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USER'S GUIDE FOR THE INDUSTRIAL SOURCE COMPLEX (ISC2) DISPERSION MODELS

VOLUME II - DESCRIPTION OF MODEL ALGORITHMS

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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NOTICE

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PREFACE

This volume of the User's Guide for the Industrial Source Complex (ISC2) Dispersion Models (Version 2) describes the dispersion algorithms utilized in the IS2C models. Much of the discussion in this document is based on Section 2.0 of the Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition (Revised), EPA-450/4-88-002a, (EPA,1987). The ISC2 User's Guide has been developed as part of a larger effort to restructure and reprogram the ISC models, and to improve the "end-user" documentation for the models. Volume I of the ISC2 User's Guide provides user instructions for setting up and running the ISC2 models. Volume III provides a guide to programmers, including a description of the structure of the computer code and information about installing and maintaining the code on various computer systems.

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SYMBOLS

Symbol	Definition
A	Linear decay term for vertical dispersion in Schulman-Scire downwash
D	Exponential decay term for Gaussian plume equation
d_s	Stack inside diameter (m)
F_b	Buoyancy flux parameter (m^4/s^3)
F_m	Momentum flux parameter (m^4/s^2)
f	Frequency of occurrence of a wind speed and stability category combination
g	Acceleration due to gravity (9.80616 m/s^2)
h_b	Building height (m)
h_e	Plume (or effective stack) height (m)
h_s	Physical stack height (m)
h_{ter}	Height of terrain above stack base (m)
h_s'	Release height modified for stack-tip downwash (m)
h_w	Crosswind projected width of building adjacent to a stack (m)
L_y	Initial plume length for Schulman-Scire downwash sources with enhanced lateral plume spread
L_b	Lesser of the building height and crosswind projected building width (m)
p	Wind speed power law profile exponent
Q_A	Area Source pollutant emission rate (g/s)
Q_s	Pollutant emission rate (g/s)
Q_τ	Total amount of pollutant emitted during time period τ
R_o	Initial plume radius for Schulman-Scire downwash sources
r	Radial distance range in a polar receptor network

s	Stability parameter = $g\frac{\partial\theta/\partial z}{T_a}$
S	Smoothing term for smoothing across adjacent sectors in the Long Term model
T_a	Ambient temperature (K)
T_s	Stack gas exit temperature (K)
u_{ref}	Wind speed measured at reference anemometer height (m/s)
u_s	Wind speed adjusted to release height (m/s)
V	Vertical term of the Gaussian plume equation
v_s	Stack gas exit velocity (m/s)
X	X-coordinate in a Cartesian grid receptor network
x_o	Length of side of square area source (m)
Y	Y-coordinate in a Cartesian grid receptor network
θ	Direction in a polar receptor network
x	Downwind distance from source to receptor (m)
x_y	Lateral virtual point source distance (m)
x_z	Vertical virtual point source distance (m)
x_f	Downwind distance to final plume rise (m)
x^*	Downwind distance at which turbulence dominates entrainment (m)
y	Crosswind distance from source to receptor (m)
z_r	Receptor height above ground (i.e. flagpole) (m)
z_i	Mixing height (m)
β	Entrainment coefficient used in buoyant rise for Schulman-Scire downwash sources = 0.6
β_j	Jet entrainment coefficient used in gradual momentum plume rise calculations $= \frac{1}{3} + \frac{u_s}{v_s}$

Δh	Plume rise (m)
$\partial\theta/\partial z$	Potential temperature gradient with height (K/m)
γ	Reflection coefficient for large particulates
π	pi = 3.14159
ψ	Decay coefficient = $0.693/T_{1/2}$ (s^{-1})
ϕ	Fraction of mass in a particular settling velocity category for large particulates
σ_y	Horizontal (lateral) dispersion parameter (m)
σ_{yo}	Initial horizontal dispersion parameter for virtual point source (m)
σ_{ye}	Effective lateral dispersion parameter including effects of buoyancy-induced dispersion (m)
σ_z	Vertical dispersion parameter (m)
σ_{zo}	Initial vertical dispersion parameter for virtual point source (m)
σ_{ze}	Effective vertical dispersion parameter including effects of buoyancy-induced dispersion (m)
χ	Concentration ($\mu g/m^3$)

1.0 THE ISC2 SHORT-TERM DISPERSION MODEL EQUATIONS

The Industrial Source Complex (ISC2) dispersion models described in this document refer to restructured and reprogrammed versions of the original ISC models described in the ISC Dispersion Model User's Guide - Second Edition (Revised) (EPA,1987). The models were reprogrammed in order to improve the quality of the computer code, to improve the user interface, and to improve the end user documentation of the models.

The Industrial Source Complex (ISC2) Short Term dispersion model provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emissions from stacks, emissions from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the like. Emission sources are categorized into three basic types of sources, i.e., point sources, volume sources, and area sources. The volume source option may also be used to simulate line sources. The algorithms used to model each of these source types are described in detail in the following sections. The point source algorithms are described in Section 1.1. The volume and area source model algorithms are described in Section 1.2. Section 1.3 gives the optional algorithms for calculating dry deposition for point, volume and area sources.

The ISC2 Short Term model accepts hourly meteorological data records to define the conditions for plume rise, transport and diffusion. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. The user also has the option of selecting averages for the entire period of input meteorology.

1.1 POINT SOURCE EMISSIONS

The ISC2 Short Term dispersion model uses a steady-state Gaussian plume equation to model emissions from point sources, such as stacks, isolated vents, and the like. This section describes the Gaussian point source model, including the basic Gaussian equation, the plume rise formulas, and the formulas used for determining dispersion parameters.

1.1.1 The Gaussian Equation

The ISC2 short term concentration model for stacks uses the steady-state Gaussian plume equation for a continuous elevated source. For each source and each hour, the origin of the source's coordinate system is placed at the ground surface at the base of the stack. The x axis is positive in the downwind direction, the y axis is crosswind (normal) to the x axis and the z axis extends vertically. The fixed receptor locations are converted to each source's coordinate system for each hourly concentration calculation. The hourly concentrations calculated for each source at each receptor are summed to obtain the total concentration produced at each receptor by the combined source emissions.

The hourly concentration at downwind distance x (meters) and crosswind distance y (meters) is given by:

$$\chi = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (1\text{-}1)$$

where:

Q = pollutant emission rate (mass per unit time)

K = a scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6 for Q in g/s and concentration in $\mu g/m^3$)

V = vertical term (See Section 1.1.6)

D = decay term (See Section 1.1.7)

σ_y, σ_z = standard deviation of lateral and vertical concentration distribution (m)

u_s = mean wind speed (m/s) at release height

Equation (1-1) includes a Vertical Term, a Decay Term, and dispersion parameters (σ_y and σ_z) as discussed below. It should be noted that the Vertical Term includes the effects of source elevation, receptor elevation, plume rise, limited mixing in the vertical, and the gravitational settling and dry deposition of larger particulates (with diameters greater than about 20 micrometers).

1.1.2 Downwind and Crosswind Distances

The ISC2 models use either a polar or a Cartesian receptor network as specified by the user. The new version of the model allows for the use of both types of receptors and for multiple networks in a single run. All receptor points are converted to Cartesian (X,Y) coordinates prior to performing the dispersion calculations. In the polar coordinate system, the radial coordinate of the point (r, θ) is measured from the user-specified origin and the angular coordinate θ is measured clockwise from the north. In the Cartesian coordinate system, the X axis is positive to the east of the user-specified origin and the Y axis is positive to the north. For either type of receptor network, the user must define the location of each source with respect to the origin of the grid using Cartesian coordinates. In the polar coordinate system, assuming the origin is at $X = X_o$, $Y = Y_o$, the X and Y coordinates of a receptor at the point (r, θ) are given by:

$$X(R) = r\sin\theta - X_o \qquad (1\text{-}2)$$

$$Y(R) = r\cos\theta - Y_o \qquad (1\text{-}3)$$

If the X and Y coordinates of the source are X(S) and Y(S), the downwind distance x to the receptor, along the direction of plume travel, is given by:

$$x = -(X(R)-X(S))\sin(WD) - (Y(R)-Y(S))\cos(WD) \qquad (1\text{-}4)$$

where WD is the direction <u>from</u> which the wind is blowing. If any receptor is located within 1 meter of a source, a warning message is printed and no concentrations are calculated for the source-receptor combination. The crosswind distance y to the receptor from the plume centerline is given by:

$$y = (X(R)-X(S))\cos(WD) - (Y(R)-Y(S))\sin(WD) \qquad (1\text{-}5)$$

1.1.3 <u>Wind Speed Profile</u>

The wind power law is used to adjust the observed wind speed, u_{ref}, from a reference measurement height, z_{ref}, to the stack or release height, h_s. The equation is of the form:

$$u_s = u_{ref}\left(\frac{h_s}{z_{ref}}\right)^p \qquad (1\text{-}6)$$

where p is the wind profile exponent. Values of p may be provided by the user as a function of stability category and wind speed class. Default values are as follows:

Stability Category	Rural Exponent	Urban Exponent
A	0.07	0.15
B	0.07	0.15
C	0.10	0.20
D	0.15	0.25
E	0.35	0.30
F	0.55	0.30

The stack height wind speed, u_s, is not allowed to be less than 1.0 m/s.

1.1.4 Plume Rise Formulas

The Briggs plume rise equations are discussed below. The description follows Appendix B of the Addendum to the MPTER User's Guide (Chico and Catalano, 1986) for plumes unaffected by building wakes. The distance dependent momentum plume rise equations, as described in (Bowers, et al., 1979), are used to determine if the plume is affected by the wake region for building downwash calculations. These plume rise calculations for wake determination are made assuming no stack-tip downwash for both the Huber-Snyder and the Schulman-Scire methods. When the model executes the building downwash methods of Schulman and Scire, the reduced plume rise suggestions of Schulman and Scire (1980) are used.

