Appendix I: Dispersion Methodology

Appendix I: Dispersion Methodology

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Appendix I: Dispersion Methodology

I1 BACKGROUND

The methodology used in dispersion modeling is quite different from the emissions inventory methodologies given in this document. Whereas the latter achieve their results using information specific to the sources, dispersion models provide a consideration of the context of the emissions, including the atmosphere, topography, and location of sensitive areas, as illustrated in Figure I-1. Accordingly, the computational requirements for dispersion modeling are much greater than for emission inventory modeling. In practice, however, computer-based dispersion models act as a sort of "black box"; as long as data inputs are properly specified, the dispersion model performs the necessary calculations and produces a summary of pollutant concentrations at each receptor. However, the user of a dispersion model should have an understanding of the basic modeling concepts and limitations prior to using the model in regulatory applications.

This section provides an overview of the procedures in the dispersion modeling process as well as a discussion of the mathematics of dispersion modeling.

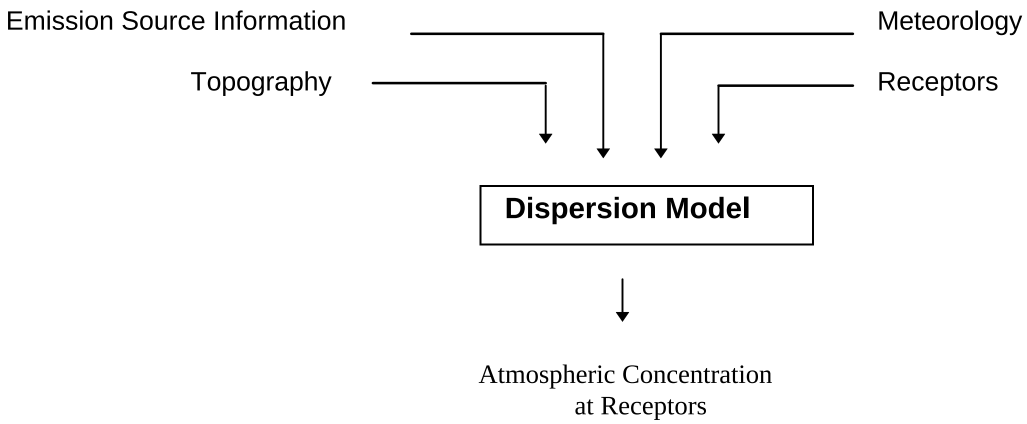

Figure I-1: Inputs and Outputs From Dispersion Modeling

The first step in dispersion modeling is to compile detailed information on the source or group of sources being modeled. This typically includes output from computer-based emission models, which should be properly formatted as input to the dispersion model. Additional information, such as source location coordinates and source geometry, is required by dispersion models. Second, local meteorological information is required, which typically is supplied by publicly available databases. For those locations with variable topography on or near the site, some dispersion models can accept as input a local topographic data set. However, the terrain around airports is usually flat enough to allow the modeler to ignore the effects of topography on pollutant dispersion.

Finally, receptor locations are identified by the user. These are the locations for which pollutant concentrations will be calculated by the model. If an overall view of the air quality on and off the site is required, then a grid of receptors may be used. If a small number of "sensitive" locations is the only area of interest, computational requirements may be reduced by specifying receptors only at those locations. “Sensitive” locations generally include any areas where the public is likely to be present — a key component for NAAQS assessments. Receptors may be located any distance away from the emission sources, but most models rely on relatively simple mathematical models that restrict the distance from the source for which a dispersion calculation may be considered accurate. Selection of receptor locations should follow the guidelines set forth below or as required by the appropriate regulatory agency.

For each time period specified, the contribution of each emission source to the concentration at each receptor must be calculated. Therefore if 50 separate sources are modeled at an airport, with 100 receptors specified, then 5,000 dispersion calculations must be made for each time period being modeled. This can lead to a very large computational requirement if a large number of time periods is modeled.

