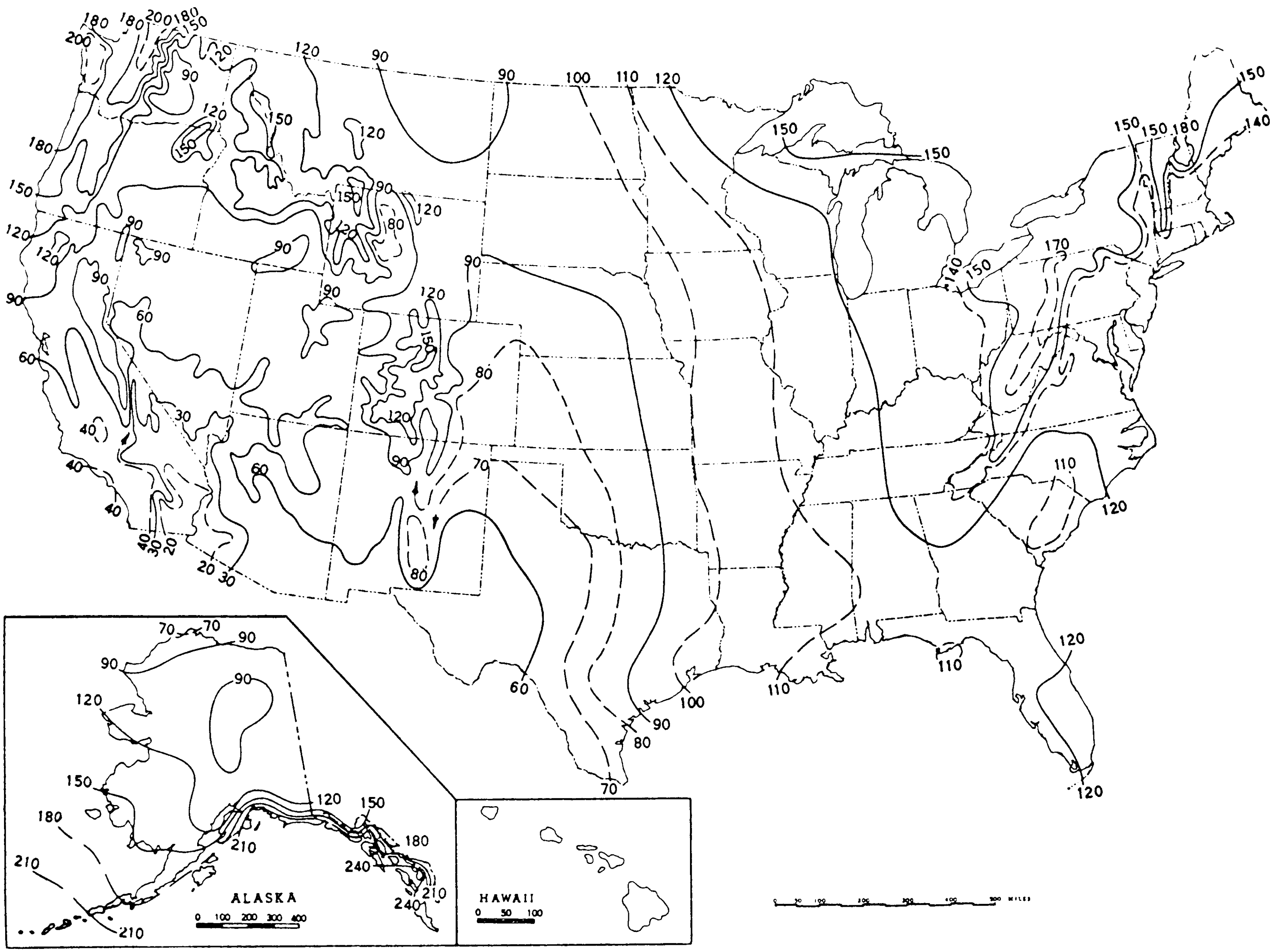

Figure 4-4. Map of Precipitation Frequency

Once the contaminant emission rates associated with wind and traffic entrainment have been calculated, the next step is to estimate the duration of exposure to the airborne contaminant. This is done by comparing the annual average contaminant mass emission rate to the total mass of contaminant available for entrainment. In the case of a deep horizon of surface contamination, long-term wind erosion will be limited to the depth of surface material that is unprotected by large non-erodible elements; on the other hand mechanical entrainment by vehicle traffic can wear the surface indefinitely.

As a first approximation of the duration of exposure, the total initial mass of contaminant in the form of PM_{10} particles on the surface should be divided by the initial value of the annual average contaminant emission rate (R_{10}). If the resulting value exceeds 70 years (the time basis for lifetime exposure assessment), no correction for decay in emission rate is required. Otherwise, the annual average contaminant emission rate must be adjusted downward, to account for the significant depletion in the contaminant mass. This situation would be expected, for example, in the case of a spill of a powder which neither penetrates nor adheres to the soil.

If the duration of exposure obtained above does not exceed 70 years, it is recommended that the expected decay in emission be derived from first order kinetics, based on the principle that the contaminant emission rate at any point in time is proportional to the amount of contaminant remaining in the exposed surface material. The decay constant is given by:

$$k = R_{10}/M_{10} \qquad (4\text{-}10)$$

where k = decay constant (1/time)

R_{10} = initial value of combined annual average emission rate (mass/time)

M_{10} = initial mass of the contaminant in the form of PM_{10} particles on the surface (mass)

Based on this model, the times required to entrain 90% or more of the initial mass of contaminant, and the average emission rates during these time periods are as follows:

Fraction of initial mass remaining	Time required	Ratio of average to initial emission rate
10%	2.3/k	0.39
1%	4.6/k	0.21
0.1%	6.9/k	0.14

It is recommended that exposure assessment be carried out to the point in time at which 10% of the initial contaminant mass remains. Thus, the calculated initial annual average emission rate should be multiplied by 0.39.

4.2 DISPERSION MODELING

In order to obtain estimates of ambient concentrations attributable to particulate emissions from surface contamination sites, an atmospheric dispersion model is required. The modeling procedure described below is based on using previously obtained computer dispersion model output in a way that allows the user to quickly scale these results for the particular site being assessed. The development of this modeling approach and the rationale for selection of the core dispersion models are described in Appendix C. The following sections discuss the procedure to be followed in transforming the annual and worst-case emission rates determined in the previous section, to corresponding spatial distributions of annual and worst-case respirable particulate concentrations in the vicinity of the contamination land area.

4.2.1 Annual Average Concentration Estimates

Annual Concentration Model

A series of Industrial Source Complex - Long Term (ISCLT) model outputs have been tabulated using averaged meteorological data for each of the seven climatic regions shown in Figure 4-5. ISCLT is a refined model in the EPA's UNAMAP family of models and incorporates features particularly well-suited for wind erosion applications. A description of this model is found in Appendix C and more detail may be found in the user's guide (Bowers et al., 1979). Rationale for the regional delineation shown in Figure 4-5 is also provided in Appendix C.

Four separate model outputs (annual concentration estimates) are tabulated in Appendix D for each climatic region for unit emission rates. Emissions from both wind erosion and mechanical resuspension were modeled for each of two area source sizes: a 10 m x 10 m square and a 100 m x 100 m square. The choice of source sizes was based on examination of a data base of contamination sites with "actual soil contamination" (John Schaum, EPA, personal communication, 1984). During the development of the methodology sources larger (175 m^2, 250 m^2) and smaller (55 m^2) than 100 m^2 were also considered; however, the resultant concentration estimates from the 10 and 100 m^2 sources were found to be reasonable approximations to the concentrations for the other source sizes. More specifically, for a constant emission rate, the maximum difference in concentration estimates was < 20% at 1 km from the source center, regardless of source size; differences decreased rapidly beyond this point.

Although ISCLT requires that all individual area sources be squares, it is unlikely that any contamination site will match the shape or the dimensions of either area source. Because tabulated results from ISCLT are used, the analyst is not able to use the exact source configuration in the modeling process. This is not believed restrictive because in most emergency response situations, the spatial extent of the contamination (or, in other words the size of the emitting source) will probably be difficult to estimate. The possible exception to this may be for spill incidents in which the surface contaminant boundary may be well defined. It is necessary to decide which of the two area sources better represents the site to be modeled.

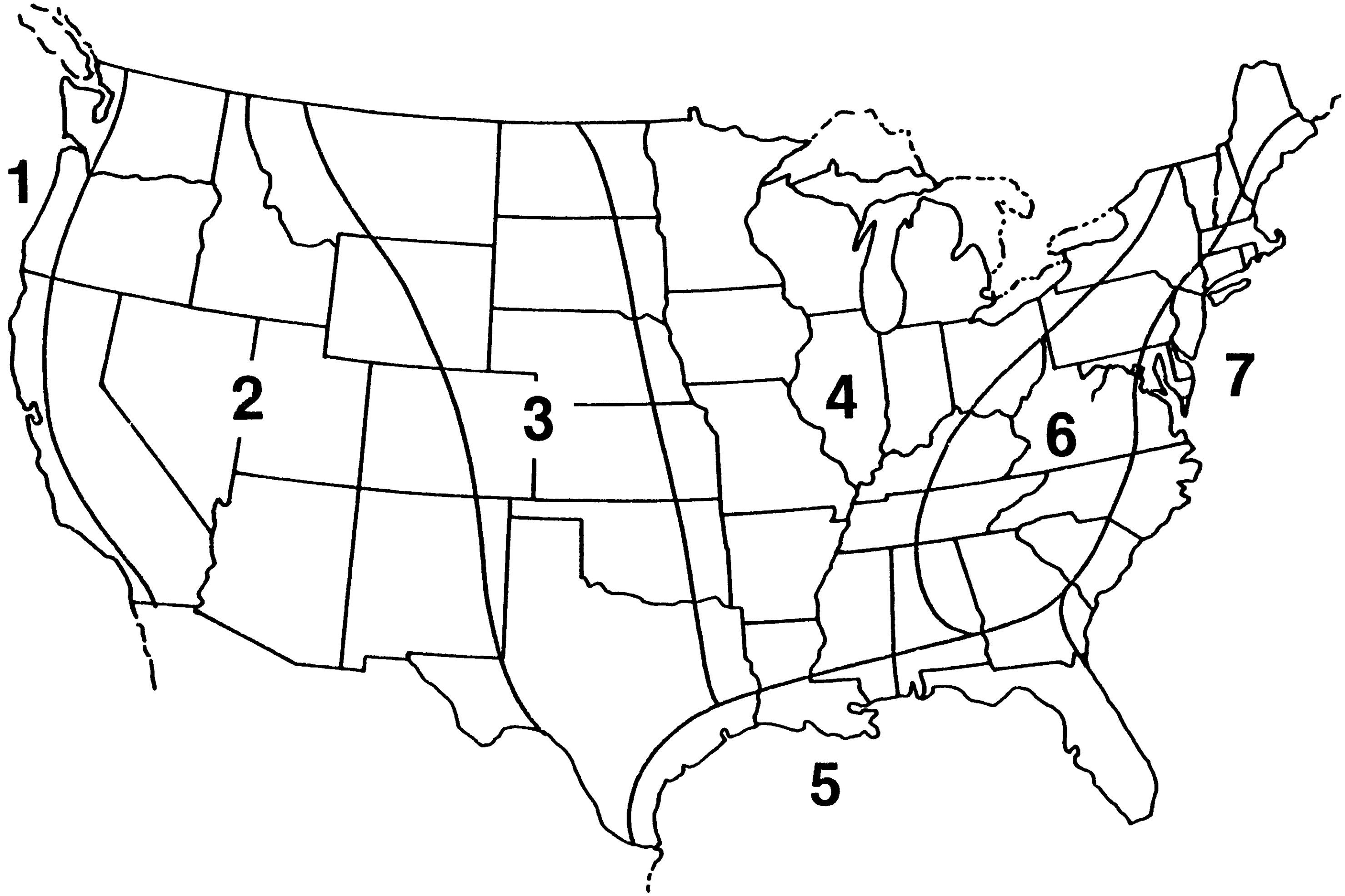

Figure 4-5. Climatic Region

Although no hard and fast rules are possible, a few general guidelines are provided below:

1. If most of the emissions emanate from a small, confined area, the 10 m x 10 m will probably better represent the site.

2. If the nearest population center lies in the direction of the prevailing wind, the 10 m x 10 m will generally provide the larger exposure estimates. Otherwise, the 100 m x 100 m will tend to provide the higher (more conservative) estimates of exposure. (See the discussion at the end of Section 4.2.1.)

3. If the surface contamination extends over an area of 1/2 acre or more, the 100 m x 100 m source is more appropriate.

There are 192 receptor points at which concentration estimates may be obtained. These points are arranged in a polar coordinate system at distances from 200 to 7000 m away from the center of the contaminated site. The maximum distance of 7 km corresponds to the 4-mile radius used in the Hazard Ranking System (HRS) as an indicator of the "population which may be harmed should hazardous substances be released to the air" (Federal Register, 1982).

The receptors are grouped into "fine" and "coarse" grids as shown in Figure 4-6.

Fine Grid	Coarse Grid
32 receptors at 4 distances (200, 300, 400, 500 m) along 8 directions (N, NE,...NW radials).	160 receptors at 10 distances (750-7,000 m) along 16 directions (N, NNE,...NNW radials).

The complete receptor network should be plotted on an overlay of scale 1:24,000. A partial receptor network of the correct scale, from which the overlay can readily be prepared on translucent paper, is provided on page G-2 of Appendix G.

The scale of the overlay will be the same as that used in United States Geological Survey (USGS) 7.5 min topographic map series. Thus, once the spatial variation of concentrations has been determined and plotted, the overlay may be placed on the USGS maps to determine populated areas exposed to specific concentration levels. No more than six USGS maps will be required for any one site. It is suggested that response teams either maintain a set of maps of the areas for which they are responsible, or identify a source from which the necessary maps are available in an emergency.

Scaling and Plotting of Results

In order to estimate annual average ambient respirable concentrations attributable to a surface contamination site, it is necessary to first complete the worksheet shown in Figure 4-7. Each data item is summarized below:

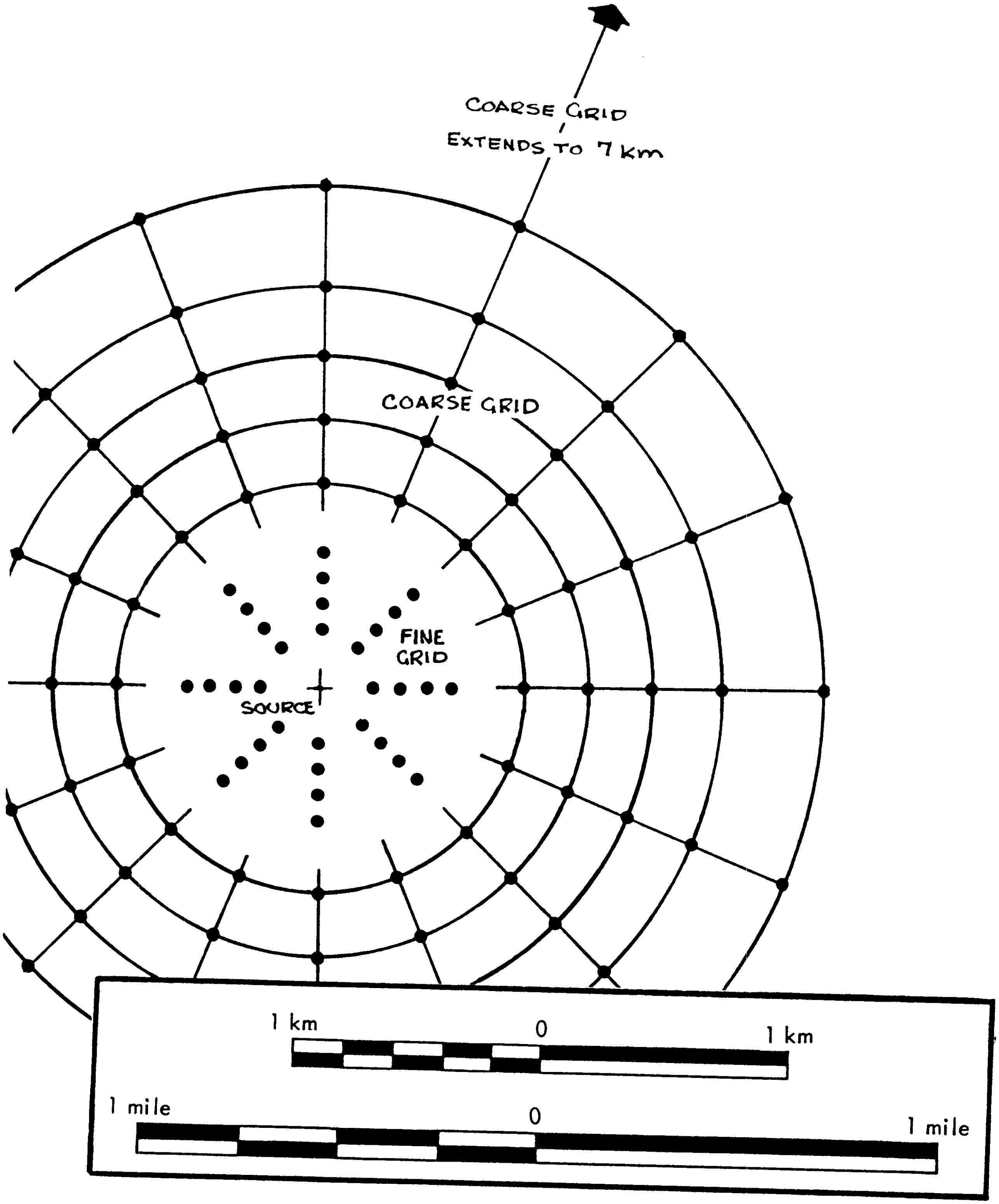

Figure 4-6. Portion of Receptor Network Showing
Coarse and Fine Grids

DISPERSION MODELING WORKSHEET

Climatic Region ________

Date ________
By ________
Checked ________

Source Size 10 m x 10 m ____
or
100 m x 100 m ____

ANNUAL ESTIMATES

I Annual Wind Erosion Scaling Factor, Q_I

A. Annual Wind Erosion Rate, R_{10} = ________________ g/s

B. Select approproate value of P_R from below

Climatic Region	1	2	3	4	5	6	7
P_R	0.152	0.262	0.396	0.288	0.182	0.134	0.296

C. Annual Scaling Factor, $Q_I = \frac{R_{10}}{P_R}$ = ________________ g/s

---

II Annual Mechanical Resuspension Scaling Factor, Q_{II}

Q_{II} = Annual Mechanical Emission Rate, R_{10} = ________________ g/s

Figure 4-7. Annual Dispersion Model Worksheet

Climatic Region	-	Determine according to Figure 4-5
Source Size	-	Estimate according to the guidelines presented in the preceeding subsection
Annual Wind Erosion Rate	-	Estimate as product of emission factor (based on the guidelines presented in Section 4.1) and annual source extent
P_R	-	Take value from the table on the worksheet (Figure 4-7) for the appropriate climate region. P_r represents the fraction of time in the model runs that wind erosion occurs.
Q_I	-	Wind erosion scaling factor.
Q_{II}	-	Mechanical scaling factor which equals annual mechanical emission rate.

After determining Q_I for wind erosion and Q_{II} for mechanical resuspension, the analyst may proceed to scale the model output (i.e., concentrations). The scaling process is represented as follows:

$$\chi = Q_I f_I + Q_{II} f_{II} \tag{4-11}$$

where χ = respirable concentration (mass/volume)

Q_I = wind erosion scaling factor (mass/time), from Figure 4-7

Q_{II} = mechanical resuspension scaling factor (mass/time), from Figure 4-7

f_I = unscaled concentration (time/volume) due a unit erosion rate from Appendix D

f_{II} = unscaled concentration (time/volume) due to a unit mechanical emission rate from Appendix D

The concentration units depend on the units used for the scaling factors. It is critical that Q_I and Q_{II} be expressed in <u>identical units</u>. The most suitable units involve SI mass units and seconds. The following is a table of corresponding scaling factor and concentration units.

Q_I and Q_{II} Units	Respirable Concentration Units
g/s	μg/m³
mg/s	ng/m³
μg/s	pg/m³
ng/s	fg/m³
pg/s	ag/m³

As can be seen from the two sets of units above and Equation 4-11, the units for f_I and f_{II} are μs/m³. Once again, it is imperative that both scaling factors be expressed in the same units.

The values of f_I and f_{II} are tabulated for the two source sizes for each climatic region in Tables D-1 through D-14 in Appendix D. For purposes of illustration, the tables for the 10 m x 10 m source in Region 3 are reproduced as Figures 4-8 and 4-9. The steps involved in plotting the concentration are as follows:

1. Beginning with the fine grid and the north direction (N) multiply the entry under 200 m for wind erosion by Q_I and add that to the product of the corresponding entry for mechanical resuspension and Q_{II}. Write the result next to the point 200 m to the north of the source on the receptor grid overlay prepared by the analyst.

2. Continue with the 300, 400, and 500 m entries in the north direction.

3. Repeat the process with the NE direction and continue until all of the fine grid has been completed.

4. Repeat the process for the coarse grid. Again starting with the N direction, multiply corresponding entries by the appropriate scaling factor, starting with 750 m and ending at 7000 m.

5. Repeat the process in Step 4 with the NNE, NE, etc., radials until the coarse grid is completed.

A few remarks on the above are in order:

a. If no mechanically generated emissions are present at the site then the analyst, of course, needs to consider only the concentration field due to wind erosion.

b. A programmable calculator (or at least one with multiple memories) is recommended to reduce the number of keystrokes (and, hence, the chance of error).

c. If certain radials are in the direction of areas in which inhalation exposure is of no concern (e.g., bodies of water, uninhabited areas, etc.), the concentrations at those points need not be calculated.

d. If an estimated concentration falls below a lower limit of interest in terms of inhalation exposure, the process may be shortened by moving immediately to the innermost distance along the next radial.

Construction of Isopleths

Once the annual concentration estimates have been plotted on the 1:24,000 receptor overlay, the next step in conducting the assessment is to draw

REGION 3 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	8.573	4.169	2.508	1.685
NE	2.326	1.078	0.629	0.415
E	2.953	1.415	0.844	0.564
SE	5.052	2.399	1.422	0.947
S	5.105	2.436	1.450	0.968
SW	1.699	0.802	0.474	0.315
W	1.300	0.621	0.370	0.247
NW	2.898	1.351	0.793	0.524

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	55.299	28.003	17.106	11.595
NE	17.769	8.631	5.135	3.419
E	24.456	12.326	7.511	5.083
SE	22.641	11.174	6.727	4.519
S	28.413	14.143	8.563	5.771
SW	18.987	9.392	5.655	3.799
W	21.242	10.641	6.452	4.349
NW	29.882	14.680	8.796	5.888

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

Figure 4-8. Unscaled Ambient Concentrations (μs/m³) - Fine Grid

REGION 3 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	750	1000	1250	1500	2000	3000	4000	5000	6000	7000
					RANGE (M)					
N	0.814	0.486	0.336	0.249	0.155	0.079	0.050	0.035	0.026	0.020
NNE	0.400	0.236	0.162	0.119	0.074	0.037	0.023	0.016	0.012	0.009
NE	0.195	0.115	0.079	0.058	0.036	0.018	0.011	0.008	0.006	0.005
ENE	0.168	0.099	0.068	0.050	0.031	0.016	0.010	0.007	0.005	0.004
E	0.271	0.161	0.111	0.082	0.051	0.026	0.016	0.011	0.009	0.007
ESE	0.287	0.169	0.116	0.086	0.053	0.027	0.017	0.012	0.009	0.007
SE	0.452	0.268	0.185	0.137	0.085	0.043	0.027	0.019	0.014	0.011
SSE	0.600	0.357	0.247	0.183	0.114	0.058	0.037	0.026	0.019	0.015
S	0.463	0.275	0.190	0.140	0.087	0.045	0.028	0.020	0.015	0.011
SSW	0.223	0.131	0.090	0.067	0.041	0.021	0.013	0.009	0.007	0.005
SW	0.150	0.088	0.061	0.045	0.028	0.014	0.009	0.006	0.005	0.004
WSW	0.108	0.064	0.044	0.032	0.020	0.010	0.006	0.004	0.003	0.003
W	0.118	0.070	0.048	0.036	0.022	0.011	0.007	0.005	0.004	0.003
WNW	0.106	0.062	0.042	0.031	0.019	0.010	0.006	0.004	0.003	0.002
NW	0.247	0.146	0.100	0.074	0.046	0.023	0.015	0.010	0.008	0.006
NNW	0.541	0.320	0.221	0.163	0.101	0.052	0.032	0.023	0.017	0.013

Q_I = SCALING FACTOR = ______________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	750	1000	1250	1500	2000	3000	4000	5000	6000	7000
					RANGE (M)					
N	5.692	3.466	2.398	1.777	1.108	0.581	0.373	0.266	0.202	0.160
NNE	2.638	1.583	1.085	0.799	0.495	0.257	0.164	0.116	0.088	0.069
NE	1.634	0.979	0.671	0.495	0.305	0.158	0.101	0.072	0.054	0.043
ENE	1.806	1.090	0.750	0.554	0.344	0.179	0.115	0.082	0.062	0.049
E	2.489	1.512	1.045	0.774	0.482	0.252	0.162	0.115	0.087	0.069
ESE	1.705	1.020	0.701	0.517	0.320	0.166	0.106	0.075	0.057	0.045
SE	2.188	1.321	0.911	0.673	0.419	0.218	0.139	0.099	0.075	0.059
SSE	2.531	1.523	1.051	0.777	0.483	0.251	0.160	0.114	0.086	0.068
S	2.809	1.701	1.174	0.869	0.541	0.282	0.181	0.129	0.097	0.077
SSW	2.167	1.305	0.900	0.666	0.413	0.215	0.138	0.098	0.074	0.058
SW	1.840	1.111	0.767	0.568	0.353	0.184	0.118	0.084	0.063	0.050
WSW	1.588	0.956	0.657	0.484	0.300	0.156	0.100	0.071	0.054	0.043
W	2.117	1.283	0.885	0.654	0.407	0.212	0.136	0.097	0.073	0.058
WNW	1.943	1.173	0.806	0.595	0.369	0.192	0.123	0.088	0.067	0.053
NW	2.836	1.711	1.177	0.869	0.539	0.281	0.179	0.128	0.097	0.076
NNW	4.732	2.860	1.976	1.463	0.909	0.475	0.303	0.216	0.164	0.129

Q_{II} = SCALING FACTOR = ______________________
(UNITS)

Figure 4-9. Unscaled Ambient Concentrations ($\mu s/m^3$) - Coarse Grid isopleths of concentration. These isopleths indicate the spatial variation of concentration and are used to develop estimates of population exposure. The procedure described below uses the entire concentration field obtained by scaling the tabulated results in order to construct isopleths.

