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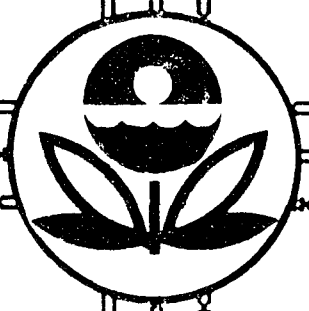
INTERIM
GUIDELINE ON AIR QUALITY MODELS



U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Air Quality Planning and Standards

Research Triangle Park, North Carolina

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# GUIDELINE ON AIR QUALITY MODELS

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MONITORING AND DATA ANALYSIS DIVISION
OFFICE OF AIR QUALITY PLANNING AND STANDARDS
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA

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## ACKNOWLEDGEMENT

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## Preface

In late 1976 it became clear from needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by deliberations of Congress that greater consistency in the use of air quality models is needed. Consistency is required so that air pollution control agencies, industry and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits.

To meet this need, EPA undertook a series of steps that would lead to a widely reviewed guide on the use of air quality models. After initial opinions from EPA's Regional Offices were received, the Office of Air Quality Planning and Standards prepared a draft guide. This guide was submitted for critical review to a conference of specialists.* The individual conferees were widely recognized experts in the development and use of air quality models. Based on the judgments and suggestions of the conferees, the guide was revised and presented for public comment at meetings** in Atlanta, Chicago, Denver, New York and San Francisco. These meetings were attended by approximately 500 representatives of control agencies, industry, environmental groups and the scientific community. These attendees submitted extensive oral and written comments which were evaluated and considered in the preparation of this guide.

During the development of the guide the Clean Air Act Amendments of 1977 were signed into law. These amendments require the promulgation of regulations which specify models to be used in analyses pertinent to prevention of significant deterioration. They also require EPA to conduct a conference on air quality modeling. This guide is published for interim use, pending development of the regulations required by the Clean Air Act. The guide will be used as a point of departure for the Modeling Conference and the subsequent development of regulations.

Due to the continuing development of a wide variety of air quality models and numerous gaps in our ability to simulate the atmospheric dispersion process, EPA plans to review and update this document periodically.

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*Roberts, J. J., Ed. "Report to the U. S. EPA of the Specialists' Conference on the EPA Modeling Guidelines." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1977.

**Slater, H. H., Chairman, "Comments and Recommendations Concerning the Draft Guidelines on Air Quality Models." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May/June 1977.

TABLE OF CONTENTS

Page

# 1.0 INTRODUCTION

The purpose of this guide is to recommend air quality modeling techniques that may be applied to air pollution control strategy evaluations and to new source reviews, including prevention of significant deterioration. It is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, by State and local agencies and by industry and its consultants. Similarly, it serves to identify for all interested parties those techniques and data bases that EPA considers acceptable. The guide is not intended to be a compendium of modeling techniques. Rather it should serve as a basis by which air quality managers, supported by sound scientific judgment, have a common measure of acceptable technical analyses.

This guide makes specific recommendations concerning (1) air quality models, (2) data bases and (3) general requirements for concentration estimates. It should be followed in all evaluations relative to State Implementation Plans (SIPs). However, it may be found that (1) the recommended air quality model is not appropriate for a particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other data, models and techniques deemed appropriate by the Regional Administrator may be used. Thus, even though specific recommendations are made, they should not be considered rigid requirements. The preferred model is that which best simulates atmospheric transport and dispersion in the area of interest. However, deviations from this guide should be fully supported and documented.

The contents of this guide are summarized in Figure 1. The basic steps in applying an air quality model to a practical situation, and the necessary data bases and information, are shown. The numbers in parentheses refer to specific sections of the guide.

As indicated in Figure 1, it is generally advisable to first apply a model requiring a minimum expenditure of resources (i.e., a preliminary screening technique). The purpose of a screening technique is to single out, with minimum effort, those sources that clearly will not cause or contribute to ambient concentrations in excess of the National Ambient Air Quality Standards (NAAQS) or allowable concentration increments. In doing so, unwarranted expenditure of resources (a refined analysis when a simple approach would suffice) can be avoided. Another advantage of first applying a relatively simple model is to obtain concentration estimates or receptor information that can be helpful in a more refined analysis.

If the screening analysis indicates that the source may pose an air quality problem, application of a relatively sophisticated model is then warranted for obtaining more refined concentration estimates. The selection of an appropriate model should be based upon all the factors indicated in Figure 1. Of particular importance are the source and meteorological data used in the application.

Given the selection of a refined air quality model, an appropriate receptor field must be designated. The model can then be applied giving

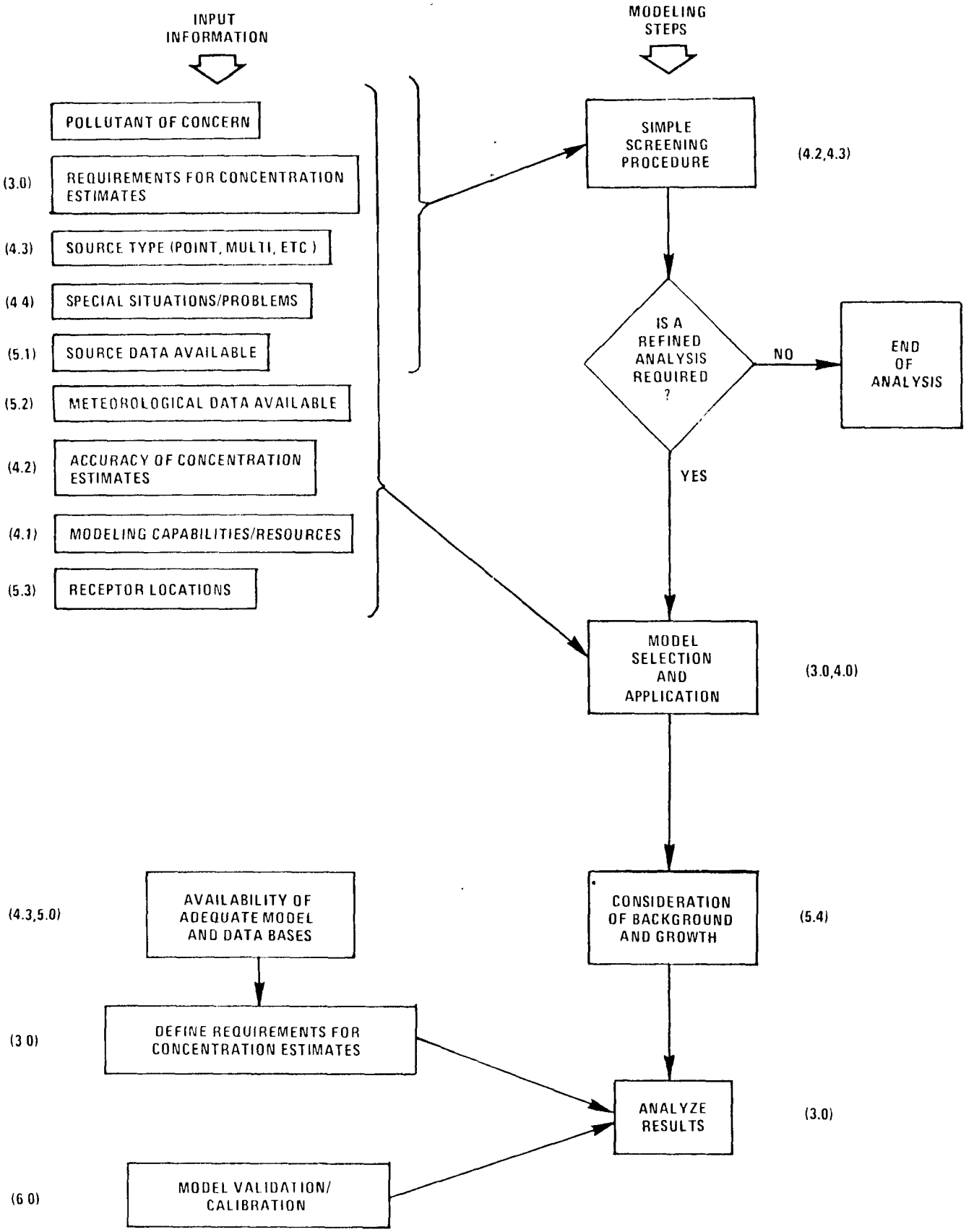


Figure 1 Selection and application of air quality models and data bases. (Applicable sections of the guideline are indicated in parentheses.)

appropriate consideration to background concentrations and future growth. The resulting concentration estimates can be used to analyze source impact as required by the particular application. However, any analytical technique may have deficiencies that cause estimated concentrations to be in error. Therefore, information on the accuracy of the model should be available prior to evaluation of control strategies and determination of allowable emissions.

## 2.0 OVERVIEW

Air quality models have been widely used to identify potential violations of the National Ambient Air Quality Standards (NAAQS) and to determine emission limits. The need for air quality models in the development and revision of SIP-related control strategies was identified very early.[1] However, due to the initial demands of the Clean Air Act (1970) on available resources, it has not generally been possible to use air quality models to the extent desired. Thus, many SIPs are based on an example region concept and a simple emissions rollback model. In recent years, however, air quality models have been more widely used. As these models and associated data bases increase in sophistication, they allow more precision in estimating concentrations and in assessing the adequacy of control strategies.

In addition to their use in development and revision of control strategies, air quality models are also required in the New Source Review program to insure attainment and maintenance of NAAQS, and to prevent significant air quality deterioration. Judgments must be made concerning allowable emission rates and the placement of new sources that may cause specific air quality levels to be exceeded or that may contribute significantly to existing violations.

It would be advantageous to categorize the various control programs and to apply a designated model to each proposed source which comes under a given program. However, the diversity of the nation's topography and climate, and variations in source

configurations and operating characteristics dictate against a routine "cookbook" analysis. There is no single model capable of properly addressing all conceivable situations. Meteorological phenomena associated with threats to air quality standards are rarely amenable to simple mathematical treatment. Any modeling effort should be directed by highly competent individuals with a broad range of experience and knowlege in air pollution meteorology and coordinated closely with specialists in emissions characteristics and data processing. The judgment of well-trained professional analysts is essential.

Nevertheless, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations and by the deliberations of Congress[2] that greater consistency in the use of models and data bases is in order. Consistency is required so that air pollution control agencies and the general public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. This guide promotes the required consistency.

## 3.0 REQUIREMENTS FOR CONCENTRATION ESTIMATES

Specific air quality standards and increments of pollutant concentrations must be considered for control strategy evaluations and for new source reviews, including prevention of significant deterioration. This section specifies general requirements for concentration estimates and identifies the relationship between emission limits and air quality standards/increments for these applications.

### 3.1 Control Strategy Evaluations

SIP-related emission limits should be based on concentration estimates for the averaging time which results in the most stringent control requirements. In all cases these concentration estimates are assumed to be a sum of the concentration contributed by the source and an appropriate background concentration (see pp. 34-37).

If the annual average air quality standard is exceeded by a greater degree (percentage) than standards for other averaging times, the annual average is considered the restrictive standard. In this case the sum of the highest estimated annual average concentration and the annual average background provides the concentration which should be used to specify emission limits. However, if a short-term standard is exceeded by a greater degree and is thus identified as the restrictive standard, other considerations are required because the frequency of occurrence must also be taken into account.

Historically, when dispersion model estimates are used to assist in judging whether short-term NAAQS will be met, and ultimately in

specifying appropriate emission limits, one of three types of concentration estimates is used: (1) The highest of all estimated concentrations, (2) the second-highest of all estimated concentrations, or (3) the highest of second-highest concentrations estimated for a field of receptor sites. The highest of second-highest concentrations for a field of receptors is obtained as follows: (1) Frequency distributions of short-term concentrations are estimated for each site in a field of receptors; (2) the highest estimated concentration at each receptor is discarded; (3) the highest of the remaining concentration estimates from the field of receptor sites is identified. Throughout this guideline that concentration estimate is referred to as the "highest, second-highest" concentration.