1.1.4.1 Stack-tip Downwash.

In order to consider stack-tip downwash, modification of the physical stack height is performed following Briggs (1974, p. 4). The modified physical stack height h_s' is found from:

$$h_s' = h_s + 2d_s\left[\frac{v_s}{u_s} - 1.5\right] \qquad \text{for} \quad v_s < 1.5u_s$$

or

$$h_s' = h_s \qquad \text{for} \quad v_s \geq 1.5u_s \tag{1-7}$$

where h_s is physical stack height (m), v_s is stack gas exit velocity (m/s), and d_s is inside stack top diameter (m). This h_s' is used throughout the remainder of the plume height computation. If stack tip downwash is not considered, $h_s' = h_s$ in the following equations.

1.1.4.2 Buoyancy and Momentum Fluxes.

For most plume rise situations, the value of the Briggs buoyancy flux parameter, F_b (m^4/s^3), is needed. The following equation is equivalent to Equation (12), (Briggs, 1975, p. 63):

$$F_b = g v_s d_s^2 \left(\frac{\Delta T}{4 T_s} \right) \tag{1-8}$$

where $\Delta T = T_s - T_a$, T_s is stack gas temperature (K), and T_a is ambient air temperature (K).

For determining plume rise due to the momentum of the plume, the momentum flux parameter, F_m (m^4/s^2), is calculated based on the following formula:

$$F_m = v_s^2 d_s^2 \frac{T_a}{4 T_s} \tag{1-9}$$

1.1.4.3 Unstable or Neutral - Crossover Between Momentum and Buoyancy.

For cases with stack gas temperature greater than or equal to ambient temperature, it must be determined whether the plume rise is dominated by momentum or buoyancy. The crossover temperature difference, $(\Delta T)_c$, is determined by setting Briggs' (1969, p. 59) Equation 5.2 equal to the combination of Briggs' (1971, p. 1031) Equations 6 and 7, and solving for ΔT, as follows:

for $F_b < 55$,

$$(\Delta T)_c = 0.0297 T_s \frac{v_s^{1/3}}{d_s^{2/3}} \tag{1-10}$$

and for $F_b \geq 55$,

$$(\Delta T)_c = 0.00575 T_s \frac{v_s^{2/3}}{d_s^{1/3}} \tag{1-11}$$

If the difference between stack gas and ambient temperature, ΔT, exceeds or equals $(\Delta T)_c$, plume rise is assumed to be buoyancy dominated, otherwise plume rise is assumed to be momentum dominated.

1.1.4.4 Unstable or Neutral - Buoyancy Rise.

For situations where ΔT exceeds $(\Delta T)_c$ as determined above, buoyancy is assumed to dominate. The distance to final rise, x_f, is determined from the equivalent of Equation (7), (Briggs, 1971, p. 1031), and the distance to final rise is assumed to be $3.5x^*$, where x^* is the distance at which atmospheric turbulence begins to dominate entrainment. The value of x_f is calculated as follows:

for $F_b < 55$:

$$x_f = 49F_b^{5/8} \tag{1-12}$$

and for $F_b \geq 55$:

$$x_f = 119F_b^{2/5} \tag{1-13}$$

The final effective plume height, h_e (m), is determined from the equivalent of the combination of Equations (6) and (7) (Briggs, 1971, p. 1031):

for $F_b < 55$:

$$h_e = h_s' + 21.425\frac{F_b^{3/4}}{u_s} \tag{1-14}$$

and for $F_b \geq 55$:

$$h_e = h_s' + 38.71\frac{F_b^{3/5}}{u_s} \tag{1-15}$$

1.1.4.5 Unstable or Neutral - Momentum Rise.

For situations where the stack gas temperature is less than or equal to the ambient air temperature, the assumption is made that the plume rise is dominated by momentum. If ΔT is less than $(\Delta T)_c$ from Equation (1-10) or (1-11), the assumption is also made that the plume rise is dominated by momentum. The plume height is calculated from Equation (5.2) (Briggs, 1969, p. 59):

$$h_e = h_s' + 3d_s \frac{v_s}{u_s} \qquad (1\text{-}16)$$

Briggs (1969, p. 59) suggests that this equation is most applicable when v_s/u_s is greater than 4.

1.1.4.6 Stability Parameter.

For stable situations, the stability parameter, s, is calculated from the Equation (Briggs, 1971, p. 1031):

$$s = g\frac{\partial\theta/\partial z}{T_a} \qquad (1\text{-}17)$$

As a default approximation, for stability class E (or 5) $\partial\theta/\partial z$ is taken as 0.020 K/m, and for class F (or 6), $\partial\theta/\partial z$ is taken as 0.035 K/m.

1.1.4.7 Stable - Crossover Between Momentum and Buoyancy.

For cases with stack gas temperature greater than or equal to ambient temperature, it must be determined whether the plume rise is dominated by momentum or buoyancy. The crossover temperature difference, $(\Delta T)_c$, is determined by setting Briggs' (1975, p. 96) Equation 59 equal to Briggs' (1969, p. 59) Equation 4.28, and solving for ΔT, as follows:

$$(\Delta T)_c = 0.019582\, T_s v_s \sqrt{s} \qquad (1\text{-}18)$$

If the difference between stack gas and ambient temperature, ΔT, exceeds or equals $(\Delta T)_c$, plume rise is assumed to be buoyancy dominated, otherwise plume rise is assumed to be momentum dominated.

1.1.4.8 Stable - Buoyancy Rise.

For situations where ΔT exceeds $(\Delta T)_c$ as determined above, buoyancy is assumed to dominate. The distance to final rise, x_f, is determined by the equivalent of a combination of Equations (48) and (59) in Briggs, (1975), p. 96:

$$x_f = 2.0715 \frac{u_s}{\sqrt{S}} \tag{1-19}$$

The plume height, h_e, is determined by the equivalent of Equation (59) (Briggs, 1975, p. 96):

$$h_e = h_s' + 2.6\left(\frac{F_b}{u_s S}\right)^{1/3} \tag{1-20}$$

1.1.4.9 Stable - Momentum Rise.

Where the stack gas temperature is less than or equal to the ambient air temperature, the assumption is made that the plume rise is dominated by momentum. If ΔT is less than $(\Delta T)_c$ as determined by Equation (1-18), the assumption is also made that the plume rise is dominated by momentum. The plume height is calculated from Equation 4.28 of Briggs ((1969), p. 59):

$$h_e = h_s' + 1.5\left(\frac{F_m}{u_s\sqrt{S}}\right)^{1/3} \tag{1-21}$$

The equation for unstable-neutral momentum rise (1-16) is also evaluated. The lower result of these two equations is used as the resulting plume height.

1.1.4.10 All Conditions - Distance Less Than Distance to Final Rise.

Where gradual rise is to be estimated for unstable, neutral, or stable conditions, if the distance downwind from source to receptor, x, is less than the distance to final rise, the equivalent of Equation 2 of Briggs ((1972), p. 1030) is used to determine plume height:

$$h_e = h_s' + 1.60\left(\frac{F_b^{1/3} x^{2/3}}{u_s}\right) \tag{1-22}$$

This height will be used only for buoyancy dominated conditions; should it exceed the final rise for the appropriate condition, the final rise is substituted instead.

For momentum dominated conditions, the following equations (Bowers, et al, 1979) are used to calculate a distance dependent momentum plume rise:

a) <u>unstable conditions</u>:

$$h_e = h_s' + \left(\frac{3F_m x}{\beta_j^2 u_s^2}\right)^{1/3} \tag{1-23}$$

where x is the downwind distance (meters), with a maximum value defined by x_{max} as follows:

$$\begin{aligned} x_{max} &= \frac{4d_s(v_s + 3u_s)^2}{v_s u_s} && \text{for } F_b = 0 \\ &= 49F_b^{5/8} && \text{for } 0 < F_b \le 55m^4/s^3 \\ &= 119F_b^{2/5} && \text{for } F_b > 55m^4/s^3 \end{aligned} \tag{1-24}$$

b) <u>stable conditions</u>:

$$h_e = h_s' + \left[3F_m \frac{\sin(x\sqrt{s}/u_s)}{\beta_j^2 u_s \sqrt{s}}\right]^{1/3} \tag{1-25}$$

where x is the downwind distance (meters), with a maximum value defined by x_{max} as follows:

$$x_{max} = 0.5\frac{\pi u_s}{\sqrt{s}} \tag{1-26}$$

The jet entrainment coefficient, β_j, is given by,

$$\beta_j = \frac{1}{3} + \frac{u_s}{v_s} \qquad (1\text{-}27)$$

As with the buoyant gradual rise, if the distance-dependent momentum rise exceeds the final rise for the appropriate condition, then the final rise is substituted instead.

1.1.4.10.1 Calculating the plume height for wake effects determination.

The building downwash algorithms in the ISC2 models always require the calculation of a distance dependent momentum plume rise. When building downwash is being simulated, the equations described above are used to calculate a distance dependent momentum plume rise at a distance of two building heights downwind from the leeward edge of the building. However, stack-tip downwash is not used when performing this calculation (i.e. $h_s' = h_s$). This wake plume height is compared to the wake height based on the GEP formula to determine whether the building wake effects apply to the plume for that hour.

The procedures used to account for the effects of building downwash are discussed more fully in Section 1.1.5.3. The plume rise calculations used with the Schulman-Scire algorithm are discussed in Section 1.1.4.11.

1.1.4.11 Plume Rise When Schulman and Scire Building Downwash is Selected.

The Schulman-Scire downwash algorithms are used by the ISC2 models when the stack height is less than the building height plus one half of the lesser of the building height or width. When these criteria are met, the ISC2 models estimate plume rise during building downwash conditions following the suggestion of Scire and Schulman (1980). The plume rise during building downwash conditions is reduced due to the initial dilution of the plume with ambient air.