Use of a programmable calculator is especially recommended for this procedure. Figure 4-10 presents a program for a Texas Instruments TI-55; programs for other calculators are similar.

The equation which is solved by this program is

$$d = \frac{\chi_t - \chi_o}{\chi_1 - \chi_o} \qquad (4\text{-}12)$$

where d = relative distance from receptor 0 to receptor 1 where concentration equals χ_t

χ_t = target concentration (i.e., concentration to which the isopleth corresponds)

χ_0 = (lower) concentration value at receptor 0

χ_1 = (higher) concentration value at receptor 1

and $\chi_0 \leqq \chi_t \leqq \chi_1$.

The linear interpolation given above produces a value of d between 0 and 1. If the result is not in this range, the analyst will know that an error has occurred.

Use of this program is as follows:

1. Determine the "target" concentration value for the isopleth (e.g., 100 μg/m³, 25 ng/m³) and store this value in memory 3.
2. Starting at north, locate the two adjacent receptors along that direction whose concentration values bound the target value.
3. Enter the smaller concentration and start the program.
4. When the display stops (the display should be the negative of the smaller concentration), enter the larger value and restart the program.
5. Once the display stops flashing, the value of $0 \leqq d \leqq 1$ is shown. Plot this point on north radial. The value of d represents the relative distance from receptor 0 to receptor 1. Thus a value of 0.62 implies that the isopleth intersects the radial approximately two-thirds of the way from receptor 0 to receptor 1.

2ND	CA	2ND	FIX	2
2ND	LRN			
STO	1	+/-	+	
2ND	R/S	=	1/X	
X	(	RCL	3	
-	RCL	1	)	
=	2ND	R/S	2ND	RST
2ND	LRN	2ND	RST	

Figure 4-10. Calculator Program for Isopleth Construction

6. Continue with the next radial until all have been completed.

7. Connect the points with straight lines to form the isopleth.

8. Choose a new target value and repeat the process.

A number of remarks about the procedure follow:

a. Selection of the target values should be made in conjunction with an examination of nearby centers of population. Clearly, if there are no people residing within the first, say, 2 km of the site, then there is no need to construct isopleths in the uninhabited area in order to assess direct inhalation exposure.

b. It is not necessary to use a scale to pinpoint the location of the isopleth; the calculator program is designed to allow the user to roughly "eyeball" the location, by using the nearest third, quarter, and so on.

c. Because only one source is modeled, the isopleths for different target values should be of approximately the same geometric shape. (See isopleths in Example One in Section 5.)

The preceding is a description of how isopleths of estimated annual pollutant concentration can be developed using the model output results. There are a number of situations in which the analyst may want to modify the plotted concentration field. One possible situation might involve the need to incorporate more site-specific, and thus presumably more realistic, meteorological information concerning the local-scale wind flows. This is particularly true with respect to wind direction, since it is known to be highly variable in both time and space.

One possible modification would involve "rotation" of the initial concentration field so that the axis or radial of maximum concentration is oriented parallel to the prevailing wind direction. Although rotation could be applied separately to both wind erosion and mechanical resuspension emissions, the complexity involved in combining the results is not considered worthwhile in the rapid assessment procedure. Such a rotation should be applied only in cases <u>in which erosion is the dominant resuspension mechanism and only if the results of the site survey, including consultation with an expert meteorologist, suggest that this procedure is warranted</u>.

A second modification applicable to both the wind erosion and mechanically generated concentration estimates, involves the construction of concentric circles (or isopleths). This may be accomplished by first scaling the concentrations at 750 m from the site (for each direction), and then determining the radial with the largest concentration estimates. The remaining estimates are then calculated for each downwind distance on this radial, and concentric isopleths may be then be drawn. The advantages of this method are (a) it is inherently very conservative and (b) it can be accomplished very quickly thus leaving additional time for the analyst to refine the critical emission rate and source extent estimates. An example of this procedure is provided in Section 5.2.

4.2.2 Worst-Case Concentration Estimates

A series of VALLEY model runs have been prepared for use in the manual in order to assess worst-case, short-term conditions. VALLEY is a screening model contained in the EPA's UNAMAP series, and is typically employed in evaluating worst-case scenarios. The model is designed to produce conservatively high estimates of 24-hr average concentrations (Burt, 1977). Although there is a short-term version of ISC, the VALLEY model was selected for use because it requires considerably fewer site-specific assumptions for the meteorological input. A description of VALLEY is provided in Appendix C; greater detail may be found in the user's manual (Burt, 1977).

Worst-case estimates of concentration depend on both emission rates and meteorological conditions. It is particularly important to distinguish between mechanically generated emissions and those attributable to wind erosion in this type of analysis. Most emissions from open dust sources are essentially independent of wind speed; maximum concentrations due to these sources are associated with very stable atmospheric conditions and light winds. Wind erosion, of course, is highly dependent on wind speed; however, higher winds act to enhance dispersion and thus reduce the air quality impact. It is important that the analyst realize that the worst case for mechanical resuspension and that for wind erosion cannot occur simultaneously. Thus, two separate worst-case meteorological conditions must be considered:

Scenario	Source of Emissions	Wind Speed (m/s)	Atmospheric Stability Class
1	Mechanical resuspension	2.5	F
2	Mechanical resuspension and wind erosion	4.3	E

Each scenario above was considered using the two different source sizes employed earlier. If no mechanically generated emissions are present at the site, then only scenario 2 is considered using a zero value for the mechanical resuspension rate.

Once the worst-case emission rates are available, it is a relatively easy matter to determine which scenario produces higher ambient concentrations. If the worst-case mechanical emission rate is at least one-half the value for wind erosion, then scenario 1 will generally result in larger estimates for worst-case concentration values.

The output of four VALLEY runs have been plotted in Figures 4-11a and b. These figures have been reduced from the originals which are provided as masters for map overlays, on pages G-3 and G-4 of Appendix G at the end of this manual. These masters have a scale of 1:24,000, so that the overlays (of the same scale) may be placed directly upon USGS 7.5 min maps. Prior to interpretation, however, the values of the concentration isopleths must be scaled for use at the specific site.

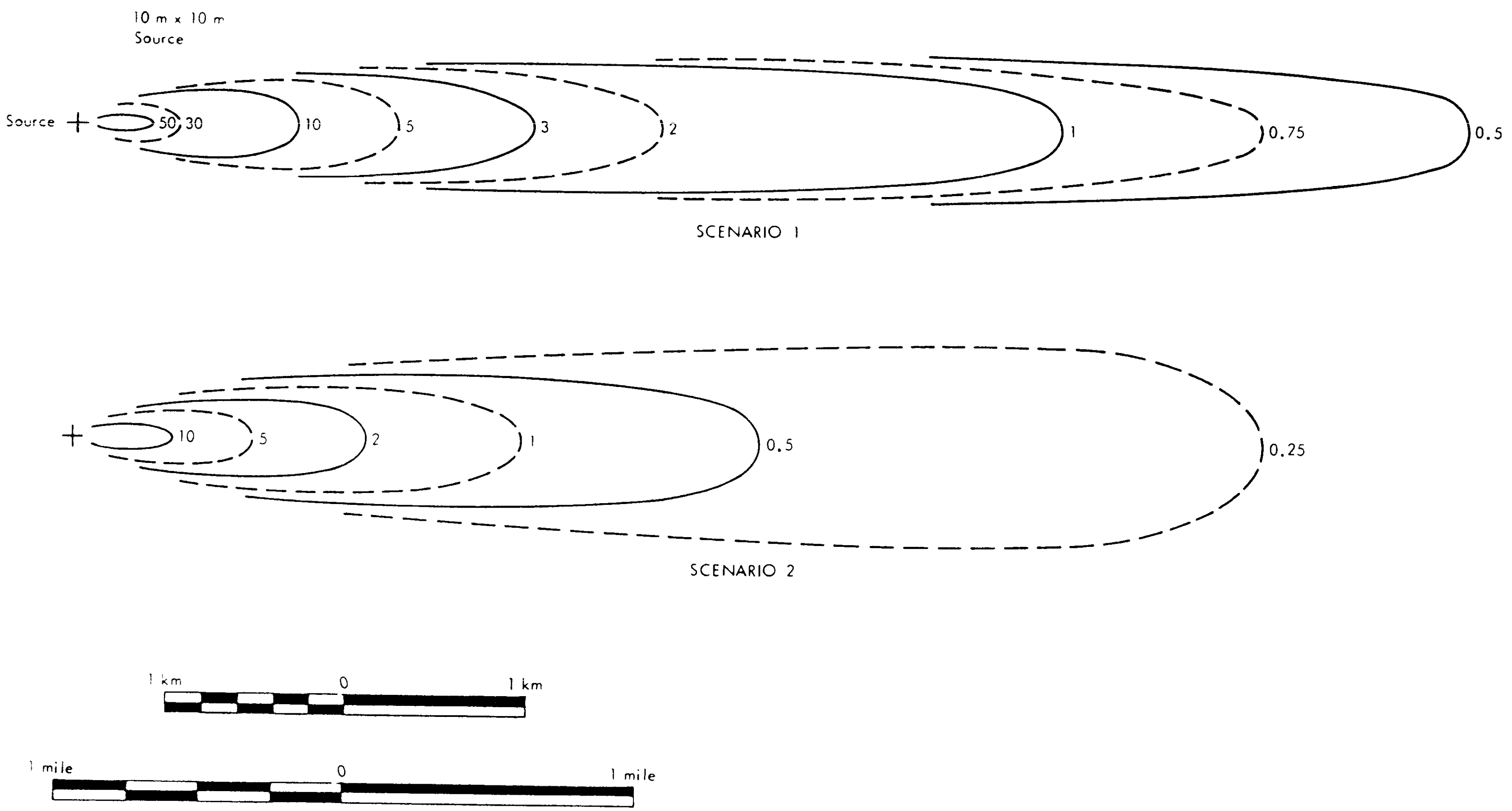

Figure 4-11a. Worst-Case Isopleths for a 10 m x 10 m Source.

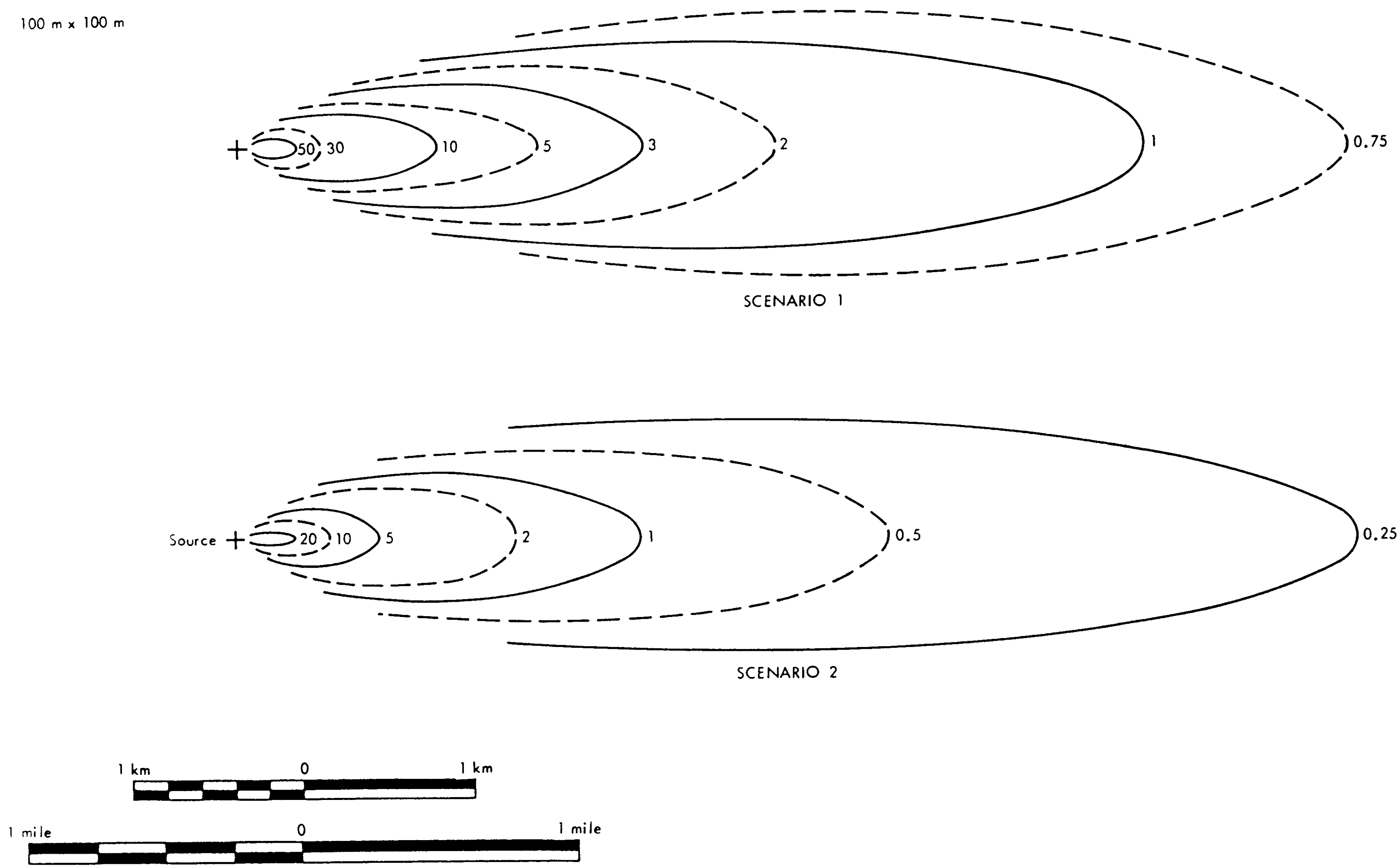

Figure 4-11b. Worst-Case Isopleths for a 100 m x 100 m Source

Scaling of worst-case concentration estimates is considerably simpler than that for annual estimates. The following describes the scaling process:

Scenario	Scaling Factor
1	Worst-case mechanical emission rate
2	Sum of worst-case mechanical and erosion emission rates

The earlier remarks concerning corresponding scaling factor and concentration units and the importance of expressing the emission rates in identical units are equally applicable here.

Thus, for a 10 m x 10 m source, if the worst-case emission rates are 17 lb/day = 0.089 g/s (mechanical) and 12 lb/day = 0.063 g/s (wind erosion), the farthest isopleths in Figure 4-10 would correspond to 0.044 $\mu g/m^3$ and 0.038 $\mu g/m^3$ for scenarios 1 and 2, respectively. If an isopleth for a particular concentration value is required, Figure 4-12 provides a means of quickly constructing an additional isopleth. For the example given above, suppose the 0.5 $\mu g/m^3$ isopleth is required. In scenario 1, the unscaled concentration corresponding to 0.5 $\mu g/m^3$ for scaling factor of 0.089 g/s is

$$\frac{0.5\ \mu g/m^3}{0.0089\ g/s} = 5.6\ \mu s/m^3 \qquad (4\text{-}13)$$

Entering Figure 4-12 at the ordinate 5.6, it is seen that, for scenario 1, the required isopleth extends 1.8 km downwind from the source. For scenario 2, the required unscaled concentration is

$$\frac{0.5\ \mu g/m^3}{(0.089 + 0.063)\ g/s} = 3.3\ \mu s/m^3 \qquad (4\text{-}14)$$

Thus, in the second scenario, the isopleth extends 1.3 km downwind. Knowing the extent of these isopleths, the user could then draw curves going through the point and having the same general shape as those drawn in the figures. (See also the example problems in Section 5.0.)

Figure 4-12 may also be used to construct very conservative estimates of worst-case concentrations. Conceivably, this could be done if the contaminated site is located in the middle of a populated area and thus any wind direction would transport the contamination toward a portion of the receptor population. In this case, downwind distances corresponding to specific (scaled) concentrations are obtained from the figure and concentric

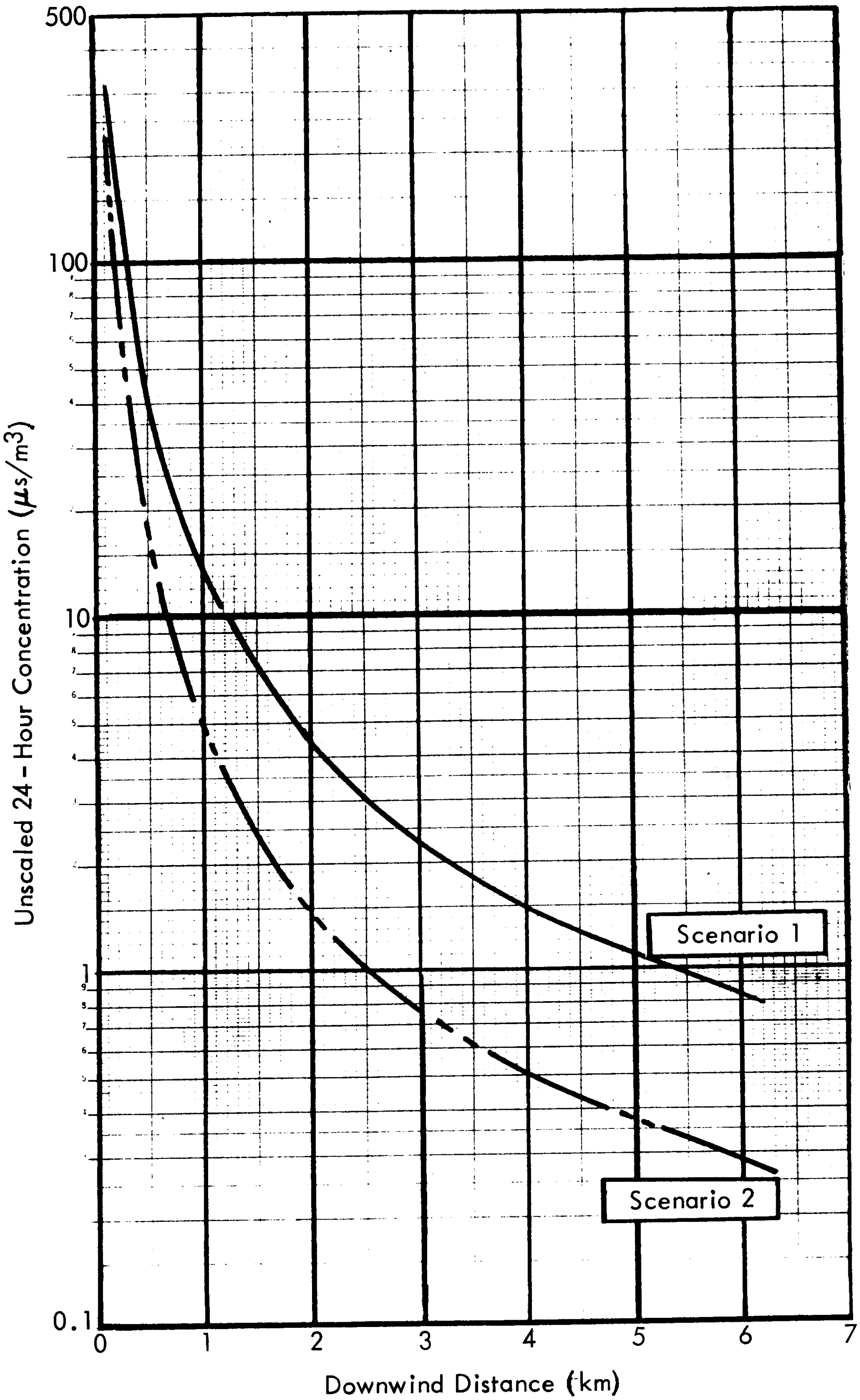

Figure 4-12. Unscaled Worst-Case Concentration Versus Downwind Distance.

circles are drawn. Although such an isopleth is extremely conservative, it does provide a rapid means of determining a maximum population potentially exposed as a worst case and may prove useful in a screening application.

4.3 ESTIMATION OF EXPOSURE

By this point, the analyst will have maps showing annual and worst case concentrations for the particular site being assessed. The final step in the emergency response assessment consists of estimating levels of contamination to which surrounding residents may be exposed. Direct human exposure due to respirable particulate from the surface contamination site is the primary interest in this manual.

However, users should be aware that particulate emissions can also cause human exposure in a variety of other ways:

- Deposition on soil resulting in human exposure via dermal absorption or ingestion,
- Deposition on crops or pasture lands and introduction into the human food chain, and
- Deposition on waterways, uptake through aquatic organisms, and eventual human consumption.

In order to facilitate health effects risk calculations, exposure is generally calculated as a daily dose rate averaged over an individual's lifetime and bodyweight:

$$\text{Average Daily Lifetime Exposure} = \frac{\begin{bmatrix}\text{Contaminant} \\ \text{Concentration}\end{bmatrix}\begin{bmatrix}\text{Respiration} \\ \text{Rate}\end{bmatrix}\begin{bmatrix}\text{Exposure} \\ \text{Duration}\end{bmatrix}\begin{bmatrix}\text{Absorption} \\ \text{Fraction}\end{bmatrix}}{(\text{Body Weight})\ (\text{Lifetime})} \qquad (4\text{-}15)$$

Recommendations for how to estimate each factor in the above equation are given below:

1. Contaminant Concentration - This is the contaminant concentration in the air as calculated in Section 4.2 Since the exposure could be occurring over long time periods (i.e. up to 70 yr) the user must consider whether degradation of the contaminant at the source could occur. The chemical and biological degradation properties of the contaminant should be reviewed. If significant degradation is likely to occur, exposure calculations become much more complicated. In that case, source contaminant levels, resulting air concentrations and exposure levels must be calculated at frequent intervals and summed over the exposure period. This procedure would be very cumbersome via the approach presented in this manual and is really only practical via computer programs. Assuming first order kinetics, an approximation of the degradation effects can be achieved by multiplying the concentration by: $(1-e^{-kt})/(kt)$,

where k = degradation rate constant $(\text{days})^{-1}$ and t = time period over which exposure occurs (days). The k value is compound-specific and this approach should be applied after consultation with experts.

2. Respiration Rate - In situations where a person is exposed 24 hr/day, a respiration rate of 23 m^3/day should be used. This value is based on Snyder et al. (1975) who report that an average adult male spends 8 hr/day resting at a respiration rate of 7.5 l/min and 12 hr/day engaged in light activity at a respiration rate of 20 l/min. If the exposure occurs during only a portion of the day, the respiration rate should be reduced accordingly.

3. Exposure Duration - This is the time that exposure occurs. In a worst case analysis assume that the exposure occurs 24 hr/day for an entire life-time (70 year) for a total of 25,550 days. However, this value should be adjusted to reflect site conditions such as the behavior patterns of the exposed population. For example, the travel habits of the exposed people and time spent indoors versus outdoors could affect the exposure duration.

4. Absorption Fraction - This is the fraction of the contaminant entering in the lungs which is absorbed into the body. The fraction of particles which are inspired (i.e. enter the respiratory system) depends on numerous factors such as breathing rate, particle size distribution, wind speed, and whether breathing is done through the nose or mouth. The International Standards Organization (1981) has estimated the inspired fraction as a function of particle size under average conditions (Figure 4-13). The procedures in this manual provide concentration estimates of the PM_{10} particles which are generally considered most important in estimating health effects. Virtually all of these particles will be inspired.

   However, the fate of PM_{10} particles after entering the lungs is less certain. Generally, the heavier particles deposit in the upper regions of the respiratory tract, the lighter particles in the lower regions, and the very lightest are exhaled. Most of the deposited particles in the upper regions and some in the lower region are cleared by ciliary action and swallowed. Lacking specific particle size distribution information, the fate of inspired particles should be assumed to follow the recommendations of the International Commission on Radiological Protection (1968) as given in Table 4-3.

   After determining the fraction of particles swallowed, the overall absorption fraction can be further refined on the basis of GI tract absorption. This is a chemical specific phenomenom and must be based on available literature.