The first two types of estimates have been applied most often in specifying emission limits. However, they may be unnecessarily restrictive in many situations. The third type of estimate is more consistent with the criteria for determining violations of the NAAQS, which are identified in "Guidelines for Interpretation of Air Quality Standards."[3] That guideline specifies that a violation of a short-term standard occurs at a site when the standard is exceeded a second time. Thus, emission limits which are to be based on an averaging time of 24-hours or less should be based on the highest, second-highest estimated concentration plus a background concentration which can reasonably be assumed to occur with that concentration. (See the section on background air quality for a discussion of the factors and variety of situations that should be considered.)

An estimate of the highest, second-highest concentration which is based on many well-chosen receptor sites may well reveal previously unidentified "hot spots." Such an estimate may provide a more conservative and realistic indication of the potential for NAAQS violations and of the appropriate emission limits than do actual measurements at a few monitoring sites. However, if the data available for modeling are limited to a short period, or source data are generalized, the estimated highest, second-highest concentration is unlikely to provide a true indication of the threat to air quality standards. Thus it is essential that an adequate data base be available (see Section 5.0). Data for a time period of sufficient length should be considered so that there is reasonable certainty that meteorological conditions associated with the greatest impacts on air quality are identified. Similarly, detailed source data are required so that the air quality impact can be assessed for the source conditions likely to result in the greatest impact.

There are two exceptions to the above requirement to use the highest, second-highest estimated concentrations. The first situation occurs where monitored air quality data from specific sites indicate that concentrations greater than those estimated can occur with little or no impact from the source(s) in question. For the purpose of specifying emission limits, these measured concentrations should be ranked ahead of the estimated concentrations in the frequency distribution of concentrations at that specific monitoring (receptor) site.

The second situation occurs where the Regional Administrator identifies inadequacies in the data base or the models for a particular application. As a result of these inadequacies he may determine that there is a lack of confidence in an emission limit based on the highest, second-highest concentration or that this concentration simply cannot be estimated. In this case, until such time as the necessary data bases are acquired or analytical techniques are improved, the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified.

## 3.2 New Source Reviews

Reviews for new sources that require an air quality impact analysis should determine if the source will (1) cause or exacerbate violations of a NAAQS or (2) cause air quality deterioration which is greater than allowable increments. The following subsections identify requirements for concentration estimates associated with air quality standards and with prevention of significant deterioration.

### 3.2.1 Meeting Air Quality Standards

For each new major source* or major modification of a source, an air quality analysis should be performed to determine if the source will cause or exacerbate a violation of a NAAQS. For a new major source located in an attainment area, the concentration estimates should meet the same requirements that are applicable to control strategy evaluations.

*As defined in section 302(j) of the Clean Air Act, a major source is any stationary facility which directly emits, or has the potential to emit, 100 tons or more per year of any air pollutant.

The determination of whether or not the source will cause an air quality violation should be based on (1) the highest estimated concentration for annual averages and (2) the highest, second-highest estimated concentration for averaging times of 24-hours or less. The most restrictive standard should be used in all cases to establish the potential for an air quality violation. Background concentrations should be added in assessing the source's impact. The two exceptions to the shorter-term averaging times which were noted in the preceding section also apply here; i.e., monitored data with higher concentrations and inadequacies in data bases or model.

In some cases a new major source of sulfur dioxide, particulate matter, nitrogen oxides or carbon monoxide may be (1) located in a non-attainment area or (2) may be in an attainment area but is expected to exacerbate air quality violations known to occur in a nearby non-attainment area. In such situations, the expected incremental increase in pollutant concentrations should be estimated for meteorological conditions which accompany the existing violations. Incremental increases in pollutant concentrations that may be considered significant (for purposes of determining whether an existing violation is exacerbated) are discussed in Appendix A.* For all averaging times, the highest estimated concentration increments are used. The second highest

*A source with relatively low stack height, e.g., 30 meters, that has actual emissions greater than 15 tons per year of sulfur dioxide or particulate matter may have a significant impact as defined in Appendix A. If the impact is significant, the source is subject to emissions offsets as discussed in EPA's Interpretive Ruling.

is not used in the case of short-term concentrations since the incremental increase is added to a concentration which is already based on the highest, second-highest value.

3.2.2 Prevention of Significant Deterioration

Air quality models should be used in all significant deterioration evaluations. Allowable increments for sulfur dioxide and particulate matter are set forth in the Clean Air Act Amendments of 1977.[2] These maximum allowable increases in pollutant concentrations may be exceeded once per year, except for the annual increment. Thus, in significant deterioration evaluations for short-term periods the highest, second-highest increase in estimated concentrations should be less than or equal to the permitted increment.

Where an exemption to the Class I increments is requested and approved pursuant to section 165(d)(2)(D) of the Clean Air Act, the source may cause the Class I increments to be exceeded on a total of 18 days during any annual period. In this case it is necessary to select the highest estimated concentration in the field of receptors for each of the 365 days. These 365 values are then ranked and the 19th highest is used to determine emission limits. However, the highest, second-highest concentration may not exceed a somewhat higher increment specified in section 165(d)(2)(D)(iii).

## 4.0 AIR QUALITY MODELS

This Section recommends air quality models* for a wide variety of specific applications. Factors are discussed that determine the suitability of models for individual situations, classes and sub-classes of models are identified, and special modeling problems are addressed.

Air quality models recommended in this section are state-of-the-art analytical techniques that make it possible to perform control strategy evaluations and new source reviews, including prevention of significant deterioration. However, the responsible Regional Administrator may find that (1) the recommended air quality model is not appropriate for the particular application, (2) the required data base is unavailable, or (3) a better model or analytical procedure is available and applicable. In such cases, alternatives indicated in this guide or other models deemed appropriate by the Regional Administrator may be used. However, all deviations from this guide should be fully supported and documented.

It must not be construed that the models recommended in this guide are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality. Similar models that are available from other governmental agencies and private consultants have been summarized and discussed by Lamb, et al.,[6] Moses,[7] Stern[8] and others.

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*A discussion of each specific model or refined analytical technique is presented in Appendix B. Some of the models recommended here are also applicable to the development and use of Supplementary Control Systems (SCS). However, such control systems are not considered in the context of this guideline and the reader is referred to other publications on SCS.[4,5]

In all cases, and particularly when models and data bases other than those recommended in this guide are being proposed, early discussions among the Regional Office staff, the control agencies and industry representatives are encouraged. Concurrence on the technical approach, prior to the actual analyses, will help avoid disagreements concerning the final results. The Office of Air Quality Planning and Standards is routinely available to the Regional Offices for consultation on particularly difficult or complex problems.

It should be noted that models applicable to photochemical oxidants are not discussed in this guide. These models are undergoing a critical review. Requirements for such models and associated data bases will be specified at a later time.

## 4.1 Suitability of Models

The extent to which a specific air quality model is suitable for the evaluation of source impact and control strategies depends upon several factors that should be judged by the responsible Regional Administrator. These include (1) the detail and accuracy of the data base, i.e., emission inventory, meteorological data, air quality data; (2) the meteorological and topographic complexities of the area; (3) the technical competence of those undertaking such simulation modeling; and (4) the resources available. These factors, as well as others deemed appropriate by the responsible Regional Administrator, should be considered in determining the suitability of a particular model application.

The data base required for air quality models includes source data, meteorological data and air quality data (see Section 5.0).

Appropriate data should be available before any attempt is made to apply a model. A model which requires detailed, precise input data should not be applied when such data are unavailable. However, assuming the data are adequate, the greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distingush the effects of various control strategies.

Most air quality models that describe atmospheric transport and dispersion apply to areas with relatively simple topography. However, areas subject to major topographic or marine influence experience meteorological complexities that are extremely difficult to simulate. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time that better models and data bases become available.

Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. Whenever a model is applied, the services of knowledgeable, well-trained air pollution engineers, meteorologists and air quality analysts should be engaged. The need for specialists is particularly critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly or with inappropriately chosen data can lead to serious misjudgments regarding the source impact or the effectiveness of a control strategy.

The resource demands generated by use of air quality models vary widely depending on the specific application. Resources required are dependent on the nature of the model and its complexity, the detail of the data base, the difficulty of the application, and the amount and level of expertise required. The costs of manpower and computational facilities are also important factors.

## 4.2 Classes of Models

The air quality modeling procedures discussed in this guide can be categorized into four generic classes: Gaussian, numerical, statistical or empirical, and physical. Within some of these classes a large number of individual "computational algorithms" exist, each with its own specific applications. While each of these algorithms may have the same generic basis, e.g., Gaussian, it is accepted practice to refer to them individually as models. For example, the Climatological Dispersion Model, the Air Quality Display Model and the Texas Climatological Model are commonly referred to as individual models. In fact, they are all variations of a basic Gaussian model. In many cases the only real difference between models is the degree of detail considered in the input or output data.

Gaussian models are generally considered to be state-of-the-art techniques for estimating the impact of nonreactive pollutants. Numerical models are more appropriate than Gaussian models for multi-source applications which involve reactive pollutants. However, they frequently require more extensive resources and are not as widely applied. Statistical or empirical techniques are frequently employed in situations where incomplete scientific understanding of the physical and chemical

processes make the use of a Gaussian or numerical model impractical. Various specific models of these three generic types are recommended in this guideline.

Physical modeling, the fourth generic type, involves the use of wind tunnel or other fluid modeling facilities. This type of modeling may be very useful in evaluating the air quality impact of a source or group of sources in a geographic area limited to a few square kilometers. Where physical modeling is available and applicable, it is recommended. However, physical modeling is a complex process which requires a high level of technical expertise and is beyond the scope of this guide.

In addition to the various classes of models, this guide considers two levels of sophistication. The first level consists of general, relatively simple estimation techniques that provide conservative estimates of the air quality impact of a specific source, or source category. The purpose of such techniques is to eliminate from further consideration those sources that clearly will not cause or contribute to ambient concentrations in excess of NAAQS or allowable concentration increments. Conversely, these techniques can be used to identify those control strategies that have the potential to meet NAAQS and allowable increments. The second level consists of those analytical techniques which provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies.

In some cases, the first level of models may be equated with screening techniques to determine if a second or more refined analysis is required. However, while the use of screening techniques followed by a more refined analysis is desirable, there are situations where the screening techniques are practically and technically the only viable option for estimating source impact and evaluating control strategies.

## 4.3 Recommended Models

To meet the need for consistency identified in Section 2, selected point source and multi-source models applicable to specific pollutants and averaging times are recommended in this subsection. Ideally, air quality models that are recommended should meet prescribed standards of performance for particular applications and should be subjected to specific validation procedures. However, there are no generally accepted standards of performance and validation procedures (see p. 39). The models recommended in this guideline are simply those which are (1) representative of the state-of-the-art for atmospheric simulation models and (2) those most readily available to air pollution control agencies.

### 4.3.1 Point Source Models for Sulfur Dioxide and Particulate Matter (All Averaging Times)

Gaussian models are considered to be state-of-the-art techniques for estimating concentrations of sulfur dioxide and particulate matter. They are the best choice for most point source evaluations. For all point sources two levels of sophistication in the use of models are suggested. The first level is composed of models which can provide a preliminary estimate of concentrations. It is recommended that such a

screening technique be applied to all major sources. If it is found from the screening technique that the source will cause a concentration that is more than one-half of an allowable air quality increment, then that source should be subjected to a more refined analysis.

For flat terrain situations that have no significant meteorological complexities, there are several standard publications[9-11] and computerized models[12] that can be used for screening. In addition Pooler[13] and Carpenter et al.[14] have discussed simplified techniques for estimating concentrations during inversion-breakup fumigation. Lyons[15] has summarized information and techniques applicable to lake/sea breezes. Huber and Snyder[16,17] and Briggs[18] have presented various techniques applicable to aerodynamic downwash. Several authors[19-22] have outlined techniques that are useful for situations where long-range transport (greater than 50 kilometers) is important. The Valley Model[23] is applicable to some complex terrain situations; Egan[24] has summarized information on other applicable techniques. Volume 10 of the Guidelines for Air Quality Maintenance Planning and Analysis,[25] "Procedures for Evaluating Air Quality Impact of New Stationary Sources" has summarized, in a format useful for screening, techniques applicable to both flat terrain and more complex situations; those techniques are recommended for use.