The plume rise is estimated as follows. The initial dimensions of the downwashed plume are approximated by a line source of length L_y and depth $2R_o$ where:

$$R_o = \sqrt{2} A \sigma_z \qquad x = 3L_B \tag{1-28}$$

$$L_y = \sqrt{2\pi}\,(\sigma_y - \sigma_z) \qquad x = 3L_B,\ \ \sigma_y \geq \sigma_z \tag{1-29a}$$

$$L_y = 0 \qquad x = 3L_B,\ \ \sigma_y < \sigma_z \tag{1-29b}$$

L_B equals the minimum of h_b and h_w, where h_b is the building height and h_w the projected (crosswind) building width. A is a linear decay factor and is discussed in more detail in Section 1.1.5.3.2. If there were no enhancement of σ_y or if the enhanced σ_y is less than the enhanced σ_z, the initial plume would be represented by a circle of radius R_o. The $\sqrt{2}$ factor converts the Gaussian σ_z to an equivalent uniform circular distribution and $\sqrt{2\pi}$ converts σ_y to an equivalent uniform rectangular distribution. Both σ_y and σ_z are evaluated at $x = 3L_B$, and are taken as the larger of the building enhanced sigmas and the sigmas obtained from the curves (see Section 1.1.5.3). The value of σ_z used in the calculation of L_y also includes the linear decay term, A.

The rise of a downwashed finite line source was solved in the BLP model (Scire and Schulman, 1980). The neutral distance-dependent rise (Z) is given by:

$$Z^3 + \left(\frac{3L_y}{\pi\beta} + \frac{3R_o}{\beta}\right) Z^2 + \left(\frac{6R_oL_y}{\pi\beta^2} + \frac{3R_o^2}{\beta^2}\right) Z = \frac{3F_b x^2}{2\beta^2 u_s^3} + \frac{3F_m x}{\beta_j^2 u_s^2} \tag{1-30}$$

The stable distance-dependent rise is calculated by:

$$Z^3 + \left(\frac{3L_y}{\pi\beta} + \frac{3R_o}{\beta}\right) Z^2 + \left(\frac{6R_oL_y}{\pi\beta^2} + \frac{3R_o^2}{\beta^2}\right) Z = \frac{3F_b x^2}{2\beta^2 u_s^3} + \frac{3F_m \sin\left(\frac{x\sqrt{s}}{u_s}\right)}{\beta_j^2 u_s \sqrt{s}} \qquad (1\text{-}31a)$$

with a maximum stable buoyant rise given by:

$$Z^3 + \left(\frac{3L_y}{\pi\beta} + \frac{3R_o}{\beta}\right) Z^2 + \left(\frac{6R_o L_y}{\pi\beta^2} + \frac{3R_o^2}{\beta^2}\right) Z = \frac{6F_b}{\beta^2 u_s s} \qquad (1\text{-}31b)$$

where:

F_b = buoyancy flux term (Equation 1-8) (m^4/s^3)

F_m = momentum flux term (Equation 1-9) (m^4/s^2)

x = downwind distance (m)

u_s = wind speed at release height (m/s)

v_s = stack exit velocity (m/s)

d_s = stack diameter (m)

β = entrainment coefficient (=0.6)

β_j = jet entrainment coefficient $= \frac{1}{3} + \frac{u_s}{v_s}$

s = stability parameter $= g\frac{\partial\theta/\partial z}{T_a}$

The larger of momentum and buoyant rise, determined separately by alternately setting F_b or $F_m = 0$ and solving for Z, is selected for plume height calculations for Schulman-Scire downwash. In the ISC2 models, Z is determined by solving the cubic equation using Newton's method.

1.1.5 The Dispersion Parameters

1.1.5.1 Point Source Dispersion Parameters.

Equations that approximately fit the Pasquill-Gifford curves (Turner, 1970) are used to calculate σ_y and σ_z (in meters) for the rural mode. The equations used to calculate σ_y are of the form:

$$\sigma_y = 465.11628(x)\tan(TH) \tag{1-32}$$

where:

$$TH = 0.017453293[c - d\ln(x)] \tag{1-33}$$

In Equations (1-32) and (1-33) the downwind distance x is in kilometers, and the coefficients c and d are listed in Table 1-1. The equation used to calculate σ_z is of the form:

$$\sigma_z = ax^b \tag{1-34}$$

where the downwind distance x is in kilometers and σ_z is in meters. The coefficients a and b are given in Table 1-2.

Tables 1-3 and 1-4 show the equations used to determine σ_y and σ_z for the urban option. These expressions were determined by Briggs as reported by Gifford (1976) and represent a best fit to urban vertical diffusion data reported by McElroy and Pooler (1968). The Briggs functions are assumed to be valid for downwind distances less than 100m. However, the user is cautioned that concentrations at receptors less than 100m from a source may be suspect.

TABLE 1-1

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_y

	$\sigma_y = 465.11628\ (x)\tan(TH)$ $TH = 0.017453293\ [c - d\ \ln(x)]$	
Pasquill Stability Category	c	d
A	24.1670	2.5334
B	18.3330	1.8096
C	12.5000	1.0857
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

where σ_y is in meters and x is in kilometers

TABLE 1-2

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

Pasquill Stability Category	x (km)	σ_z(meters) = ax^b (x in km) a	b
A*	<.10	122.800	0.94470
	0.10 - 0.15	158.080	1.05420
	0.16 - 0.20	170.220	1.09320
	0.21 - 0.25	179.520	1.12620
	0.26 - 0.30	217.410	1.26440
	0.31 - 0.40	258.890	1.40940
	0.41 - 0.50	346.750	1.72830
	0.51 - 3.11	453.850	2.11660
	>3.11	**	**
B*	<.20	90.673	0.93198
	0.21 - 0.40	98.483	0.98332
	>0.40	109.300	1.09710
C*	All	61.141	0.91465
D	<.30	34.459	0.86974
	0.31 - 1.00	32.093	0.81066
	1.01 - 3.00	32.093	0.64403
	3.01 - 10.00	33.504	0.60486
	10.01 - 30.00	36.650	0.56589
	>30.00	44.053	0.51179

* If the calculated value of σ_z exceed 5000 m, σ_z is set to 5000 m.

** σ_z is equal to 5000 m.

TABLE 1-2
(CONTINUED)

PARAMETERS USED TO CALCULATE PASQUILL-GIFFORD σ_z

Pasquill Stability Category	x (km)	σ_z(meters) = ax^b (x in km) a	b
E	<.10	24.260	0.83660
	0.10 - 0.30	23.331	0.81956
	0.31 - 1.00	21.628	0.75660
	1.01 - 2.00	21.628	0.63077
	2.01 - 4.00	22.534	0.57154
	4.01 - 10.00	24.703	0.50527
	10.01 - 20.00	26.970	0.46713
	20.01 - 40.00	35.420	0.37615
	>40.00	47.618	0.29592
F	<.20	15.209	0.81558
	0.21 - 0.70	14.457	0.78407
	0.71 - 1.00	13.953	0.68465
	1.01 - 2.00	13.953	0.63227
	2.01 - 3.00	14.823	0.54503
	3.01 - 7.00	16.187	0.46490
	7.01 - 15.00	17.836	0.41507
	15.01 - 30.00	22.651	0.32681
	30.01 - 60.00	27.074	0.27436
	>60.00	34.219	0.21716

TABLE 1-3

BRIGGS FORMULAS USED TO CALCULATE McELROY-POOLER σ_y

Pasquill Stability Category	σ_y(meters)*
A	$0.32\ x\ (1.0 + 0.0004\ x)^{-1/2}$
B	$0.32\ x\ (1.0 + 0.0004\ x)^{-1/2}$
C	$0.22\ x\ (1.0 + 0.0004\ x)^{-1/2}$
D	$0.16\ x\ (1.0 + 0.0004\ x)^{-1/2}$
E	$0.11\ x\ (1.0 + 0.0004\ x)^{-1/2}$
F	$0.11\ x\ (1.0 + 0.0004\ x)^{-1/2}$

* Where x is in meters

TABLE 1-4

BRIGGS FORMULAS USED TO CALCULATE McELROY-POOLER σ_z

Pasquill Stability Category	σ_z(meters)*
A	$0.24\ x\ (1.0 + 0.001\ x)^{1/2}$
B	$0.24\ x\ (1.0 + 0.001\ x)^{1/2}$
C	0.20
D	$0.14\ x\ (1.0 + 0.0003\ x)^{-1/2}$
E	$0.08\ x\ (1.0 + 0.0015\ x)^{-1/2}$
F	$0.08\ x\ (1.0 + 0.0015\ x)^{-1/2}$

* Where x is in meters.

1.1.5.2 <u>Lateral and Vertical Virtual Distances.</u>

The equations in Tables 1-1 through 1-4 define the dispersion parameters for an ideal point source. However, volume sources have initial lateral and vertical dimensions. Also, as discussed below, building wake effects can enhance the initial growth of stack plumes. In these cases, lateral (x_y) and vertical (x_z) virtual distances are added by the ISC2 models to the actual downwind distance x for the σ_y and σ_z calculations. The lateral virtual distance <u>in kilometers</u> for the rural mode is given by:

$$x_y = \left(\frac{\sigma_{yo}}{p}\right)^{1/q} \tag{1-35}$$

where the stability-dependent coefficients p and q are given in Table 1-5 and σ_{yo} is the standard deviation in meters of the lateral concentration distribution at the source. Similarly, the vertical virtual distance in kilometers for the rural mode is given by:

*b130Wt<▲

$$x_z = \left(\frac{\sigma_{zo}}{a}\right)^{1/b} \tag{1-36}$$

where the coefficients a and b are obtained form Table 1-2 and σ_{zo} is the standard deviation in meters of the vertical concentration distribution at the source. It is important to note that the ISC2 model programs check to ensure that the x_z used to calculate σ_z at $(x + x_z)$ in the rural mode is the x_z calculated using the coefficients a and b that correspond to the distance category specified by the quantity $(x + x_z)$.