The output of a dispersion model is the average concentration of a pollutant or set of pollutants at each receptor over a specified time period, typically corresponding to the time periods required by NAAQS assessments. Depending on the pollutants modeled, the concentrations are given as a one-hour average, eight-hour average, 24-hour average, or annual arithmetic mean.

Computer-based dispersion models typically require the user to provide only the requested input data in the proper format; no understanding of the mathematics behind the model is necessary. However, the basics of dispersion modeling are presented below so that the reader may appreciate the techniques and limitations of these models.

Most dispersion models use a relatively simple mathematical approximation to estimate the steady-state concentration of pollutants at a receptor resulting from a single emission source, such as a boiler stack. Multiple emission sources are treated individually. A Gaussian approximation, as given in Equation I-1, has been found to simulate adequately the steady-state dispersion of pollutants from a continuous point source:

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

Where:

C - point concentration at receptor, μg/m^3
H - effective height of emissions, m
Q - mass flow of contaminants from receptor, μg/s
u - wind speed, m/s
x,y,z - ground level coordinates of receptor, m
σ_y - standard deviation of plume concentration distribution in y plane, m
σ_z - standard deviation of plume concentration distribution in z plane, m

Equation I-1: Gaussian Approximation

A common simplification is to assume that all receptors are at ground level. This allows simplification of Equation I-1 to Equation I-2:

$$C\,(x;y;0;H) \;=\; \frac{Q}{\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

Equation I-2: Gaussian Approximation (Receptors at Ground Level)

This model of pollutant dispersion makes several key assumptions. The main assumption is that the plume of dispersed pollutants follows a Gaussian distribution in both the horizontal and vertical planes, as illustrated in Figure I-2.

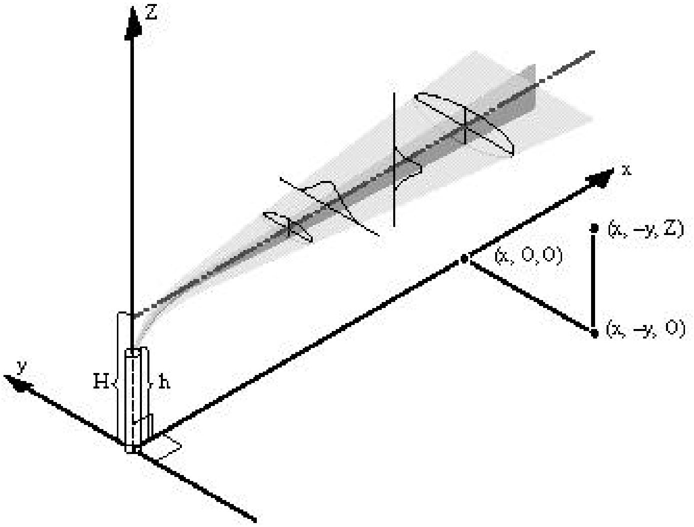

Figure I-2: Coordinate System Showing Gaussian Distributions in the Horizontal and Vertical Planes

Wind tunnel tests have shown this to be an adequate representation of some pollutant plumes, although in practice large variations from the ideal have been observed. The standard deviation factors σ_y and σ_z represent the degree of “spreading” of pollutants horizontally and vertically during plume movement. High standard deviation values would result from an unstable, turbulent atmosphere, whereas low values would occur in less turbulent atmospheric conditions. These factors are calculated using the Pasquill-Gifford stability classification system, described in paragraph 2.2.2.

Other assumptions include a constant wind speed from the negative-x direction, with no adjustment for changing wind speed with height; continuous emissions from a single point source at a rate indicated by the factor Q; upwind pollutant concentration of zero; no removal of pollutants by settling and deposition on the ground (i.e. total reflection of the plume at the earth’s surface); and no removal of pollutants by chemical transformation to other species. The combination of these assumptions allows a calculation of steady-state concentration at any specified receptor downwind of the source. The assumption of zero upwind concentration of each pollutant allows the modeling of only those emissions resulting from the sources being modeled. When performing an NAAQS assessment, however, it is necessary to add those dispersion model results to ambient or background pollutant levels measured for the area to determine whether or not the source will produce enough additional pollution to cause a violation of the NAAQS.