   In summary, the overall absorption fraction is calculated as follows:

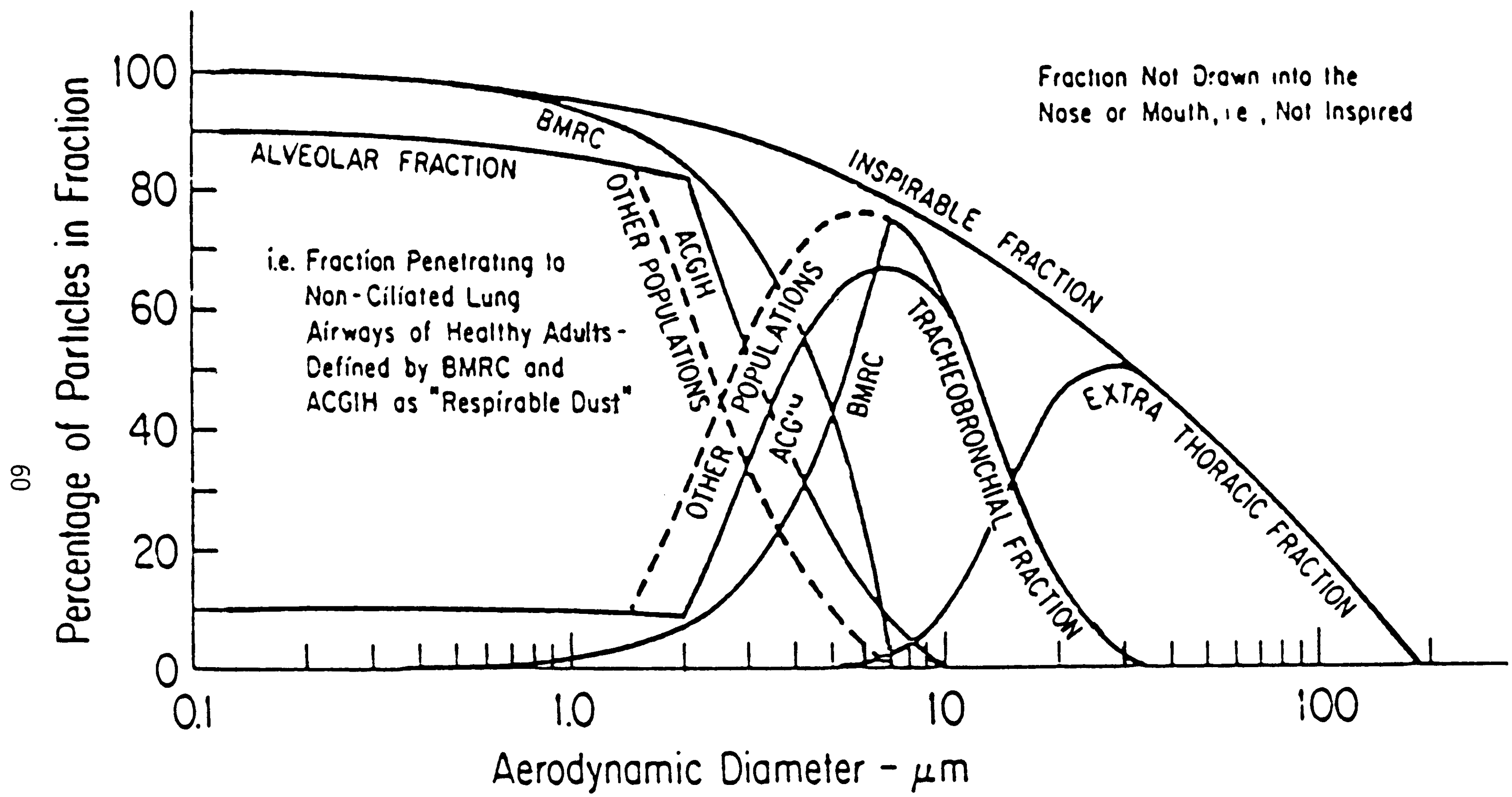

Figure 4-13. Inspired fraction versus particle size. This figure shows recommended values of size-cuts for occupational and environmental health related air sampling. There are three optional boundaries between the tracheobronchial and alveolar components of the thoracic fraction. Two of these are the traditional recommendations for working adults, i.e., the British Medical Research Council (BMRC) and the American Conference of Governmental Industrial Hygienists (ACGIH). The third, labeled other populations, corresponds to sensitive members of the general population who have constricted bronchial airways. Source: International Standards Organization, 1981.

$$\text{Absorption Fraction} = \text{Inspired Fraction}\left[\text{Fraction Remaining in Lungs} + \left(\text{Fraction Swallowed}\right)\left(\text{GI Tract Absorption Fraction}\right)\right] \quad (4\text{-}16)$$

The inspired fraction should be assumed equal to 100% for PM_{10} particles; the fractions remaining in lungs and swallowed are determined from Table 4-3; and the GI tract absorption fraction is determined from the available literature on the specific contaminant.

5. Body Weight - This is generally considered equal to 70 kg which represents an average adult male (Snyder et al., 1975). If data are available on the exposed population which suggests that a different bodyweight may be more representative, this value should be adjusted accordingly.

6. Lifetime - This is generally assumed equal to 70 years which represents an average U.S. male.

TABLE 4-3. DISTRIBUTION OF INSPIRED PARTICLES

	Readily soluble compounds (%)	Other compounds (%)
Exhaled	25	25
Deposited in upper respiratory passages and subsequently swallowed	50	50
Deposited in the lungs (lower respiratory passages)	25[a]	25[b]

[a] This is taken up into the body.

[b] Of this, half is eliminated from the lungs and swallowed in the first 24 hr, making a total of 62.5% swallowed. The remaining 12.5% is retained in the lungs with a half-life of 120 days, it being assumed that this portion is taken up into the body fluids.

Source: International Commission on Radiological Protection, 1968.

Exposures can be calculated on the basis of the annual concentration estimates from Section 4.2, using the model just presented. A different model would be necessary to calculate acute exposure from the worst-case concentration field. The exposure estimates can be used to estimate risk on the basis of the toxicological properties of the contaminants. However, the details on how to calculate risks are beyond the scope of this manual. After exposure estimates are completed, they can be plotted and isopleths constructed as done for the concentration estimates.

The isopleths for annual exposure obtained in the preceding section are now used to assess direct exposure to people living in the vicinity of the contamination site. Because the isopleths are drawn on a 1:24,000 map scale, they may be overlaid directly onto USGS maps. Because the USGS topographic maps indicate populated areas, it is an easy matter to identify populated areas exposed to certain concentration levels. It is more difficult, however, to determine the number of residents contained within these isopleths; the techniques used to estimate population by receptor area will largely depend on the location of the site.

For example, if the contamination site is located in a sparsely populated area, then the USGS maps will show individual buildings. Consultation with knowledgeable officials (such as the sheriff, county agent, county clerk, local utility personnel, etc.) should result in reliable estimates of population. Should it not prove feasible to consult with other personnel because of time constraints or inaccessibility, a default value of 3.8 persons per dwelling may be used in conjunction with the USGS maps (or, possibly, aerial photgraphs). A standard road atlas or a state highway map with populations listed may also prove valuable.

On the other hand, if the site is located near a densely populated area, then other means of estimating population are available. In this instance, authorities of the type discussed above may again be consulted. In addition, a greater amount of Bureau of the Census data may be available to the user. The smallest statistical units reported by the Bureau are block groups, enumeration districts, and census tracts. Complete-count statistics are available for areas as small as a city block. Additional sources of information include the Federal Emergency Management Agency (FEMA), municipal libraries, assessor offices, and election boards. A readily available technique for estimates in this type of area would be to assume a uniform density for the town or city in question, and then multiply the population (taken from a road atlas) by the fraction of the town contained in the isopleth.

It is recommended that response personnel contact the appropriate regional offices of the Bureau of the Census (Table 4-4) well in advance of an emergency in order to identify the types of data generally available and to establish a means of rapidly obtaining information (especially during evenings and weekends).

It is clear that no fixed set of rules may be followed to obtain population estimates. For example, a contaminated site might be located at the edge of a town. In this case, it may be necessary to employ different techniques for the urban and rural areas. By using a road atlas as well as the 3.8 persons per residence assumption, it is possible to obtain rapid estimates of population within isopleths without outside consultation. It is strongly recommended, however, that outside help be sought if possible and at a very early stage of the assessment procedure. Because population estimates for smaller areas surrounding the contamination site may be developed independently of the emission/concentration estimation process, it is quite possible to have a well-defined population field at the time when direct exposure is assessed.

TABLE 4-4. CENSUS BUREAU REGIONAL OFFICES - INFORMATION SERVICES

Atlanta, GA	404/881-2274
Boston, MA	617/223-0026
Charlotte, NC	704/371-6144
Chicago, IL	312/353-0980
Dallas, TX	214/767-0625
Denver, CO	303/234-5825
Detroit, MI	313/226-4675
Kansas City, KS	913/236-3731
Los Angeles, CA	213/209-6612
New York, NY	212/264-4730
Philadelphia, PA	215/597-8313
Seattle, WA	206/442-7080

4.4 ASSUMPTIONS, LIMITATIONS, AND PARAMETER SENSITIVITY

4.4.1 Assumptions and Limitations of the Assessment Procedure

The assumptions inherent in the Gaussian dispersion model as applied here are as follows:

a. There is no diffusion in the direction of the wind.

b. There is no variation in meteorology between the source and receptor

c. Ground level concentrations are estimated assuming that there is no deposition or reaction at the ground surface.

The above are basic assumptions of the Gaussian algorithm. Assumptions specific to the particular problem at hand are:

a. Only particulate less than 10 μm are considered.

b. All sources are modeled as either 10 m or 100 m side squares. These source sizes were chosen after discussion with EPA on NPL sites and consideration of sources of different sizes.

c. The meteorology at the site may be adequately represented using average climatological data from the climatic regions.

d. The emissions are uniformly distributed over the area source.

The assumptions specific to the problem are not considered to be too restrictive in light of the emergency response. The intent in this phase of the manual was to provide a means of quickly obtaining estimates of ambient concentrations with accuracy similar to that associated with UNAMAP models.

The accuracy of estimates obtained by Gaussian dispersion models is often expressed as a factor of two (i.e., +100%, - 50%) for flat terrain. There are several factors (dispersion in complex terrain, for example) however, that may significantly affect the accuracy of the model estimates. No attempt has been made in this manual to include these complexities because of their very site-specific nature. The modeling approach adopted here is, in many ways, quite similar to that which might be used by a regulatory agency in screening potential air quality impacts.

Assumptions related to the direct exposure analysis are:

a. The indoor contaminant concentration is identical to the ambient concentration.

b. Only residents are considered in determining the exposed population.

Neither of the above assumptions are deemed restrictive in light of the emergency. It should be noted that HRS counts transients such as workers in factories, offices, restaurants, motels, and students in addition to residents. The manual does not consider these potentially exposed persons because their inclusion would require either canvassing or consultation with knowledgeable officials. Because of the time involved in this process, these transients are excluded in conducting the 24-hr assessment. Should additional time or personnel be available during the emergency response, inclusion of transients may be accomplished using the above methods.

The most restrictive assumptions in the assessment process are related to the emission rates:

a. The level of contamination in potentially airborne particle size range is identical to that in the bulk material.

b. Vehicular traffic is the only mechanical resuspension process considered.

c. The Rayleigh distribution provides an acceptable fit to the annual wind speed distribution at a given site.

There is evidence to suspect that smaller particles may contain higher levels of contamination than larger ones. This is obviously the case if the contaminant adheres to the surface of an individual particle; because of their greater surface to mass ratio, these smaller particles have greater contamination level (on a mass basis) than does the bulk material as a whole. It is strongly recommended that a contamination level be determined for silt sample of the surface because the silt represents the portion of the surface material that may become airborne.

Vehicular traffic on unpaved surfaces easily represents the largest open dust source in most industrial settings. Because materials handling operations are generally accomplished by a good deal of vehicular traffic, it is mostly likely that any other source of mechanical resuspension would be considerably less than that due to traffic.

4.4.2 Sensitivity of the Solution

The concentration estimates obtained in Sections 4.2 are the product of numerous prior calculations. Because the estimated concentration field is essentially the final result of the assessment, it is important to realize "how the pieces fit together" and what effect a change in one of the parameters has on the final results.

The single most important piece of information in the procedure is α, the level of contamination. This parameter influences all subsequent calculations. The effect of α on all the calculations is linear; that is, if α is estimated 50% too low, then the resulting emission/erosion rates and the concentrations will all be 50% low, assuming that all other parameters are correct. This is the only parameter which is capable by itself of affecting the entire assessment process in such a manner. As noted in the section above, it is strongly suggested that the contamination level be determined for a silt sample if at all possible.

The concentration field is also highly dependent on the emission factors and source extent calculations, because the results are employed in the scaling process. The collection of relevant, site-specific data with which to estimate the necessary parameters may easily present the greatest limitation in the procedure. It is strongly recommended that prior to the scaling of the dispersion model results, users perform a sensitivity analysis in order to assess the impact of parameter variation.

It is important to note that, once the site is located in a climatic region and erosion/emission rates are calculated, the resulting concentration field is then predetermined. This is due to the fact that previously obtained computer model output is used to generate the field. Of course this procedure will not allow the user to vary the meteorological input and this will make it difficult to assess the uncertainties associated with the average meteorological input for given emergency response situations. Although this is something of a limitation, the intent in preparing the manual was to provide the user with a means of quickly obtaining dispersion estimates of UNAMAP quality. During the manual preparation period, alternative approaches were evaluated. The approach adopted here represents a condensed form of a typical screening process employed by a regulatory agency.

The use of regional climatologies in the modeling process serves to emphasize the large-scale meteorology in describing the near surface wind field for the site. The common practice of employing a STAR deck recorded tens of miles away may emphasize small-scale differences at the recording station. Thus, in the absence of climatological data recorded at the contamination site, it is believed that the regional climatologies employed better represent the meteorology, especially in the case of wind erosion (which is potentially present at all sites), because wind speeds of this magnitude are typically associated with passage of large-scale frontal systems.

To summarize, numerous assumptions have been made in developing the assessment procedure. In many cases, the "presolved" nature of the procedure does not allow the analyst the flexibility of modifying these basic assumptions. Table 4-5, however, provides a quantitative evaluation of parameter variability on emission rates as well as a qualitative evaluation of the expected sensitivity of the overall results to input parameters that the analyst may choose to vary in the course of conducting an emergency response assessment. The table is intended primarily as guidance for the response team in deciding how to best allocate data collection resources so as to obtain the most reliable concentration estimates within the 24 hr time frame.

TABLE 4-5. SENSITIVITY ANALYSIS GUIDELINES

		Influence on Emission Rates[c]			
Parameter[a]	Inherent Variability[b]	Mechanical	Limited Erosion	Unlimited Erosion	Overall Effect on Results[d]
Contamination Level	H	10%	10%	10%	C
Contamination Area (or, Travel Length Contaminated)	H	10%	10%	10%	C
Traffic Volume	M	10%	N/A	N/A	C-M
Threshold Wind Speed	M	N/A	-10%	-20%[e]	C-M
Vegetative Cover	M				
Sparse (< 20%)		N/A	-2.5% to 0%[f]	-2.5% to 0%[f]	L
Dense (> 80%)		N/A	<-40%[g]	<-40%[g]	C
Frequency of Disturbance	M	N/A	10%	N/A	M
Silt	M-L	10%	N/A	N/A	M
Vehicle Speed	L	8%	N/A	N/A	M-L
Vehicle Weight	M-L	3%	N/A	N/A	L
Wheels	L	12%	N/A	N/A	M

a Average climatological variables given in tables or figures not considered.
b H = Highly variable; M = moderately variable; L = little variability
c Values given represent percent change when parameter is increased 10%.
d C = critical, M = moderate; L = low
e Change highly dependent on original estimate of u_t. Example value is based on u_t = 10 m/s, [u] = 5 m/s.
f Decrease of less than 2.5%
g Decrease of more than 40%.

SECTION 5

EXAMPLE APPLICATIONS

5.1 EXAMPLE ONE

This example illustrates the use of the emergency response assessment manual. The hypothetical site is located in Climatic Region 3 and the nearest NWS station in Table 4-1 is North Platte, Nebraska.

The site survey indicated that the contamination extended approximately 6 in. below the surface and that the soil itself consisted of finely divided material. Furthermore, the contaminated surface was essentially unvegetated with no nonerodible elements and no evidence of crusting. Thus, the surface was characterized as one of unlimited wind erosion potential. Because no evidence of traffic (e.g., tire tracks, ruts, etc.) was found during the survey, the resuspension mechanisms were considered to be limited to wind erosion only. Finally, a contamination level (α) of 6.4 ppm in the bulk surface material had triggered the emergency response assessment.

A sketch of the site was also made during the survey, and is shown in Figure 5-1. The site is located in a sparsely settled area in a large valley oriented from SW to NE. Information obtained from the county sheriff and the county agent indicates that the only residents within a 7 km (4 mi) radius are the Loner family, whose farm is approximately 2 km NW of the site and residents of a mobile home park roughly 3 km to the NE.

The on-site coordinator (OSC) has decided that an emergency response assessment for both worst-case and annual conditions must be carried out within 24 hr. Using the guidelines presented in Section 4, the following are determined.

1. Because the source covers more than 1/2 acre, the 100 m x 100 m source representation is selected. The area of the source is 150 m x 300 m = 45,000 m^2.

2. Based on the particle size mode of 500 μm obtained from a hand sieving test of the surface material, Figure 3-4 is used to estimate a wind erosion threshold friction velocity of 50 cm/s.

3. Using a z_0 value of 2 cm (value in Figure 3-5 for grassland which characterizes most of the surrounding area), the equivalent 7 m threshold wind speed is found (using Figure 4-1) to be

$$15 \text{ (50 cm/s)} = 7.5 \text{ m/s}$$

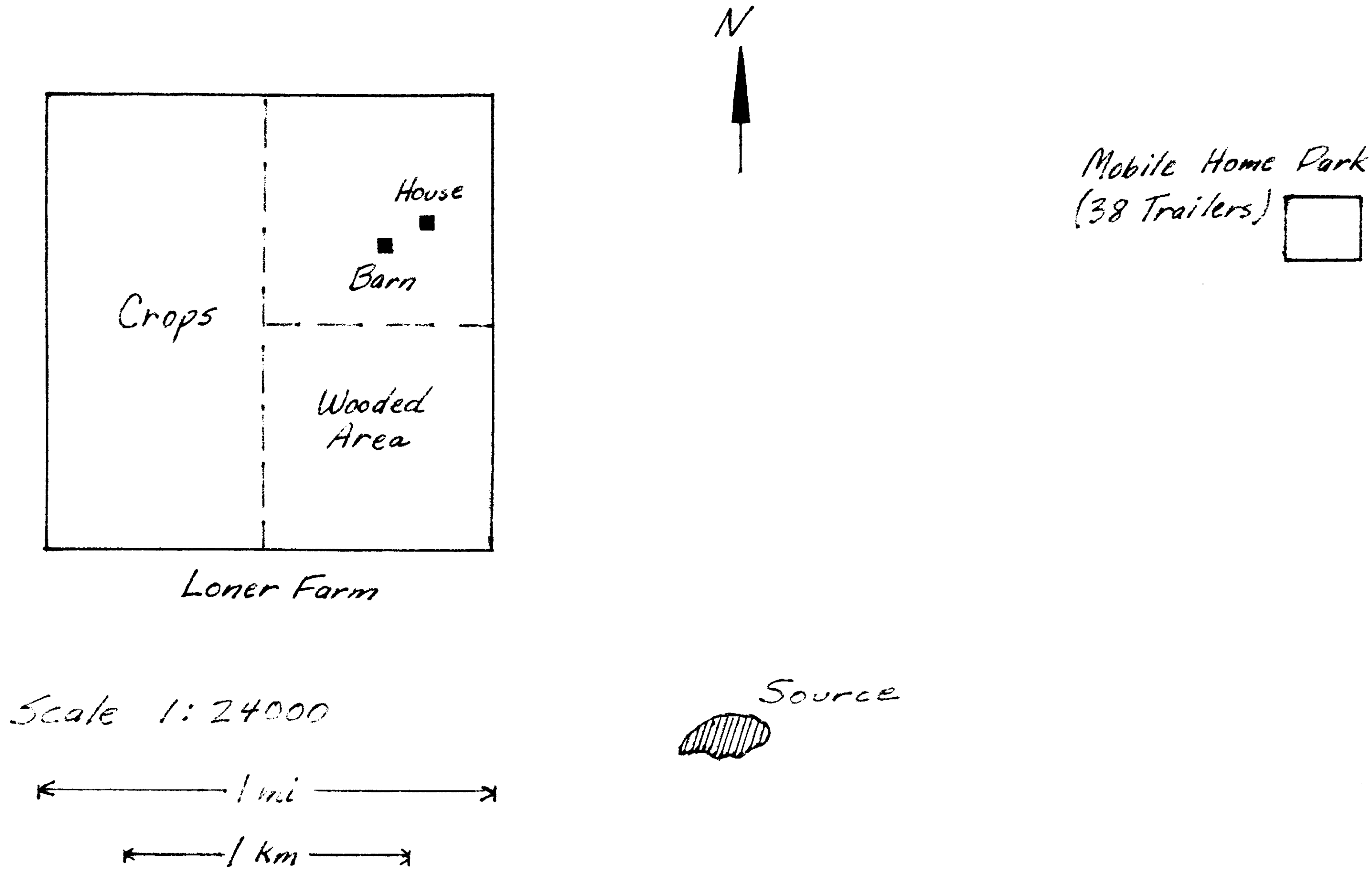

Figure 5-1. Sketch of the Hypothetical Site (Example One)

4. Because the threshold friction velocity is less than 75 cm/s, the "unlimited reservoir" emission model for wind erosion (Section 4.1.2) is used. From the data for North Platte in Table 4-1, the mean annual wind speed is 4.6 m/s. Thus,

$$x = 0.886\ (7.5\ m/s)/(4.6\ m/s) = 1.4$$

and from Figure 4-3,

$$F(1.4) = 1.0$$

Thus, Equation 4-4 gives an annual average PM_{10} emission factor of

$$E_{10} = 0.036\ (4.6/7.5)^3\ F(x) = 0.0083\ g/hr/m^2$$

5. The annual average PM_{10} emission rate is found by multiplying the area by the emission factor

$$(45{,}000\ m^2)\ (0.0083\ g/hr/m^2) = 370\ g/hr = 0.10\ g/s$$

The annual emission rate of the contaminant in the form of PM_{10} is

$$6.4\ (10^{-6})\ (0.10) = 0.67\ \mu g/s$$

using α = 6.4 ppm.

6. For worst-case 24-hr conditions, Equation 4-6 gives

$$\begin{aligned}[u_{6\text{-}hr}] &= [u^+] - 2\ m/s \\ &= 27.7 - 2 \\ &= 25.7\ m/s\end{aligned}$$

using the data for North Platte in Table 4-1. Thus, by Equation 4-5, the PM_{10} emission factor is

$$E_{10} = 0.036\ (25.7)^3 = 610\ g/hr/m^2$$

The corresponding contaminant emission rate is

$$6.4\ (10^{-6})\ (610\ g/hr/m^2)\ (45{,}000) = 180\ g/hr = 49\ mg/s$$

As an additional step in the procedure, the analyst must consider whether or not "rotation" of the annual concentration field is appropriate. "Rotation" of the field implies that one should orient the axis of maximum concentration parallel to the direction of prevailing winds for the site in question. This should be done if it appears that channeling of the wind flow by topographic features (including buildings) would be likely. This should be considered after consulting people living in the area and an expert meteorologist familiar with local wind conditions. Because the valley in this example problem is relatively shallow, no rotation was deemed necessary.

Annual Estimates

The annual dispersion modeling worksheet is next completed as shown in Figure 5-2. Because only wind erosion is present at the site, only the upper portion of Figure 5-2 is used in estimating the concentration field. Also, because all population within the 7 km radius is within 3 km and north of the site, only the receptors in this area are considered. The results of the scaling are shown in Figure 5-3. Note that the concentrations are in units of pg/m^3.

Isopleths drawn using the data of Figure 5-3 are shown superimposed on the sketch of the site in Figure 5-4. From this figure, it may be seen that the seven members of the Loner family are exposed to annual ambient concentration of ~ 0.125 pg/m^3.

Using the method outlined in Section 4.3, the average daily lifetime exposure (ADLE) may be calculated using the pertinent parameters given in Table 5-1.

TABLE 5-1. VALUES TO COMPUTE AVERAGE DAILY LIFETIME EXPOSURE (ADLE)

Parameter	Value
Respiration rate	23 m^3/day
Exposure duration	70 yr
Inspired fraction	100% (10 μm or less)
Fraction remaining in lungs	12.5%
Fraction swallowed	62.5%
GI tract absorption fraction	100%
Body weight	70 kg
Life time	70 yr

All the above are based on the parameter estimation guidelines presented in Section 4.3, with the exception of GI tract absorption which has been set equal to its most conservative value. Using the above, Equation 4-15 estimates ADLE at the Loner farm as 0.031 pg/kg-day, corresponding to the airborne contaminant concentration of 0.125 pg/m^3.