To determine virtual distances for the urban mode, the functions displayed in Tables 1-3 and 1-4 are solved for x. The solutions are quadratic formulas for the lateral virtual distances; and for vertical virtual distances the solutions are cubic equations for stability classes A and B, a linear equation for stability class C, and quadratic equations for stability classes D, E, and F. The cubic equations are solved using Newton's method.

TABLE 1-5

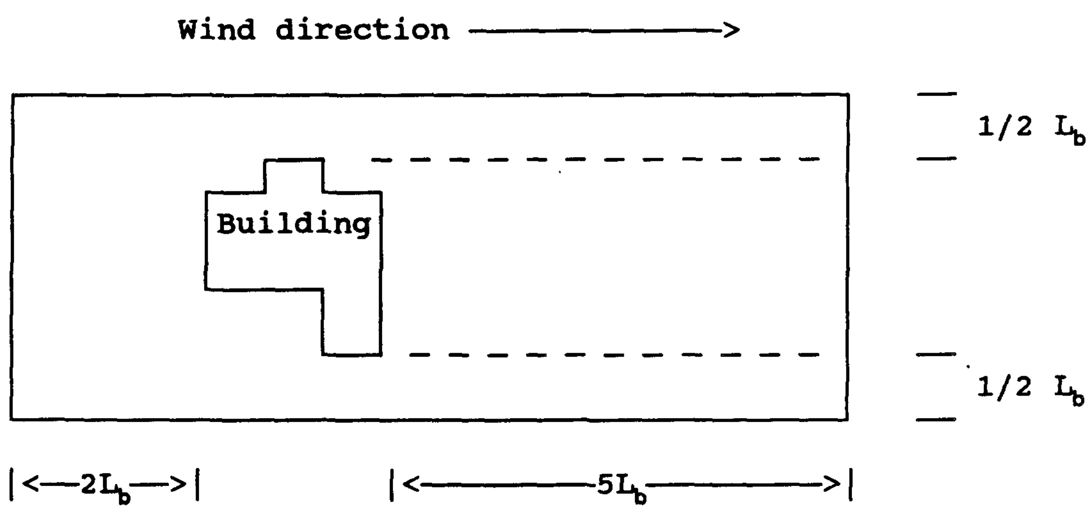
COEFFICIENTS USED TO CALCULATE LATERAL VIRTUAL DISTANCES FOR PASQUILL-GIFFORD DISPERSION RATES

Pasquill Stability Category	$x_y = \left(\frac{\sigma_{yo}}{p}\right)^{1/q}$	
	p	q
A	209.14	0.890
B	154.46	0.902
C	103.26	0.917
D	68.26	0.919
E	51.06	0.921
F	33.92	0.919

1.1.5.3 Procedures Used to Account for the Effects of Building Wakes on Effluent Dispersion.

The procedures used by the ISC2 models to account for the effects of the aerodynamic wakes and eddies produced by plant buildings and structures on plume dispersion originally followed the suggestions of Huber (1977) and Snyder (1976). Their suggestions are principally based on the results of wind-tunnel experiments using a model building with a crosswind dimension double that of the building height. The atmospheric turbulence simulated in the wind-tunnel experiments was intermediate between the turbulence intensity associated with the slightly unstable Pasquill C category and the turbulence intensity associated with the neutral D category. Thus, the data reported by Huber and Snyder reflect a specific stability, building shape and building orientation with respect to the mean wind direction. It follows that the ISC2 wake-effects evaluation procedures may not be strictly applicable to all situations. The ISC2 models also provide for the revised treatment of building wake effects for certain sources, which uses modified plume rise algorithms, following the suggestions of Schulman and Hanna (1986). This treatment is largely based on the work of Scire and Schulman (1980). When the stack height is less than the building height plus half the lesser of the building height or width, the methods of Schulman and Scire are followed. Otherwise, the methods of Huber and Snyder are followed. In the ISC2 models, direction-specific building dimensions may be used with either the Huber-Snyder or Schulman-Scire downwash algorithms.

The wake-effects evaluation procedures may be applied by the user to any stack on or adjacent to a building. For regulatory application, a building is considered sufficiently close to a stack to cause wake effects when the distance between the stack and the nearest part of the building is less than or equal to five times the lesser of the height or the projected width of the building. For downwash analyses with direction-specific building dimensions, wake effects are assumed to occur if the stack is within a rectangle composed of two lines perpendicular to the wind direction, one at $5L_b$ downwind of the building and the other at $2L_b$ upwind of the building, and by two lines parallel to the wind direction, each at $0.5L_b$ away from each side of the building, as shown below:



L_b is the lesser of the height and projected width of the building for the particular direction sector. For additional guidance on determining whether a more complex building configuration is likely to cause wake effects, the reader is referred to the Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations) - Revised (EPA, 1986). In the following sections, the Huber and Snyder building downwash method, as used in all versions of ISC, are described followed by a description of the Schulman and Scire building downwash method.

1.1.5.3.1 Huber and Snyder building downwash procedures.

The first step in the wake-effects evaluation procedures used by the ISC2 model programs is to calculate the gradual plume rise due to momentum alone at a distance of two building heights using Equation (1-23) or Equation (1-25). If the plume height, h_e, given by the sum of the stack height (no stack-tip downwash adjustment) and the momentum rise is greater than either 2.5 building heights (2.5 h_b) or the sum of the building height and 1.5 times the building width (h_b + 1.5 h_w), the plume is assumed to be unaffected by the building wake. Otherwise the plume is assumed to be affected by the building wake.

The ISC2 model programs account for the effects of building wakes by modifying both σ_y and σ_z for plumes with plume height to building height ratios less than or equal to 1.2 and by modifying only σ_z for plumes from stacks with plume height to building height ratios greater than 1.2 (but less than 2.5). The plume height used in the plume height to stack height ratios is the same plume height used to determine if the plume is affected by the building wake. The ISC2 models defines buildings as squat ($h_w \geq h_b$) or tall ($h_w < h_b$). The ISC2 models includes a general procedure for modifying σ_z and σ_y at distances greater than or equal to $3h_b$ for squat buildings or $3h_w$ for tall buildings. The air flow in the building cavity region is both highly turbulent and generally recirculating. The ISC2 models are not appropriate for estimating concentrations within such regions. The ISC2 assumption that this recirculating cavity region extends to a downwind distance of $3h_b$ for a squat building or $3h_w$ for a tall building is most appropriate for a building whose width is not much greater than its height. The ISC2 user is cautioned that, for other types of buildings, receptors located at downwind distances of $3h_b$ (squat buildings) or $3h_w$ (tall buildings) may be within the recirculating region.

The modified σ_z equation for a squat building is given by:

$$\sigma_z' = 0.7h_b + 0.067(x-3h_b) \quad \text{for} \quad 3h_b \leq x < 10h_b$$

or (1-37)

$$= \sigma_z\{x + x_z\} \quad \text{for} \quad x \geq 10h_b$$

where the building height h_b is in meters. For a tall building, Huber (1977) suggests that the width scale h_w replace h_b in Equation (1-37). The modified σ_z equation for a tall building is then given by:

$$\sigma_z' = 0.7h_w + 0.067(x-3h_w) \quad \text{for} \quad 3h_w \leq x < 10h_w$$

or (1-38)

$$= \sigma_z\{x + x_z\} \quad \text{for} \quad x \geq 10h_w$$

where h_w is in meters. It is important to note that σ_z' is not permitted to be less than the point source value given in Tables 1-2 or 1-4, a condition that may occur.

The vertical virtual distance, x_z, is added to the actual downwind distance x at downwind distances beyond $10h_b$ for squat buildings or beyond $10h_w$ for tall buildings, in order to account for the enhanced initial plume growth caused by the building wake. The virtual distance is calculated from solutions to the equations for rural or urban sigmas provided earlier.

As an example for the rural options, Equations (1-34) and (1-37) can be combined to derive the vertical virtual distance x_z for a squat building. First, it follows from Equation (1-37) that the enhanced σ_z is equal to $1.2h_b$ at a downwind distance of $10h_b$ in meters or $0.01h_b$ in kilometers. Thus, x_z for a squat building is obtained from Equation (1-34) as follows:

$$\sigma_z\{0.01h_b\} = 1.2h_b = a(0.01h_b + x_z)^b \quad (1\text{-}39)$$

$$x_z = \left(\frac{1.2h_b}{a}\right)^{1/b} - 0.01h_b \quad (1\text{-}40)$$

where the stability-dependent constants a and b are given in Table 1-2. Similarly, the vertical virtual distance for tall buildings is given by:

$$x_z = \left(\frac{1.2h_w}{a}\right)^{1/b} - 0.01h_w \quad (1\text{-}41)$$

For the urban option, x_z is calculated from solutions to the equations in Table 1-4 for $\sigma_z = 1.2h_b$ or $\sigma_z = 1.2\ h_w$ for tall or squat buildings, respectively.

For a squat building with a building width to building height ratio h_w/h_b less than or equal to 5, the modified σ_y equation is given by:

$$\sigma_y' = 0.35h_w + 0.067(x-3h_b) \qquad \text{for } 3h_b \le x < 10h_b$$

or (1-42)

$$= \sigma_y\{x + x_y\} \qquad \text{for } x \ge 10h_b$$

The lateral virtual distance is then calculated for this value of σ_y.