In those cases where a more refined analysis is required and there are no significant meteorological or terrain complexities, the Single Source (CRSTER) Model[26] is recommended for use. If meteorological or terrain complexities cause substantial uncertainties, then a model that

is more detailed or more suitable than the Single Source (CRSTER) Model should be applied. No refined, widely available models applicable to complex situations are identified. It is recommended that each complex situation be treated on a case-by-case basis with the assistance of expert advice.

If the data bases required to apply the Single Source (CRSTER) Model are unavailable or if other refined models applicable to a complex situation do not exist, then it may be necessary to base estimates of source impact and the evaluation of control strategies on only the estimates provided by the screening techniques. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

Models specified here and in the following subsection are also applicable to stationary sources of lead pollutants, provided the pollutants can be assumed to behave as a gas.

### 4.3.2 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Annual Average)

Due to the complexity of most multi-source situations and the wide acceptability of several models, a screening process is not generally conducted. If a preliminary assessment of the adequacy of a control strategy is desired, the Rollback Model[27] may be used. However, in most cases such a screening does not constitute an adequate control strategy demonstration.

The Climatological Dispersion Model (CDM),[12,28,29] the Air Quality Display Model (AQDM)[30] and the Texas Climatological Model (TCM)[31] are recommended for evaluating the long-term impact of urban multi-source complexes. In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

#### 4.3.3 Multi-Source Models for Sulfur Dioxide and Particulate Matter (Short-Term Averages)

As noted in the preceding subsection, a Rollback Model may be used for the preliminary assessment of a control strategy. The Real-Time Air-Quality Simulation Model (RAM)[32] is recommended for evaluating the impact of multi-source complexes on air quality averaged over short-term periods. It is applicable to both urban and rural situations. The Texas Episodic Model (TEM)[33] may be used if the data bases required to apply RAM are unavailable. Also, if the resources required to operate RAM or TEM are not available, then CDM, AQDM or TCM may be used to estimate short-term concentrations of $SO_2$ and particulate matter. CDM and AQDM incorporate procedures, such as that discussed by Larsen,[34] to convert 3-hour and 24-hour average concentrations from annual average concentration estimates. Such statistical techniques are valid only in urban, multi-source areas and should not be used in situations dominated by large point sources.

In regions with major meteorological or topographic complexities, more detailed or suitable models may be used. If the meteorological or topographic complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

### 4.3.4 Models for Carbon Monoxide

The recommendations for point source screening procedures and models are also applicable to evaluate point sources of carbon monoxide (CO). The models, procedures and requirements described in Volume 9 of the Guidelines for Air Quality Maintenance Planning and Analysis,[35] "Guidelines for Review of the Impact of Indirect Sources on Ambient Air Quality," are recommended for screening all sources of CO which fulfill the definition of an indirect source. The indirect source guideline is based on the use of HIWAY[12,36] and other simple dispersion techniques. It is acceptable to apply these latter techniques, e.g. HIWAY, independently of the indirect source guideline if it is found that the guideline does not adequately consider a wide enough set of circumstances. If a preliminary assessment of the adequacy of a control strategy applicable to an urban area is desired, the Rollback Model may be used.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for

this model are available, it may be used. An example of such a refined technique is APRAC-1A.[12,37] However, if a region-wide analysis is necessary and the complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

4.3.5 Models for Nitrogen Dioxide

The recommendations for point source screening techniques and models are also applicable to evaluate point sources of nitrogen oxides ($NO_x$) under limited circumstances. The circumstances require an assumption that all $NO_x$ is emitted in the form of $NO_2$ or is converted to $NO_2$ by the time it reaches the ground and that $NO_2$ is a nonreactive pollutant.

For sources located where atmospheric photochemical reactions are significant, a Rollback Model may be used as a preliminary assessment to evaluate the control strategies for multiple sources (mobile and stationary) of $NO_x$. Another acceptable screening technique for multiple sources is to make an assumption similar to that required for point sources and then to use a model for nonreactive pollutants, such as CDM.

Specific refined modeling techniques are not recommended here. Situations that require more refined techniques should be considered on a case-by-case basis with the use of expert consultation. If a suitable model is available and the data and technical competence required for this model are available, it may be used to estimate average concentrations of $NO_2$. However, if a region-wide analysis is necessary and the

complexities are such that the use of any available air quality model is precluded, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

## 4.4 Special Situations

Models with a wide applicability are not generally available for dealing with long-range transport, deposition, wind-blown particulate matter and unique topographic or meteorological circumstances, e.g., complex terrain, aerodynamic downwash. Thus with proper support and documentation, the Regional Administrator may determine that a particular model, not specifically recommended here, is appropriate for a special situation. Examples of these situations are discussed for clarification.

The administration of the national prevention of significant deterioration policy may require that the air quality impact of a source be estimated for great distances downwind. It is uncertain, however, what the impact of sources at such great distances is. Knowledge of the dispersion coefficients for air quality models* becomes increasingly tenuous with downwind distance. Plume transport beyond about 50 kilometers usually requires substantial travel time. As travel time increases, diurnal variations in meteorological conditions and movement of weather systems are more likely to alter plume trajectories and

*Vertical dispersion in these situations is more appropriately treated with numerical models. There are also inherent difficulties with Gaussian models in cases where plume depletion through chemical and physical removal processes is significant. Plume depletion would normally be significant at distances beyond about 50 kilometers for tall stacks under conditions of appreciable vertical mixing, and at considerably shorter distances for near-ground sources.

dispersion characteristics. Even though the impact at greater than 50-100 kilometers may be relatively small, the impact can still be significant for large sources and for situations where the merging of plumes occurs. Techniques are available to examine these impacts, but only limited experience in their use is currently available. If it appears that a large source (for example, a 2000-MW coal-fired power plant meeting new source performance standards) may constitute a threat to ambient air quality standards or prevention of significant deterioration increments at large distances, that source should be considered on a case-by-case basis with available techniques.[19-22]

The models presented in this guide for estimating ambient concentrations of suspended particulate matter assume that the particles disperse as a gas and emanate from well-defined sources. Unfortunately, in many areas, particularly where the air quality standards are not being attained, these assumptions may not hold. Windblown dust, re-entrained street dust, dry-land farming, and raw-material handling operations, all of which are often referred to as fugitive dust sources, can be significant sources of particulate matter.[38] EPA has several on-going studies concerned with fugitive sources of dust; however, the rate and distribution of particulate emissions from these sources is not yet fully known. As a result, a widely applicable model for routinely estimating particulate concentrations attributable to fugitive sources is not available.[39]

Terrain dominated flows and wakes that develop in the vicinity of pollutant sources are involved in many situations.[16-18,23,24] The basic

theoretical principles of these flows are generally understood. However, the variety of terrain features is so great and the spectrum of atmospheric circumstances so broad that no generally applicable model is available that can adequately deal with the range of conditions encountered.

EPA will provide guidance on data bases and assessment procedures to deal with special situations as the results of on-going field investigations and research on these matters become available.

## 5.0 DATA REQUIREMENTS

It is essential that appropriate source and meteorological data be used with any recommended model. Such data, and related procedures for estimating these data, constitute an integral part of the model. It is often overlooked that few of the variables input to a model are directly measured or routinely available. Submodels must appropriately convert the available source and meteorological data to a form that the air quality model can accept. It is also important that a variety of load/emissions conditions, and that a wide range of meteorological conditions based on several years of data, be considered in evaluating control strategies and in determining source impact for new source reviews, including prevention of significant deterioration. In addition, there is a need to judiciously choose receptor sites and to specify background air quality. This section identifies requirements for these data bases.

### 5.1 Source Data

Sources of pollutants generally can be classified as point, line and area sources. Major point sources are defined as those that emit, or have the potential to emit, 100 tons or more per year of any air pollutant. Line sources are generally confined to roadways and streets along which there are well-defined movements of motor vehicles. Area sources include the multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within

each grid square. Descriptions of individual models should be referenced for specific emissions inventory requirements.

For situations involving one or a few point sources the following are minimum requirements for new source review and control strategy evaluations. Design process rate or design load conditions must be considered in determining pollutant emissions. Other operating conditions that may result in high pollutant concentrations should also be identified. A range of operating conditions, emission rates, and physical plant characteristics based on the most recently available data, should be used with the multiple years of meteorological data (see Section 5.2) to estimate the source impact. The following example (power plant) typifies the kind of data on source characteristics and operating conditions that are required:

1. Plant layout. The connection scheme between boilers and stacks, and the distance and direction between stacks, building parameters (length, width, height, location and orientation relative to stacks) for plant structures which house boilers, control equipment, etc.

2. Stack parameters. For all stacks, the stack height and diameter (meters), and the temperature (K) and volume flow rate (actual cubic meters per second) or exit gas velocity (meters per second) for operation at 100 percent, 75 percent and 50 percent load.

3. Boiler size. For all boilers, the associated megawatts and pounds of steam per hour, and the design and/or actual fuel consumption rate for 100 percent load for coal (tons/hour), oil (barrels/hour), and natural gas (thousand cubic feet/hour).

4. Boiler parameters. For all boilers, the percent excess air used, the boiler type (e.g., wet bottom, cyclone, etc.), and the type of firing (e.g., pulverized coal, front firing, etc.).

5. Operating conditions. For all boilers, the type, amount and pollutant contents of fuel, the total hours of boiler operation and the boiler capacity factor during the year, and the percent load for winter and summer peaks.

6. Pollution control equipment parameters. For each boiler served and each pollutant affected, the type of emission control equipment, the year of its installation, its design efficiency and mass emission rate, the date of the last test and the tested efficiency, the number of hours of operation during the latest year, and the best engineering estimate of its projected efficiency if used in conjunction with coal combustion; data for any anticipated modifications or additions.

7. Data for new boilers or stacks. For all new boilers and stacks under construction and for all planned modifications to existing boilers or stacks, the scheduled date of completion, and the data or best estimates available for items 1 through 6 above following completion of construction or modification.

Typically for line sources, such as streets and highways, data are required on the width of the roadway and its center strip, the types and amounts (grams per second per meter) of pollutant emissions, the number of lanes, the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments must be specified in appropriate grid coordinates. More detailed information and data requirements for modeling mobile sources of pollution are provided in the guideline[35] on indirect sources.

For multi-source urban situations, detailed source data are often impractical to obtain. In these cases, source data should be based on annual average conditions. Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated, representative stack height for the area, the location of the centroid or the southwest corner of

the source in appropriate grid coordinates. If the model accepts data on area-wide diurnal variations in emissions, such as those estimated by emissions models which are based on urban activity levels and other factors, those data should be used.

In cases where the required source data are not available and cannot be obtained, the data limitation should be identified. Due to the uncertainties associated with such a limitation the use of the highest estimated concentration to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

For control strategy evaluations the impact of growth on emissions should be considered for the next 10-20 year period. Increases in emissions due to planned expansion of the sources considered or planned fuel switches should be identified. Increases in emissions at each source which may be associated with general industrial/commercial/residential expansion in multi-source urban areas should also be considered. Such information should be used to estimate the air quality impact of those sources in future years. However, for new source reviews, the impact of growth on emissions should only be considered for the period prior to the start-up date for the source. Such changes in emissions should consider increased area source emissions, changes in existing point source emissions which would not be subject to preconstruction review, and emissions due to sources with permits to construct.

## 5.2 Meteorological Data

For a dispersion model to provide useful and valid results, the meteorological data used in the model must be representative of the transport and dispersion conditions in the vicinity of the source that the model is attempting to simulate. The representativeness of the data is dependent on (1) the proximity of the meteorological monitoring site to the area under consideration, (2) the complexity of the terrain in the area, (3) the exposure of the meteorological monitoring site and (4) the period of time during which the data are collected. The representativeness of the data can be adversely affected by large distances between the source and receptors of interest and valley-mountain, land-water, and urban-rural characteristics of the area.