Worst Case Estimates

Using the worst-case emission factor of 49 mg/s and the curve for Scenario 2 in Figure 4-12,it is seen that at 3 km, the estimated contaminant concentration is

$$(49 \text{ mg/s})\ (0.8\ \mu\text{s/m}^3) = 39 \text{ ng/m}^3$$

DISPERSION MODELING WORKSHEET

Climatic Region **3**

Date ______
By ______
Checked ______

Source Size 10 m x 10 m ____
or
100 m x 100 m ✓

ANNUAL ESTIMATES

I Annual Wind Erosion Scaling Factor, Q_I

A. Annual Wind Erosion Rate, R_{10} = **0.67 μ** g/s

B. Select approproate value of P_R from below

Climatic Region	1	2	3	4	5	6	7
P_R	0.152	0.262	0.396	0.288	0.182	0.134	0.296

C. Annual Scaling Factor, $Q_I = \frac{R_{10}}{P_R}$ = **1.7 μ** g/s

II Annual Mechanical Resuspension Scaling Factor, Q_{II}

Q_{II} = Annual Mechanical Emission Rate, R_{10} = **N/A** g/s

Figure 5-2. Completed Worksheet for Hypothetical Site (Example One)

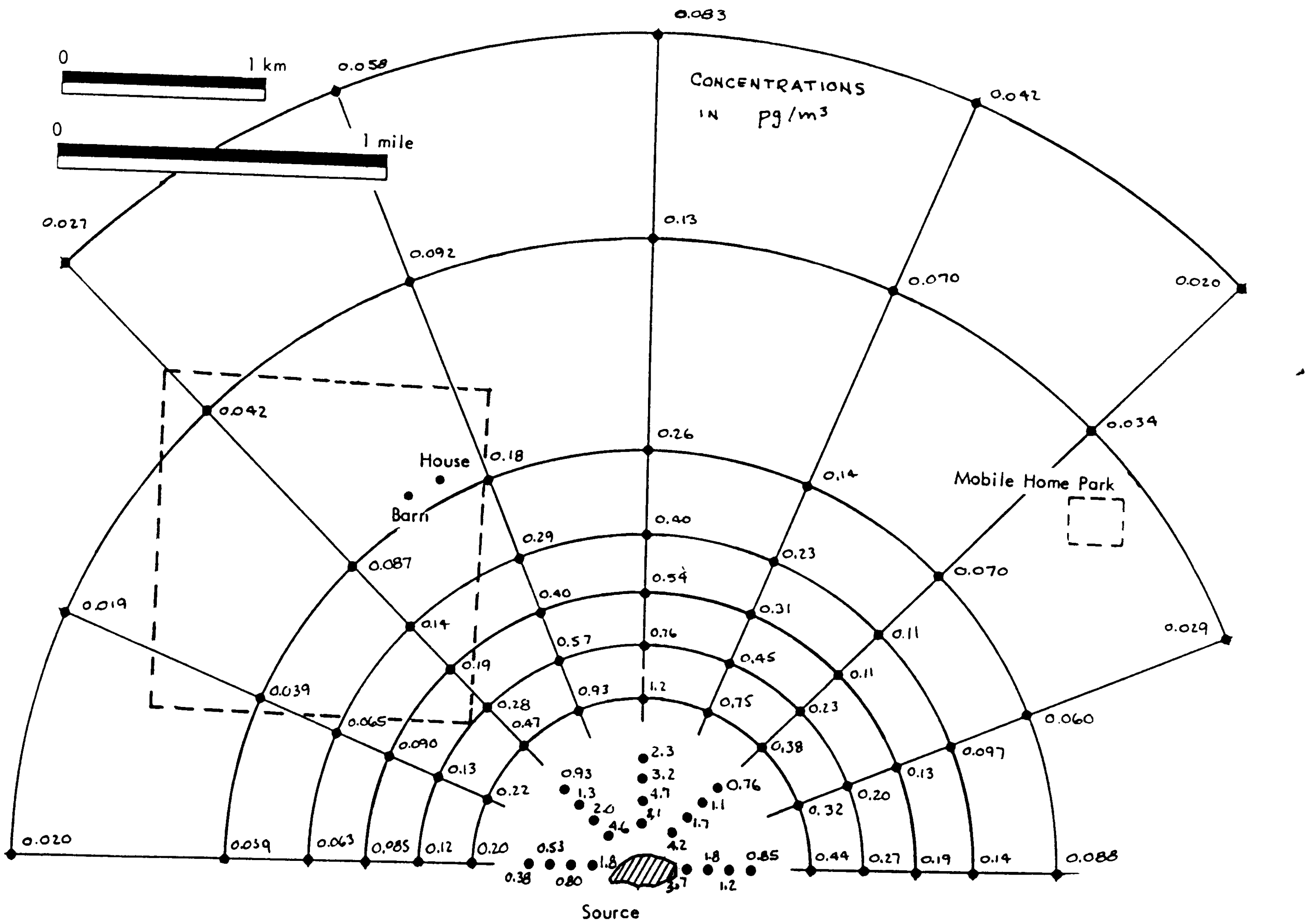

Figure 5-3. Annual Ambient Concentration Field for the Hypothetical Site (Example One)

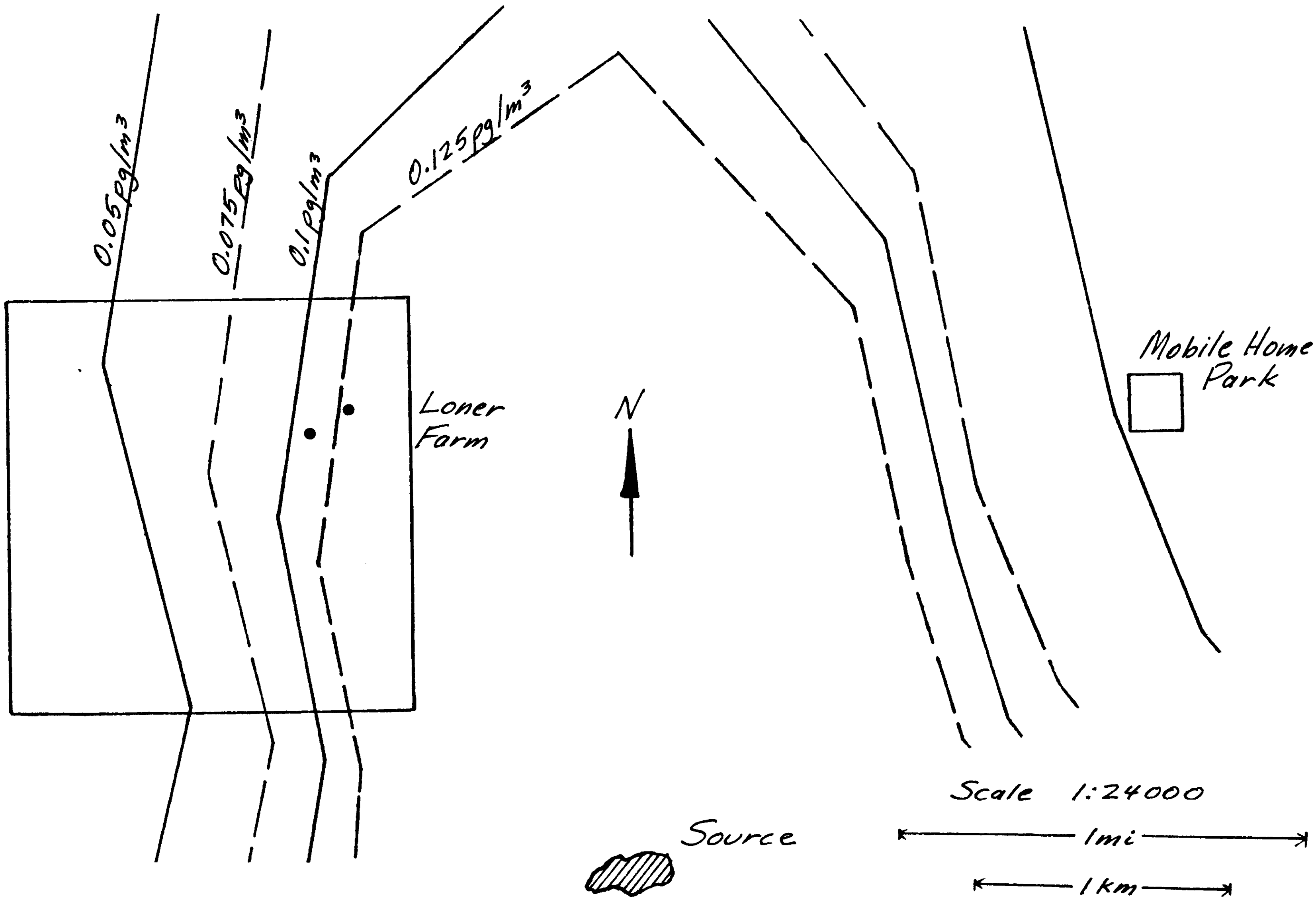

Figure 5-4. Annual Concentration Isopleths for the Hypothetical Site (Example One)

The isopleths from Figure 4-11 are shown superimposed on the sketch in Figure 5-5. The worst-case isopleths are aimed at the mobile home park because more people reside at this location in comparison to the Loner farm house which is approximately the same distance from the source. Additional isopleths may be drawn using the technique discussed in the text.

5.2 EXAMPLE TWO

The hypothetical site in this example is located in Climatic Region 4 and the nearest NWS station in Table 4-1 is Grand Rapids, Michigan. The contamination level is 100,000 ppm.

The source is located approximately halfway between Extown (population 1,500) and the Point, a peninsula extending into Lake Extown. The lake itself is fairly large, and all populated areas within 7 km lie in the sector south to southwest from the source, as shown in Figure 5-6.

Details of the contamination are sketchy, but roughly 1/5 acre appears to have been contaminated (Figure 5-7). However, approximately 80% of the area is covered by continuous vegetation, with the only unvegetated portion of contaminated area consisting of a 100-ft length of an unpaved road 15 ft wide. This road is fairly well traveled (approximately 2,000 round trips per month).

A hand sieving procedure showed that the mode of distribution was approximately 6 mm. The threshold friction velocity is thus approximately 150 cm/s (from Figure 3-4) or 22 m/s at 7 m (Figure 4-1), assuming a roughness height of 2 cm (value for grassland in Figure 3-6). Because this value is greater than u^+ for Grand Rapids, only road emissions were considered in the modeling process.

Discussion with the sheriff confirmed the 2,000 round trip figure and also yielded the following traffic parameters:

Average vehicle speed	=	20 mph = 32 kph
Average vehicle weight	=	3 tons = 2.7 mg
Average no. wheels	=	4

Using Equation 4-7 with a silt value of 10% and p=140 (taken from Figure 4-4) yields an annual average PM_{10} emission factor of

$$E_{10} = 0.85 \left(\frac{10}{10}\right) \left(\frac{32}{24}\right)^{0.8} \left(\frac{2.7}{7}\right)^{0.3} \left(\frac{4}{6}\right)^{1.2} \left(\frac{365-140}{365}\right) = 0.305 \frac{\text{kg}}{\text{VKT}}$$

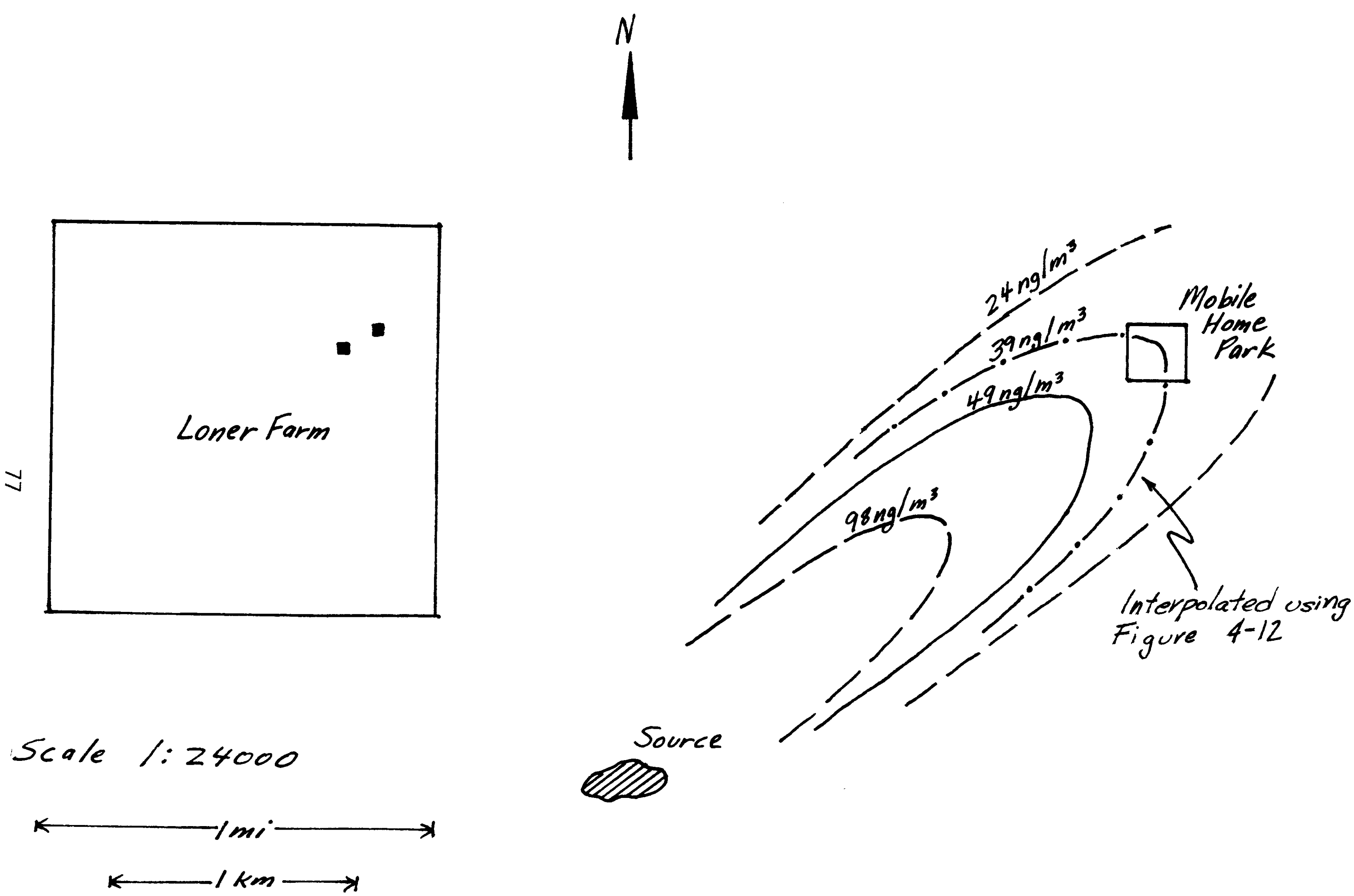

Figure 5-5. Worst-Case Isopleths for the Hypothetical Site (Example One)

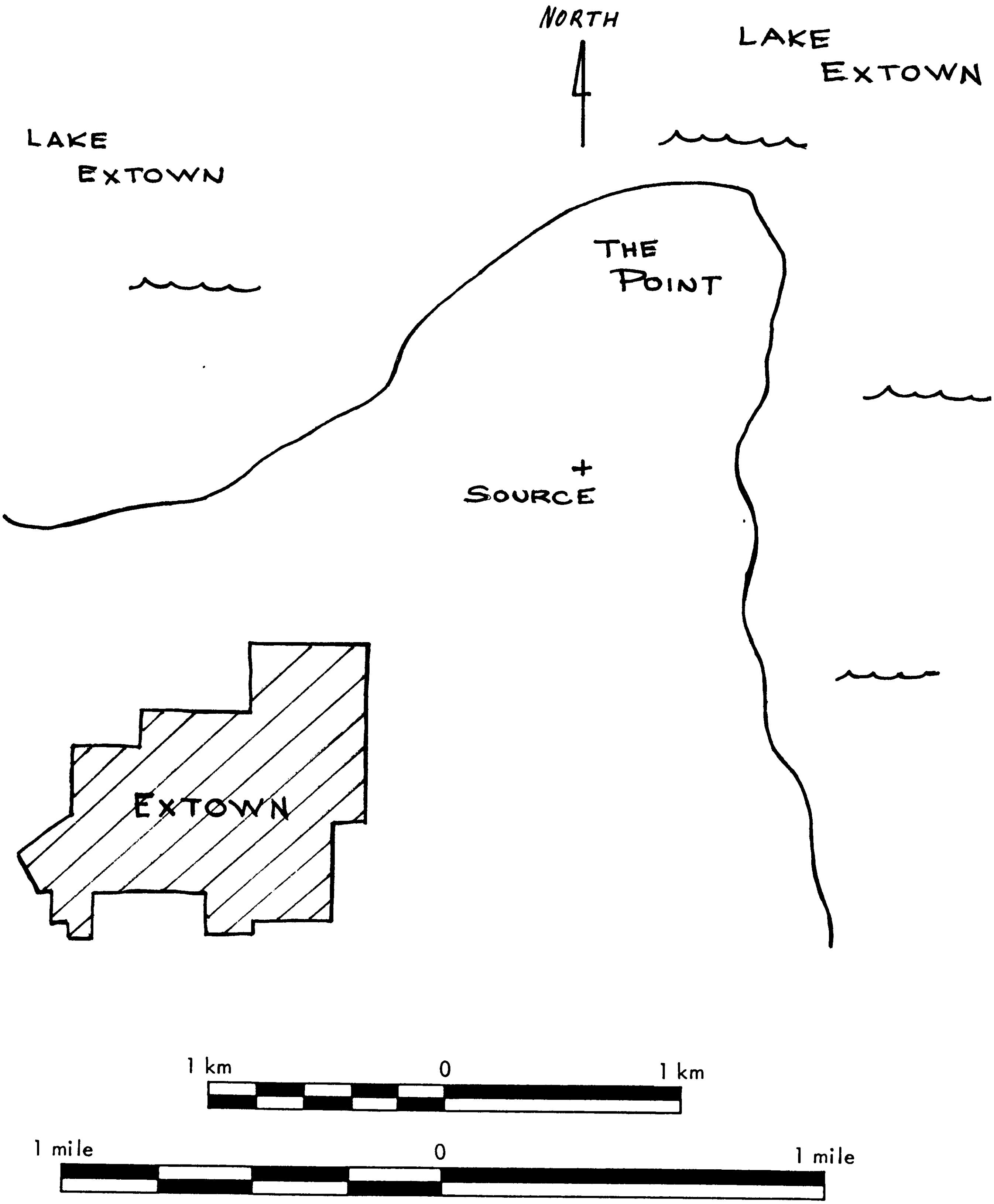

Figure 5-6. Sketch of the Hypothetical Site (Example Two)

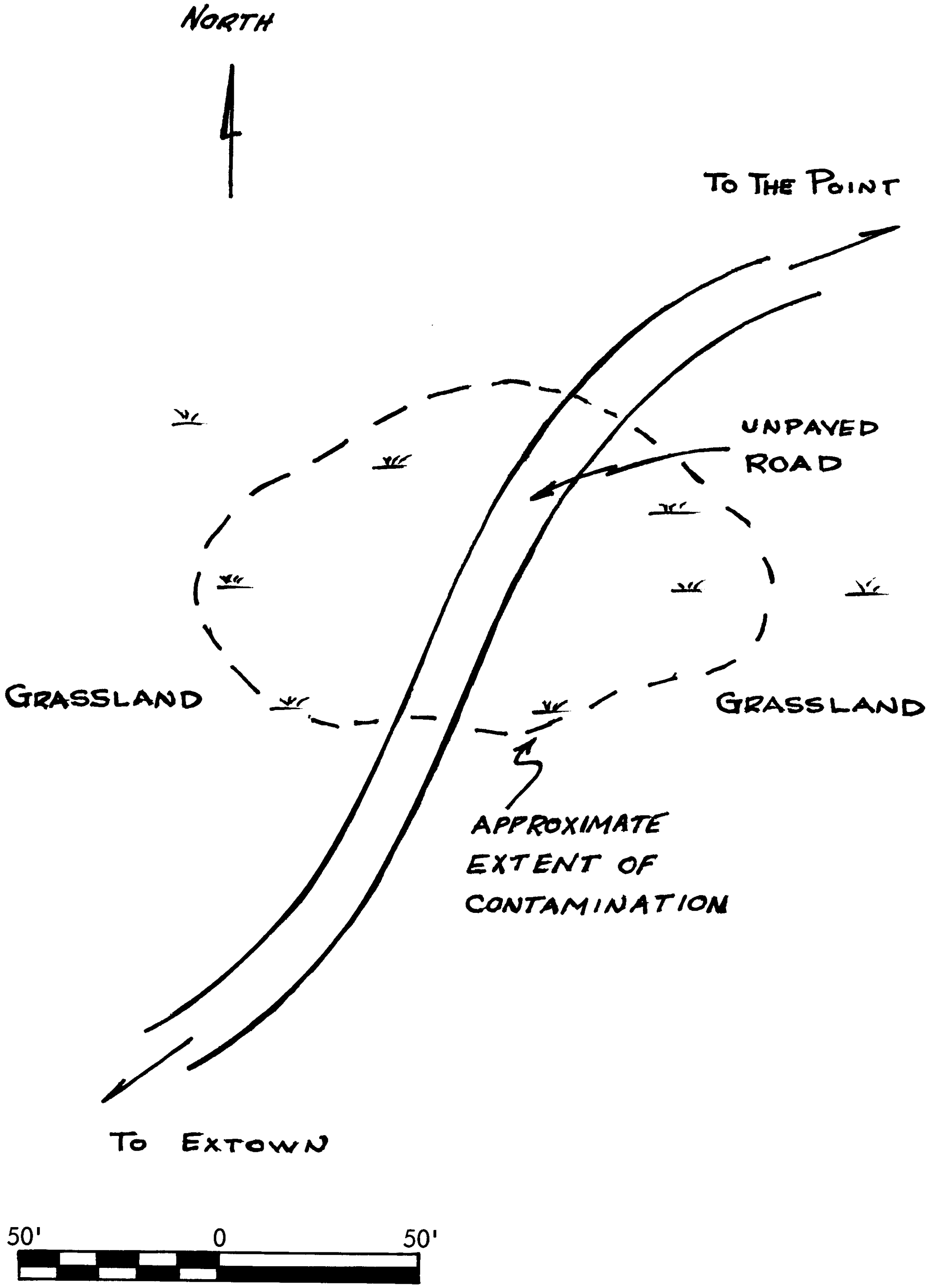

Figure 5-7. Sketch of Contaminated Area (Example Two)

The annual source extent is

$$2{,}000 \frac{\text{round trips}}{\text{month}} \cdot \frac{\text{2 vehicles}}{\text{round trip}} \cdot \frac{\text{100 ft}}{\text{vehicle}} \cdot \frac{\text{1 mile}}{\text{5280 ft}} \cdot \frac{\text{12 month}}{\text{year}}$$

on 910 veh-mile/year = 1,460 veh-km/yr. Thus for $\alpha = 0.1$ the annual average contaminant emission rate is

$$0.1 \cdot 0.305 \frac{\text{kg}}{\text{VKT}} \cdot 1{,}460 \frac{\text{VKT}}{\text{yr}} = 44.6 \text{ kg/yr} = 1.4 \text{ mg/s}$$

The resulting annual average concentration estimates are in units of

$$\frac{\text{mg}}{\text{s}} \cdot \frac{\mu\text{s}}{\text{m}^3} = \frac{\text{ng}}{\text{m}^3}$$

For worst-case emissions, the OSC has determined to consider a dry day ($p = 0$) with a total vehicle count of 500 round trips. Thus, the worst-case PM_{10} emission factor (from Equation 4-7) is

$$0.85 \left[\frac{10}{10}\right] \left[\frac{32}{24}\right]^{0.8} \left[\frac{2.7}{7}\right]^{0.3} \left[\frac{4}{6}\right]^{1.2} = 0.494 \text{ kg/VKT}$$

The corresponding worst-case contaminant emission rate (from Equation 2-1) is

$$\alpha \left(0.494 \frac{\text{kg}}{\text{VKT}}\right) \left(\frac{1{,}000 \text{ veh}}{\text{day}}\right) \left(\frac{100 \text{ ft}}{\text{veh}}\right) \left(\frac{1.609 \text{ km}}{5{,}280 \text{ ft}}\right) = 15.0 \text{ kg/day} = 0.017 \text{ g/s}$$

Thus, the worst-case scaling factor is 0.017 g/s (as seen from the table on page 56) and resulting concentration estimates are in units of $\mu g/m^3$.

A conservative annual average concentration field (as discussed at the end of Section 4.2.1) was obtained by scaling the radial for Region 4 with the largest unscaled concentration estimates (i.e., north, from the tables on pages D-15 and D-16) and then constructing concentric isopleths. Because the actual emitting area is fairly small, the 10m x 10m source was used. The result is shown as Figure 5-8.

Using the same assumptions for the ADLE calculation as in the preceding example, the following values result:

Annual average concentration (ng/m^3)	Fraction of town within isopleth (%)	ADLE (ng/kg-day)
4.5	1	1.1
3.5	7	0.86
2.5	17	0.62
1.75	32	0.43
1.25	43	0.31

Thus, approximately 100 persons (7% of the population) have an ADLE value of 0.86 ng/kg-day, for example. This estimate assumes that population is uniformly distributed over the town's area.