For building width to building height ratios h_w/h_b greater than 5, the presently available data are insufficient to provide general equations for σ_y. For a building that is much wider than it is tall and a stack located toward the center of the building (i.e., away form either end), only the height scale is considered to be significant. The modified σ_y equation for a very squat building is then given by:

$$\sigma_y' = 0.35h_b + 0.067(x-3h_b) \qquad \text{for } 3h_b \le x < 10h_b$$

or (1-43)

$$= \sigma_y\{x + x_y\} \qquad \text{for } x \ge 10h_b$$

For h_w/h_b greater than 5 and a stack located laterally within about 2.5 h_b of the end of the building, lateral plume spread is affected by the flow around the end of the building. With end effects, the enhancement in the initial lateral spread is assumed not to exceed that given by Equation (1-42) with h_w replaced by 5 h_b. The modified σ_y equation is given by:

$$\sigma_y' = 1.75h_b + 0.067(x-3h_b) \qquad \text{for } 3h_b \leq x < 10h_b$$

or (1-44)

$$= \sigma_y\{x + x_y\} \qquad \text{for } x \geq 10h_b$$

The upper and lower bounds of the concentrations that can be expected to occur near a building are determined respectively using Equations (1-43) and (1-44). The user must specify whether Equation (1-43) or Equation (1-44) is to be used in the model calculations. In the absence of user instructions, the ISC2 models use Equation (1-43) if the building width to building height ratio h_w/h_b exceeds 5.

Although Equation (1-43) provides the highest concentration estimates for squat buildings with building width to building height ratios (h_w/h_b) greater than 5, the equation is applicable only to a stack located near the center of the building when the wind direction is perpendicular to the long side of the building (i.e., when the air flow over the portion of the building containing the source is two dimensional). Thus, Equation (1-44) generally is more appropriate then Equation (1-43). It is believed that Equations (1-43) and (1-44) provide reasonable limits on the extent of the lateral enhancement of dispersion and that these equations are adequate until additional data are available to evaluate the flow near very wide buildings.

The modified σ_y equation for a tall building is given by:

$$\sigma_y' = 0.35h_w + 0.067(x-3h_w) \qquad \text{for } 3h_w \le x < 10h_w$$

or (1-45)

$$= \sigma_y\{x + x_y\} \qquad \text{for } x \ge 10h_w$$

The ISC2 models print a message and do not calculate concentrations for any source-receptor combination where the source-receptor separation is less than 1 meter, and also for distances less than 3 h_b for a squat building or 3 h_w for a tall building under building wake effects. It should be noted that, for certain combinations of stability and building height and/or width, the vertical and/or lateral plume dimensions indicated for a point source by the dispersion curves at a downwind distance of ten building heights or widths can exceed the values given by Equation (1-37) or (1-38) and by Equation (1-42) or (1-43). Consequently, the ISC2 models do not permit the virtual distances x_y and x_z to be less than zero.

1.1.5.3.2 Schulman and Scire refined building downwash procedures.

The revised procedures for treating building wake effects include the use of the Schulman and Scire downwash method. The revised procedures only use the Schulman and Scire method when the physical stack height is less than h_b + 0.5 L_B, where h_b is the building height and L_B is the lesser of the building height or width. In regulatory applications, the maximum projected width is used. The features of the Schulman and Scire method are: (1) reduced plume rise due to initial plume dilution, (2) enhanced vertical plume spread as a linear function of the effective plume height, and (3) specification of building dimensions as a function of wind direction. The reduced plume rise equations were previously described in Section 1.1.4.11.

When the Schulman and Scire method is used, the ISC2 dispersion models specify a linear decay factor, to be included in the σ_z's calculated using Equations (1-37) and (1-38), as follows:

$$\sigma_z'' = A\sigma_z' \qquad (1\text{-}46)$$

where σ_z' is from either Equation (1-37) or (1-38) and A is the linear decay factor determined as follows:

$$\begin{aligned} A &= 1 && \text{if } h_e \le h_b \\ A &= \frac{h_b - h_e}{2L_B} + 1 && \text{if } h_b < h_e \le h_b + 2L_B \\ A &= 0 && \text{if } h_e > h_b + 2L_B \end{aligned} \qquad (1\text{-}47)$$

where the plume height, h_e, is the height due to gradual momentum rise at 2 h_b used to check for wake effects. The effect of the linear decay factor is illustrated in Figure 1-1. For Schulman-Scire downwash cases, the linear decay term is also used in calculating the vertical virtual distances with Equations (1-40) to (1-41).

When the Schulman and Scire building downwash method is used the ISC2 models require direction specific building heights and projected widths for the downwash calculations. The ISC2 models also accept direction specific building dimensions for Huber-Snyder downwash cases. The user inputs the building height and projected widths of the building tier associated with the greatest height of wake effects for each ten degrees of wind direction. These building heights and projected widths are the same as are used for good engineering practice (GEP) stack height calculations. The user is referred to EPA (1986) for calculating the appropriate building heights and projected widths for each direction. Figure 1-2 shows an example of a two tiered building with different tiers controlling the height that is appropriate for use for different wind directions. For an east or west wind the lower tier defines the appropriate height and width, while for a north or south wind the upper tier defines the appropriate values for height and width.

1.1.5.4 Procedures Used to Account for Buoyancy-Induced Dispersion.

The method of Pasquill (1976) is used to account for the initial dispersion of plumes caused by turbulent motion of the plume and turbulent entrainment of ambient air. With this method, the effective vertical dispersion σ_{ze} is calculated as follows:

$$\sigma_{ze} = \left[\sigma_z^2 + \left(\frac{\Delta h}{3.5}\right)^2\right]^{1/2} \qquad (1-48)$$

where σ_z is the vertical dispersion due to ambient turbulence and Δh is the plume rise due to momentum and/or buoyancy. The lateral plume spread is parameterized using a similar expression:

$$\sigma_{ye} = \left[\sigma_y^2 + \left(\frac{\Delta h}{3.5}\right)^2\right]^{1/2} \qquad (1-49)$$

where σ_y is the lateral dispersion due to ambient turbulence. It should be noted that Δh is the distance-dependent plume rise if the receptor is located between the source and the distance to final rise, and final plume rise if the receptor is located beyond the distance to final rise. Thus, if the user elects to use final plume rise at all receptors the distance-dependent plume rise is used in the calculation of buoyancy-induced dispersion and the final plume rise is used in the concentration equations. It should also be noted that buoyancy-induced dispersion is not used when the Schulman-Scire downwash option is in effect.

1.1.6 The Vertical Term

1.1.6.1 The Vertical Term for Gases and Small Particulates.

In general, the effects on ambient concentrations of gravitational settling and dry deposition can be neglected for gaseous pollutants and small particulates (diameters less than about 20 micrometers). The Vertical Term is then given by:

$$V = \exp\left[-0.5\left(\frac{z_r - h_e}{\sigma_z}\right)^2\right] + \exp\left[-0.5\left(\frac{z_r + h_e}{\sigma_z}\right)^2\right]$$

$$+ \sum_{i=1}^{\infty}\left\{\exp\left[-0.5\left(\frac{H_1}{\sigma_z}\right)^2\right] + \exp\left[-0.5\left(\frac{H_2}{\sigma_z}\right)^2\right]\right.$$

$$\left. + \exp\left[-0.5\left(\frac{H_3}{\sigma_z}\right)^2\right] + \exp\left[-0.5\left(\frac{H_4}{\sigma_z}\right)^2\right]\right\} \qquad (1\text{-}50)$$

where:

$h_e = h_s + \Delta h$

$H_1 = z_r - (2iz_i - h_e)$

$H_2 = z_r + (2iz_i - h_e)$

$H_3 = z_r - (2iz_i + h_e)$

$H_4 = z_r + (2iz_i + h_e)$

z_r = receptor height above ground (flagpole) (m)

z_i = mixing height (m)

The infinite series term in Equation (1-50) accounts for the effects of the restriction on vertical plume growth at the top of the mixing layer. As shown by Figure 1-3, the method of image sources is used to account for multiple reflections of the plume from the ground surface and at the top of the mixed layer. It should be noted that, if the effective stack height, h_e, exceeds the mixing height, z_i, the plume is assumed to fully penetrate the elevated inversion and the ground-level concentration is set equal to zero.

Equation (1-50) assumes that the mixing height in rural and urban areas is known for all stability categories. As explained below, the meteorological preprocessor program uses mixing heights derived from twice-daily mixing heights calculated using the Holzworth (1972) procedures. These mixing heights are believed to be representative, at least on the average, of mixing heights in urban areas under all stabilities and of mixing heights in rural areas during periods of instability or neutral stability. However, because the Holzworth minimum mixing heights are intended to include the heat island effect for urban areas, their applicability to rural areas during periods of stable meteorological conditions (E or F stability) is questionable. Consequently, the ISC2 models in the Rural Mode currently delete the infinite series term in Equation (1-50) for the E and F stability categories.

The Vertical Term defined by Equation (1-50) changes the form of the vertical concentration distribution from Gaussian to rectangular (uniform concentration within the surface mixing layer) at long downwind distances. Consequently, in order to reduce computational time without a loss of accuracy, Equation (1-50) is changed to the form:

$$V = \frac{\sqrt{2\pi}\,\sigma_z}{z_i} \qquad (1\text{-}51)$$

at downwind distances where the σ_z/z_i ratio is greater than or equal to 1.6.

The meteorological preprocessor program, RAMMET, used by the ISC2 Short Term model uses an interpolation scheme to assign hourly rural and urban mixing heights in the basis of the early morning and afternoon mixing heights calculated using the Holzworth (1972) procedures. The procedures used to interpolate hourly mixing heights in urban and rural areas are illustrated in Figure 1-4, where:

$H_m\{max\}$ = maximum mixing height on a given day
$H_m\{min\}$ = minimum mixing height on a given day
MN = midnight
SR = sunrise
SS = sunset

The interpolation procedures are functions of the stability category for the hour before sunrise. If the hour before sunrise is neutral, the mixing heights that apply are indicated by the dashed lines labeled neutral in Figure 1-4. If the hour before sunrise is stable, the mixing heights that apply are indicated by the dashed lines labeled stable. It should be pointed out that there is a discontinuity in the rural mixing height at sunrise if the preceding hour is stable. As explained above, because of uncertainties about the applicability of Holzworth mixing heights during periods of E and F stability, the ISC2 models ignore the interpolated mixing heights for E and F stability, and treat such cases as having unlimited vertical mixing.