In modeling a complex emission system, such as an airport, a dispersion model is likely to represent sources as point, line, and area emissions, based on the type of sources identified in the emissions inventory. Point sources include stationary emission points such as sand piles, boiler stacks, and painting operations. Modeling of these sources is straightforward, using the Gaussian point source approximation given above. In some cases, mobile sources may also be modeled as point sources. For example, the takeoff roll and climb of an aircraft are most easily modeled as a series of "puffs," each of which is treated as a single Gaussian point source with a duration of a few seconds.

Roadways may be modeled as line sources or a series of point sources. The line source approximation involves the solving of an integral along the specified line, which results in a greater computational requirement than the approximation as a series of point sources. Both calculations are based on the Gaussian model, with similar results expected in most cases. A dispersion model may include adjustments for factors associated with roadways that affect turbulence, such as surface roughness. Surface roughness of the area near the roadway has an effect on dispersion because the source of emissions is very close to the ground, and may be required as input to some dispersion models.

Parking lots may be modeled as area sources, a series of line sources, or as a series of point sources. Because each type of model relies upon the same Gaussian approximation, results should be independent of the type of model used as long as the receptor is located far enough away from the parking lot. The key factors in choosing one source model over another are the difference in computational demand and whether EPA has "approved" the model for use on the particular type of application.

Dispersion models using a Gaussian approximation of pollutants have been applied for many years to emissions from stacks at industrial and utility sites. For those cases, the important issues in dispersion modeling have been incorporating estimates of plume rise and downwash of the plume at the stack tip and nearby buildings. At airports, stack emissions make up a very small component of the total emissions, with the majority arising instead from mobile sources such as aircraft, passenger vehicles, and ground support equipment. However, the Gaussian approximation is a general-purpose dispersion equation that has been modified for use on mobile source emissions as well as stack emissions.

I2 DATA INPUTS

This section outlines various data inputs required for a dispersion modeling run. These include characteristics of each emission source, meteorological parameters such as wind speed and direction, local topography, and receptor locations.

I2.1 Emission Sources

Dispersion models require several pieces of information about each emission source being included in the model, including:

- Source type.
- Emissions of each pollutant for each time period being investigated.

Depending on the source type, some additional information about the sources is likely to be required to model dispersion of pollutant emissions. These additional information requirements include:

- Source layout, including location and height.
- For stack emissions, parameters including stack gas temperature, exit velocity, and inside stack diameter.
- For mobile sources, surface roughness length of surrounding area.

The data requirements and likely sources of information are listed below.

I2.1.1 Source Type

Dispersion models for complex sites such as airports provide categories for each of the source types likely to be found on the site. These categories are necessary because of the differences in the way that the sources are represented in the dispersion model. For example, stacks are modeled as stationary point sources with a rising plume whereas roadways may be modeled as a line source with no plume rise but with consideration of the effect of surface roughness on dispersion. Therefore, specification of the source category type tells the computer how to model a given source and which additional pieces of information are required.

I2.1.2 Emissions of Each Pollutant

The main goal of the source inventory is to estimate the emissions of pollutants from each source. The pollutants of concern at airports are generally CO, NO_x, SO_2, PM-10, and HC. For some sources, such as aircraft engines, emission factors are available for all of these. Other sources emit only one pollutant. For example, particulate matter is the only air pollution problem associated with sand or salt piles. The emissions inventory typically provides an average rate of emissions of each pollutant for each source.

I2.1.3 Location and Height of Emission Sources

The physical layout of the emission sources is required by a dispersion model because the goal is to provide a pollutant concentration in air that varies with location. To this end, all sources should be located on a master grid that is used for the dispersion model. The height of the emission point is also required for each source, as it is used in the Gaussian equation to calculate ground-level concentrations downwind. Estimates of source location and height should be readily available from the airport operator or base operations section.