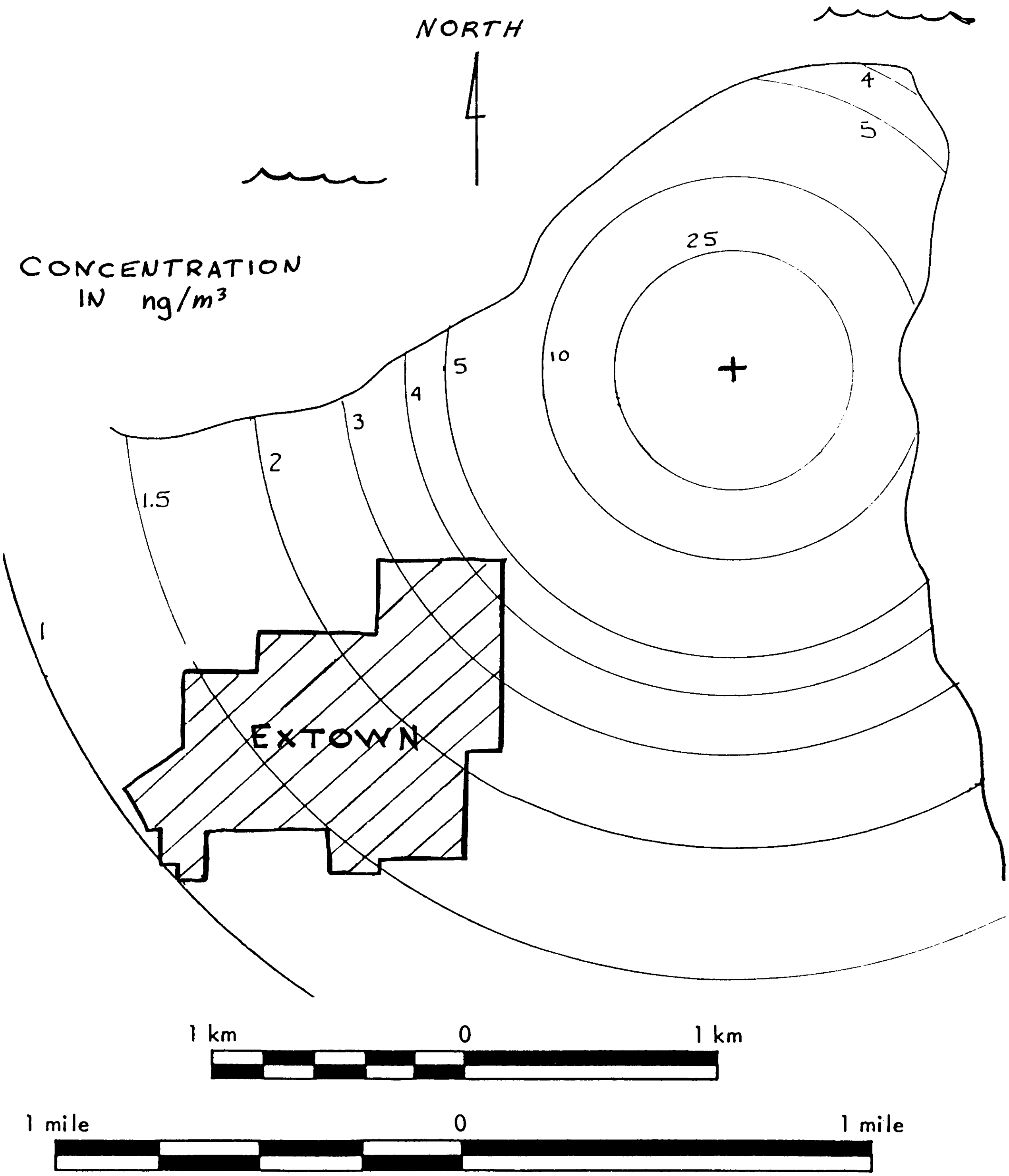

Figure 5-8. Conservative Annual Concentration Isopleths for Hypothetical Site (Example Two)

The worst-case 24-hr concentrations are plotted in Figure 5-9. Figure 4-12 was used to construct these isopleths. Note that a value of 0.03 μg/m^3 was conservatively assumed for portions of the town outside the lowest isopleth shown in Figure 5-9.

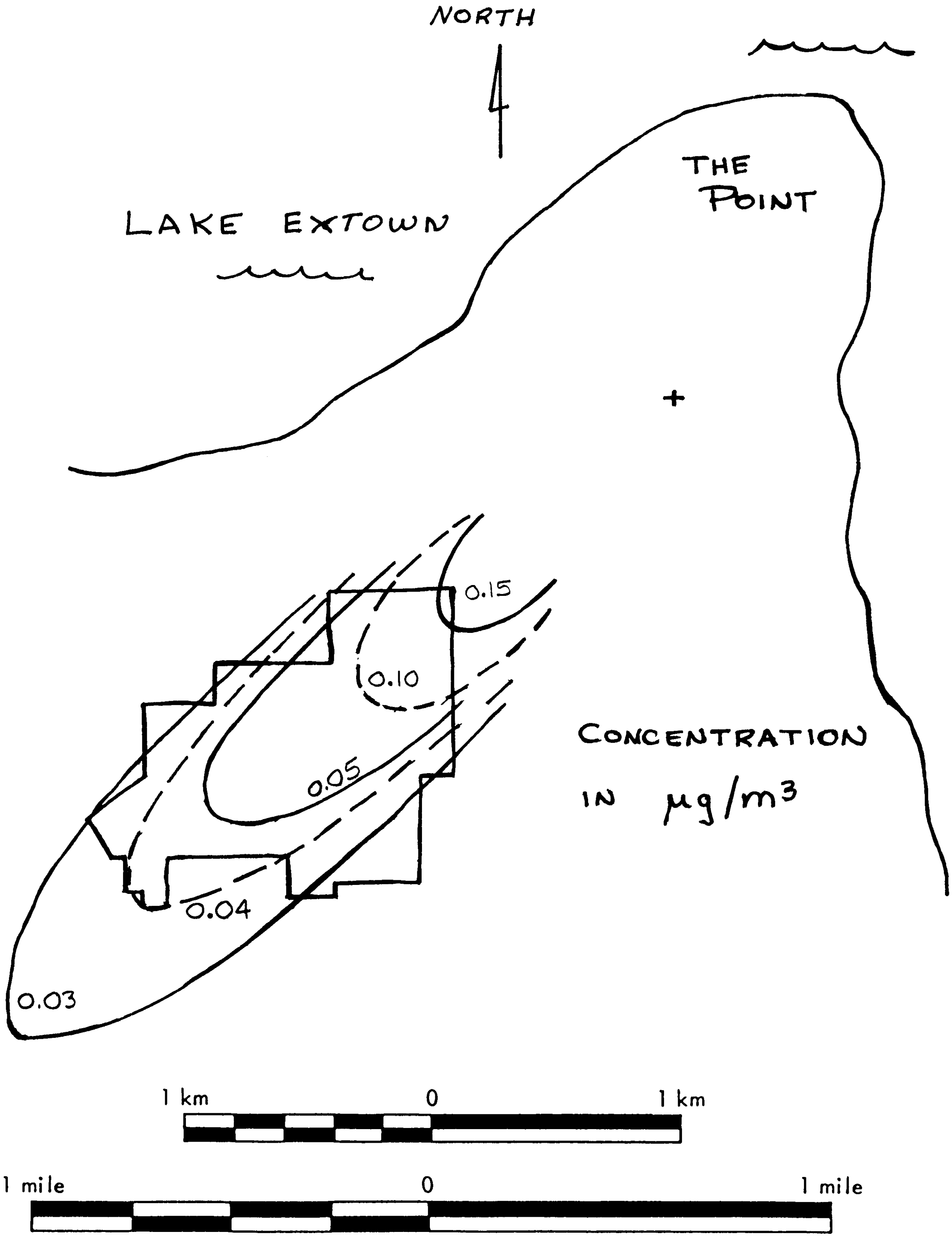

Figure 5-9. Worst-Case Concentration Isopleths for Hypothetical Site (Example Two)

SECTION 6

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APPENDIX A

PHOTOGRAPHS OF NONERODIBLE ELEMENT DISTRIBUTIONS

This Appendix presents a series of photographs of nonerodible element distributions along with the associated multipliers for correcting the threshold friction velocity (u_{*t}) determined only for the erodible material. The non-erodible elements are generally larger than about 1 cm in equivalent physical diameter. The appearance of the contaminated surface in question should be compared to the photographs for the purpose of determining the appropriate correction factor.

The correction factors for the subsequent figures are as follows:

Figure A-1	No correction.	$L_c < 10^{-3}$
Figure A-2	$\frac{(u_{*t}) \text{ corrected}}{(u_{*t}) \text{ uncorrected}} = 2$	$L_c \simeq 0.01$
Figure A-3	$\frac{(u_{*t}) \text{ corrected}}{(u_{*t}) \text{ uncorrected}} = 5$	$L_c \simeq 0.1$

The remaining photographs illustrate the appearance of dusted surfaces and a surface protected by dried vegetation. Figure A-4 shows a dusted surface covered with an appreciable amount of both erodible and nonerodible particles. Figure A-5 shows a dusted surface with a negligible reservoir of loose erodible material; the quarter coin in the photograph indicates approximate scale. Figure A-6 shows a surface that is well protected by dried vegetation, rendering the surface nonerodible; the white square in the photograph is of 1 mx 1 m inside dimensions.

Figure A-1

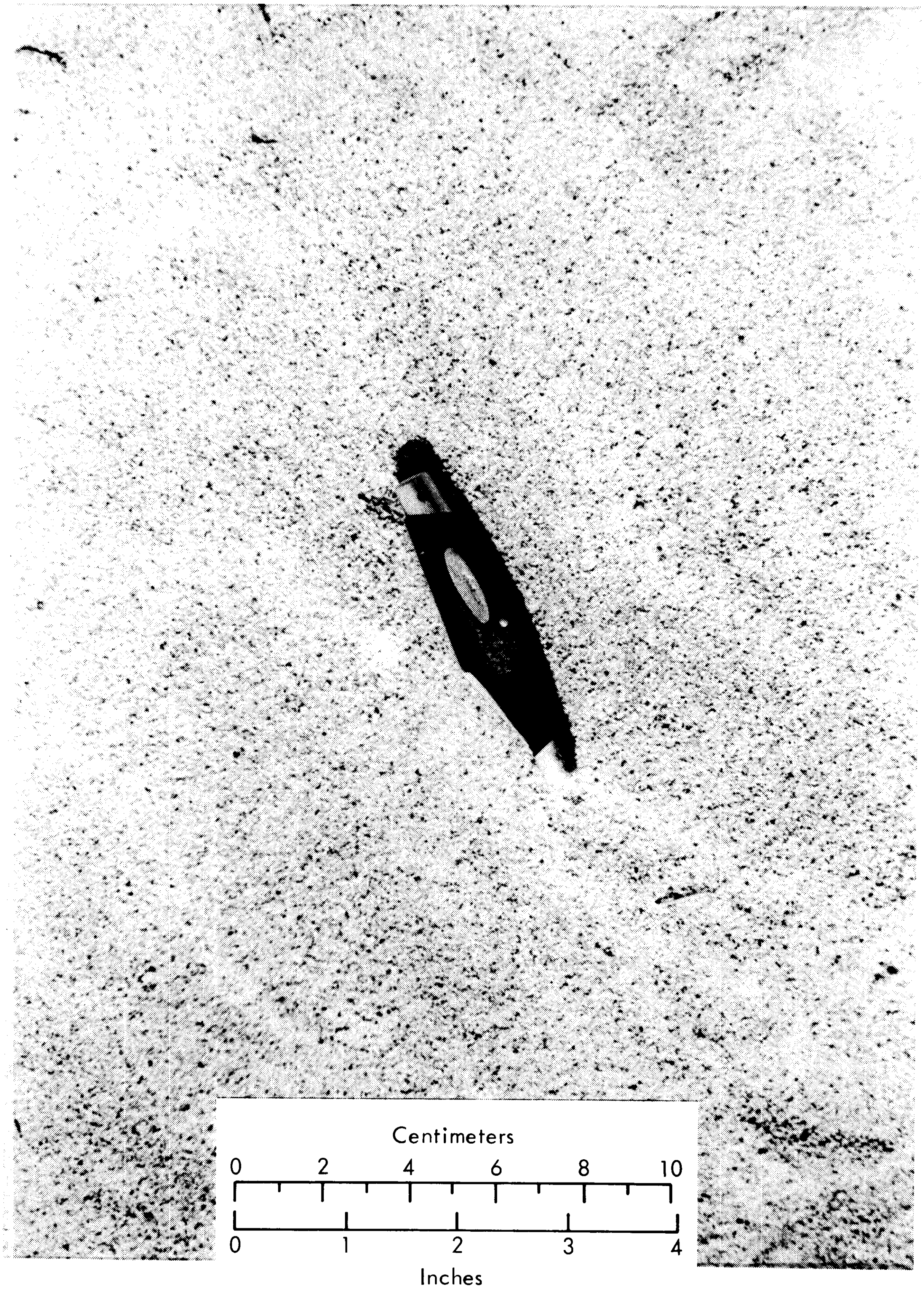

Figure A-2

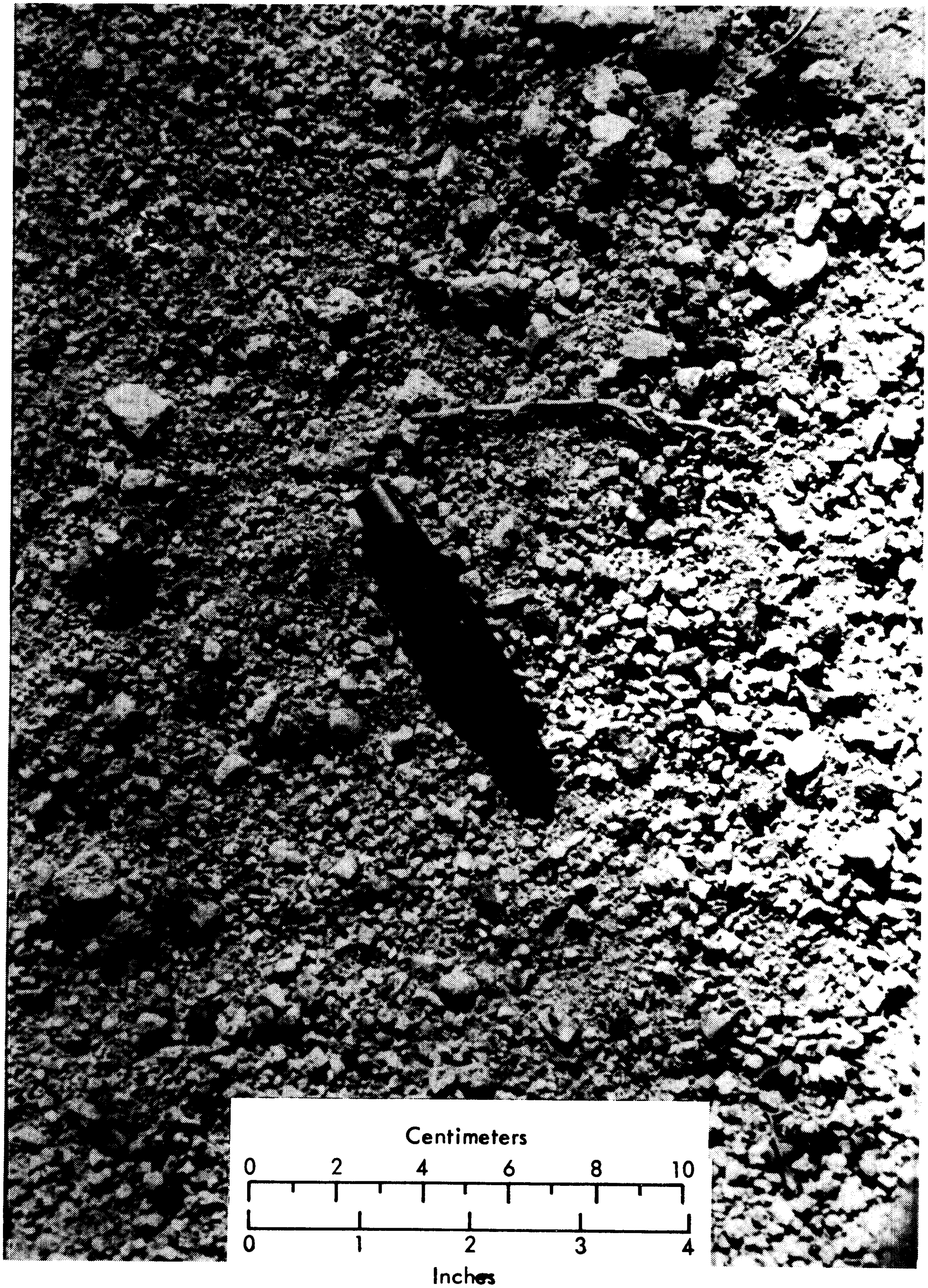

Figure A-3

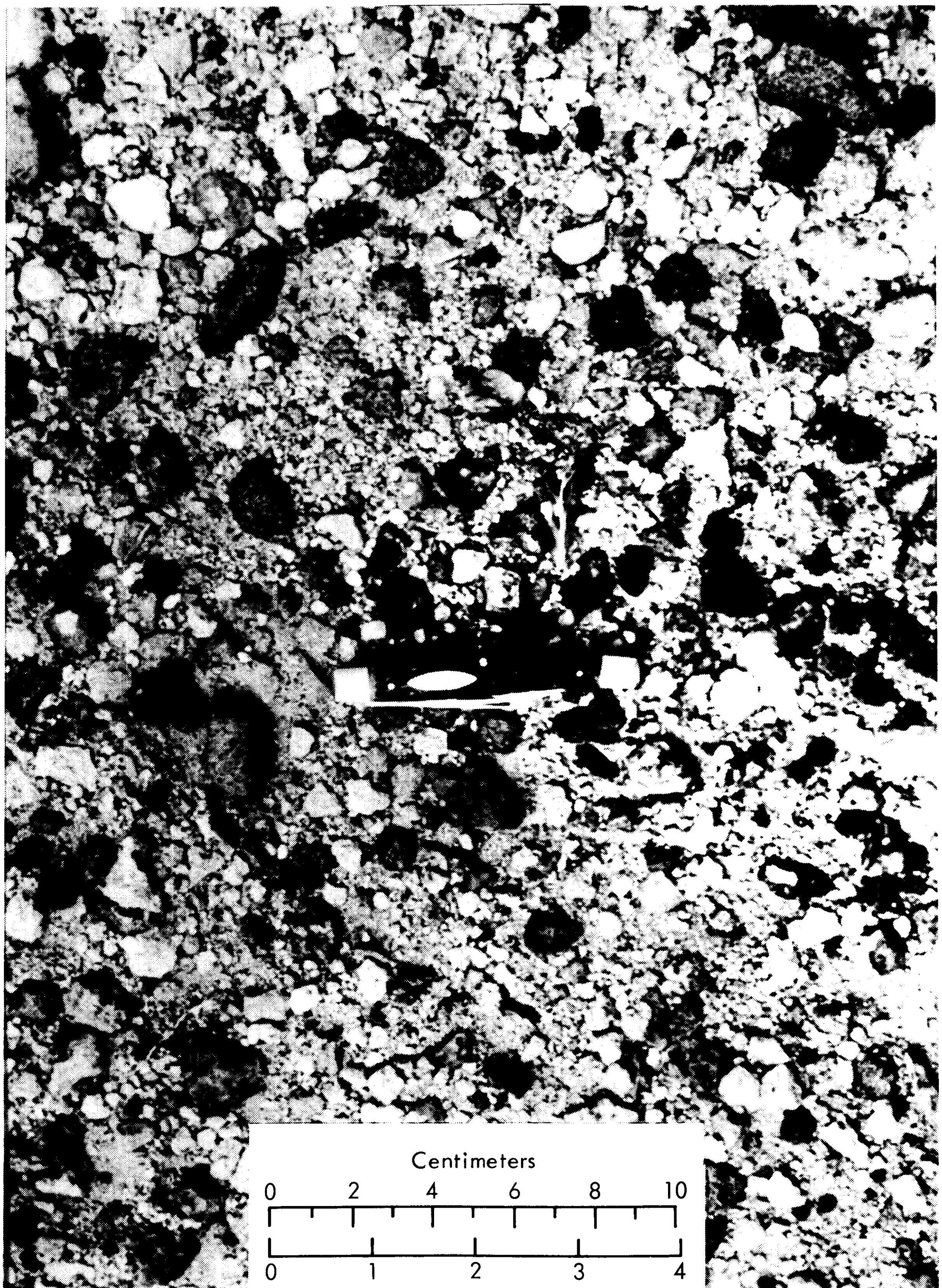

Figure A-4

Figure A-5

Figure A-6

APPENDIX B

FUNCTION NEEDED FOR UNLIMITED EROSION MODEL

The integral

$$I([u],u_t) = \int_{u_t}^{\infty} \text{freq}(u)\, u^3\, du$$

is used in establishing emissions from surfaces with unlimited erosion potential. This represents an expected value of the cube of wind speed and may be evaluated as follows:

$$I([u], u_t) = ([u])^3 F(x)$$

where

$$x = \frac{\sqrt{\pi}}{2} \frac{u_t}{[u]} = 0.886 \frac{u_t}{[u]}$$

F(x) = function plotted in Figure 4-4.

The above relationship assumes that the wind speed distribution for a given site may be represented by a Rayleigh distribution

$$\text{freq}(u) = \frac{\pi}{2} \frac{u}{[u]^2} \exp\left(-\frac{\pi}{4} \frac{u^2}{[u]^2}\right)$$

This type of distribution has been proposed as an appropriate model to fit wind speed data for use in wind power studies (Hennessy, 1977; Cortis, et al, 1978). The determination of the resulting integral was accomplished by making use of properties of the incomplete gamma function (Ambramowitz and Stegun, 1970).

Two remarks are in order concerning F(x). The limiting value of F(x) for small values of x is given by

$$\lim_{x \to 0} F(x) = \frac{6}{\pi} = 1.91$$

Furthermore, for values of x greater than 2, F(x) may be approximated by

$$F(x) = 0.18\,(8x^3 + 12x)\exp(-x^2)$$

APPENDIX C

ATMOSPHERIC DISPERSION MODELS AND METEOROLOGICAL INPUT DATA

C.1 ATMOSPHERIC DISPERSION MODELS

Air quality models may be divided into two broad categories: (a) statistical models, and (b) simulation models. Statistical models differ from simulation models in that they require actual atmospheric monitoring data and do not attempt to explicitly describe the physical processes involved in pollutant dispersion. Instead, relationships between measured pollutant concentrations and various meteorlogical and source parameters are determined empirically through statistical techniques.

Simulation models, commonly referred to as "dispersion" models, attempt to simulate the physical processes of the transport and dilution of airborne pollutants. The principal requirements are source emission rates and meteorlogical input consisting of wind speed, direction, and atmospheric stability. The model then predicts time-averaged concentrations at specific locations for these emission rates, based on mathematical relationships using empirical data corresponding to the particular meteorlogical condition. It is important to realize that this type of model does not attempt to describe instantaneous conditions but rather time-averaged conditions. Because they are developed in terms of fundamental physical principles of general applicability, simulation models have the important property of being transferable from one location to another and thus, are much more applicable in the present analysis.

The fundamental dispersion equation for a ground level point emission source with no plume rise is

$$\chi\ (x,y,z) = \frac{Q}{\pi\sigma_y\sigma_z u} \quad \exp \quad \frac{-\ y^2}{2\sigma_y{}^2} \quad \exp \quad \frac{-\ z^2}{2\sigma_z{}^2}$$

where

χ = concentration (mass/volume)
Q = emission rate (mass/time)
σ_y,σ_z = horizontal and vertical dispersion coefficients, respectively (length)
u = wind speed (length/time)
x = downwind coordinate (length)
y,z = horizontal and vertical coordinates, respectively (length)

The dispersion coefficients are empirical functions of x and stability class. Furthermore, for area sources of the type considered in this manual, a "virtual point" source may be used in the modeling process. This type of source has a non-zero initial (i.e., at x=0) horizontal dispersion coefficient. A virtual distance x_y is found by determining the distance downwind from a point source at which σ_y equals the initial value for the appropriate stability class. Subsequent horizontal dispersion coefficients are determined as a function of $x + x_y$ (Turner, 1970).

The basic assumptions underlying this model are: (a) the plume spread follows a Gaussian distribution (which accounts for the term "Gaussian dispersion model"); (b) the emission rate is uniformly distributed over the source and is continuous; (c) meteorlogical conditions remain constant between the source at the coordinate origin and the receptor point (x,y,z); and (d) no deposition or reaction occurs at the ground surface.

Because of the large number of source-receptor combinations in a typical application, many computerized dispersion models have been developed over the years. The most important air quality models are those approved by the EPA and included in its User's Network for Applied Modeling of Air Pollution (UNAMAP) series. Both models selected for inclusion in this manual are members of the UNAMAP family. All are based on the assumptions described above. The differences between models are mostly due to variations in the treatment of: (a) plume rise, (b) pollutant half-life, (c) diffusion limitations due to mixing heights, (d) source configurations, and (e) dispersion coefficients to characterize plume growth.

C.2 MODEL ACCURACY/LIMITATIONS

Three major factors influence the accuracy of air quality simulation models (AMS, 1981; AMS, 1978). These are: (a) the capability of the algorithms to reproduce the important physical and chemical processes; (b) the quality of the emission data; and (c) the quality or appropriateness of the meteorlogical data. The overall accuracy of the Gaussian dispersion model will be dependent upon the specific application.

The Gaussian model will perform best under the conditions used to form the basis for the current models. These conditions include:

<u>Source</u>: Low-level, continuous, nonbuoyant emission, in simple terrain.

<u>Meteorology</u>: Near neutral stability, steady and relatively homogeneous wind field.

<u>Estimate</u>: Local, short-term, concentrations of inert pollutants.

Under these relatively simple conditions, "factor of two" agreement between predicted and observed concentrations is probably realistic. This estimate of accuracy assumes that the controlling meteorlogical parameters are measured on-site, an assumption that in many practical applications is not valid. At present, routine dispersion modeling applications often rely on ground-level observations taken hourly at NWS airport sites. These observations are intended primarily for aviation needs.

With a complete range of meteorlogical measurements and correspondingly accurate emission data, true concentrations for the simple dispersion case can probably be estimated to within ± 40% (AMS, 1978). Addition of complicating features will substantially increase the uncertainties. Such features include:

1. Aerodynamic wake flows of all kinds.
2. Buoyant fluid flows and accidental releases of heavy toxic gases.

3. Flows over surfaces markedly different from those represented in the basic experiments, e.g., forests, cities, water, rough terrain.
4. Dispersion in extremely stable and unstable conditions.
5. Dispersion at great downwind distances (> 10 to 20 km).