For new source review and control strategy evaluation, the meteorological data required as a minimum to describe transport and dispersion in the atmosphere are wind direction, wind speed, atmospheric stability, mixing height or related indicators of atmospheric turbulence and mixing. Site-specific data are preferable to data collected off-site. The availability of such meso- and micro-meteorological data collections permits more detailed meteorological analyses and subsequent improvement of model estimates. Local universities, industry, pollution control agencies and consultants may be sources of such data. The parameters typically required can also be derived from routine measurements by National Weather Service stations. The data are available as individual observations and in summarized form from the National Climatic Center, Asheville, N. C. Descriptions of individual models should be referred

to for specific meteorological data requirements. Many models require either hourly meteorological data or annual stability wind roses.

It is preferable for the meteorological data base used with the air quality models to include several years of data. Such a multi-year data base allows the consideration of variations in meteorological conditions that occur from year to year. The exact number of years needed to account for such variations in meteorological conditions is uncertain and depends on the climatic extremes in a given area. Generally five years[40] yields an adequate meteorological data base.* For compatibility of model estimates with the NAAQS, the single year with the highest, second-highest short-term concentration estimate (or the highest annual estimate) should then be used in evaluating source impact. However, if long-term data records are not available, it may be necessary to limit the modeling and subsequent analyses to a single year of meteorological data. The use of one year of data might also be justified if the climatological representativeness of that data can be demonstrated. A longer record from a nearby National Weather Service site could be used to check for representativeness.

The number of National Weather Service stations for which multiple years of hourly weather data are available is increasing significantly.

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*An alternative approach is to use a shorter meteorological data base and to use statistical techniques to identify the occurrence of a rare event (highest, second-highest concentration that exceeds the NAAQS) over a longer period of record. This is equivalent to applying the "100-year flood" concept to air pollution control. EPA is studying this concept but for the present recommends using a meteorological data base of at least one year.

Several EPA offices have ordered such data for a large number of stations. It is clear that more detailed analyses than previously considered for SIP evaluations and new source review are necessary. Thus, for areas where meteorological conditions are adequately represented by weather stations, the use of multiple years of meteorological data appears to be viable and justified.

Where representative meteorological observations are not available, the concentration estimates may be limited to consideration of worst case conditions. An analysis of worst case conditions should be based on reasonable interpretations of climatological data and should consider such critical plume characteristics as looping, coning, limited mixing, fumigation, aerodynamic downwash and plume impaction on terrain. Due to the uncertainties of this approach, the use of the highest estimated concentration (as opposed to the highest, second-highest concentration) to determine source impact and to evaluate control strategies may be justified until such time that a better data base becomes available.

## 5.3 Receptor Sites

A receptor site is a location for which an air pollution concentration is estimated. The choice of locations for receptor sites significantly affects the evaluation of source impact and control strategy effectiveness. It is most important to identify the location where the maximum concentrations occur, both short- and long-term. The receptor grid must allow sufficient spatial detail and resolution so that the location of the maximum or highest, second-highest concentration is identified.

The receptor sites in the vicinity of large point sources at which maximum concentrations are likely to occur can be identified by (1) estimating concentrations for a sufficiently dense array of receptors to identify concentration gradients and (2) subsequently refining the location of the maximum by estimating concentrations for a finer array of receptors in the general areas of maximum concentrations. Another technique is to use a model such as PTMAX[12] in combination with joint frequency distributions of wind speed, wind direction and stability to identify the downwind distance and direction at which the highest concentrations are most likely to occur. However, other areas around the source(s) should not be ignored, particularly if they are on elevated terrain. In addition, a receptor should be specified at any site where a monitor is located.

## 5.4 Background Air Quality

To adequately assess the significance of the air quality impact of a source, background concentrations must be considered. Background air quality relevant to a given source includes those pollutant concentrations due to natural sources and distant, unidentified man-made sources. For example, it is commonly assumed that the annual mean background concentration of particulate matter is 30-40 $\mu g/m^3$ over much of the Eastern United States.[41] Typically, air quality data are used to establish background concentrations in the vicinity of the source under consideration. However, where the source is not isolated, it may be necessary to use a multi-source model to establish the impact of all other nearby sources during dispersion conditions conducive to high concentrations.

If the point source is truly isolated and not affected by other readily identified man-made sources, two options for determining background concentrations from air quality data are available. The preferable option is to use air quality data collected in the vicinity of the source to determine mean background concentrations for the averaging times of interest when the point source itself is not impacting on the monitor. The second option applies when no monitors are located in the vicinity of the source. In that case, average measured concentrations from a "regional" site can be used to establish a background concentration.

For the first option it is a relatively straightforward effort to identify an annual average background from available air quality data. For shorter averaging times, background concentrations are determined by the following procedure. First, meteorological conditions are identified for the day and similar days when the highest, second-highest estimated concentration due to the source occurs. Then the average background concentration on days with similar meteorological conditions is determined from air quality measurements. The background for each hour is assumed to be an average of hourly concentrations measured at sites outside of a 90° sector downwind of the source. The 1-hour concentrations are then averaged to obtain the background concentration for the averaging time of concern.

If air quality data from a local monitoring network are not available, then monitored data from a "regional" site may be used for the

second option. Such a site should characterize air quality across a broad area, including that in which the source is located. The technique of characterizing meteorological conditions and determining associated background concentrations can then be employed.

If a small number of other identifiable sources are located nearby, the impact of these sources should be specifically determined. The background concentration due to natural or distant sources can be determined using procedures already described. The impact of the nearby sources must be summed for locations where interactions between the effluents of the point source under consideration and those of nearby sources can occur. Significant locations include (1) the area of maximum impact of the point source, (2) the area of maximum impact of nearby sources, and (3) the area where all sources combine to cause maximum impact. It may be necessary to identify these locations through a trial and error analysis.

If the point source is located in or near an urban multi-source area, there are several possibilities for estimating the impact of all other sources. If a comprehensive air monitoring network is available, it may be possible to rely entirely on the measured data. It is necessary that the network include monitors judiciously located so as to measure air quality at the locations of the point source's maximum impact and locations of the highest concentrations in the area. If the point source is not yet operating, its calculated impact can be added to these measured concentrations. If the source already exists and is contributing to the measured concentrations, its calculated contribution

should be subtracted from the measured values to estimate the concentration caused by other man-made sources and by background.

If the monitored data are inadequate for such an analysis, then multi-source models can be used to establish the impact of all other sources. These models should be used for appropriate pollutants and averaging times to identify concentrations at the times and locations of maximum point source impact. The times and locations of maximum impact due to all other sources must also be identified. If a model is not available for the appropriate averaging times, statistical techniques can be used with an appropriate model to extrapolate from one averaging time to another. All statements in this guide regarding the data requirements and validity of air quality models are applicable to analyses of this type.

For control strategy evaluations, the impact of growth on area-wide emissions and on concentrations caused by nearby sources should also be considered for the next 10-20 year period. To determine concentrations in future years, existing air quality should be proportionately adjusted by the anticipated percent change in emissions in the vicinity of individual monitoring sites. However, for new source reviews, changes in existing air quality should only be considered for the period prior to the start-up date of the source (see Section 5.1).

## 6.0 MODEL VALIDATION/CALIBRATION

Any application of an air quality model may have deficiencies which cause estimated concentrations to be in error. When practical to obtain a measure of confidence in the estimates, they should be compared with observed air quality data and their validity determined.

The model validation process* consists of a series of analytical steps: (1) Comparing estimated concentrations with observed values, (2) determining the cause of discrepancies, (3) correcting and improving data bases, (4) modifying the model (if necessary) in a manner that provides a better mathematical representation of physical reality, and (5) documenting, for others, the accuracy of the estimates. Statistical methods available for validation of models include skill scores, contingency tables, correlation analyses, time series and spatial analyses, and others. If evaluation by one or more statistical techniques indicates that the concentration estimates are not a satisfactory representation of observed concentrations, then it is likely that one or both of the following problems exist: the source, meteorological or air quality data are not appropriate, reliable and complete; or the model itself is inadequate for the area under consideration.

The availability and accuracy of the input data significantly influence the accuracy of the model estimates. The source factors

*There is a clear need for specific and uniform validation procedures and for standards of performance. The feasibility of specifying such procedures and standards for air quality models is being studied by EPA. However, for the present time, the generalized recommendations presented in this section are suggested for use.

that have the greatest impact on the accuracy of the estimates are the accuracy and completeness of the (1) emissions data, (2) physical plant parameters, and (3) site coordinates of the sources. Often the validation will reveal deficiencies in the emissions inventory, which can be corrected to improve the accuracy of the model estimates. The accuracy of the concentration estimates is also affected by the location and exposure of the instrumentation used for obtaining the meteorological data and the overall representativeness and completeness of those data. Similarly, the validation of the dispersion model is affected by the location, exposure and representativeness of the air quality sampling sites and by the accuracy and completeness of the air quality data itself. These data should be available for the same averaging times as the concentration estimates and should describe the spatial variation of pollutant concentrations across the area. If the air quality data are in any way unsuitable or incorrect, the accuracy of the dispersion model estimates cannot be determined.

The following factors most frequently cause a model to be considered inadequate or inappropriate for a given area: (1) The model is applied to an area with complex or unique terrain or meteorological conditions; (2) the source emissions vary markedly or irregularly with time; (3) the pollutant is subject to major or highly variable atmospheric chemical reactions or removal processes; (4) the model is applied to pollutants with characteristics other than those considered in its development. If any of these circumstances are encountered, it may be necessary to select a more appropriate model or appropriately modify the model being used.

When any analytical technique is employed, the analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the procedure. Thus, in all applications of models an effort should be made to identify the reliability of the model estimates for that particular area or similar areas and to determine the magnitude and sources of error associated with the use of the model. In addition, sensitivity analyses are useful for determining the effect of variations or uncertainties in the data bases on the range of likely concentrations. Such information may be very useful in determining source impact and evaluating control strategies. Where possible, information on sensitivity should be made available by the modeler.

Due to limitations of the data base, lack of scientific knowledge or limitations on time and resources, it may not always be possible to perform a thorough and complete model validation. Thus, in some situations, it has been necessary to revert to calibration of the model. Calibration of a model is the process of identifying systematic errors and applying a correction factor. In many cases this involves the application of regression analysis or other statistical techniques to adjust model estimates in order to increase agreement with measured data.

Calibration of long-term multi-source models is a widely used procedure. It is acceptable provided that reasonable resources have been expended to validate the model, e.g., the five steps listed at the beginning of this section. Limitations imposed by statistical

theory on the reliability of the calibration process for long-term estimates have been identified.[42] In some cases, though, calibration may be the only alternative for improving the accuracy of estimated concentrations and the control strategy evaluation. However, if the model accounts for less than 50 percent of the variation of measured concentrations, it is doubtful that there is justification for using the model.

Calibration of short-term models has not been widely performed and is subject to a greater amount of error and misunderstanding. There have been attempts by some to compare short-term estimates and measurements on an event-by-event basis and then to calibrate the model with results of the comparison. This approach is severely limited by uncertainties in source and meteorological data and thus one's ability to precisely estimate the concentration at an exact location for a specific increment of time. These uncertainties make attempts to calibrate a short-term model questionable. As a result, it appears that the most reliable direct comparison between estimated and measured short-term concentrations involves the upper percentiles of the respective frequency distributions. Even here, considerable variation may be found from site-to-site and plant-to-plant. In such comparisons[43,44] for one basic Gaussian point source model it was found that short-term estimates of highest concentrations are generally accurate within a factor of two. This accuracy is consistent with the empirical basis[45,46] for these models. However, in general, estimates which are both too high and too low may be expected.