I2.1.4 Stack Characteristics

Stack emissions, which make up a very small percentage of the overall emissions at airports, require an estimate of plume rise before the Gaussian approximation may be applied. Plume rise is a result of thermal buoyancy of the stack gas and the vertical momentum of the gas as it leaves the stack. Three parameters are required to calculate plume rise that are not otherwise collected in the emissions inventory: stack gas temperature, vertical velocity of the gas exiting the stack, and the inside diameter of the stack. These may be obtained by direct sampling of the stack.

I2.1.5 Surface Roughness Length

The surface roughness length of the area surrounding the roadway is often a required input parameter in the dispersion modeling of emissions from mobile source. The surface roughness length, in meters or centimeters, is a measure of the near-surface wind resistance. Table I-1 provides typical surface roughness lengths for a variety of land uses.

Surface Type	Surface Roughness Length (cm)
Smooth desert	0.03
Grass (4 cm)	0.14
Grass (5-6 cm)	0.75
Alfalfa (15.2 cm)	2.72
Grass (60-70 cm)	11.40
Wheat (60 cm)	22.00
Corn (220 cm)	74.00
Citrus Orchard	198.00
Fir Forest	283.00
City Land Use:	
- Apartment residential	370.00
- Central business district	321.00
- Office	175.00
- Park	127.00
- Single family residential	108.00

Table I-1: Surface Roughness Lengths for Various Land Uses[1]

I2.2 Meteorology

Dispersion of pollutants in the atmosphere is largely dependent upon meteorological conditions, especially the following:

- Wind speed and direction,
- Atmospheric stability,
- Mixing depth.

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[1] Source: EPA Office of Air Quality Planning and Standards, *User's Guide to CAL3QHC Version 2.0*, EPA-454/R-92-006, September 1995, p. 30.

A wide range of meteorological data is collected hourly at most airports. This information is available from the National Climatic Data Center in a digital format ready for use by most dispersion models. One year to several years' data is required by regulatory agencies for a modeling run to be considered valid.

I2.2.1 Wind Speed and Direction

Wind speed and direction are important parameters in modeling the dispersion of pollutants in the atmosphere. The Gaussian approximation assumes that wind speed is constant from one direction for a given time period being modeled, usually one hour. Wind speeds are usually measured by an anemometer at a height of 20 feet or sometimes 10 m. These measurements may or may not be corrected by the dispersion model to account for increasing wind speed with height.

For those time periods in which the wind speed is given as zero or "calm", a model will generally assign a minimum wind speed. If a wind speed of zero were specified, the Gaussian equation would compute an infinite concentration of the pollutant at the source, with no dispersion. In reality, diffusion of pollutants into the surrounding atmosphere would take place in calm conditions.

I2.2.2 Atmospheric Stability

Atmospheric stability and the presence of atmospheric turbulence are predominant factors that determine the rate at which airborne pollutants are diffused. A region of the atmosphere with strong vertical motion enhances dispersion by scattering pollutants through a larger volume of air. Atmospheric stability determines the extent to which vertical mixing will occur and, consequently, the degree to which airborne pollutants are mixed within a parcel of air. Stability is influenced strongly by vertical temperature distribution. Horizontal mixing of the atmosphere also influences the pathway of airborne pollutants through wind speed and related turbulence. In general, atmospheric stability is a function of the temperature distribution with height, solar radiation, cloud cover, and wind speed.

The stability is expressed in terms of the Pasquill-Gifford (P-G) stability classification system, which identifies six classes ranging from A (very unstable) to F (very stable). In unstable atmospheric conditions, the high turbulence and associated vertical mixing produce a peak ground-level pollutant concentration near the emission source, with low concentrations at distances far from the source. The most unstable conditions occur during daylight hours, with low wind speeds and high solar radiation contributing to higher instability. In stable atmospheric conditions, the low level of vertical mixing results in a low ground-level steady-state concentration near the source, with comparatively higher concentrations at long distances from the source. The most stable atmospheric conditions occur at night, during times of low wind speeds and clear skies. Dispersion models convert wind speed data, cloud cover data, and solar radiation to the corresponding stability category, according to Table I-2. Some models require the direct input of stability categories along with other meteorological data.