No estimates of accuracy are available for cases where the basic point source model is extended (with modifications) to the prediction of dispersion from large area sources, or for long-term average dispersion. However, it is generally accepted that more confidence can be placed in long-term predicted concentrations than in short-term predictions of worst-case impacts (EPA, 1980).

C.3 DESCRIPTION OF MODELS USED IN MANUAL

Several hand calculation algorithms based on Gaussian dispersion equations have been proposed for use in assessing the impact of surface contamination sites (Versar 1983; Dynamac 1983; EPA, 1981). These algorithms were examined in terms of their applicability in an emergency response assessment. Although these calculation schemes are fairly easy to implement, they may not be suitable for application in areas close to the source where the largest concentrations will occur. Furthermore, these models underestimate the concentrations at receptor points because the contribution of wind directions other than those directly along the line between the source and the receptor are not addressed. Because the complexities introduced to account for these other contributions effectively destroy the attractiveness of a hand dispersion algorithm, an alternate approach has been adopted in this manual.

C.3.1 ISC

The Industrial Source Complex (ISC) model is the most versatile of the EPA models for analyzing concentrations because of its numerous features that aid the user. If used unwisely, it can prove to be very expensive in terms of computer time.

Sources may be grouped together, thus alowing calculation of average concentrations or deposition from combined sources. The ISC model considers point, area, and volume sources. Emission rates may be varied. Receptors may be specified with either Cartesian or polar coordinates. The effects of stack-tip downwash, building wakes, and gravitational settling are also optional. ISC also has one rural and two urban modes. The pollutant may be depleted by an exponential time-dependent decay mechanism, with the user specifying a decay coefficient. Particulate matter with appreciable gravitational settling can be simulated. The user divides particulate emissions into at most 20 categories according to particle size. The settling velocity, mass fraction and surface reflection coefficient must be specified for each category. Emission rates may be varied by season, stability class, and wind speed category.

The user selects either a Cartesian or polar coordinate system for receptors. For a single source or a group of sources in close proximity, the polar system is easiest to use. For widely separated sources, the Cartesian system is usually more convenient.

C.3.2 VALLEY

This model is used to estimate 24-hr and annual concentrations at 112 receptors located at seven distances from the source on sixteen radial lines. The user also specifies worst case short-term meteorology. Short-term calculated concentrations from area or point sources are calculated using Briggs' plume rise and Pasquill-Gifford vertical dispersion coefficients. In the horizontal direction, the plume is assumed to be 22.5° wide. The model assumes that a given meteorology will persist for 6 hr out of 24. The short-term calculated values are divided by 4 to produce a 24-hr estimate. The output consists of a print-plots of calculated concentrations.

C.4 METEOROLOGICAL INPUT FOR LONG-TERM ESTIMATES

For many routine modeling applications in which the desired product is seasonal or annual concentration estimates, the meteorology/climatology of a site is represented by a STAR (stability array) tabulation. Derived from historical data (usually 1-5 years), these STAR listings are multivariate frequency distributions of surface wind speed versus direction as a function of stability class. The latter serves as an indicator of the degree of atmospheric turbulence and is normally inferred from surface observations (Turner, 1961). A typical STAR tabulation contains 576 elements (6 stability classes · 6 wind speeds · 16 wind directions) with each element representing the percentage of time that the wind is from a particular direction and in a given wind speed class and stability class.

It must be stressed that these STAR tabulations are developed from observations taken at first-order or Class A National Weather Service (NWS) stations. Hourly wind speeds and direction are not based on continuous or integrated measurements but rather represent an approximately 15-20 sec average centered on the time of observation. In principle, these observations represent open, relatively uniform terrain conditions. Although observations of this type are routinely employed for dispersion modeling purposes, it is generally understood that the spatial and temporal variability of most climate elements and particularly the near surface wind field, makes it highly desirable to obtain continuous measurements in close proximity to the site in question. The use of NWS observations rather than actual on-site meteorology may be expected to introduce additional uncertainties in the concentration estimates computed by a Gaussian dispersion model.

The assessment procedure was developed based on the view that compilation of appropriate meteorological/climatological data for use in a dispersion algorithm would be a primary constraint imposed by the 24 hour emergency response. It was further assumed that the emergency response team would not have access to either:

1. On-site meteorological measurements from which to construct a suitable STAR tabulation

2. A preprocessed STAR tabulation from a nearby (less than 10-20 km) location that presumably would be representative of conditions at the site in question.

Based on these considerations, the decision was made to develop regional STAR tabulations as the necessary meteorological input to the annual dispersion algorithm. By using the regional STAR tabulation it becomes possible to obtain annual concentration estimates from a relatively sophisticated dispersion model, and at the same time present these results in a convenient form in the assessment manual.

Climatic regions, as shown in Figure 4-4, were delineated in part based on the results of a factor analysis of climatological data from 59 first-order National Weather Service stations. Factor analysis is one of a group of "pattern recognition" techniques that has been widely used to help define relationships among large sets of interrelated observations (Harman, 1967). Details concerning the climatological parameters in the analysis are summarized below.

Regional STAR tabulations were developed by averaging individual station STAR tabulations for between three and six stations in each region. The station selection process was based on the criteria of:

1. STAR tabulation availability in pre-processed form from the National Climatic Data Center.

2. Format compatibility with the annual model.

3. Record length of 5 years (in most cases 1967-71 or 1968-72).

4. No change in anemometer height (h) with h = 6 m ± 1 m.

A major assumption involved in this procedure is that the uncertainties created by using regional data are of the same order as those associated with using data from a single station that is not on or very near (say, ≤ 10 km) the site in question. This is a plausible assumption given the great variations in the near-surface boundary layer that occur over short distance. Use of average or regional data may have certain advantages over the use of a single station located say 50 km or more away from the site in question. The latter is a common practice in many routine dispersion modeling applications. The averaging process may, for example, help smooth local-scale influences present in a given station record while at the same time tend to emphasize the large-scale wind and stability features that are most closely tied to the general circulation. This is particularly important for wind erosion emissions, because events of sufficient force to entrain particulate will typically occur in conjunction with the periodic passage of large-scale frontal systems across the continent.

Factor analysis was used to examine the interrelationships between 3 basic sets of climatological parameters for 59 NWS stations selected so as to provide relatively uniform coverage over the continuous United States. The parameters considered in the analysis include the following:

1. WIND SPEED/DIRECTION

   a Percentage of hourly observations in each of the "standard" wind speed classes: 0-3 mph; 4-7 mph; 8-12 mph; 13-18 mph; 19-24 mph; 25-31 mph; > 31 mph.

   b. Percentage of hourly observations for the most frequently occurring wind direction, defined in terms of a 45° sector.

   c. Mean seasonal wind speeds.

2. PRECIPITATION: Seasonal "normals" of number of days with precipitation $\geq$ 2.54 mm (0.10 in.).

3. MIXING HEIGHTS: Seasonal mean morning and afternoon mixing heights.

These parameters were chosen for their ready availability and because they represent physical processes which are known to be important in the resuspension and dispersion of particulate from ground-level sources.

Group 1 a,b data were taken from the United States Weather Bureau publication, Climatography of the United States No. 82 of the Decennial Census of United States Climate, Summary of Hourly Observations. These summaries cover the periods 1951-60 or 1956-60. In large part, these data are biased by the relocation of wind instruments that occurred between 1955 and 1959 at most civilian airports. Group Ic data were taken from the publication Local Climatological Data, Annual Summaries 1977, prepared by the National Climatic Center. These data are for variable record lengths and presumably suffer from the same bias noted above. In addition, it should be recognized that this type of noncontinuous wind speed observation tends to overestimate prevailing wind speed, though the extent of the bias is presently unknown (Coty, et al., 1975).

Group 2 data are for the "normal" period 1951-80. These data were developed in part by MRI under existing National Science Foundation Grant ATM-8219370. Group 3 data were taken from Holzworth (1972).

The results of the factor analysis procedures were far from conclusive; part of the reason for this may be the nonhomogeneous quality of much of the initial input data. Nevertheless, the procedure did indicate a fair degree of spatial coherence in the climate elements, particularly the wind speed data which is of primary importance to the present problem. The actual delineation of the regional boundaries shown in Figure 4-4, was based both on the factor analysis results and a consideration of a variety of other sources of climatological information (Coty et al. 1975; McCormick and Holzworth, 1976).

APPENDIX D

ANNUAL UNSCALED CONCENTRATION VALUES

The following pages contain the unscaled concentration values for each of the seven regions. There are eight tables per region; these are organized as follows:

	Source Size	Process	Grid Type
1	10 x 10 m	Wind erosion	Fine
2	10 x 10 m	Mechanical resuspension	Fine
3	10 x 10 m	Wind erosion	Coarse
4	10 x 10 m	Mechanical resuspension	Coarse
5	100 x 100 m	Wind erosion	Fine
6	100 x 100 m	Mechanical resuspension	Fine
7	100 x 100 m	Wind erosion	Coarse
8	100 x 100 m	Mechanical resuspension	Coarse

The units for the unscaled concentration are $\mu s/m^3$.

The results for specific climatic regions are found as follows:

Region	Pages
1	D-3 through D-6
2	D-7 through D-10
3	D-11 through D-14
4	D-15 through D-18
5	D-19 through D-22
6	D-23 through D-26
7	D-27 through D-30

REGION 1 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	5.680	2.778	1.678	i.130
NE	3.198	1.528	0.909	0.607
E	1.510	0.733	0.440	0.296
SE	0.733	0.333	0.192	0.126
S	1.531	0.740	0.443	0.297
SW	0.273	0.124	0.072	0.047
W	0.322	0.155	0.093	0.062
NW	0.619	0.286	0.167	0.110

Q_I = SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	87.596	44.720	27.406	18.604
NE	39.247	19.470	11.718	7.861
E	41.914	20.803	12.510	8.380
SE	50.004	25.132	15.189	10.214
S	52.801	26.793	16.327	11.034
SW	25.884	12.835	7.706	5.161
W	45.186	23.002	14.031	9.494
NW	56.571	28.641	17.420	11.772

Q_{II} = SCALING FACTOR = ____________________
(UNITS)

REGION 1 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.548	0.328	0.227	0.168	0.105	0.054	0.034	0.024	0.018	0.014
NNE	0.413	0.245	0.168	0.124	0.077	0.039	0.025	0.017	0.013	0.010
NE	0.290	0.172	0.119	0.088	0.055	0.028	0.017	0.012	0.009	0.007
ENE	0.100	0.058	0.039	0.029	0.018	0.009	0.006	0.004	0.003	0.002
E	0.143	0.085	0.059	0.043	0.027	0.014	0.009	0.006	0.005	0.004
ESE	0.082	0.048	0.033	0.024	0.015	0.008	0.005	0.003	0.002	0.002
SE	0.058	0.034	0.023	0.017	0.010	0.005	0.003	0.002	0.002	0.001
SSE	0.123	0.073	0.050	0.037	0.023	0.012	0.007	0.005	0.004	0.003
S	0.143	0.085	0.059	0.043	0.027	0.014	0.009	0.006	0.004	0.003
SSW	0.063	0.037	0.025	0.019	0.012	0.006	0.004	0.003	0.002	0.001
SW	0.022	0.013	0.009	0.006	0.004	0.002	0.001	0.001	0.001	0.001
WSW	0.016	0.009	0.006	0.005	0.003	0.001	0.001	0.001	0.000	0.000
W	0.030	0.018	0.012	0.009	0.006	0.003	0.002	0.001	0.001	0.001
WNW	0.031	0.018	0.012	0.009	0.006	0.003	0.002	0.001	0.001	0.001
NW	0.052	0.030	0.021	0.015	0.009	0.005	0.003	0.002	0.002	0.001
NNW	0.137	0.080	0.054	0.040	0.024	0.012	0.008	0.005	0.004	0.003

SCALING FACTOR = ______________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	9.152	5.585	3.868	2.867	1.789	0.938	0.604	0.431	0.327	0.258
NNE	4.923	2.956	2.025	1.491	0.923	0.479	0.305	0.217	0.164	0.129
NE	3.799	2.294	1.581	1.169	0.725	0.378	0.242	0.172	0.130	0.103
ENE	2.794	1.678	1.148	0.845	0.522	0.271	0.173	0.123	0.093	0.074
E	4.041	2.442	1.678	1.237	0.766	0.400	0.257	0.183	0.139	0.110
ESE	6.031	3.689	2.556	1.898	1.183	0.624	0.404	0.289	0.220	0.175
SE	4.959	3.020	2.081	1.537	0.956	0.502	0.324	0.232	0.177	0.140
SSE	4.680	2.838	1.955	1.444	0.897	0.470	0.303	0.217	0.165	0.130
S	5.391	3.282	2.263	1.672	1.039	0.543	0.350	0.249	0.189	0.150
SSW	2.992	1.799	1.234	0.910	0.562	0.292	0.187	0.133	0.101	0.080
SW	2.489	1.505	1.036	0.765	0.474	0.248	0.159	0.114	0.086	0.068
WSW	3.016	1.833	1.262	0.933	0.580	0.305	0.196	0.141	0.107	0.085
W	4.653	2.844	1.968	1.458	0.909	0.479	0.310	0.222	0.169	0.134
WNW	5.010	3.054	2.109	1.564	0.974	0.513	0.331	0.237	0.180	0.143
NW	5.757	3.514	2.431	1.803	1.124	0.591	0.382	0.273	0.208	0.165
NNW	5.412	3.260	2.245	1.656	1.028	0.536	0.345	0.246	0.186	0.148

SCALING FACTOR = ______________________
(UNITS)

REGION 1 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	3.089	1.756	1.195	0.867
NE	2.438	1.150	0.765	0.545
E	1.057	0.490	0.331	0.238
SE	0.796	0.336	0.217	0.150
S	0.886	0.506	0.341	0.245
SW	0.347	0.125	0.081	0.056
W	0.235	0.111	0.074	0.053
NW	0.900	0.269	0.175	0.122

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	53.650	29.567	20.250	14.730
NE	34.919	15.603	10.415	7.420
E	34.437	17.335	11.551	8.206
SE	41.016	21.040	14.057	10.012
S	35.622	19.029	12.908	9.312
SW	25.223	11.075	7.360	5.220
W	34.050	17.610	11.899	8.553
NW	45.667	22.198	14.964	10.742

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 1 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.464	0.295	0.209	0.158	0.100	0.052	0.033	0.023	0.017	0.014
NNE	0.425	0.260	0.180	0.133	0.082	0.041	0.026	0.018	0.013	0.010
NE	0.282	0.174	0.121	0.090	0.056	0.029	0.018	0.012	0.009	0.007
ENE	0.141	0.082	0.055	0.039	0.023	0.011	0.007	0.004	0.003	0.002
E	0.126	0.079	0.056	0.042	0.026	0.014	0.009	0.006	0.005	0.004
ESE	0.089	0.054	0.037	0.027	0.017	0.008	0.005	0.004	0.003	0.002
SE	0.074	0.043	0.029	0.021	0.013	0.006	0.004	0.003	0.002	0.001
SSE	0.118	0.073	0.051	0.038	0.024	0.012	0.008	0.005	0.004	0.003
S	0.129	0.081	0.057	0.042	0.027	0.014	0.009	0.006	0.004	0.003
SSW	0.071	0.043	0.029	0.021	0.013	0.006	0.004	0.003	0.002	0.002
SW	0.027	0.016	0.011	0.008	0.005	0.002	0.001	0.001	0.001	0.001
WSW	0.019	0.011	0.008	0.006	0.003	0.002	0.001	0.001	0.001	0.000
W	0.028	0.017	0.012	0.009	0.006	0.003	0.002	0.001	0.001	0.001
WNW	0.034	0.021	0.014	0.010	0.006	0.003	0.002	0.001	0.001	0.001
NW	0.061	0.036	0.025	0.018	0.011	0.005	0.003	0.002	0.002	0.001
NNW	0.195	0.114	0.076	0.055	0.032	0.015	0.009	0.006	0.005	0.003

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	7.998	5.122	3.630	2.730	1.735	0.923	0.599	0.428	0.324	0.257
NNE	5.584	3.407	2.335	1.711	1.041	0.528	0.332	0.232	0.174	0.137
NE	3.864	2.401	1.666	1.233	0.763	0.396	0.252	0.178	0.134	0.106
ENE	3.217	1.958	1.339	0.978	0.594	0.301	0.189	0.133	0.099	0.078
E	4.255	2.637	1.821	1.342	0.828	0.426	0.272	0.192	0.144	0.114
ESE	5.665	3.594	2.527	1.889	1.188	0.630	0.409	0.292	0.222	0.176
SE	5.221	3.246	2.251	1.663	1.027	0.534	0.342	0.242	0.183	0.145
SSE	4.965	3.079	2.128	1.571	0.968	0.501	0.320	0.226	0.171	0.135
S	4.981	3.156	2.215	1.653	1.039	0.547	0.353	0.251	0.190	0.151
SSW	3.381	2.069	1.417	1.037	0.632	0.322	0.203	0.142	0.107	0.084
SW	2.695	1.665	1.147	0.844	0.519	0.267	0.170	0.120	0.090	0.071
WSW	3.272	2.025	1.399	1.032	0.635	0.328	0.209	0.148	0.112	0.088
W	4.545	2.868	2.007	1.495	0.937	0.493	0.319	0.227	0.172	0.136
WNW	5.211	3.249	2.260	1.674	1.038	0.541	0.347	0.246	0.186	0.147
NW	5.685	3.572	2.502	1.861	1.163	0.611	0.393	0.280	0.212	0.168
NNW	6.262	3.828	2.625	1.921	1.172	0.597	0.376	0.264	0.198	0.156

SCALING FACTOR = ____________________
(UNITS)

REGION 2 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	5.043	2.448	1.471	0.988
NE	3.910	1.852	1.096	0.729
E	4.476	2.176	1.309	0.879
SE	1.621	0.759	0.446	0.296
S	3.617	1.767	1.066	0.718
SW	1.738	0.824	0.488	0.325
W	0.566	0.262	0.153	0.101
NW	0.920	0.428	0.250	0.165

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	78.479	40.228	24.693	16.780
NE	47.143	23.419	14.103	9.471
E	48.445	24.583	14.993	10.144
SE	31.709	15.894	9.608	6.465
S	54.949	28.226	17.332	11.774
SW	27.648	13.817	8.340	5.601
W	23.455	11.854	7.201	4.852
NW	27.295	13.684	8.267	5.556

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 2 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.477	0.284	0.196	0.145	0.090	0.046	0.029	0.020	0.015	0.012
NNE	0.393	0.232	0.160	0.118	0.073	0.037	0.023	0.016	0.012	0.009
NE	0.347	0.205	0.141	0.104	0.064	0.033	0.021	0.014	0.011	0.008
ENE	0.312	0.184	0.126	0.093	0.058	0.029	0.018	0.013	0.009	0.007
E	0.425	0.254	0.175	0.130	0.081	0.041	0.026	0.018	0.014	0.011
ESE	0.194	0.114	0.078	0.057	0.035	0.018	0.011	0.008	0.006	0.005
SE	0.140	0.083	0.057	0.042	0.026	0.013	0.008	0.006	0.004	0.003
SSE	0.162	0.095	0.065	0.048	0.030	0.015	0.009	0.007	0.005	0.004
S	0.348	0.208	0.144	0.107	0.067	0.034	0.022	0.015	0.011	0.009
SSW	0.208	0.123	0.084	0.062	0.039	0.020	0.012	0.009	0.006	0.005
SW	0.155	0.092	0.063	0.047	0.029	0.015	0.009	0.007	0.005	0.004
WSW	0.107	0.064	0.044	0.032	0.020	0.010	0.006	0.005	0.003	0.003
W	0.047	0.028	0.019	0.014	0.009	0.004	0.003	0.002	0.001	0.001
WNW	0.031	0.018	0.012	0.009	0.005	0.003	0.002	0.001	0.001	0.001
NW	0.078	0.046	0.031	0.023	0.014	0.007	0.005	0.003	0.002	0.002
NNW	0.187	0.109	0.075	0.055	0.034	0.017	0.011	0.007	0.006	0.004

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	8.270	5.055	3.500	2.594	1.619	0.851	0.549	0.392	0.298	0.236
NNE	6.064	3.679	2.535	1.875	1.167	0.612	0.393	0.281	0.213	0.169
NE	4.587	2.776	1.915	1.418	0.881	0.461	0.296	0.212	0.160	0.127
ENE	4.261	2.582	1.778	1.315	0.816	0.427	0.274	0.196	0.148	0.118
E	4.968	3.029	2.094	1.551	0.966	0.507	0.327	0.234	0.178	0.141
ESE	3.174	1.911	1.313	0.969	0.599	0.312	0.200	0.143	0.108	0.085
SE	3.140	1.909	1.316	0.972	0.604	0.317	0.204	0.146	0.111	0.088
SSE	3.172	1.907	1.309	0.964	0.597	0.311	0.199	0.142	0.108	0.085
S	5.798	3.545	2.452	1.816	1.132	0.594	0.383	0.274	0.208	0.165
SSW	2.978	1.783	1.220	0.898	0.553	0.286	0.183	0.130	0.098	0.078
SW	2.711	1.639	1.127	0.833	0.515	0.268	0.172	0.122	0.093	0.073
WSW	1.861	1.115	0.761	0.559	0.344	0.178	0.114	0.081	0.061	0.048
W	2.361	1.435	0.987	0.728	0.451	0.236	0.152	0.108	0.082	0.065
WNW	1.809	1.089	0.745	0.548	0.338	0.176	0.113	0.081	0.061	0.048
NW	2.692	1.634	1.123	0.830	0.514	0.268	0.172	0.123	0.093	0.074
NNW	3.424	2.050	1.403	1.032	0.636	0.330	0.211	0.151	0.114	0.090

SCALING FACTOR = ____________________
(UNITS)

REGION 2 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION
===========

DIR	RANGE (M) 200	300	400	500
N	2.978	1.634	1.103	0.795
NE	3.151	1.472	0.973	0.689
E	2.704	1.440	0.974	0.702
SE	1.694	0.654	0.429	0.302
S	2.051	1.134	0.770	0.558
SW	1.397	0.657	0.434	0.308
W	0.582	0.242	0.157	0.110
NW	1.046	0.382	0.249	0.175

Q_I = SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION
======================

DIR	RANGE (M) 200	300	400	500
N	47.633	26.821	18.379	13.373
NE	41.777	19.765	13.180	9.377
E	33.968	17.821	12.079	8.708
SE	28.458	12.764	8.546	6.100
S	33.180	18.345	12.590	9.172
SW	22.969	10.517	7.050	5.041
W	17.764	8.633	5.825	4.184
NW	25.015	10.726	7.186	5.132

Q_{II} = SCALING FACTOR = ____________________
(UNITS)

REGION 2 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.421	0.265	0.187	0.140	0.088	0.046	0.029	0.020	0.015	0.012
NNE	0.407	0.248	0.172	0.127	0.078	0.039	0.024	0.017	0.012	0.010
NE	0.352	0.216	0.149	0.110	0.068	0.034	0.021	0.015	0.011	0.009
ENE	0.343	0.207	0.142	0.104	0.064	0.032	0.020	0.014	0.010	0.008
E	0.373	0.235	0.166	0.124	0.079	0.041	0.026	0.018	0.013	0.011
ESE	0.227	0.136	0.093	0.068	0.041	0.020	0.012	0.008	0.006	0.005
SE	0.152	0.092	0.063	0.047	0.029	0.014	0.009	0.006	0.005	0.003
SSE	0.193	0.115	0.079	0.057	0.035	0.017	0.010	0.007	0.005	0.004
S	0.298	0.189	0.134	0.101	0.064	0.033	0.021	0.015	0.011	0.009
SSW	0.227	0.138	0.095	0.070	0.043	0.021	0.013	0.009	0.007	0.005
SW	0.158	0.097	0.067	0.050	0.031	0.016	0.010	0.007	0.005	0.004
WSW	0.106	0.065	0.046	0.034	0.021	0.011	0.007	0.005	0.003	0.003
W	0.055	0.033	0.022	0.016	0.010	0.005	0.003	0.002	0.002	0.001
WNW	0.041	0.024	0.016	0.012	0.007	0.003	0.002	0.001	0.001	0.001
NW	0.087	0.053	0.036	0.026	0.016	0.008	0.005	0.003	0.002	0.002
NNW	0.221	0.132	0.090	0.065	0.039	0.019	0.012	0.008	0.006	0.005

SCALING FACTOR = ______________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	7.267	4.656	3.298	2.479	1.574	0.839	0.545	0.390	0.296	0.235
NNE	6.358	3.945	2.737	2.024	1.251	0.648	0.413	0.292	0.221	0.174
NE	4.867	3.016	2.087	1.541	0.951	0.492	0.313	0.221	0.167	0.132
ENE	4.535	2.806	1.943	1.432	0.883	0.457	0.290	0.205	0.155	0.122
E	4.652	2.946	2.069	1.545	0.972	0.513	0.331	0.236	0.179	0.142
ESE	3.548	2.177	1.495	1.096	0.670	0.342	0.216	0.152	0.114	0.090
SE	3.193	1.991	1.385	1.026	0.636	0.332	0.212	0.150	0.114	0.090
SSE	3.702	2.257	1.542	1.127	0.684	0.347	0.219	0.153	0.115	0.090
S	5.000	3.211	2.277	1.713	1.089	0.582	0.378	0.271	0.206	0.164
SSW	3.498	2.124	1.447	1.054	0.638	0.322	0.202	0.141	0.105	0.083
SW	2.646	1.655	1.151	0.853	0.530	0.276	0.177	0.125	0.094	0.075
WSW	2.131	1.296	0.884	0.645	0.391	0.198	0.124	0.087	0.065	0.051
W	2.221	1.400	0.979	0.728	0.456	0.239	0.154	0.110	0.083	0.066
WNW	2.093	1.275	0.870	0.635	0.386	0.195	0.123	0.087	0.065	0.051
NW	2.690	1.678	1.168	0.864	0.536	0.279	0.179	0.126	0.096	0.075
NNW	4.219	2.550	1.731	1.257	0.757	0.380	0.237	0.166	0.124	0.097