## 7.0 REFERENCES*


1. National Air Pollution Control Administration. "Guidelines for the Development of Air Quality Standards and Implementation Plans." DHEW, Public Health Service, Washington, D. C., May 1969.

2. U. S. Congress. "Clean Air Act Amendments of 1977." Public Law 95-95, Government Printing Office, Washington, D. C., August 1977.

3. Environmental Protection Agency. "Guidelines for Interpretation of Air Quality Standards." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, September 1976.

4. Environmental Protection Agency. "Guidelines for Evaluating Supplementary Control Systems." Publication No. EPA-450/2-76-003, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1976.

5. Environmental Protection Agency. "Technique for Supplementary Control System Reliability Analysis and Upgrading." Publication No. EPA-450/2-76-015, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, March 1976.

6. Lamb, D. V., F. I. Badgley, and A. T. Rossano. "A Critical Review of Mathematical Diffusion Modeling Techniques for Air Quality with Relation to Motor Vehicle Transportation." A study prepared for the Washington State Highway Commission, Department of Highways, University of Washington, Seattle, Washington, June 1973.

7. Moses, H. "Mathematical Urban Air Pollution Model." Report No. ANL/ES-RPY-001, Argonne National Laboratory, Argonne, Illinois April 1969.

8. Stern, A. C. "Proceedings of Symposium of Multiple-Source Urban Diffusion Models." Air Pollution Control Office Publication No. AP-86 (NTIS PB 198400), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1970.

9. Slade, D. H., Ed. Meteorology and Atomic Energy 1968. USAEC. Division of Technical Information Extension, Oak Ridge, Tennessee, July 1968.

10. Smith, M. E., Ed. "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents." The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, New York, 1973. (Revised)


*All references with a "PB" number are available from the National Technical Information Service, Springfield, Virginia 22151.

11. Turner, D. B. "Workbook of Atmospheric Dispersion Estimates." PHS Publication No. 999-AP-26 (NTIS PB 191482), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1969.

12. Environmental Protection Agency. "User's Network for Applied Modeling of Air Pollution (UNAMAP)." (Computer Programs on Tape for Point Source Models, HIWAY, Climatological Dispersion Model and APRAC-1A), NTIS PB 229771, National Technical Information Service, Springfield, Virginia, 1974.

13. Pooler, F. "Potential Dispersion of Plumes from Large Power Plants." PHS Publication No. 999-AP-16 (NTIS PB 168790). Superintendent of Documents, Government Printing Office, Washington, D. C., 1965.

14. Carpenter, S. B., et al. "Principle Plume Dispersion Models: TVA Power Plants." J. Air Poll. Control Assn., Vol. 22, No. 8, pp. 491-495, 1971.

15. Lyons, W. A. "Turbulent Diffusion and Pollutant Transport in Shoreline Environments." Lectures on Air Pollution and Environmental Impact Analyses, American Meteorological Society, Boston, Massachusetts, September 1975.

16. Huber, A. H., and W. H. Snyder. "Stack Placement in the Lee of a Mountain Ridge: A Wind Tunnel Study." Publication No. EPA-600/4-76-047 (NTIS PB 259877), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1976.

17. Huber, A. H., and W. H. Snyder. "Building Wake Effects on Short Stack Effluents." Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, American Meteorological Society, Boston, Massachusetts, September 1976.

18. Briggs, G. A. "Diffusion Estimation for Small Emissions." ATDL Contribution File No. (Draft) 79, Air Resources Atmospheric Turbulence and Diffusion Laboratory, Oak Ridge, Tennessee, May 1973.

19. Heffter, J. L. and G. A. Ferber. "A Regional-Continental Scale Transport Diffusion and Deposition Model." NOAA Technical Memorandum ERL ARL-50, Air Resources Laboratories, NOAA, Silver Spring, Maryland, June 1975.

20. Rao, K. S., J. S. Lague, and B. A. Egan. "An Air Trajectory Model for Regional Transport of Atmospheric Sulfates." Third Symposium on Atmospheric Turbulence, Diffusion and Air Quality, American Meteorological Society, Boston, Massachusetts, September 1976.

21. Scriven, R. A., and B. E. A. Fisher. "The Long Range Transport of Airborne Material and Its Removal by Deposition and Washout. Atmospheric Environment, Vol. 9, pp. 49-68, 1975.

22. Hales, J. M., D. C. Powell, and T. D. Fox. "STRAM - An Air Pollution Model Incorporating Nonlinear Chemistry, Variable Trajectories, and Plume Segment Diffusion." Publication No. EPA 450/3-77-012 (NTIS PB 270778/AS). Environmental Protection Agency, Research Triangle Park, North Carolina 27711, April 1977.

23. Burt, E. "Valley Model User's Guide." Publication No. EPA-450/2-77-018, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1977.

24. Egan, B. A. "Turbulent Diffusion in Complex Terrain" Lectures on Air Pollution and Environmental Impact Analyses, American Meteorological Society, Boston, Massachusetts, September 1975.

25. Budney, L. J. "Procedures for Evaluating Air Quality Impact of New Stationary Sources." Guidelines for Air Quality Maintenance Planning and Analysis, Volume 10 (OAQPS No. 1.2-029R), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, October 1977.

26. Environmental Protection Agency. "User's Manual for Single Source (CRSTER) Model." Publication No. EPA-450/2-77-013 (NTIS PB 271360) Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, July 1977.

27. de Nevers, N., and J. R. Morris. "Rollback Modeling: Basic and Modified," J. Air Pollution Control Assn., Vol. 25, No. 9, pp. 943-947, 1975.

28. Busse, A. D., and J. R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.

29. Brubaker, K. L., P. Brown, and R. R. Cirillo. "Addendum to User's Guide for Climatological Dispersion Model." Publication No. EPA-450/3-77-015. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May 1977.

30. TRW Systems Group. Air Quality Display Model." Prepared for National Air Pollution Control Administration under Contract No. PH-22-68-60 (NTIS PB 189194), DHEW, U. S. Public Health Service, Washington, D. C., November 1969.

31. Christiansen, J. H., and R. A. Porter. "User's Guide to the Texas Climatological Model." Texas Air Control Board, Austin, Texas, May 1976.

32. Turner, D. B., and J. H. Novak. "User's Guide for RAM." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1977.

33. Christiansen, J. H. "Users Guide to the Texas Episodic Model." Texas Air Control Board, Austin, Texas, May 1976.

34. Larsen, R. I. "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards." Office of Air Programs Publication No. AP-89 (NTIS PB 205277), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, November 1971.

35. Environmental Protection Agency. "Guidelines for the Review of the Impact of Indirect Sources on Ambient Air Quality," Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9, OAQPS No. 1.2-028, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1975.

36. Zimmerman, J. R., and R. S. Thompson. "User's Guide for HIWAY: A Highway Air Pollution Model." Publication No. EPA-650/4-74-008 (NTIS PB 239944/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1975.

37. Mancuso, R. L., and F. L. Ludwig. "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program." Publication No. EPA-650/3-73-001 (NTIS PB 213091), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1972.

38. Environmental Protection Agency. "Control Strategy Preparation Manual for Particulate Matter." OAQPS No. 1.2-049, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1977.

39. Richard, G., J. Avery, and T. Baboolal. "An Implementation Plan for Suspended Particulate Matter in the Phoenix Area: Volume III Model Simulation of Total Suspended Particulate Levels." Publication No. EPA-450/3-77-021c, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, August 1977.

40. Doty, S. R., B. L. Wallace, and G. C. Holzworth. "A Climatological Analysis of Pasquill Stability Categories Based on 'STAR' Summaries." National Climatic Center, National Oceanic and Atmospheric Administration, Asheville, North Carolina 28801, April 1976.

41. McCormick, R. A. "Air Pollution Climatology." In Air Pollution Volume 1, edited by A. Stern, Academic Press, New York, New York, 1968.

42. Brier, G. W. "Validity of the Air Quality Display Model Calibration Procedure." Publication No. EPA-R4-73-017, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, January 1973.

43. Mills, M. T., and F. A. Record. "Comprehensive Analysis of Time-Concentration Relationships and Validation of a Single-Source Dispersion Model." Publication No. EPA-450/3-75-083 (NTIS PB 250814/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, March 1975.

44. Mills, M. T., and R. W. Stern. "Model Validation and Time-Concentration Analysis of Three Power Plants." Publication No. EPA-450/3-76-002 (NTIS PB 250685/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1975.

45. Pasquill, F. Atmospheric Diffusion, 2nd ed., John Wiley and Sons, New York, New York, 1974.

46. Weber, A. H. "Atmospheric Dispersion Parameters in Gaussian Plume Modeling: Part I. Review of Current Systems and Possible Future Developments." Publication No. EPA-600/4-76-030a, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, July 1976.

## Glossary of Selected Terms

Air Quality - Ambient pollutant concentrations and their temporal and spatial distributions.

Algorithm - A specific mathematical calculation procedure.

Background - Ambient pollutant concentrations due to natural sources and distant, unidentified man-made sources.

Calibration - An adjustment applied to concentration estimates, based on a comparison with measured air quality data, in order to improve the accuracy of the model.

Computer code - A set of statements that comprise a computer program.

Model - A quantitative or mathematical representation or simulation which attempts to describe the characteristics or relationships of physical events.

Receptor - A location at which ambient air quality is measured or estimated.

Rollback - A simple model that assumes that if emissions from each source affecting a given receptor are decreased by the same percentage, ambient air quality concentrations decrease proportionately.

Screening Procedure - A relatively simple analysis technique to determine if a given source is likely to pose a threat to air quality.

Validation - Determination of the reliability of a model by comparing the model estimates with measured air quality data.

# Appendix A

## Significant Air Quality Increment for Non-Attainment Areas

Appendix A

Significant Air Quality Increments

for Non-Attainment Areas

A new major source of sulfur dioxide ($SO_2$), particulate matter (PM), nitrogen oxides ($NO_2$*) or carbon monoxide (CO) located in an attainment area may cause or exacerbate a known existing air quality violation in a nearby nonattainment area. In this case it is necessary to determine if the air quality impact of the source is significant. The incremental increase in concentration at the location of a violation may be considered significant if it is greater than the following concentrations:

| Pollutant | Averaging Time | | | | |
|---|---|---|---|---|---|
| | Annual | 24-Hour | 8-Hour | 3-Hour | 1-Hour |
| $SO_2$ | 1 $\mu g/m^3$ | 5 $\mu g/m^3$ | | 25 $\mu g/m^3$ | |
| PM | 1 $\mu g/m^3$ | 5 $\mu g/m^3$ | | | |
| $NO_2$ | 1 $\mu g/m^3$ | | | | |
| CO | | | 0.5 $mg/m^3$ | | 2 $mg/m^3$ |

These incremental concentrations of $SO_2$, PM and $NO_2$ are partially based on allowable $SO_2$ increments for Class I areas. However, the annual concentration increment is reduced to 1 $\mu g/m^3$ since this value may be considered significant for a point source in an area which exceeds the NAAQS. The increments for CO are based on concentrations which are

*For simplicity, all emissions of nitrogen oxides are treated as if they are nitrogen dioxide ($NO_2$); see Section 4.3.5.

5 percent of the CO NAAQS. All of these increments apply to the highest estimated concentration for all averaging times. The second highest is not used since the incremental increase in concentration is added to a concentration which is already based on the highest, second-highest concentration.

# Appendix B

## Summaries[1] of Recommended Air Quality Models

[1] Summaries presented in this appendix are largely based on similar information summarized by J. J. Roberts (Ed.) in "Report to the U.S. EPA of the Specialists' Conference on the EPA Modeling Guidelines," Environmental Protection Agency, Research Triangle Park, North Carolina 27711, February 1977.

## B.1 AIR QUALITY DISPLAY MODEL (AQDM)

Reference: TRW Systems Group. "Air Quality Display Model." Prepared for National Air Pollution Control Administration, DHEW, U.S. Public Health Service, Washington, D.C., November 1969, (NTIS PB 189194).