Once the proper P-G stability category has been identified, the Gaussian standard deviation factors σ_y and σ_z may be calculated. Dispersion models perform this calculation internally, with no additional input required from the user. A methodology for calculating these values is given in Turner's "Workbook of Atmospheric Dispersion Estimates," in EPA's *APTI Course 423: Dispersion of Air Pollution — Theory and Model Application, Selected Readings Packet,* p. 1-6 (Reference 40).

Surface Wind Speed (at 10m) (m/s)	Day			Night	
	Incoming Solar Radiation			Cloudy	Clear[2]
	Strong	Moderate	Slight[3]		
<2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Table I-2: Key To P-G Stability Categories[4]

I2.2.3 Mixing Layer Height

In some models, the dispersion calculation is modified to consider the effects of the mixing layer height on pollutant concentration. The mixing layer height (also known as the mixing depth or inversion layer height) is the elevation of the boundary between the vertically mixed layer of air closest to the earth’s surface and the relatively stable layer of air above. Vertical diffusion of pollutants occurs readily within the mixing layer but does not occur to any significant degree within the stable layer. The height of the mixing layer generally ranges between 1,000 ft and 4,000 ft depending upon weather conditions and time of day. The boundary between the two layers is evidenced by the bottom of cumulus clouds.

The presence of a stable layer above the mixing layer has the effect of restricting vertical diffusion of pollutants. This “lidding” effect requires a modification of the simple Gaussian approximation for it to remain accurate at distances greater than several kilometers downwind of the emission source. For applications such as airports, however, where the major pollutant of concern (CO) is not likely to be transported at high concentration very far from the source, mixing depth effects on downwind pollutant concentrations may be ignored without too much loss of accuracy.

I2.3 Topography

Many dispersion models require topographic information for the area being modeled. Digitized topographic information for all sites in the U.S. is available from the United States Geological Survey and other sources, but this data must be properly formatted and aligned with the grid used to determine the layout of the site.

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[2] Meteorologists divide the sky into eight sections to determine the degree of cloud cover. If three or fewer sections contain clouds, the sky is considered clear: if four or more section have clouds, the sky is considered cloudy.

[3] Category D should be used for overcast conditions during day or night.

[4] Source: Turner's "Workbook of Atmospheric Dispersion Estimates," in EPA's *APTI Course 423: Dispersion of Air Pollution — Theory and Model Application, Selected Readings Packet,* p. 1-6.

The simple Gaussian approximation given above is not reliable in areas of complex terrain (i.e., areas in which the terrain rises above the effective emission height), and may not be valid in intermediate terrain (i.e., areas in which the terrain rises above the stack height but not the effective emission height). Models have been developed for use in complex and intermediate terrain, but the focus of these models is stationary point source emissions rather than mobile sources, which are the greatest emission sources at airports and air bases.

Terrain in the vicinity of airports is usually quite flat because of the requirement for a level runway, approach, and climb-out area. Dispersion models can take advantage of this property of airport locations to make the simplifying assumption that the terrain is flat. This assumption allows the model to use the Gaussian approximation with no modifications that would increase the computational requirement.

I2.4 Receptors

Receptors are defined by the user as those areas in which pollutant concentrations in air are to be calculated. If an overall view of pollutant concentration on and off the site is desired, then a grid of receptors should be defined. For many applications, however, only those locations defined as “sensitive” (i.e., where the public is likely to come into contact with emissions) may be modeled in order to reduce the computational requirement. For a complex emissions scenario such as an airport, reducing the number of receptors may be necessary because each receptor defined may add hours to the computation time.