SCALING FACTOR = ______________________
(UNITS)

REGION 3 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	8.573	4.169	2.508	1.685
NE	2.326	1.078	0.629	0.415
E	2.953	1.415	0.844	0.564
SE	5.052	2.399	1.422	0.947
S	5.105	2.436	1.450	0.968
SW	1.699	0.802	0.474	0.315
W	1.300	0.621	0.370	0.247
NW	2.898	1.351	0.793	0.524

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	55.299	28.003	17.106	11.595
NE	17.769	8.631	5.135	3.419
E	24.456	12.326	7.511	5.083
SE	22.641	11.174	6.727	4.519
S	28.413	14.143	8.563	5.771
SW	18.987	9.392	5.655	3.799
W	21.242	10.641	6.452	4.349
NW	29.882	14.680	8.796	5.888

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 3 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.814	0.486	0.336	0.249	0.155	0.079	0.050	0.035	0.026	0.020
NNE	0.400	0.236	0.162	0.119	0.074	0.037	0.023	0.016	0.012	0.009
NE	0.195	0.115	0.079	0.058	0.036	0.018	0.011	0.008	0.006	0.005
ENE	0.168	0.099	0.068	0.050	0.031	0.016	0.010	0.007	0.005	0.004
E	0.271	0.161	0.111	0.082	0.051	0.026	0.016	0.011	0.009	0.007
ESE	0.287	0.169	0.116	0.086	0.053	0.027	0.017	0.012	0.009	0.007
SE	0.452	0.268	0.185	0.137	0.085	0.043	0.027	0.019	0.014	0.011
SSE	0.600	0.357	0.247	0.183	0.114	0.058	0.037	0.026	0.019	0.015
S	0.463	0.275	0.190	0.140	0.087	0.045	0.028	0.020	0.015	0.011
SSW	0.223	0.131	0.090	0.067	0.041	0.021	0.013	0.009	0.007	0.005
SW	0.150	0.088	0.061	0.045	0.028	0.014	0.009	0.006	0.005	0.004
WSW	0.108	0.064	0.044	0.032	0.020	0.010	0.006	0.004	0.003	0.003
W	0.118	0.070	0.048	0.036	0.022	0.011	0.007	0.005	0.004	0.003
WNW	0.106	0.062	0.042	0.031	0.019	0.010	0.006	0.004	0.003	0.002
NW	0.247	0.146	0.100	0.074	0.046	0.023	0.015	0.010	0.008	0.006
NNW	0.541	0.320	0.221	0.163	0.101	0.052	0.032	0.023	0.017	0.013

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	5.692	3.466	2.398	1.777	1.108	0.581	0.373	0.266	0.202	0.160
NNE	2.638	1.583	1.085	0.799	0.495	0.257	0.164	0.116	0.088	0.069
NE	1.634	0.979	0.671	0.495	0.305	0.158	0.101	0.072	0.054	0.043
ENE	1.806	1.090	0.750	0.554	0.344	0.179	0.115	0.082	0.062	0.049
E	2.489	1.512	1.045	0.774	0.482	0.252	0.162	0.115	0.087	0.069
ESE	1.705	1.020	0.701	0.517	0.320	0.166	0.106	0.075	0.057	0.045
SE	2.188	1.321	0.911	0.673	0.419	0.218	0.139	0.099	0.075	0.059
SSE	2.531	1.523	1.051	0.777	0.483	0.251	0.160	0.114	0.086	0.068
S	2.809	1.701	1.174	0.869	0.541	0.282	0.181	0.129	0.097	0.077
SSW	2.167	1.305	0.900	0.666	0.413	0.215	0.138	0.098	0.074	0.058
SW	1.840	1.111	0.767	0.568	0.353	0.184	0.118	0.084	0.063	0.050
WSW	1.588	0.956	0.657	0.484	0.300	0.156	0.100	0.071	0.054	0.043
W	2.117	1.283	0.885	0.654	0.407	0.212	0.136	0.097	0.073	0.058
WNW	1.943	1.173	0.806	0.595	0.369	0.192	0.123	0.088	0.067	0.053
NW	2.836	1.711	1.177	0.869	0.539	0.281	0.179	0.128	0.097	0.076
NNW	4.732	2.860	1.976	1.463	0.909	0.475	0.303	0.216	0.164	0.129

SCALING FACTOR = ____________________
(UNITS)

REGION 3 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	4.789	2.747	1.859	1.341
NE	2.505	0.988	0.644	0.450
E	2.204	1.046	0.698	0.498
SE	3.712	1.896	1.256	0.890
S	3.527	1.856	1.235	0.878
SW	1.532	0.656	0.432	0.306
W	1.067	0.469	0.312	0.222
NW	2.729	1.192	0.780	0.547

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	34.215	19.415	13.221	9.573
NE	18.713	7.771	5.129	3.618
E	16.715	8.732	5.927	4.280
SE	18.246	8.841	5.912	4.220
S	20.173	10.662	7.175	5.145
SW	15.937	7.596	5.074	3.618
W	16.112	7.952	5.360	3.847
NW	26.349	12.608	8.372	5.937

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 3 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.712	0.449	0.317	0.238	0.150	0.078	0.049	0.035	0.026	0.020
NNE	0.443	0.267	0.183	0.135	0.082	0.041	0.025	0.017	0.013	0.010
NE	0.224	0.135	0.092	0.067	0.041	0.020	0.012	0.009	0.006	0.005
ENE	0.191	0.115	0.079	0.057	0.035	0.017	0.011	0.007	0.005	0.004
E	0.259	0.160	0.112	0.083	0.052	0.027	0.017	0.012	0.009	0.007
ESE	0.316	0.191	0.131	0.097	0.059	0.029	0.018	0.013	0.009	0.007
SE	0.457	0.280	0.195	0.144	0.089	0.045	0.028	0.020	0.015	0.011
SSE	0.563	0.350	0.246	0.183	0.115	0.059	0.037	0.026	0.019	0.015
S	0.454	0.280	0.195	0.145	0.090	0.046	0.029	0.020	0.015	0.012
SSW	0.254	0.153	0.105	0.077	0.047	0.023	0.014	0.010	0.007	0.006
SW	0.156	0.095	0.066	0.048	0.030	0.015	0.009	0.006	0.005	0.004
WSW	0.118	0.071	0.049	0.036	0.022	0.011	0.007	0.005	0.003	0.003
W	0.115	0.071	0.050	0.037	0.023	0.012	0.007	0.005	0.004	0.003
WNW	0.132	0.078	0.053	0.038	0.023	0.011	0.007	0.005	0.003	0.003
NW	0.275	0.166	0.114	0.083	0.051	0.025	0.016	0.011	0.008	0.006
NNW	0.549	0.336	0.234	0.173	0.107	0.054	0.034	0.023	0.017	0.013

SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	5.148	3.274	2.309	1.731	1.094	0.579	0.374	0.266	0.202	0.160
NNE	3.046	1.854	1.269	0.929	0.564	0.285	0.179	0.125	0.094	0.074
NE	1.843	1.125	0.771	0.564	0.344	0.175	0.110	0.077	0.057	0.045
ENE	1.931	1.190	0.823	0.606	0.373	0.192	0.121	0.086	0.064	0.051
E	2.289	1.450	1.020	0.763	0.480	0.253	0.163	0.116	0.088	0.069
ESE	1.957	1.192	0.816	0.597	0.364	0.184	0.115	0.081	0.060	0.047
SE	2.202	1.368	0.953	0.707	0.439	0.227	0.144	0.102	0.077	0.060
SSE	2.578	1.599	1.111	0.824	0.510	0.263	0.167	0.118	0.088	0.069
S	2.714	1.702	1.190	0.886	0.555	0.289	0.185	0.131	0.099	0.078
SSW	2.269	1.403	0.972	0.718	0.443	0.229	0.145	0.102	0.077	0.060
SW	1.884	1.171	0.813	0.602	0.373	0.193	0.123	0.087	0.065	0.051
WSW	1.754	1.075	0.740	0.544	0.333	0.170	0.107	0.075	0.057	0.044
W	2.035	1.278	0.894	0.665	0.416	0.217	0.139	0.099	0.075	0.059
WNW	2.159	1.324	0.911	0.669	0.410	0.209	0.133	0.093	0.070	0.055
NW	3.060	1.883	1.301	0.957	0.588	0.302	0.191	0.134	0.101	0.080
NNW	4.697	2.933	2.046	1.518	0.945	0.492	0.314	0.222	0.167	0.132

SCALING FACTOR = ____________________ (UNITS)

REGION 4 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION
============

DIR	RANGE (M) 200	300	400	500
N	6.096	2.974	1.793	1.206
NE	2.857	1.351	0.799	0.531
E	4.190	2.012	1.202	0.804
SE	4.833	2.327	1.391	0.931
S	3.182	1.536	0.921	0.617
SW	0.992	0.466	0.274	0.182
W	1.353	0.647	0.385	0.257
NW	2.167	1.019	0.600	0.398

Q_r = SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION
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DIR	RANGE (M) 200	300	400	500
N	61.345	31.293	19.167	13.009
NE	30.722	15.298	9.218	6.190
E	31.350	15.713	9.525	6.420
SE	31.455	15.723	9.516	6.412
S	39.107	20.041	12.301	8.360
SW	15.768	7.780	4.670	3.129
W	31.106	15.506	9.371	6.304
NW	53.652	27.369	16.721	11.335

Q_a = SCALING FACTOR = ____________________
(UNITS)

REGION 4 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.584	0.349	0.241	0.179	0.111	0.057	0.036	0.025	0.019	0.015
NNE	0.316	0.186	0.128	0.094	0.058	0.030	0.018	0.013	0.010	0.007
NE	0.252	0.149	0.103	0.076	0.047	0.024	0.015	0.010	0.008	0.006
ENE	0.227	0.134	0.092	0.068	0.042	0.021	0.013	0.009	0.007	0.005
E	0.386	0.230	0.159	0.117	0.073	0.037	0.023	0.016	0.012	0.010
ESE	0.387	0.229	0.158	0.117	0.072	0.037	0.023	0.016	0.012	0.009
SE	0.448	0.267	0.184	0.136	0.085	0.043	0.027	0.019	0.014	0.011
SSE	0.297	0.175	0.120	0.089	0.055	0.028	0.018	0.012	0.009	0.007
S	0.297	0.177	0.122	0.091	0.056	0.029	0.018	0.013	0.009	0.007
SSW	0.130	0.077	0.052	0.039	0.024	0.012	0.008	0.005	0.004	0.003
SW	0.086	0.051	0.035	0.026	0.016	0.008	0.005	0.004	0.003	0.002
WSW	0.080	0.047	0.033	0.024	0.015	0.008	0.005	0.003	0.002	0.002
W	0.123	0.073	0.050	0.037	0.023	0.012	0.007	0.005	0.004	0.003
WNW	0.135	0.080	0.055	0.041	0.025	0.013	0.008	0.006	0.004	0.003
NW	0.189	0.112	0.077	0.057	0.035	0.018	0.011	0.008	0.006	0.005
NNW	0.312	0.184	0.126	0.093	0.058	0.029	0.018	0.013	0.010	0.007

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	6.399	3.905	2.704	2.004	1.251	0.656	0.423	0.302	0.229	0.181
NNE	3.601	2.175	1.494	1.102	0.684	0.357	0.229	0.163	0.124	0.098
NE	2.998	1.814	1.251	0.926	0.574	0.300	0.193	0.138	0.104	0.083
ENE	2.965	1.802	1.243	0.920	0.572	0.300	0.193	0.138	0.105	0.083
E	3.126	1.897	1.309	0.968	0.602	0.315	0.202	0.144	0.109	0.086
ESE	2.527	1.520	1.046	0.773	0.479	0.249	0.159	0.113	0.086	0.068
SE	3.119	1.891	1.305	0.965	0.601	0.314	0.201	0.143	0.108	0.086
SSE	2.885	1.736	1.195	0.882	0.547	0.285	0.182	0.130	0.098	0.078
S	4.121	2.521	1.747	1.295	0.809	0.425	0.275	0.196	0.149	0.118
SSW	1.906	1.142	0.784	0.578	0.357	0.185	0.119	0.084	0.064	0.050
SW	1.510	0.910	0.627	0.463	0.287	0.150	0.096	0.068	0.052	0.041
WSW	1.533	0.919	0.629	0.463	0.286	0.149	0.095	0.067	0.051	0.040
W	3.060	1.853	1.278	0.944	0.587	0.307	0.197	0.140	0.106	0.084
WNW	4.415	2.690	1.858	1.378	0.858	0.451	0.291	0.208	0.158	0.125
NW	5.569	3.408	2.361	1.753	1.094	0.577	0.372	0.267	0.203	0.161
NNW	4.353	2.620	1.803	1.331	0.824	0.430	0.276	0.196	0.149	0.118

SCALING FACTOR = ____________________
(UNITS)

REGION 4 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION
============

DIR	RANGE (M) 200	300	400	500
N	3.425	1.914	1.300	0.940
NE	2.564	1.090	0.720	0.509
E	2.937	1.463	0.978	0.699
SE	3.265	1.670	1.119	0.801
S	2.167	1.077	0.723	0.519
SW	0.983	0.396	0.260	0.183
W	1.007	0.486	0.324	0.231
NW	1.986	0.859	0.565	0.398

Q_I = SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION
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DIR	RANGE (M) 200	300	400	500
N	39.834	21.285	14.546	10.560
NE	27.546	12.712	8.486	6.043
E	23.777	12.025	8.093	5.801
SE	24.467	11.915	8.017	5.750
S	24.573	13.404	9.180	6.677
SW	15.717	6.491	4.321	3.070
W	24.926	12.302	8.251	5.896
NW	39.259	20.254	13.731	9.905

Q_{II} = SCALING FACTOR = ____________________
(UNITS)

REGION 4 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.502	0.317	0.225	0.169	0.107	0.056	0.035	0.025	0.019	0.015
NNE	0.357	0.215	0.147	0.108	0.065	0.032	0.020	0.014	0.010	0.008
NE	0.260	0.159	0.110	0.081	0.050	0.025	0.016	0.011	0.008	0.006
ENE	0.261	0.157	0.107	0.078	0.048	0.024	0.014	0.010	0.007	0.006
E	0.364	0.227	0.159	0.118	0.074	0.038	0.024	0.017	0.012	0.010
ESE	0.405	0.247	0.171	0.126	0.078	0.039	0.024	0.017	0.012	0.010
SE	0.418	0.260	0.183	0.137	0.085	0.044	0.028	0.019	0.014	0.011
SSE	0.328	0.198	0.136	0.100	0.061	0.031	0.019	0.013	0.010	0.007
S	0.272	0.170	0.120	0.089	0.056	0.029	0.018	0.013	0.010	0.007
SSW	0.153	0.092	0.063	0.046	0.028	0.014	0.008	0.006	0.004	0.003
SW	0.093	0.056	0.039	0.029	0.017	0.009	0.005	0.004	0.003	0.002
WSW	0.090	0.054	0.037	0.027	0.017	0.008	0.005	0.004	0.003	0.002
W	0.119	0.074	0.052	0.038	0.024	0.012	0.008	0.005	0.004	0.003
WNW	0.144	0.088	0.060	0.045	0.027	0.014	0.009	0.006	0.004	0.003
NW	0.202	0.123	0.085	0.062	0.038	0.019	0.012	0.008	0.006	0.005
NNW	0.344	0.208	0.143	0.105	0.064	0.032	0.020	0.014	0.010	0.008

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	5.711	3.647	2.579	1.936	1.226	0.651	0.422	0.301	0.229	0.181
NNE	4.069	2.493	1.713	1.257	0.768	0.392	0.248	0.174	0.131	0.103
NE	3.143	1.951	1.351	0.998	0.616	0.319	0.203	0.144	0.108	0.085
ENE	3.067	1.908	1.326	0.980	0.608	0.316	0.202	0.143	0.108	0.085
E	3.060	1.920	1.340	0.996	0.622	0.325	0.208	0.148	0.111	0.088
ESE	2.786	1.710	1.177	0.865	0.530	0.271	0.171	0.120	0.090	0.071
SE	3.032	1.900	1.330	0.989	0.617	0.323	0.206	0.146	0.110	0.087
SSE	3.216	1.973	1.356	0.997	0.610	0.311	0.197	0.138	0.104	0.081
S	3.627	2.324	1.647	1.238	0.787	0.419	0.273	0.195	0.148	0.118
SSW	2.265	1.376	0.939	0.685	0.415	0.209	0.131	0.092	0.069	0.054
SW	1.589	0.983	0.680	0.501	0.309	0.159	0.101	0.071	0.054	0.042
WSW	1.811	1.099	0.750	0.548	0.332	0.167	0.105	0.073	0.055	0.043
W	3.089	1.929	1.341	0.994	0.618	0.321	0.205	0.145	0.109	0.086
WNW	4.503	2.813	1.960	1.454	0.904	0.472	0.303	0.215	0.163	0.129
NW	5.293	3.349	2.357	1.760	1.106	0.586	0.379	0.270	0.205	0.163
NNW	5.031	3.075	2.108	1.543	0.940	0.478	0.301	0.211	0.159	0.125

SCALING FACTOR = ____________________
(UNITS)

REGION 5 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	3.613	1.743	1.044	0.699
NE	0.568	0.265	0.155	0.103
E	0.358	0.168	0.099	0.065
SE	1.026	0.483	0.285	0.189
S	3.410	1.670	1.009	0.680
SW	1.426	0.671	0.396	0.263
W	1.632	0.764	0.449	0.297
NW	4.285	2.061	1.231	0.824

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	83.080	43.203	26.660	18.175
NE	38.341	19.597	11.938	8.070
E	39.708	20.436	12.508	8.475
SE	35.700	18.184	11.059	7.468
S	78.805	41.136	25.427	17.349
SW	52.575	26.532	16.068	10.820
W	75.198	38.594	23.645	16.041
NW	62.602	31.760	19.325	13.062

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 5 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.336	0.200	0.138	0.102	0.064	0.032	0.020	0.014	0.011	0.008
NNE	0.098	0.057	0.039	0.028	0.017	0.009	0.005	0.004	0.003	0.002
NE	0.048	0.028	0.019	0.014	0.009	0.004	0.003	0.002	0.001	0.001
ENE	0.033	0.019	0.013	0.010	0.006	0.003	0.002	0.001	0.001	0.001
E	0.031	0.018	0.012	0.009	0.006	0.003	0.002	0.001	0.001	0.001
ESE	0.042	0.025	0.017	0.013	0.008	0.004	0.002	0.002	0.001	0.001
SE	0.090	0.053	0.037	0.027	0.017	0.009	0.005	0.004	0.003	0.002
SSE	0.165	0.097	0.067	0.049	0.030	0.016	0.010	0.007	0.005	0.004
S	0.330	0.197	0.137	0.101	0.063	0.032	0.020	0.014	0.011	0.008
SSW	0.160	0.094	0.065	0.048	0.029	0.015	0.009	0.007	0.005	0.004
SW	0.125	0.074	0.051	0.037	0.023	0.012	0.007	0.005	0.004	0.003
WSW	0.126	0.075	0.051	0.038	0.023	0.012	0.007	0.005	0.004	0.003
W	0.141	0.083	0.057	0.042	0.026	0.013	0.008	0.006	0.004	0.003
WNW	0.219	0.129	0.089	0.065	0.040	0.021	0.013	0.009	0.007	0.005
NW	0.395	0.235	0.162	0.120	0.075	0.038	0.024	0.017	0.012	0.010
NNW	0.376	0.222	0.153	0.113	0.070	0.036	0.022	0.016	0.012	0.009

SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	9.008	5.544	3.848	2.857	1.787	0.946	0.615	0.441	0.336	0.267
NNE	4.200	2.543	1.744	1.286	0.797	0.418	0.270	0.193	0.147	0.117
NE	3.950	2.417	1.672	1.240	0.773	0.408	0.265	0.190	0.145	0.115
ENE	3.562	2.175	1.500	1.110	0.690	0.364	0.236	0.169	0.129	0.102
E	4.163	2.554	1.766	1.308	0.815	0.431	0.280	0.201	0.153	0.122
ESE	3.336	2.033	1.403	1.039	0.646	0.341	0.221	0.158	0.121	0.096
SE	3.650	2.235	1.544	1.143	0.713	0.376	0.244	0.175	0.134	0.106
SSE	4.164	2.517	1.730	1.276	0.791	0.415	0.268	0.191	0.146	0.115
S	8.609	5.304	3.682	2.734	1.710	0.906	0.589	0.423	0.322	0.256
SSW	5.079	3.074	2.114	1.562	0.967	0.507	0.327	0.234	0.178	0.141
SW	5.264	3.204	2.212	1.638	1.018	0.535	0.346	0.248	0.189	0.150
WSW	6.104	3.718	2.561	1.894	1.177	0.619	0.400	0.286	0.218	0.173
W	7.892	4.835	3.346	2.479	1.546	0.815	0.528	0.379	0.288	0.229
WNW	5.396	3.265	2.242	1.657	1.026	0.537	0.345	0.247	0.187	0.148
NW	6.389	3.903	2.699	2.002	1.247	0.657	0.424	0.304	0.231	0.183
NNW	6.391	3.878	2.678	1.981	1.231	0.646	0.417	0.299	0.227	0.180

SCALING FACTOR = ____________________ (UNITS)

REGION 5 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION
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DIR	RANGE (M) 200	300	400	500
N	2.333	1.217	0.817	0.586
NE	0.669	0.231	0.151	0.106
E	0.341	0.142	0.093	0.066
SE	0.951	0.402	0.265	0.187
S	1.850	1.049	0.715	0.519
SW	1.294	0.558	0.368	0.259
W	1.496	0.655	0.430	0.302
NW	2.789	1.474	0.987	0.706

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION
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DIR	RANGE (M) 200	300	400	500
N	53.034	29.110	20.003	14.580
NE	34.356	15.646	10.536	7.553
E	29.840	15.417	10.447	7.524
SE	32.765	14.777	9.930	7.105
S	48.508	26.991	18.604	13.593
SW	47.042	21.859	14.638	10.447
W	52.465	27.824	18.923	13.677
NW	51.788	24.779	16.700	11.984

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.308	0.192	0.135	0.101	0.063	0.033	0.021	0.014	0.011	0.008
NNE	0.131	0.077	0.052	0.037	0.022	0.011	0.006	0.004	0.003	0.002
NE	0.053	0.032	0.022	0.016	0.010	0.005	0.003	0.002	0.002	0.001
ENE	0.035	0.021	0.015	0.011	0.007	0.003	0.002	0.001	0.001	0.001
E	0.033	0.020	0.014	0.010	0.006	0.003	0.002	0.001	0.001	0.001
ESE	0.049	0.029	0.020	0.015	0.009	0.004	0.003	0.002	0.001	0.001
SE	0.095	0.058	0.040	0.029	0.018	0.009	0.006	0.004	0.003	0.002
SSE	0.184	0.111	0.076	0.056	0.034	0.017	0.010	0.007	0.005	0.004
S	0.278	0.177	0.126	0.095	0.060	0.031	0.020	0.014	0.011	0.008
SSW	0.186	0.112	0.076	0.056	0.034	0.017	0.010	0.007	0.005	0.004
SW	0.132	0.080	0.055	0.041	0.025	0.013	0.008	0.005	0.004	0.003
WSW	0.129	0.079	0.055	0.040	0.025	0.013	0.008	0.005	0.004	0.003
W	0.152	0.092	0.063	0.047	0.028	0.014	0.009	0.006	0.004	0.003
WNW	0.239	0.145	0.099	0.073	0.045	0.022	0.014	0.009	0.007	0.005
NW	0.369	0.229	0.161	0.120	0.075	0.038	0.024	0.017	0.013	0.010
NNW	0.381	0.233	0.162	0.119	0.074	0.037	0.023	0.016	0.012	0.009

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	7.965	5.126	3.637	2.737	1.742	0.935	0.611	0.439	0.335	0.266
NNE	5.101	3.110	2.122	1.549	0.938	0.476	0.301	0.211	0.159	0.125
NE	3.992	2.509	1.750	1.299	0.810	0.426	0.275	0.196	0.149	0.118
ENE	3.826	2.379	1.648	1.215	0.750	0.390	0.250	0.178	0.134	0.106
E	4.019	2.547	1.784	1.330	0.834	0.441	0.287	0.205	0.156	0.124
ESE	3.617	2.247	1.553	1.145	0.706	0.366	0.235	0.167	0.126	0.100
SE	3.742	2.344	1.634	1.212	0.753	0.395	0.255	0.181	0.138	0.109
SSE	4.961	3.033	2.073	1.515	0.920	0.468	0.296	0.208	0.156	0.123
S	7.464	4.821	3.428	2.585	1.649	0.888	0.582	0.419	0.319	0.255
SSW	5.859	3.596	2.465	1.805	1.101	0.563	0.357	0.252	0.189	0.149
SW	5.467	3.413	2.368	1.752	1.085	0.566	0.363	0.258	0.195	0.154
WSW	6.431	4.000	2.773	2.050	1.266	0.659	0.421	0.299	0.226	0.179
W	7.349	4.674	3.289	2.459	1.550	0.822	0.534	0.382	0.290	0.230
WNW	6.128	3.762	2.584	1.895	1.158	0.592	0.375	0.264	0.199	0.156
NW	6.340	3.983	2.787	2.071	1.293	0.680	0.438	0.311	0.236	0.187
NNW	7.029	4.348	3.002	2.209	1.359	0.702	0.447	0.316	0.238	0.188