Abstract: AQDM is a climatological steady state Gaussian plume model that estimates annual arithmetic average sulfur dioxide and particulate concentrations at ground level in urban areas. A statistical model based on Larsen[1] is used to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

For both point and area sources:

$$\chi = \sum_{k=1}^{16} \sum_{\ell=1}^{6} \sum_{m=1}^{5} \phi_{k\ell m} \chi_{k\ell m}$$

where:

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{2Q}{\sqrt{2\pi}\,\sigma_z\, u_\ell} \left(\frac{c-y}{c}\right) \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad \text{for } x \leq x_L$$

$$\chi_{k\ell m} = \frac{16}{2\pi x} \cdot \frac{Q}{u_\ell L} \left(\frac{c-y}{c}\right) \quad \text{for } x \geq 2x_L$$

linear interpolation for $x_L < x < 2x_L$

$x_L$ defined by $\sigma_z(x_L) = 0.47L$

y = crosswind distance between receptor and sector k centerline

c = sector width at receptor location

$\sigma_z(x) = ax^b + c$; a,b,c = functions of stability class a,b,c for neutral conditions split into $x > 1000$m case and $x \leq 1000$m case.

$Q$ = emission rate (g/s)

$H$ = plume height (m)

$u$ = wind speed (m/s)

$\phi$ = relative frequency of occurrence from stability wind rose

$\sigma_z$ = vertical standard deviation of plume concentrations (m)

$x$ = downwind distance (m)

a. Source-Receptor Relationship

Arbitrary location and stack height for each point source
Arbitrary location and size for each area source
Up to 225 receptors located on uniform rectangular grid
Up to 12 user-specified receptor locations
Unique release height for each point, area source
Unique separation for each source-receptor pair
Receptors at ground level
No terrain differences between source and receptor

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
Each source treated by effective single point source approximation
No temporal variation allowed

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Holland[2] formula for point sources, with adjustment for stability
Calculations based on single arbitrary values of stack diameter, stack gas exit velocity and stack gas temperature for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash
If stack height plus plume rise is greater than mixing height, ground level concentration assumed equal to zero

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
No variation in wind speed with height
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Climatological approach
Uniform 22.5° wide plume assumed
Frequency of occurrence interpolated between sector centerlines
Averaging times from 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[3]
Neutral stability split internally into 60% day, 40% night
Dispersion coefficients from Pasquill and Gifford
Neutral dispersion coefficients used for stable class
No provision for variations in surface roughness

i. Chemistry/Reaction Mechanism

No provision for treatment

j. Physical Removal

No provision for treatment

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): perfect reflection
Upper boundary (mixing height): no effect until $\sigma_z \geq 0.47L$ (this occurs at $x = x_L$) For $x_L < x < 2x_L$, $\sigma_z$ is linearly interpolated between its value at $x_L$ and its value at $2x_L$

m. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Emission rate - not correlated with any other factor
Non-sequential (climatological) limited correlation
Mixing height adjusted according to stability class:
  Class A - 1.5 times the afternoon climatological value
  Classes B, C, and D(day) - equal to the afternoon climatological value
  Class E - 100 meters

n. Validation/Calibration

Calibration option available
Substantial experience but limited documentation

o. Output

1 month to 1 year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen procedure (typically 1 - 24 hours)
  Assumes
  (1) lognormal concentration distribution,
  (2) power law dependence of median and maximum concentrations on averaging time
Up to 225 gridded receptor locations, 12 arbitrary locations
Individual point, area source culpability list for each receptor

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Useable for urban areas only

## B.2 APRAC-1A

Reference: Mancuso, R. L. and F. L. Ludwig. "User's Manual for the APRAC-1A Urban Diffusion Model Computer Program." Publication No. EPA-650/3-73-001 (NTIS PB 213091), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, September 1972.

Abstract: APRAC is a model which computes hourly average carbon monoxide concentrations for any urban location. The model calculates contributions from dispersion on various scales: extraurban, mainly from sources upwind of the city of interest; intraurban, from freeway, arterial, and feeder street sources; and local, from dispersion within a street canyon. APRAC requires an extensive traffic inventory for the city of interest.

Equations:

$$\text{Extraurban - } \chi_e = \frac{5.15 \times 10^{-11} F}{uL}$$

F = annual fuel consumption within 22.5° sector extending from 32 km to 1000 km upwind of receptor.

$$\text{Intraurban - } \chi_{ij} = \frac{0.8 Q_i}{u\, a_{ij}} \quad \frac{x_{i+1}^{1-b_{ij}} - x_i^{1-b_{ij}}}{1-b_{ij}}$$

Until this expression equals the "box model value"

$$\frac{Q_i}{uL}(x_{i+1} - x_i)$$

Thereafter the box model formula is used.
i = upwind area segment label
j = stability class label
$a_{ij}$ and $b_{ij}$ from $(\sigma_z)_{ij} = a_{ij} x^{b_{ij}}$ for x within segment i

$$\text{Street Canyon - Lee side } \chi_L = \frac{KQ_s}{(u+0.5)[(x^2+z^2)^{1/2} + L_o]}$$

$$\text{Windward side } \chi_w = \frac{KQ_s(H-z)}{(u+0.5)\, WH}$$

Intermediate wind direction(less than $\pm$ 30° from street (direction)

$$x_L = \frac{1}{2}(x_L + x_W)$$

where:

x = horizontal distance from traffic lane (m)

z = height above pavement (m)

K = constant ≈ 7

$L_o$ = vehicle size ≈ 2m

u = rooftop wind speed (m/s)

$Q_s$ = CO emission rate (g/s-m)

W = Street width (m)

H = average building height ≈ 38.8 m

a. Source-Receptor Relationship

User specifies set of traffic links (line sources) by providing link end points, road type, daily traffic volume
The traffic links may have arbitrary length and orientation
Off-link traffic allocated to two mile square grid
Link traffic emissions are aggregated into a receptor oriented area source array
The boundaries of the area sources actually treated are (1) arcs at radial distances from the receptor which increase in geometric progression, (2) the sides of a 22.5° sector oriented upwind for distances greater than 1000 m, and (3) the sides of a 45° sector oriented upwind for distances less than 1000 m.
A similar area source array is established for each receptor
Sources assumed at ground level
Up to 10 receptors
Receptors at ground level
Receptor locations are arbitrary
Four internally defined receptor locations on each user-designated street are used in a special street canyon sub-model

b. Emission Rate

Daily traffic volume for each link and off-link grid square is input and modified by various factors to produce hour-by-hour emissions from each link
Link emissions aggregated as described above: sector area source contributions obtained analytically
Off-link traffic emissions on the two mile square grid are added into sector area sources
In street canyon sub-model, a separate hourly emission rate is provided by user for the link in question

c. Chemical Composition

Treats one inert pollutant

d. Plume Behavior

Does not treat plume rise
Does not treat fumigation or downwash except in street canyon sub-model
In street canyon sub-model, a helical circulation pattern is assumed

e. Horizontal Wind Field

Hourly wind speed and direction in tens of degrees are input
No variation of wind speed or direction with height
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero except in street canyon sub-model
Helical circulation assumed by street canyon sub-model

g. Horizontal Dispersion

Sector averaging uniform distribution within sectors
22.5° sectors beyond 1 km
45.0° sectors within 1 km

h. Vertical Dispersion

Semi-empirical/Gaussian plume
6 stability classes; stability class determined internally from user-supplied meteorological data [modified from Turner[3]]
Dispersion coefficients from McElroy and Pooler[4], modified using information in Leighton and Ditmar[5]
No adjustments made for variations in surface roughness
Downwind distance variation of $\sigma_z$ assumed to be $ax^b$ for purposes of doing analytic integration
In street canyon sub-model, empirical function of wind speed and street width and direction is used

i. Chemistry/Reaction Mechanism

Single inert pollutant

j. Physical Removal

Not treated

k. Background

Box model used to estimate contribution from upwind sources beyond 32 km based on wind speed, mixing height, annual fuel consumption
In street canyon sub-model, contribution from other streets is included in background

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection; ignores effect until concentration equals that calculated using box model; uses box model (uniform vertical distribution) thereafter
Mixing height determined from morning radiosonde data as follows:
midnight to dawn: constant at pre-dawn value obtained using minimum urban temperature
dawn to sunset: afternoon maximum temperature used to obtain maximum height; hourly values obtained from surface temperature variations
sunset to midnight: linear interpolation with time

m. Emission and Meteorological Correlation

Emissions a function of hour of the day and day of the week
Meteorological parameters are functions of hour of the day

n. Validation/Calibration

No calibration option provided
Some documented validation experience available

o. Output

Hourly concentration values at each receptor
Frequency distribution based on hourly values can be obtained

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Limited to urban areas
No means for including point sources

## B.3 CLIMATOLOGICAL DISPERSION MODEL (CDM)

References: Busse, A. D. and J. R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.

Brubaker, K. L., P. Brown, and R. R. Cirillo. "Addendum to User's Guide for Climatological Dispersion Model." Publication No. EPA-450/3-77-015, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, May 1977.

Abstract: CDM is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground-level receptor in an urban area. An expanded version (CDMQC) includes a statistical model based on Larsen[1] to transform the average concentration data from a limited number of receptors into expected geometric mean and maximum concentration values for several different averaging times.

Equations:

$$\chi_{point} = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{\ell=1}^{6} \sum_{m=1}^{6} Q_n \, \theta_{kn\ell m} \, S_{\ell m} \, (\rho_n)/\rho_n$$

$$\chi_{area} = \frac{16}{2\pi} \int \left[ \sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi_{k\ell m} \, S_{\ell m}(\rho) \right] d\rho$$

$$\text{with } q_k(\rho) = \int_{\text{sector } k} Q(\rho,\theta) d\theta$$

$$S_{\ell m}(\rho) = \frac{2}{\sqrt{2\pi}\, \sigma_z \, u_\ell} \exp\left[ -\frac{1}{2} \left(\frac{H}{\sigma_z}\right)^2 \right] \exp\left[ -\frac{0.692\, \rho}{u_\ell \, T_{1/2}} \right]$$

$$\text{for } \sigma_z \leq 0.8L$$

$$S_{\ell m}(\rho) = \frac{1}{u_\ell L} \exp\left[-\frac{0.692\ \rho}{u_\ell\ T_{1/2}}\right] \text{ for } \sigma_z > 0.8L$$

$\sigma_z = a\rho^b$; a,b = functions of stability class (m) and downwind distance ($\rho$) - three ranges of distance used: 100-500 m, 500-5000 m, and 5000-50,000 m

$k_n$ = wind sector appropriate to the $n^{th}$ point source

$Q_n$ = emission rate of the $n^{th}$ point source (g/s)

$\rho_n$ = distance from the receptor to the $n^{th}$ point source (m)

$q_k$ = emission rate of the area source per unit area and unit time ($g/s\text{-}m^2$)

$\rho$ = distance from the receptor to an infinitesimal area source (m)

$\theta$ = angle relative to polar coordinates centered on the receptor

$\ell$ = index identifying the wind speed class

m = index identifying the class of the Pasquill stability category

$\phi(k,\ell,m)$ = joint frequency function

z = height of receptor above ground level (m)

$u_\ell$ = representative wind speed (m/s)

h = effective stack height of source distribution, i.e., the average height of area source emissions in the $k^{th}$ wind direction sector at radial distance $\rho$ from the receptor (m)

L = the afternoon mixing height (m)

$T_{1/2}$ = assumed half life of pollutant hours (s)

a. Source-Receptor Relationship

Arbitrary location for each point source
Area sources equal uniform grid squares
Receptor location arbitrary
Arbitrary release heights for point and area sources
Unique separation for each source-receptor pair
Receptors are at ground level
No terrain differences between source/receptor

b. Emission Rate

Point sources: single rate for each source
Area sources: single rate for each source
area integrations are done numerically one 22.5° sector at a time; sampling at discrete points defined by specific radial and angular intervals on a polar grid centered on the receptor
Day/night variations in emissions, same variation assumed for all sources

c. Chemical Composition

Treats one or two inert pollutants simultaneously

d. Plume Behavior

Only Briggs neutral/unstable formula used for point sources
If stack height plus plume rise is greater than mixing height, ground level concentrations assumed equal to zero
Alternative to Briggs - input value of plume rise times wind speed for each point source
No plume rise calculated for area sources
Does not treat fumigation or downwash

e. Horizontal Wind Field

Climatological approach
16 wind directions
6 wind speed classes
Wind speed corrected for release height based on power law variation exponents from DeMarrais[6]
Constant, uniform (steady-state) wind assumed