1.1.6.2 The Vertical Term in Elevated Terrain.

The ISC2 models make the following assumption about plume behavior in elevated terrain:

- The plume axis remains at the plume stabilization height above mean sea level as it passes over elevated or depressed terrain.
- The mixing height is terrain following.
- The wind speed is a function of height above the surface (see Equation (1-6)).

Thus, a modified plume stabilization height h_e' is substituted for the effective stack height h_e in the Vertical

Term given by Equation (1-50). For example, the effective plume stabilization height at the point x, y is given by:

$$h_e' = h_e + z_s - z|_{(x,y)} \quad (1\text{-}52)$$

where:

z_s = height above mean sea level of the base of the stack

$z|_{(x,y)}$ = height above mean sea level of terrain at the receptor location (x,y)

It should also be noted that, as recommended by EPA, the ISC2 models now "truncate" terrain at stack height as follows: if the terrain height $z - z_s$ exceeds the source release height, h_s, the elevation of the receptor is automatically "chopped off" at the physical release height. The user is cautioned that concentrations at these complex terrain receptors are subject to considerable uncertainty. Figure 1-5 illustrates the terrain-adjustment procedures used by the ISC2 models.

1.1.6.3 The Vertical Term for Large Particulates.

The dispersion of particulates or droplets with significant gravitational settling velocities differs from that of gaseous pollutants and small particulates in that the larger particulates are brought to the surface by the combined processes of atmospheric turbulence and gravitational settling. Additionally, gaseous pollutants and small particulates tend to be reflected from the surface, while larger particulates that come in contact with the surface may be completely or partially retained at the surface. The ISC2 Vertical Term for large particulates includes the effects of both gravitational settling and removal by dry deposition. Gravitational settling is assumed to result in a tilted plume with the plume axis inclined to the horizontal at an angle given by $\arctan(V_s/u_s)$ where V_s is the gravitational settling velocity. A user-specified fraction (γ) of the material that reaches the ground surface by the combined processes of gravitational settling and atmospheric turbulence is assumed to be reflected from the surface. Figure 1-6 illustrates the vertical concentration profiles for complete reflection from the surface (γ equal to unity), 50-percent reflection from the surface (γ equal to 0.5) and complete retention at the surface (γ equal to zero).

For a given particulate source, the user must subdivide the total particulate emissions into N settling-velocity categories (the maximum value of N is 20). The ground-level concentration of particulates with settling velocity V_{sn} is given by Equation (1-1) with the Vertical Term defined as (Dumbauld and Bjorklund, 1975):

$$V = \phi_n \left\{ \exp\left[-0.5\left(\frac{z_r - h_e}{\sigma_z}\right)^2\right] + \gamma_n \exp\left[-0.5\left(\frac{z_r + h_e}{\sigma_z}\right)^2\right] \right.$$

$$+ \sum_{i=1}^{\infty}\left(\gamma_n^{i-1} \exp\left[-0.5\left(\frac{A_1}{\sigma_z}\right)^2\right] + \gamma_n^{i} \exp\left[-0.5\left(\frac{A_2}{\sigma_z}\right)^2\right]\right.$$

$$\left.\left. + \gamma_n^{i} \exp\left[-0.5\left(\frac{A_3}{\sigma_z}\right)^2\right] + \gamma_n^{i+1} \exp\left[-0.5\left(\frac{A_4}{\sigma_z}\right)^2\right]\right)\right\} \quad (1\text{-}53)$$

where:

ϕ_n = mass fraction of particulates for n^{th} settling category

A_1 = $z_r - [2iz_i - (h_e - h_v)]$

A_2 = $z_r + [2iz_i - (h_e - h_v)]$

A_3 = $z_r - [2iz_i + (h_e - h_v)]$

A_4 = $z_r + [2iz_i + (h_e - h_v)]$

γ_n = reflection coefficient for particulates in the n^{th} settling velocity category (set equal to unity for complete reflection)

h_v = $V_{sn}\, x/u_s$ = plume height correction for plume tilt

V_{sn} = settling velocity of particulates in the n^{th} settling velocity category.

The total concentration is computed by the program by summing over the N settling-velocity categories. The optional algorithm used to calculate dry deposition is discussed in Section 1.3.

Use of Equation (1-53) requires a knowledge of both the particulate size distribution and the density of the particulates emitted by each source. The total particulate emissions for each source are subdivided by the user into a maximum of 20 categories and the gravitational settling velocity is calculated for the mass-mean diameter of each category. The mass-mean diameter is given by:

$$d = [0.25(d_1^3 + d_1^2 d_2 + d_1 d_2^2 + d_2^3)]^{1/3} \qquad (1\text{-}54)$$

where d_1 and d_2 are the lower and upper bounds of the particle-size category. McDonald (1960) gives simple techniques for calculating the gravitational settling velocity for all sizes of particulates. For particulates with a density on the order of 1 gram per cubic centimeter and diameters less than about 80 micrometers, the settling velocity is given by:

$$V_s = \frac{2\rho g r^2}{9\mu} \qquad (1\text{-}55)$$

where:

V_s = settling velocity (cm/s)

ρ = particulate density (gm/cm^3)

g = acceleration due to gravity (980.6 cm/s^2)

r = particle radius (cm)

μ = absolute viscosity of air ($\mu \sim 1.83 \times 10^{-4}$ gm/cm/s)

It should be noted that the settling velocity calculated using Equation (1-55) must be converted by the user from centimeters per second to meters per second for use in the model calculations.

The reflection coefficient γ_n can be estimated for each particle-size category using Figure 1-7 and the settling velocity calculated for the mass-mean diameter. If it is desired to include the effects of gravitational settling in calculating ambient particulate concentrations while at the same time excluding the effects of deposition, γ_n should be set equal to unity for all settling velocities. On the other hand, if it is desired to calculate maximum possible deposition, γ_n should be set equal to zero for all settling velocities. The effects of dry deposition for gaseous pollutants may be estimated by setting the settling velocity V_{sn} equal to zero and the reflection coefficient γ_n equal to the amount of material assumed to be reflected from the surface. For example, if 20 percent of a gaseous pollutant that reaches the surface is assumed to be retained at the surface by vegetation uptake or other mechanisms, γ_n is equal to 0.8.

The derivation of Equation (1-53) assumes that the terrain is flat or gently rolling. Consequently, the gravitational settling and dry deposition options cannot be used for sources located in complex terrain without violating mass continuity. However, the effects of gravitational settling alone can be estimated for sources located in complex terrain by setting γ_n equal to unity for each settling velocity category. This procedure will tend to overestimate concentrations, especially at the longer downwind distances, because it neglects the effects of dry deposition.

It should be noted that Equation (1-53) assumes that σ_z is a continuous function of downwind distance. Also, Equation (1-53) does not simplify for σ_z/z_i greater than 1.6 as does Equation (1-50). As shown by Table 1-2, σ_z for the very unstable A stability category attains a maximum value of 5,000 meters at 3.11 kilometers. Because Equation (1-53) requires that σ_z be a continuous function of distance, the coefficients a and b given in Table 1-2 for A stability and the 0.51 to 3.11 kilometer range are used by the ISC2 models in calculations beyond 3.11 kilometers. Consequently, this introduces uncertainties in the results of the calculations beyond 3.11 kilometers for A stability.

1.1.7 The Decay Term

The Decay Term, which is a simple method of accounting for pollutant removal by physical or chemical processes, is of the form:

$$D = \exp\left(-\psi \frac{x}{u_s}\right) \quad \text{for } \psi > 0$$

or

$$= 1 \quad \text{for } \psi = 0 \qquad (1\text{-}56)$$

where:

ψ = the decay coefficient (s^{-1}) (a value of zero means decay is not considered)

x = downwind distance (m)

For example, if $T_{1/2}$ is the pollutant half life in seconds, the user can obtain ψ from the relationship:

$$\psi = \frac{0.693}{T_{1/2}} \qquad (1\text{-}57)$$

The default value for ψ is zero. That is, decay is not considered in the model calculations unless ψ is specified. However, a decay half life of 4 hours (ψ = 0.0000481 s^{-1}) is automatically assigned for SO_2 when modeled in the urban mode.

1.2 VOLUME AND AREA SOURCE EMISSIONS

1.2.1 General

The volume and area sources options of the ISC2 models are used to simulate the effects of emissions from a wide variety of industrial sources. In general, the ISC2 volume source model is used to simulate the effects of emissions from sources such as building roof monitors and line sources (for example, conveyor belts and rail lines). The ISC2 area source model is used to simulate the effects of fugitive emissions from sources such as storage piles and slag dumps.

1.2.2 The Short-Term Volume Source Model

The ISC2 models use a virtual point source algorithm to model the effects of volume sources. Therefore, Equation (1-1) is also used to calculate concentrations produced by volume source emissions. If the volume source is elevated, the user assigns the effective emission height h_e. The user also assigns initial lateral (σ_{yo}) and vertical (σ_{zo}) dimensions for the volume source. Lateral (x_y) and vertical (x_z) virtual distances are added to the actual downwind distance x for the σ_y and σ_z calculations. The virtual distances are calculated from solutions to the sigma equations as is done for point sources with building downwash.

The volume source model is used to simulate the effects of emissions from sources such as building roof monitors and for line sources (for example, conveyor belts and rail lines). The north-south and east-west dimensions of each volume source used in the model must be the same. Table 1-6 summarizes the general procedures suggested for estimating initial lateral (σ_{yo}) and vertical (σ_{zo}) dimensions for single volume sources and for multiple volume sources used to represent a line source. In the case of a long and narrow line source such as a rail line, it may not be practical to divide the source into N volume sources, where N is given by the length of the line source divided by its width. The user can obtain an approximate representation of the line source by placing a smaller number of volume sources at equal intervals along the line source. In general, the spacing between individual volume sources should not be greater than twice the width of the line source. However, a larger spacing can be used if the ratio of the minimum source-receptor separation and the spacing between individual volume sources is greater than about 3. In these cases, concentrations calculated using fewer than N volume sources to represent the line source converge to the concentrations calculated using N volume sources to represent the line source as long as sufficient volume sources are used to preserve the horizontal geometry of the line source.