SCALING FACTOR = ____________________
(UNITS)

REGION 6 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	4.566	2.280	1.393	0.945
NE	1.790	0.844	0.498	0.331
E	2.206	1.057	0.630	0.421
SE	1.578	0.749	0.444	0.296
S	1.822	0.886	0.533	0.358
SW	0.837	0.411	0.248	0.167
W	0.140	0.064	0.037	0.024
NW	0.242	0.113	0.066	0.044

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	82.780	42.568	26.184	17.816
NE	49.019	24.609	14.907	10.045
E	36.967	18.389	11.094	7.452
SE	34.918	17.459	10.552	7.100
S	77.675	40.009	24.605	16.737
SW	49.906	25.036	15.147	10.198
W	71.731	36.985	22.699	15.416
NW	47.035	23.710	14.358	9.671

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 6 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.463	0.278	0.193	0.143	0.090	0.046	0.029	0.020	0.015	0.012
NNE	0.150	0.087	0.059	0.043	0.026	0.013	0.008	0.006	0.004	0.003
NE	0.157	0.093	0.064	0.047	0.029	0.015	0.009	0.006	0.005	0.004
ENE	0.205	0.122	0.084	0.062	0.039	0.020	0.012	0.009	0.006	0.005
E	0.202	0.120	0.083	0.061	0.038	0.020	0.012	0.009	0.006	0.005
ESE	0.132	0.078	0.053	0.039	0.024	0.012	0.008	0.005	0.004	0.003
SE	0.141	0.084	0.058	0.043	0.026	0.014	0.008	0.006	0.004	0.003
SSE	0.151	0.089	0.062	0.046	0.028	0.014	0.009	0.006	0.005	0.004
S	0.173	0.103	0.072	0.053	0.033	0.017	0.011	0.007	0.006	0.004
SSW	0.057	0.033	0.022	0.016	0.010	0.005	0.003	0.002	0.002	0.001
SW	0.081	0.048	0.034	0.025	0.016	0.008	0.005	0.004	0.003	0.002
WSW	0.024	0.014	0.009	0.007	0.004	0.002	0.001	0.001	0.001	0.001
W	0.011	0.007	0.004	0.003	0.002	0.001	0.001	0.000	0.000	0.000
WNW	0.016	0.010	0.007	0.005	0.003	0.002	0.001	0.001	0.001	0.000
NW	0.021	0.012	0.008	0.006	0.004	0.002	0.001	0.001	0.001	0.000
NNW	0.052	0.029	0.019	0.013	0.008	0.004	0.002	0.002	0.001	0.001

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	8.794	5.377	3.727	2.765	1.726	0.907	0.584	0.417	0.316	0.250
NNE	4.806	2.893	1.983	1.461	0.904	0.471	0.302	0.215	0.163	0.129
NE	4.889	2.967	2.049	1.518	0.944	0.494	0.317	0.227	0.172	0.136
ENE	4.114	2.490	1.715	1.267	0.786	0.410	0.263	0.187	0.142	0.112
E	3.610	2.185	1.505	1.111	0.690	0.360	0.232	0.165	0.125	0.099
ESE	3.074	1.856	1.278	0.945	0.586	0.306	0.196	0.140	0.106	0.084
SE	3.448	2.093	1.444	1.067	0.664	0.347	0.223	0.159	0.121	0.095
SSE	3.663	2.191	1.500	1.103	0.681	0.353	0.226	0.160	0.121	0.096
S	8.262	5.061	3.508	2.602	1.625	0.855	0.553	0.396	0.300	0.238
SSW	5.387	3.255	2.242	1.659	1.029	0.538	0.346	0.247	0.187	0.148
SW	4.957	3.008	2.078	1.540	0.957	0.501	0.323	0.230	0.175	0.138
WSW	4.528	2.739	1.880	1.387	0.859	0.450	0.290	0.207	0.157	0.125
W	7.597	4.664	3.230	2.394	1.494	0.789	0.513	0.368	0.280	0.223
WNW	6.407	3.919	2.707	2.008	1.251	0.660	0.427	0.306	0.233	0.185
NW	4.707	2.870	1.981	1.467	0.913	0.480	0.310	0.222	0.169	0.134
NNW	3.838	2.299	1.575	1.160	0.715	0.372	0.239	0.171	0.129	0.102

SCALING FACTOR = ____________________
(UNITS)

REGION 6 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	2.009	1.203	0.841	0.623
NE	1.678	0.693	0.457	0.323
E	1.518	0.784	0.523	0.373
SE	1.272	0.593	0.392	0.278
S	1.123	0.588	0.398	0.287
SW	0.550	0.254	0.174	0.126
W	0.187	0.063	0.041	0.028
NW	0.538	0.099	0.065	0.046

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	49.149	26.992	18.606	13.603
NE	39.803	19.050	12.802	9.171
E	29.941	14.762	9.872	7.037
SE	30.864	13.801	9.248	6.608
S	47.488	26.301	18.060	13.163
SW	43.659	20.018	13.424	9.596
W	49.128	26.626	18.133	13.119
NW	43.623	19.697	13.189	9.410

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 6 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.347	0.226	0.163	0.125	0.081	0.043	0.028	0.020	0.015	0.012
NNE	0.208	0.122	0.081	0.058	0.034	0.016	0.010	0.007	0.005	0.004
NE	0.164	0.100	0.069	0.051	0.031	0.016	0.010	0.007	0.005	0.004
ENE	0.200	0.123	0.086	0.064	0.040	0.020	0.013	0.009	0.007	0.005
E	0.194	0.120	0.084	0.062	0.039	0.020	0.013	0.009	0.006	0.005
ESE	0.147	0.089	0.061	0.045	0.027	0.014	0.008	0.006	0.004	0.003
SE	0.143	0.087	0.061	0.045	0.028	0.014	0.009	0.006	0.005	0.004
SSE	0.156	0.096	0.066	0.049	0.030	0.015	0.010	0.007	0.005	0.004
S	0.152	0.096	0.068	0.051	0.032	0.017	0.011	0.007	0.006	0.004
SSW	0.082	0.048	0.032	0.023	0.013	0.006	0.004	0.003	0.002	0.001
SW	0.068	0.043	0.031	0.023	0.015	0.008	0.005	0.003	0.003	0.002
WSW	0.032	0.019	0.012	0.009	0.005	0.003	0.002	0.001	0.001	0.001
W	0.014	0.008	0.006	0.004	0.002	0.001	0.001	0.000	0.000	0.000
WNW	0.016	0.010	0.007	0.005	0.003	0.002	0.001	0.001	0.001	0.000
NW	0.023	0.014	0.010	0.007	0.004	0.002	0.001	0.001	0.001	0.001
NNW	0.119	0.066	0.042	0.029	0.016	0.007	0.004	0.003	0.002	0.001

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	7.458	4.809	3.422	2.582	1.648	0.882	0.574	0.411	0.312	0.248
NNE	5.642	3.435	2.348	1.716	1.041	0.527	0.332	0.232	0.174	0.137
NE	4.829	3.025	2.110	1.567	0.977	0.511	0.327	0.232	0.175	0.139
ENE	4.255	2.640	1.832	1.353	0.837	0.433	0.276	0.195	0.147	0.116
E	3.674	2.288	1.588	1.175	0.729	0.378	0.241	0.171	0.129	0.101
ESE	3.293	2.034	1.404	1.035	0.637	0.328	0.208	0.147	0.111	0.087
SE	3.464	2.161	1.506	1.117	0.694	0.362	0.231	0.164	0.124	0.098
SSE	4.510	2.727	1.852	1.347	0.811	0.407	0.254	0.177	0.132	0.103
S	7.181	4.616	3.276	2.466	1.570	0.840	0.547	0.392	0.298	0.237
SSW	5.959	3.670	2.527	1.858	1.140	0.586	0.371	0.262	0.197	0.155
SW	5.031	3.144	2.187	1.621	1.007	0.525	0.336	0.238	0.180	0.142
WSW	5.236	3.207	2.198	1.610	0.981	0.501	0.317	0.223	0.167	0.132
W	7.065	4.502	3.170	2.372	1.497	0.796	0.518	0.371	0.282	0.224
WNW	6.506	4.079	2.845	2.111	1.314	0.689	0.444	0.316	0.240	0.190
NW	4.923	3.068	2.132	1.576	0.977	0.509	0.326	0.231	0.175	0.138
NNW	4.933	2.971	2.012	1.458	0.875	0.437	0.273	0.190	0.142	0.111

SCALING FACTOR = ____________________
(UNITS)

REGION 7 FINE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	3.680	1.805	1.091	0.735
NE	3.391	1.626	0.970	0.648
E	4.622	2.192	1.301	0.866
SE	5.454	2.610	1.555	1.039
S	4.151	2.000	1.198	0.802
SW	2.686	1.285	0.766	0.511
W	1.358	0.640	0.377	0.250
NW	0.668	0.305	0.177	0.116

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	43.224	22.172	13.633	9.279
NE	41.792	21.160	12.891	8.725
E	39.522	19.843	12.040	8.124
SE	29.911	14.844	8.948	6.014
S	40.962	20.833	12.744	8.645
SW	34.257	17.154	10.389	7.005
W	26.682	13.384	8.117	5.473
NW	16.752	8.328	5.017	3.369

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 7 COARSE GRID SOURCE SIZE 10M X 10M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.356	0.213	0.147	0.109	0.068	0.035	0.022	0.015	0.011	0.009
NNE	0.196	0.115	0.078	0.057	0.035	0.018	0.011	0.008	0.006	0.004
NE	0.311	0.184	0.127	0.094	0.059	0.030	0.019	0.013	0.010	0.008
ENE	0.322	0.190	0.131	0.096	0.060	0.030	0.019	0.013	0.010	0.008
E	0.413	0.245	0.169	0.125	0.077	0.039	0.025	0.017	0.013	0.010
ESE	0.495	0.294	0.203	0.150	0.093	0.048	0.030	0.021	0.016	0.012
SE	0.498	0.296	0.204	0.151	0.094	0.048	0.030	0.021	0.016	0.012
SSE	0.358	0.211	0.145	0.107	0.066	0.034	0.021	0.015	0.011	0.009
S	0.386	0.230	0.159	0.118	0.073	0.037	0.024	0.017	0.012	0.010
SSW	0.221	0.130	0.089	0.066	0.041	0.021	0.013	0.009	0.007	0.005
SW	0.245	0.145	0.100	0.074	0.046	0.024	0.015	0.010	0.008	0.006
WSW	0.203	0.121	0.083	0.062	0.038	0.020	0.012	0.009	0.006	0.005
W	0.119	0.070	0.048	0.035	0.022	0.011	0.007	0.005	0.004	0.003
WNW	0.058	0.034	0.023	0.017	0.011	0.005	0.003	0.002	0.002	0.001
NW	0.054	0.032	0.022	0.016	0.010	0.005	0.003	0.002	0.002	0.001
NNW	0.131	0.077	0.052	0.038	0.024	0.012	0.007	0.005	0.004	0.003

SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	4.583	2.802	1.944	1.442	0.901	0.474	0.305	0.218	0.165	0.131
NNE	3.017	1.818	1.248	0.921	0.571	0.299	0.191	0.137	0.104	0.082
NE	4.275	2.602	1.803	1.339	0.835	0.439	0.282	0.202	0.153	0.121
ENE	3.962	2.406	1.660	1.229	0.764	0.400	0.257	0.184	0.140	0.111
E	3.963	2.410	1.664	1.231	0.766	0.402	0.259	0.185	0.140	0.111
ESE	3.308	2.000	1.380	1.022	0.635	0.332	0.213	0.152	0.115	0.091
SE	2.914	1.764	1.216	0.898	0.558	0.291	0.186	0.133	0.101	0.079
SSE	2.576	1.545	1.061	0.782	0.484	0.252	0.161	0.114	0.086	0.068
S	4.249	2.592	1.795	1.330	0.830	0.436	0.281	0.200	0.152	0.120
SSW	3.011	1.812	1.247	0.922	0.571	0.298	0.191	0.136	0.103	0.081
SW	3.412	2.069	1.430	1.060	0.660	0.345	0.221	0.158	0.120	0.094
WSW	3.110	1.885	1.299	0.961	0.597	0.312	0.200	0.143	0.108	0.085
W	2.667	1.621	1.119	0.828	0.515	0.270	0.174	0.124	0.094	0.074
WNW	1.641	0.989	0.679	0.501	0.310	0.162	0.104	0.074	0.056	0.044
NW	1.631	0.988	0.681	0.503	0.312	0.163	0.105	0.075	0.057	0.045
NNW	1.880	1.123	0.769	0.566	0.349	0.181	0.116	0.082	0.062	0.049

SCALING FACTOR = ____________________ (UNITS)

REGION 7 COARSE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 200	300	400	500
N	2.050	1.106	0.755	0.549
NE	2.559	1.196	0.798	0.570
E	3.502	1.735	1.149	0.814
SE	3.837	1.956	1.303	0.929
S	2.893	1.422	0.954	0.683
SW	1.975	0.963	0.642	0.457
W	1.104	0.526	0.346	0.244
NW	0.881	0.302	0.195	0.135

Q_I = SCALING FACTOR = ____________________ (UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 200	300	400	500
N	26.882	14.401	9.906	7.231
NE	31.453	15.781	10.679	7.695
E	30.207	15.515	10.436	7.477
SE	25.238	11.923	7.976	5.692
S	27.523	14.442	9.843	7.131
SW	26.393	13.241	8.903	6.382
W	20.291	10.328	6.947	4.978
NW	16.270	6.811	4.547	3.239

Q_{II} = SCALING FACTOR = ____________________ (UNITS)

REGION 7 FINE GRID SOURCE SIZE 100M X 100M

WIND EROSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	0.296	0.188	0.134	0.101	0.064	0.034	0.021	0.015	0.011	0.009
NNE	0.247	0.146	0.099	0.072	0.043	0.021	0.013	0.009	0.006	0.005
NE	0.296	0.183	0.128	0.095	0.060	0.031	0.019	0.013	0.010	0.008
ENE	0.340	0.207	0.143	0.105	0.065	0.032	0.020	0.014	0.010	0.008
E	0.417	0.256	0.178	0.132	0.082	0.041	0.026	0.018	0.013	0.010
ESE	0.491	0.302	0.210	0.156	0.097	0.049	0.031	0.021	0.016	0.012
SE	0.481	0.298	0.208	0.155	0.096	0.049	0.031	0.022	0.016	0.012
SSE	0.393	0.238	0.164	0.120	0.073	0.037	0.023	0.016	0.012	0.009
S	0.358	0.223	0.157	0.117	0.073	0.038	0.024	0.017	0.012	0.010
SSW	0.257	0.154	0.105	0.077	0.047	0.023	0.014	0.010	0.007	0.006
SW	0.237	0.147	0.102	0.076	0.047	0.024	0.015	0.011	0.008	0.006
WSW	0.200	0.123	0.086	0.064	0.040	0.020	0.013	0.009	0.007	0.005
W	0.124	0.076	0.052	0.038	0.024	0.012	0.007	0.005	0.004	0.003
WNW	0.067	0.040	0.027	0.020	0.012	0.006	0.004	0.003	0.002	0.001
NW	0.067	0.039	0.027	0.019	0.012	0.006	0.003	0.002	0.002	0.001
NNW	0.159	0.095	0.064	0.047	0.028	0.014	0.008	0.006	0.004	0.003

SCALING FACTOR = ____________________
(UNITS)

MECHANICAL RESUSPENSION

DIR	RANGE (M) 750	1000	1250	1500	2000	3000	4000	5000	6000	7000
N	3.951	2.541	1.806	1.361	0.868	0.464	0.301	0.216	0.164	0.130
NNE	3.586	2.183	1.493	1.091	0.663	0.336	0.211	0.148	0.111	0.087
NE	4.095	2.584	1.813	1.353	0.849	0.448	0.288	0.205	0.155	0.123
ENE	4.119	2.561	1.780	1.316	0.815	0.424	0.270	0.191	0.144	0.114
E	3.940	2.470	1.722	1.279	0.798	0.417	0.267	0.190	0.143	0.113
ESE	3.427	2.129	1.477	1.093	0.677	0.350	0.223	0.158	0.119	0.094
SE	2.971	1.847	1.285	0.952	0.589	0.306	0.194	0.137	0.104	0.082
SSE	2.979	1.816	1.242	0.909	0.553	0.280	0.176	0.123	0.092	0.072
S	3.842	2.447	1.727	1.295	0.819	0.434	0.281	0.200	0.152	0.120
SSW	3.368	2.066	1.420	1.043	0.638	0.326	0.206	0.144	0.108	0.085
SW	3.362	2.107	1.471	1.093	0.682	0.356	0.228	0.161	0.122	0.096
WSW	3.163	1.969	1.370	1.016	0.630	0.327	0.208	0.147	0.111	0.088
W	2.624	1.646	1.149	0.854	0.533	0.279	0.179	0.127	0.096	0.076
WNW	1.846	1.131	0.777	0.569	0.348	0.177	0.112	0.079	0.059	0.046
NW	1.687	1.047	0.727	0.537	0.332	0.172	0.110	0.077	0.058	0.046
NNW	2.348	1.416	0.961	0.698	0.420	0.210	0.131	0.091	0.068	0.053

SCALING FACTOR = ____________________
(UNITS)

APPENDIX E

EMISSION FACTORS FOR OTHER FORMS OF MECHANICAL DISTURBANCE

As stated in the body of this report, vehicle traffic is the most likely mechanical entrainment mechanism for surface material contaminated by a recent spill or by prior waste dump activities that have been linked to the recently discovered surface contamination. However, other mechanical entrainment mechanisms may be significant in association with remedial action taken to eliminate the atmospheric exposure of contaminated surface materials. Such activities normally require the removal, transport and disposal of the contaminated material.

In estimating emissions from the removal and transfer of contaminated soil, it is necessary to subdivide the site activities into unit operational steps. Recently EPA (1983) issued revised particulate emission factors for agricultural tilling and for aggregate handling and storage piles. These emission factors take the form of predictive equations, and as such they must be applied within the ranges of source parameters tested in order to retain the specified quality ratings. The emission factor for agricultural tilling may be used to estimate emissions from pushing or scraping material from the surface with an implement traveling at a speed of about 8 to 10 km/hr. The loading of material into trucks or the dumping of trucks is best described by the "batch drop" equation contained in the section on aggregate handling and storage piles.

The remainder of this Appendix consists of the appropriate sections of EPA's Compilation of Air Pollutant Emission Factors, as described above.

11.2.2 AGRICULTURAL TILLING

11.2.2.1 General

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

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

11.2.2.2 Emissions and Correction Parameters

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

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

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

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

11.2.2.3 Predictive Emission Factor Equation

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

$$E = k(604)(s)^{0.6} \quad \text{(kg/hectare)} \qquad (1)$$

$$E = k(538)(s)^{0.6} \quad \text{(lb/acre)}$$

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

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

Aerodynamic Particle Size Multiplier for Equation 1

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

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

11.2.2.4 Control Methods[3]

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

References for Section 11.2.2

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

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

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

11.2.3 AGGREGATE HANDLING AND STORAGE PILES

11.2.3.1 General

Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Dust emissions occur at several points in the storage cycle, during material loading onto the pile, during disturbances by strong wind currents, and during loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

11.2.3.2 Emissions and Correction Parameters

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

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

Field investigations have shown that emissions from aggregate storage operations vary in direct proportion to the percentage of silt (particles $< 75\ \mu m$ in diameter) in the aggregate material.[1 3] The silt content is determined by measuring the proportion of dry aggregate material that passes through a 200 mesh screen, using ASTM-C-136 method. Table 11.2.3-1 summarizes measured silt and moisture values for industrial aggregate materials.

11.2.3.3 Predictive Emission Factor Equations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

[a] NA = not applicable.

For emissions from equipment traffic (trucks, front end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 11.2.1). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

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

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

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

where:
- E = total suspended particulate emission factor
- s = silt content of aggregate (%)
- p = number of days with $\geq$ 0.25 mm (0.01 in.) of precipitation per year
- f = percentage of time that the unobstructed wind speed exceeds 5.4 m/s (12 mph) at the mean pile height

The coefficient in Equation 3 is taken from Reference 1, based on sampling of emissions from a sand and gravel storage pile area during periods when transfer and maintenance equipment was not operating. The factor from Test Report 1, expressed in mass per unit area per day, is more reliable than the factor expressed in mass per unit mass of material placed in storage, for reasons stated in that report. Note that the coefficient has been halved to adjust for the estimate that the wind speed through the emission layer at the test site was one half of the value measured above the top of the piles. The other terms in this equation were added to correct for silt, precipitation and frequency of high winds, as discussed in Reference 2. Equation 3 is rated C for application in the sand and gravel industry and D for other industries.

Worst case emissions from storage pile areas occur under dry windy conditions. Worst case emissions from materials handling (batch and continuous drop) operations may be calculated by substituting into Equations 1 and 2 appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for vehicle traffic (Section 11.2.1) and for wind erosion (Equation 3), centering around parameter p, follows the methodology described in Section 11.2.1. Also, a separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity may be justified for the worst case averaging period.

11.2.3.4 Control Methods

Watering and chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical wetting agents for better wetting of fines and longer retention of the moisture film. Continuous chemical treatment of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.[8]

References for Section 11.2.3

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

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

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

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

APPENDIX F

GLOSSARY

Climatic Region - One of the seven areas shown in Figure 4-5 of the text for which regional meteorologies have been developed.

Contamination Level - The ratio of the mass of the contaminant in a sample to the total sample mass.

Dry Day - Day without measurable (0.01 in. or more) precipitation.

Emission Factor - The quantity (mass) of airborne particulate generated per unit of source extent.

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

Factor Analysis - A multivariate statistical technique useful in examining relationships between sets of intercorrelated observations.

Fastest Mile of Wind - Routinely measured variable which represents the wind speed corresponding to the whole mile of wind movement which passes by the 1 mile contact anemometer in the least amount of time.

Friction Velocity - A reference wind velocity defined by the relation $u_* = \sqrt{\tau/\rho}$ where τ is the Reynold's stress, ρ the density, and u_* the friction velocity. It is usually applied to motion near the ground where the shearing stress if often assumed to be independent of height and approximately proportional to the square of the mean velocity. The friction velocity is, therefore, exactly that velocity for which this square law would be valid.

Gaussian Dispersion - A mathematical technique used to estimate ambient air pollution concentration, assuming a bivariate normal distribution with empirically determined coefficients.

Mechanical Resuspension - The generation of airborne particulate by the movement of machinery, such as vehicular traffic on an unpaved surface or the dumping of an aggregate material.

Moisture Content - The mass portion of an aggregate sample consisting of unbound moisture as determined from weight loss in oven drying with correction for the estimated difference from total unbound moisture.

Nonerodible elements - Elements on the soil surface which remain firmly in place during a wind episode and inhibit soil loss by consuming part of the shear stress of the wind. Examples are clumps of grass or stones larger than about 1 cm in diameter.

Particle Diameter, Aerodynamic - The diameter of a hypothetical sphere of unit density (1 g/cm^3) having the same terminal settling velocity as the particle in question, regardless of its geometric size, shape, and true density.

Particulate, Respirable - Airborne particulate matter with aerodynamic diameter of 10 micrometers or less; often referred to as PM_{10}.

Precipitation-Evaporation Index - A climatic factor equal to 10 times the sum of 12 consecutive monthly ratios of precipitation in inches over evaporation in inches, which is used as a measure of the annual average moisture of exposed material on a flat surface of compacted aggregate.

Rayleigh Distribution - A chi-squared distribution with 2 degrees of freedom.

Reservoir, Limited - In wind erosion, a surface with a large amount of nonerodible elements (e.g., stones, vegetation) characterized by a high threshold velocity and an emission that decays with time.

Reservoir, Unlimited - In wind erosion, a bare surface of finely divided material (such as agricultural soil) characterized by a low threshold velocity and a particulate emission rate that is essentially time-independent.

Roughness Height - A measure of the roughness of a surface over which a fluid is flowing, defined as follows: $z_o = E/30$ where z_o is the roughness height and E is the average height of surface irregularities.

Silhouette Area - The 2-dimensional frontal view of a nonerodible element as seen by the wind velocity vector.

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

Source Extent - For open dust sources, extent is defined as area or volume from which emissions emanate. In estimating wind erosion for example, the source extent is the area (m^2) of erodible surface.

STAR (STability ARray) - Multivariate frequency distribution of wind speed, direction, and atmospheric stability.

Surface Erodibility - Potential for wind erosion losses from an unsheltered area, based on the percentage of erodible particles (smaller than 0.85 mm in diameter) in the surface material.

Threshold (Friction) Velocity - The wind velocity necessary to initiate soil erosion. This wind speed depends upon such factors as the presence or absence of surface crust, soil moisture content, size distribution of the exposed material, and the presence of nonerodible elements.

APPENDIX G

ANNUAL AND WORST-CASE OVERLAYS

This appendix contains graphics for use in creating map overlays on translucent paper, as discussed on pages 43 and 53 of the report. The overlays must retain the 1:24,000 scale (4.2 cm = 1 km) so that they can be placed directly on United States Geological Survey (USGS) 7.5 min topographic maps.