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Climatological approach
Uniform distribution within each of 16 sectors
Averaging time = 1 month to 1 year or longer

h. Vertical Dispersion

Semi-empirical/Gaussian plume
5 stability classes as defined by Turner[3]
Neutral stability split into day/night cases on input
Dispersion coefficients taken from Turner[7]
Area sources - stability class is decreased by 1 category from input values (to account for urban effects)
Neutral dispersion coefficients are used for stable classes
No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half life

j. Physical Removal

Exponential decay, user-input half life
Always applies the same rate constant

k. Background

Input single constant background value for each pollutant

l. Boundary Conditions

Lower boundary (ground): assumes perfect reflection
Upper boundary (mixing height): no effect until dispersion coefficient equals 0.8 of the mixintg height, uniform vertical mixing assumed beyond this point

m. Emission and Meteorological Correlation

Wind speed, direction, stability correlated via wind rose
Mixing height is adjusted according to stability class:
  Class A - 1.5 times afternoon climatological value
  Classes B, C, and D(day) - equal to the afternoon climatological value
  Class D(night) - average of morning and afternoon climatological value
  Class E - morning climatological value
Emission rates: day-night allowed; all sources vary by same factor
Non-sequential (climatological) limited correlation

n. Validation/Calibration

Limited validation experience
Calibration option available (CDMQC)

o. Output

One month to one-year averaging time simulated (arithmetic mean only)
Arbitrary averaging time by Larsen[1] procedure (typically 1 - 24 hr.) (CDMQC)
Assumes
(1) lognormal concentration distribution,
(2) power law dependence of median and maximum concentrations on averaging time
Arbitrary number and location of receptors
Individual point, area source culpability list for each receptor (CDMQC)
Point, area concentration rose for each receptor

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Useable for urban areas only
Area source emission densities must not vary rapidly from one area source to the next

## B.4 REAL-TIME AIR QUALITY SIMULATION MODEL (RAM)

Reference: Turner, D. B., and J. H. Novak. "User's Guide for RAM." Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1977.

Abstract: RAM is a steady state Gaussian plume model for estimating concentrations of relatively stable pollutants for averaging times from an hour to a day from point and area sources. Level or gently rolling terrain is assumed. Calculations are performed for each hour. Both rural and urban versions are available.

Equations:

Contribution from single upwind area source

$$\chi_A = \frac{q}{u} \int_{x_1}^{x_2} f \, dx \qquad \text{integral evaluated numerically}$$

$x_1$, $x_2$ = points of intersection of ray from receptor through area source in question

$q$ = emission rate per unit area of the area source ($g/s\text{-}m^2$)

$u$ = mean wind speed (m/s)

For stable conditions: $f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_2$

$$\chi_{point} = \frac{Q}{2\pi u\,\sigma_y\,\sigma_z} g_1 g_2$$

For neutral or unstable conditions, $\sigma_z \leq 1.6L$

$$f = \frac{1}{\sqrt{2\pi}\,\sigma_z} g_3$$

$$\chi_{point} = \frac{Q}{2\pi u\,\sigma_y\,\sigma_z} g_1 g_3$$

For neutral or unstable conditions, $\sigma_z > 1.6L$

$$f = \frac{1}{L}$$

$$\chi_{point} = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y} g_1$$

In which

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_2 = \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \left\{\exp\left[-\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H+2nL}{\sigma_z}\right)^2\right]\right\}$$

a. Source-Receptor Relationship

Arbitrary location for point sources
Receptors may be
(1) arbitrarily located
(2) internally located near individual source maxima
(3) on a program-generated hexagonal grid to give good coverage to a user-specified portion of the region of interest
Receptors all at same height above (or at) ground
Flat terrain assumed
Unique stack height for each point source
User may specify up to three effective release heights for area sources, each assumed appropriate for a 5 m/sec wind speed. Value used for any given area source must be one of these three
Unique separation for each source-receptor pair

b. Emission Rate

Unique, constant emission rate for each point, area source
Area source treatment-
  Narrow plume approximation
  Area source used as input; not subdivided into uniform elements
  Arbitrary emission heights input by user
  Areas must be squares; side lengths = integer multiples of a basic unit
  Effective emission height = that appropriate for 5 m/s wind
  Area source contributions obtained by numerical integration along upwind distance of narrow-plume approximation formulae for contribution from area source with given effective release height

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8,9,10] plume rise formulas
Does not treat fumigations or downwash
If plume height exceeds mixing height, ground level concentration is assumed zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, exponents from DeMarrais[6]; different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally by Turner[3] procedure, six classes used
Dispersion coefficients from McElroy and Pooler[4] (urban) or Turner[7] (rural). No further adjustments made for variations in surface roughness or transport time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
Hourly stability class determined internally
Dispersion coefficients from McElroy and Pooler[4] (urban) or Turner[7] (rural). No further adjustments made for variations in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay, user-input half-life

j. Physical Removal

Exponential decay, user-input half-life

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: perfect reflection
Neutral and unstable conditions
Multiple reflections numerically accounted for by summation of series until $\sigma_z$ = 1.6 times mixing height
Uniform mixing assumed in vertical thereafter
Stable conditions: ignore effect of upper boundary
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day
Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, wind direction, mixing height and other meteorological variables required for determination of stability class and plume rise

n. Validation/Calibration

No calibration option provided
No documented validation or comparison with observational data

o. Output

Hourly and average (up to 24 hours) concentrations at each receptor
Limited individual source contribution list
Cumulative frequency distribution based on 24-hour averages and up to 1 year of data at a limited number of receptors

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat or gently rolling terrain

## B.5 SINGLE SOURCE (CRSTER) MODEL

Reference: Environmental Protection Agency. "User's Manual for Single Source (CRSTER) Model." Publication No. EPA-450/2-77-013 (NTIS PB 271360). Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711, July 1977.

Abstract: CRSTER is a steady state Gaussian plume technique applicable to both rural and urban areas in uneven terrain. The purpose of the technique is: (1) to determine the maximum concentrations, for certain averaging times between 1-hour and 24-hours, over a one year period due to a single point source of up to 19 stacks, (2) to determine the meteorological conditions which cause the maximum concentrations, and (3) to store concentration information useful in calculating frequency distributions for various averaging times. The concentration for each hour of the year is calculated and midnight - to - midnight averages are determined for each 24-hour period.

Equations:

$$\chi = \frac{Q}{2\pi u\, \sigma_y\, \sigma_z}\, g_1\, g_3 \qquad \text{for } \sigma_z \leq 1.6L$$

$$\chi = \frac{Q}{\sqrt{2\pi}\, uL\, \sigma_y}\, g_1 \qquad \text{for } \sigma_z > 1.6L$$

$\chi = 0$ (stability class 7)

$L$ = mixing height (m)

$H$ = (stack height + plume rise)-(difference in elevation between receptor and base of stack) (m)

$$g_1 = \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$g_3 = \sum_{n=-\infty}^{+\infty} \exp\left\{\left[-\frac{1}{2}\left(\frac{2nL-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{2nL+H}{\sigma_z}\right)^2\right]\right\}$$

a. Source-Receptor Relationship

Up to 19 point sources, no area sources
All point sources assumed at the same location
Unique stack height for each source
Receptor locations restricted to 36 azimuths (every 10°) and 5 user-specified radial distances
Unique topographic elevation for each receptor; must be below top of stack

b. Emission Rate

Unique average emission rate for each source
Monthly variation in emission rate allowed

c. Chemical Composition

Treats a single inert pollutant

d. Plume Behavior

Briggs[8,9,10] final plume rise formulas
Does not treat fumigation or downwash
If plume height exceeds mixing height, concentrations further downwind assumed equal to zero

e. Horizontal Wind Field

Uses user-supplied hourly wind speeds
Uses user-supplied hourly wind directions (nearest 10°), internally modified by addition of a random integer value between -4° and +5°
Wind speeds corrected for release height based on power law variation, exponents from DeMarrais[6]; different exponents for different stability classes, reference height = 10 meters
Constant, uniform (steady-state) wind assumed within each hour

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Semi-empirical/Gaussian plume
7 stability classes used; Turner Class 7: extremely stable, elevated plume assumed not to touch the ground
Dispersion coefficients from Turner; no further adjustments made for variations in surface roughness, transport or averaging time

h. Vertical Dispersion

Semi-empirical/Gaussian plume
7 stability classes
Dispersion coefficients from Turner; no further adjustments made

i. Chemistry/Reaction Mechanism

Not treated

j. Physical Removal

Not treated

k. Background

Not treated

l. Boundary Conditions

Lower boundary: perfect reflection at the same height as the receptor
Upper boundary: perfect reflection
Multiple reflections handled by summation of series until $\sigma_z$ = 1.6 x mixing height
Uniform vertical distribution thereafter
Mixing height is constant and follows topographic variations:
Taken from base of stack for determining whether plume punches through
Taken from receptor elevation for determining vertical concentration distribution
Mixing height for a given hour is obtained by suitable interpolation using data from soundings taken twice a day. Interpolation technique dependent on mode of operation (urban or rural) and calculated stability class for the hour in question as well as the stability class for the hour just preceding sunrise.

m. Emission and Meteorological Correlation

User supplies hourly values of wind speed, direction, mixing height and other meteorological variables required for determination of stability class and plume rise
Monthly emission variation allows limited emission - meteorology correlation

n. Validation/Calibration

No calibration option provided
Comparison with observations around at least 5 separate power plants have been made

o. Output

Highest and second highest concentrations for the year at each receptor for averaging times of 1, 3, and 24-hours, plus a user-selected averaging time which may be 2, 4, 6, 8, or 12 hours
Annual arithmetic average at each receptor
For each day, the highest 1-hour and 24-hour concentrations over the receptor field
Hourly concentrations for each receptor on magnetic tape

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Not applicable to area and line sources
Use care when applying to low-level sources

## B.6 TEXAS CLIMATOLOGICAL MODEL

References: Porter, R. A. and Christiansen, J. H.. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House Va., September, 1976.

Christiansen, J. H. and Porter, R. A.. Users Guide to the Texas Climatological Model, Texas Air Control Board, Austin Texas, May, 1976.

Abstract: The TCM is a climatological model that predicts long-term arithmetic mean concentrations of nonreactive pollutants from point sources and area sources.

Equations:

Area sources are handled by an algorithm proposed by Gifford and Hanna[11]. The concentration due to area sources is given by

$$\chi_A = FQ/U$$

where $\chi_A$ = concentration ($\mu g/m^3$)

Q = area source emission rate in the vicinity of the receptor ($\mu g/s\text{-}m^2$)

U = mean ground-level wind speed (m/s)

F = a dimensionless constant

Gifford and Hanna have suggested a value of F = 50 for $SO_2$ and 225 for total suspended particulate (TSP). The area emission rate, Q, is determined by averaging the emissions in the area source square containing the receptor and in the neighboring squares. The extent of the region around each receptor to use for emission rate averaging is an input parameter.

The TCM uses steady-state Gaussian plume point source logic, with the crosswind distribution averaged across 22.5° azimuthal sectors. The only meteorological input required for area source calculations is the mean wind speed, but the point source calculations require a meteorological joint frequency function with sixteen 22.5° wind sectors, six wind speed classes (0-3, 4-6, 7-10, 11-16, 17-21, and > 21 knots), and six stability classes (Turner classes A, B, C, D (day), D (night), and E plus F).