Figure 1-8 illustrates representations of a curved line source by multiple volume sources. Emissions from a line source or narrow volume source represented by multiple volume sources are divided equally among the individual sources unless there is a known spatial variation in emissions. Setting the initial lateral dimension σ_{yo} equal to W/2.15 in Figure 1-8(a) or 2W/2.15 in Figure 1-8(b) results in overlapping Gaussian distributions for the individual sources. If the wind direction is normal to a straight line source that is represented by multiple volume sources, the initial crosswind concentration distribution is uniform except at the edges of the line source. The doubling of σ_{yo} by the user in the approximate line-source representation in Figure 1-8(b) is offset by the fact that the emission rates for the individual volume sources are also doubled by the user.

There are two types of volume sources: surface-based sources, which may also be modeled as area sources, and elevated sources. An example of a surface-based source is a surface rail line. The effective emission height h_e for a surface-based source is usually set equal to zero. An example of an elevated source is an elevated rail line with an effective emission height h_e set equal to the height of the rail line.

TABLE 1-6

SUMMARY OF SUGGESTED PROCEDURES FOR ESTIMATING INITIAL LATERAL DIMENSIONS σ_{yo} AND INITIAL VERTICAL DIMENSIONS σ_{zo} FOR VOLUME AND LINE SOURCES

Type of Source	Procedure for Obtaining Initial Dimension
(a) Initial Lateral Dimensions (σ_{yo})	
Single Volume Source	σ_{yo} = length of side divided by 4.3
Line Source Represented by Adjacent Volume Sources (see Figure 1-8(a))	σ_{yo} = length of side divided by 2.15
Line Source Represented by Separated Volume Sources (see Figure 1-8(b))	σ_{yo} = center to center distance divided by 2.15
(b) Initial Vertical Dimensions (σ_{zo})	
Surface-Based Source ($h_e \sim 0$)	σ_{zo} = vertical dimension of source divided by 2.15
Elevated Source ($h_e > 0$) on or Adjacent to a Building	σ_{zo} = building height divided by 2.15
Elevated Source ($h_e > 0$) not on or Adjacent to a Building	σ_{zo} = vertical dimension of source divided by 4.3

1.2.3 The Short-Term Area Source Model

The ISC2 area source model is based on the equation for a finite crosswind line source. Individual area sources are required to have the same north-south and east-west dimensions. However, as shown by Figure 1-9, the effects of an area source with an irregular shape can be simulated by dividing the area source into multiple squares that approximate the geometry of the area source. Note that the size of the individual area sources in Figure 1-9 varies; the only requirement is that each area source must be square. The ground-level concentration at downwind distance x (measured from the downwind edge of the area source) and crosswind distance y is given by:

$$\chi = \frac{Q_A K V E x_o}{4\sqrt{2} u_s \sigma_z} \tag{1-58}$$

where:

- Q_A = area source emission rate (mass per unit area per unit time)
- K = units scaling coefficient (Equation (1-1))
- V = vertical term (see Section 1.1.6)
- D = decay term (see Section 1.1.7)
- E = error function term = $\mathrm{erf}\left(\frac{r_o' + y}{\sqrt{2}\sigma_y}\right) + \mathrm{erf}\left(\frac{r_o' - y}{\sqrt{2}\sigma_y}\right)$
- x_o = length of the side of the area source (m)
- r_o' = effective radius of area source = $x_o/\sqrt{\pi}$ (m)

and the Vertical Term is given by Equation (1-50) or Equation (1-53) with the effective emission height h_e assigned by the user. In general, h_e should be set equal to the physical height of the source of fugitive emissions. For example, the emission height h_e of a slag dump is the physical height of the slag dump. A vertical virtual distance, equal to x_o, is added to the actual downwind distance x for the σ_z calculations. If a receptor is located within r_o' plus 1 meter of the center of an area source, a warning message is printed and no concentrations are calculated for the source-receptor combination. However, program execution is not terminated.

It is recommended that, if the separation between an area source and a receptor is less than the length of the side of the area source x_o, then the area source should be subdivided into smaller area sources. If the source-receptor separation is less than x_o, the finite line segment algorithm does not adequately represent the source-receptor geometry.

1.3 THE ISC2 SHORT-TERM DRY DEPOSITION MODEL

1.3.1 General

The Industrial Source Complex short-term dry deposition model is based on the Dumbauld, et al (1976) deposition model. This model, which is an advanced version of the Cramer, et al (1972) deposition model, assumes that a user-specified fraction γ_n of the material that comes into contact with the ground surface by the combined processes of atmospheric turbulence and gravitational settling is reflected from the surface (see Section 1.1.6.3). The reflection coefficient γ_n, which is a function of settling velocity and the ground surface for particulates and of the ground surface for gaseous pollutants, is analogous in purpose to the deposition velocity used in other deposition models. The Cramer, et al (1972) deposition model has closely matched ground-level deposition patterns for droplets with diameters above about 30 micrometers, while the more generalized Dumbauld, et al (1976) deposition model has closely matched observed deposition patterns for both large and small droplets.

Section 1.1.6.3 discusses the selection of the reflection coefficient γ_n as well as the computation of the gravitational settling velocity V_{sn}. The ISC2 dry deposition model should not be applied to sources located in elevated terrain or for receptors above local terrain. Also, as noted in Section 1.1.6.3, uncertainties in the deposition calculations are likely for the A stability category if deposition calculations are made at downwind distances greater than 3.11 kilometers. Deposition and ambient concentration calculations cannot be made in a single program execution. In an individual computer run, the ISC2 models calculate either concentration (including the effects of gravitational settling and dry deposition) or dry deposition.

1.3.2 Point and Volume Source Emissions

Deposition for particulates in the n^{th} settling-velocity category or a gaseous pollutant with zero settling velocity V_{sn} and a reflection coefficient γ_n is given by:

$$DEP_n = \frac{Q_\tau K(1-\gamma_n)\phi_n V_d D}{2\pi\sigma_y\sigma_z x} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (1\text{-}59)$$

where the Vertical Term is defined as follows:

$$V_d = [\bar{b}(h_e - h_v) + h_v] \exp\left[-0.5\left(\frac{h_e - h_v}{\sigma_z}\right)^2\right]$$

$$+ \sum_{i=1}^{\infty}\left\{\gamma_N^{i-1}[\bar{b}(2iz_i - (h_e - h_v)) - h_v] \exp\left[-0.5\left(\frac{2iz_i - (h_e - h_v)}{\sigma_z}\right)^2\right]\right.$$

$$\left. + \gamma_n^i[\bar{b}(2iz_i + (h_e - h_v)) + h_v] \exp\left[-0.5\left(\frac{2iz_i + (h_e - h_v)}{\sigma_z}\right)^2\right]\right\} \qquad (1\text{-}60)$$

K, D, and h_v were defined previously (Equations (1-1), (1-53), and (1-56)). The parameter Q_τ is the total amount of material emitted during the time period τ for which the deposition calculation is made. For example, Q_τ is the total amount of material emitted during a 1-hour period if an hourly deposition is calculated. To simplify the user input, and to keep the maximum compatibility between input files for concentration and deposition runs, the model takes emission inputs in grams per second (g/s), and converts to grams per hour for deposition calculations. For time periods longer than an hour, the program sums the deposition calculated for each hour to obtain the total deposition. The coefficient $\bar{b}$ is the average value of the exponent b for the interval between the source and the downwind distance x (see Tables 1-1 to 1-4). Values of $\bar{b}$ exist for both the Pasquill-Gifford dispersion parameters and Briggs-McElroy-Pooler curves. In the case of a volume source, the user must specify the effective emission height h_e and the initial source dimensions σ_{yo} and σ_{zo}. It should be noted that for computational purposes, the model calculates the quantity, $\sum_{n=1}^{NVS} (1-\gamma_n)\,\phi_n V_d$, as the "vertical term."

1.3.3 Area Source Emissions

For area source emissions Equation (1-59) is changed to the form:

$$DEP_n = \frac{Q_{A\tau} K (1-\gamma_n)\,\phi_n V_d D E x_o}{4\sqrt{2}\sigma_z x} \qquad (1\text{-}61)$$

K, D, V_d are defined in Equations (1-1), (1-56), and (1-60), respectively. The parameter $Q_{A\tau}$ is the total mass per unit area emitted over the time period τ for which deposition is calculated and E is the error function term defined in Equation (1-56).