The basic equation is:

$$\chi = Q_i \sum_{m=1}^{6} (K(x,H,m)\phi(k,m)/U_m) \cdot (\text{decay term})$$

where $K(x,H,m) = (32 \times 10^6/[(2\pi)^{3/2} \times \sigma_z]) \exp(-H_i^2/2\sigma_z^2)$

(K is precalculated for 20 distances, 9 effective source heights, and six stability classes)

$$S = (2/[\sqrt{2\pi}\, U_m\, \sigma_z]) \exp(-H_i^2/2\sigma_z^2) \exp(-.692x/[U_m T_{1/2}])$$

$U_m$ is a wind speed characteristic of an entire stability class, and is computed in the model by the equation:

$$U_m = \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi(k,\ell,m)\right] \left[\sum_{k=1}^{16} \sum_{\ell=1}^{6} \phi\,(k,\ell,m)/U_\ell\right]^{-1}$$

with $\chi$ = concentration, $\mu g/m^3$

$k$ = the wind sector index appropriate to source i at the receptor

$\ell$ = wind speed class index

$m$ = stability class index

$\phi$ = meteorological joint frequency function

$Q_i$ = emission rate of source i (g/s)

$H_i$ = effective height of source i (m)

$\sigma_z$ = standard deviation of vertical Gaussian concentration distribution (m)

$T_{1/2}$ = half-life for first-order pollutand decay (s)

$U_\ell$ = central wind speed of class $\ell$ (m/s)

$x$ = downwind distance (m)

a. Source-Receptor Relationship

Arbitrary location for each point source
Unlimited number of sources
Arbitrary location and square grid width for each area source
The model will allocate area sources into a uniform square grid
Receptor location is arbitrary grid (max. 50 x 50)
Release heights for point sources
The area source algorithm (Gifford-Hanna) does not consider height of release
Receptors are at ground level
No terrain difference between sources and receptors

b. Emission Rate

All sources have a single average emission rate for the averaging time period (i.e., month, season, year)

c. Chemical Composition

One, two, or three inert pollutants are treated simultaneously

d. Plume Behavior

Plume rise calculated according to Briggs[9] neutral/unstable equation
Effective stack heights less than 10 meters are considered 10 meters
Effective stack heights greater than 300 meters are considered 300 meters
No plume rise for area sources
Downwash and fumigation not considered

e. Horizontal Wind Field

Climatological approach
16 wind directions
Mean wind speed calculated for each stability class from the joint frequency function of stability, wind direction, and wind speed
Wind speed corrected for physical stack height (same as CDM)

f. Vertical Wind Speed

Assumed equal to zero

g. Horizontal Dispersion

Assumed to be uniform within each 22.5 degree sector (same as CDM)

h. Vertical Dispersion

Gaussian plume
6 stability classes (Pasquill-Gifford-Turner) A, B, C, D-Day, D-Night, E and F
No provision for variation in surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay according to user input half-life (same as CDM)

j. Physical Removal

Same as i above

k. Background

Background may be entered by calibration coefficient for each pollutant

l. Boundary Conditions

Perfect reflection assumed at ground
Mixing height not considered

m. Emission and Meteorological Correlation

Emissions not varied

n. Validation/Correlation

Model is self-calibrating with input of field receptor observations
High correlation achieved of observed to calculated values for Houston TSP 1975, Houston $SO_2$ 1972, Dallas TSP 1972

o. Output

Arithmetic mean concentration for the averaging time of the climatological input and emission data (one month to one year
Any combination of the following outputs are available:
(1) Listing of concentration for an arbitrarily spaced square grid of up to 50 by 50 elements
(2) A print plot of the grid concentrations
(3) Punched card output for isopleth maping (same as CDM)
(4) A listing of the five high contributors to the concen-concentration (by % concentration) at each grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Flat terrain, relatively constant emissions

## B.7 TEXAS EPISODIC MODEL (TEM)

References: Porter, R. A. and Christiansen, J. H. "Two Efficient Gaussian Plume Models Developed at the Texas Air Control Board." Proceedings of the 7th NATO/CCMS International Technical Meeting on Air Pollution Modeling, Airlie House, Va., September, 1976.

Christiansen, J. H. Users Guide to the Texas Episodic Model, Texas Air Control Board, May, 1976.

Abstract: The Texas Episodic Model TEM is a short-term (10 minute to 24 hour averaging time) Gaussian Plume Model for prediction of concentrations of nonreactive pollutants due to up to 300 elevated point sources and up to 200 area sources. Concentrations are calculated for 1 to 24 scenarios of meteorological conditions, averaging time, and mixing height

Equations:

The area source algorithm is due to Gifford and Hanna[11] Each area source square is affected by its own diffuse emissions and those in the N area source squares directly upwind of it:

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

with $\Delta x$ = length of side of area source grid squares (m)

$U_o$ = surface wind speed (m/s)

$Q_o$ = area emission rate of square containing the receptor ($\mu g/s\text{-}m^2$)

$Q_i$ = area emission rates of the upwind area sources ($\mu g/s\text{-}m^2$)

a,b = stability and downwind distance-dependent parameters from the equation $\sigma_z = ax^b$

The TEM employs steady-state bivariate Gaussian plume point source logic. The concentration due to an elevated point source is given by

$$\chi = \frac{10^6\, Q}{\pi \sigma_y\, \sigma_z U} \exp\,(-y^2/2\sigma_y^2)\, \exp\,(-H^2/2\sigma_z^2)\, \exp\,(-.692x/UT_{1/2})$$

where $\chi$ = concentration ($\mu g/m^3$)

$Q$ = emission rate (g/s)

$U$ = wind speed at physical source height (m/s)

$H$ = effective source height (m)

$x$ = downwind distance (m)

$y$ = crosswind distance (m)

$T_{1/2}$ = first-order pollutant decay half-life (s)

$\sigma_y$, $\sigma_z$ = the standard deviations of the plume concentration distribution,

$$\sigma_z = ax^b$$

$$\sigma_y = cx^d$$

with stability and downwind distance-dependent coefficients a, b, c, and d from Busse and Zimmerman[12] and Turner[7]. The wind speed U is the surface wind speed adjusted to the physical source height. Let $K_y$ and $K_z$ be defined by

$$K_y = \frac{1000}{\sigma_y} \exp\,(-y^2/2\sigma_y^2),$$

$$K_z = \frac{1000}{\pi\sigma_z} \exp\,(-H^2/2\sigma_z^2)$$

Then, $$\chi = \frac{K_y K_z Q}{U} \text{ (decay term)}$$

$K_y$ was calculated for each of the 1120 combinations of twenty downwind distances from 2 to 60 km, eight crosswind angles ($Tan^{-1}y/x$) from 0° to 7°, with $\delta$ varying from 1° to 5° depending on stability, and seven stability classes. For total vertical mixing below a mixing height of L meters,

$$\chi = \frac{10^6 Q}{\sqrt{2\pi}\ \sigma_y LU} \exp\ (-y^2/2\sigma_y{}^2)$$

This can be represented in the equation $\chi = \frac{K_y K_z Q}{u}$ (decay term)

by setting $K_z \simeq 398L$

a. Source-Receptor Relationship

Up to 300 arbitrarily located point sources
Up to 200 arbitrarily located area sources
A uniform square receptor grid of arbitrary spacing with up to 50 by 50 rows or columns
Terrain assumed flat
Unique release height for each source
All receptors at ground level

b. Emission Rate

Unique emission rate for each source

c. Chemical Composition

One, two, or three inert pollutants treat simultaneously

d. Plume Behavior

Plume rise according to one of six equations from Briggs selected according to stability and distance from source. Effective stack heights less than 10 meters are considered 10 meters. Effective stack heights greater than 2000 meters are considered 2000 m.
Mixing height penetration factor (P) is a user input. If effective source height (h) is greater than P times the mixing height the plume escapes. Otherwise the .47L mixing scheme from Turner[7] is used.
Does not treat downwash or fumigation

e. Horizontal Wind Field

User supplied stability, wind speed, and direction for the averaging time period (10 minutes to 3 hours) or for each 3 hour period to build a 24-hour day.
Power law variation of wind speed with release height (same as CDM).
Steady state wind for each scenario

f. Vertical Wind Speed

Equal to zero

g. Horizontal Dispersion

Semi-empirical Gaussian plume
User supplied stability class for each scenario (Pasquill-Gifford-Turner)
Turner[7] dispersion coefficients
No adjustment for surface roughness

h. Vertical Dispersion

Semi-empirical Gaussian plume
User supplied stability classes (Pasquill-Gifford-Turner) for each scenario
Turner[7] dispersion coefficients
No adjustment for surface roughness

i. Chemistry/Reaction Mechanism

Exponential decay with user supplied half-life

j. Physical Removal

Same as i above

k. Background

May be input with calibration factor

l. Boundary Conditions

Lower boundary: perfect reflection
Upper boundary: reflection from top of mixed layer by the .47L scheme of Turner[7] except as described in d above

m. Emission/Meteorological Correlation

User supplied values of wind speed, wind direction, stability class, mixing height, ambient temperature for each scenario up to 24 scenarios

n. Validation/Calibration

Limited validation with observed vinyl chloride observations
Calibration by user supplied coefficients (A, B) so that $\chi_{cal} = A + B\chi_{predicted}$

o. Output

Concentration for each receptor grid point for averaging times of:
10 minutes
30 minutes
1 hour
3 hours
24 hours (based on eight 3-hour scenarios)
Output is available for from 1 to 24 scenarios in the following formats:
listing
print plot
punched cards for isopleth maps
culpability list of the high five contributors to the concentration at each receptor grid point

p. Computer Requirements

Digital computer required
Core requirements are moderate

q. Limitations

Relatively uncomplicated terrain

## References


1. Larsen, R. I. "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards." Office of Air Programs Publication No. AP-89 (NTIS PB 205277), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, November 1971.

2. Holland, J. Z. "A Meteorological Survey of the Oak Ridge Area." Atomic Energy Commission Report ORO-99, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1953.

3. Turner, D. B. "A Diffusion Model of an Urban Area." Journal of Applied Meteorology, American Meteorological Society, Boston, Massachusetts, February 1964.

4. McElroy, J. L. and F. Pooler. St. Louis Dispersion Study, Volume II - Analyses. AP-53. National Air Pollution Control Administration, Arlington, Virginia 22203, December 1968.

5. Leighton, P. A. and R. B. Dittmar. "Behavior of Aerosol Clouds within Cities." Joint Quarterly Progress Reports Nos. 2, 4, 5, 6 (2 vols.), Contracts DA-18-064-CMC-1856 and DA-18-064-CMC-2282. Stanford University and Ralph M. Parsons Co. DDC Nos. AD 7261, AD 31509, AD 31508, AD 31507, AD 31510, AD 31511, Respectively, 1952.

6. DeMarrais, G. A. "Wind Speed Profiles at Brookhaven National Laboratory." Journal of Meteorology, Americal Meteorological Society, Boston, Massachusetts, 1959.

7. Turner, D. B. "Workbook of Atmospheric Dispersion Estimates." PHS Publication No. 999-AP-26 (NTIS PB 191482), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, 1969.

8. Briggs. Gary A. Plume Rise. U.S. Atomic Energy Commission Critical Review Series, (NTIS TID-25075) Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1969.

9. Briggs, Gary A. "Some Recent Analyses of Plume Rise Observations." Proceedings of the Second International Clean Air Congress, edited by H. M. Englund and W. T. Berry, Academic Press, New York, 1971.

10. Briggs, Gary A. Discussion on Chimney Plumes in Neutral and Stable Surroundings. Atmospheric Environment, July 1972.

11. Gifford, F. A. and S. R. Hanna. "Modeling Urban Air Pollution." Atmospheric Environment, January 1973.

12. Busse, A. D. and J. R. Zimmerman. "User's Guide for the Climatological Dispersion Model." Publication No. EPA-RA-73-024 (NTIS PB 227346/AS), Environmental Protection Agency, Research Triangle Park, North Carolina 27711, December 1973.