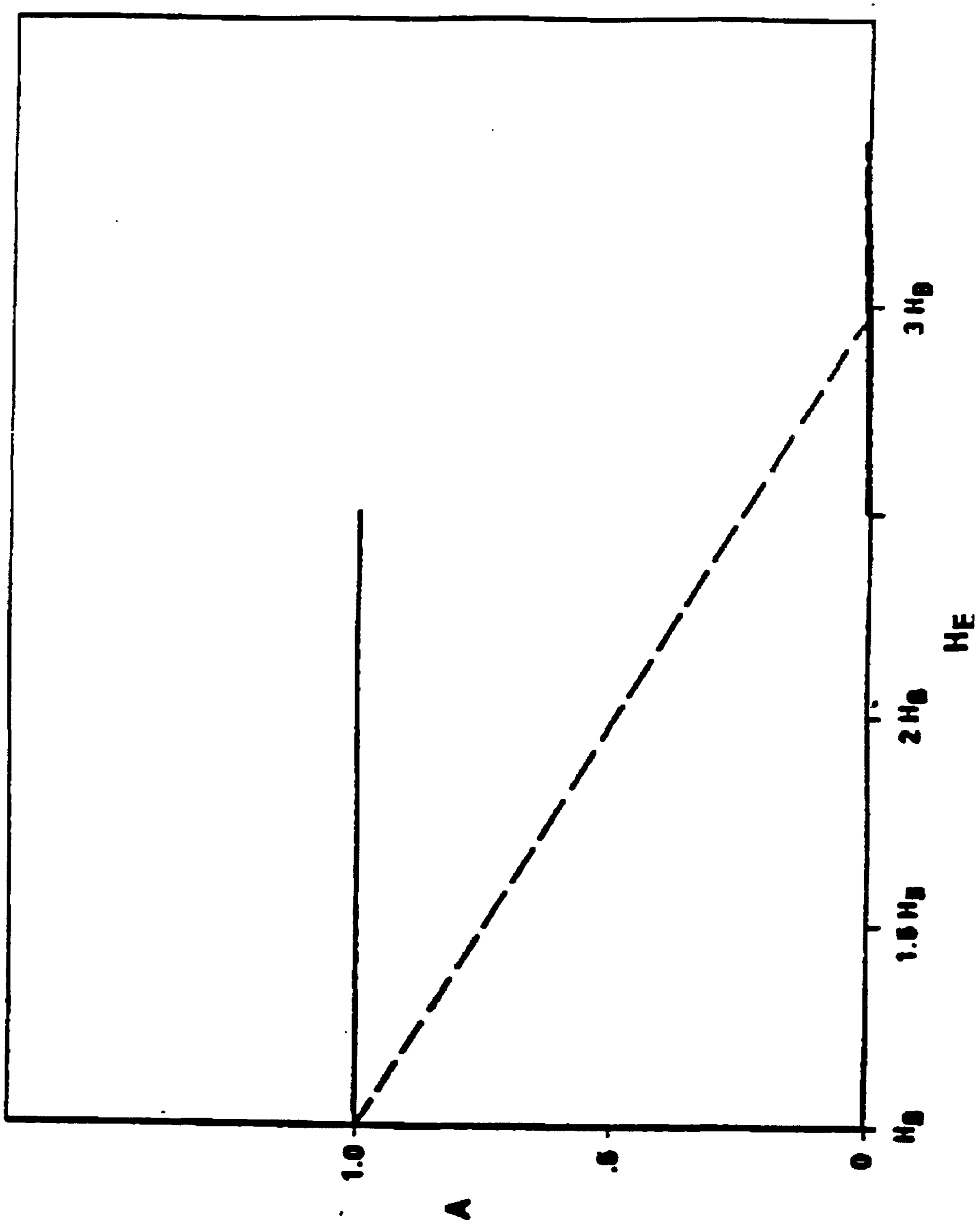
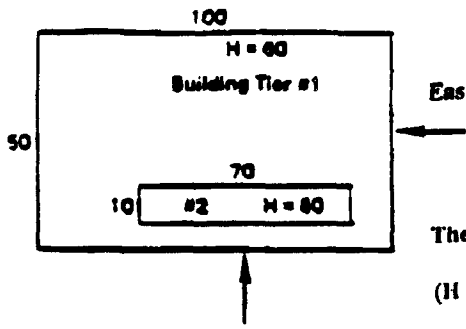


FIGURE 1-1. LINEAR DECAY FACTOR, A AS A FUNCTION OF EFFECTIVE STACK HEIGHT, H_e. A SQUAT BUILDING IS ASSUMED FOR SIMPLICITY.

Height of wake effects is $H_w = H + 1.5\ L_B$ where L_B is the lesser of the height of the width.



East and west wind:

$$H_{W1} = 60 + 1.5(50) = 135$$
$$H_{W2} = 80 + 1.5(10) = 95$$

Therefore, the lower building tier #1 width and height (H = 60, W = 50) are used

North and South wind:

$$H_{W1} = 60 + 1.5(60) = 150$$
$$H_{W2} = 80 + 1.5(70) = 185$$

Therefore, the upper building tier #2 width and height (H = 80, W = 70) are used

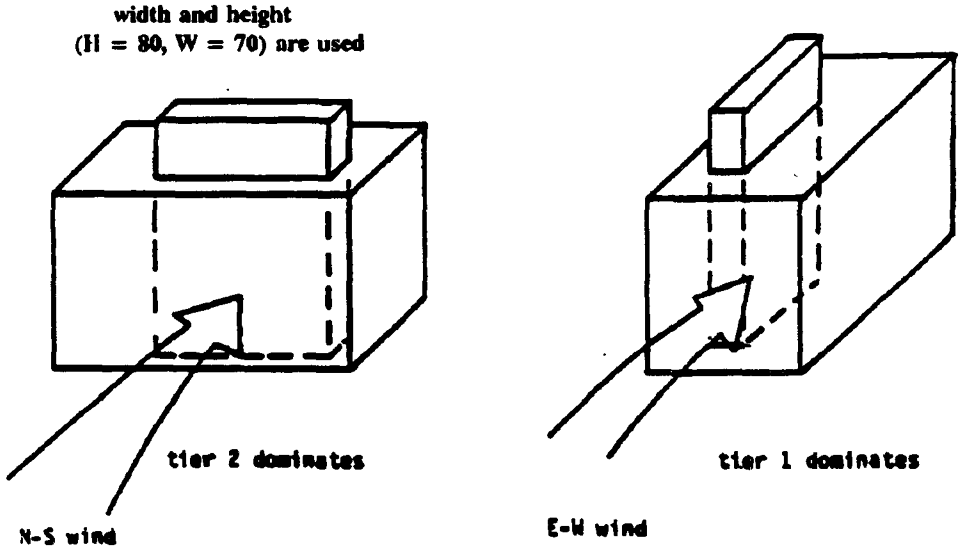


FIGURE 1-2. ILLUSTRATION OF TWO TIERED BUILDING WITH DIFFERENT TIERS DOMINATING DIFFERENT WIND DIRECTIONS

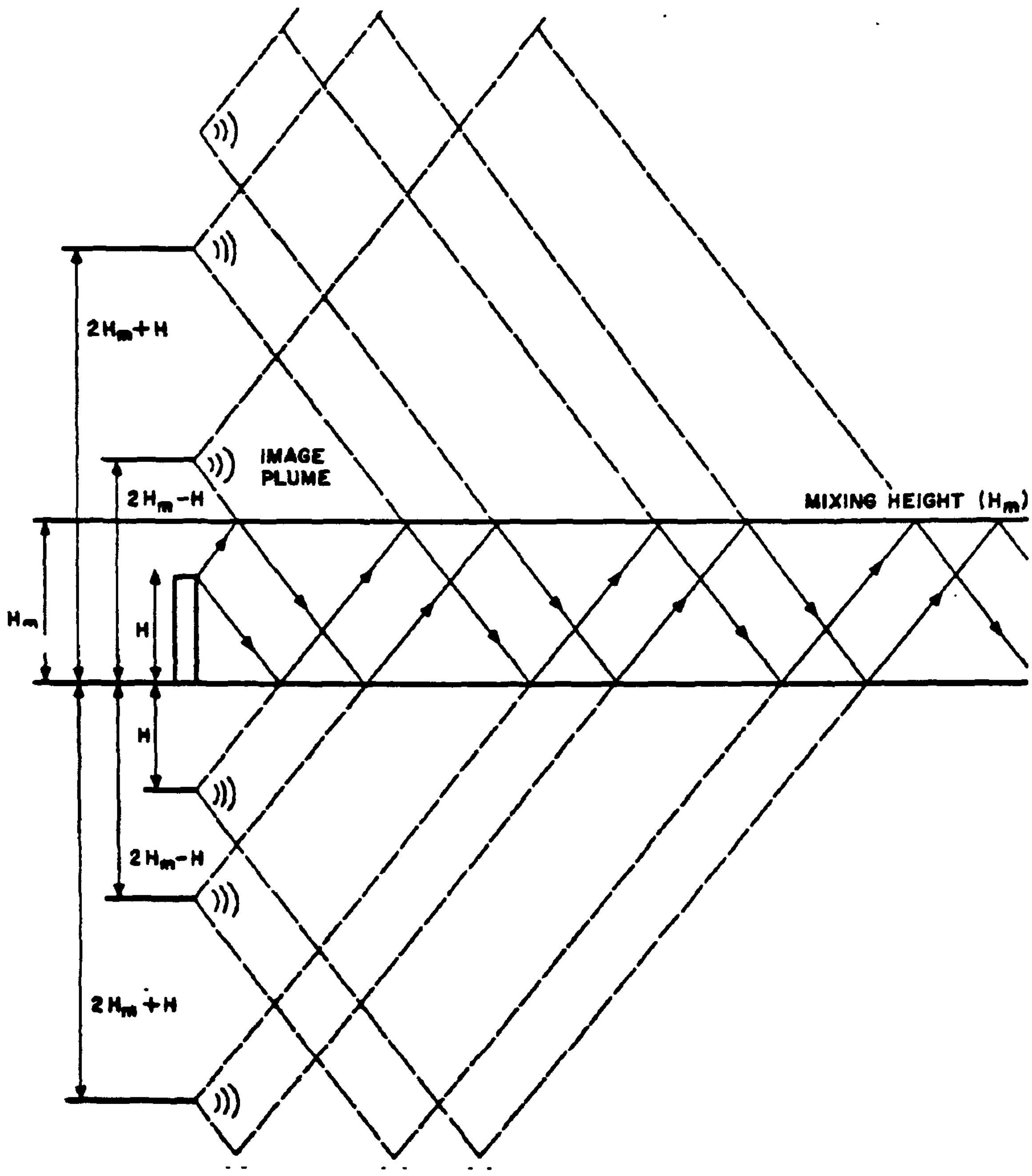


FIGURE 1-3. THE METHOD OF MULTIPLE PLUME IMAGES USED TO SIMULATE PLUME REFLECTION IN THE ISC2 MODEL

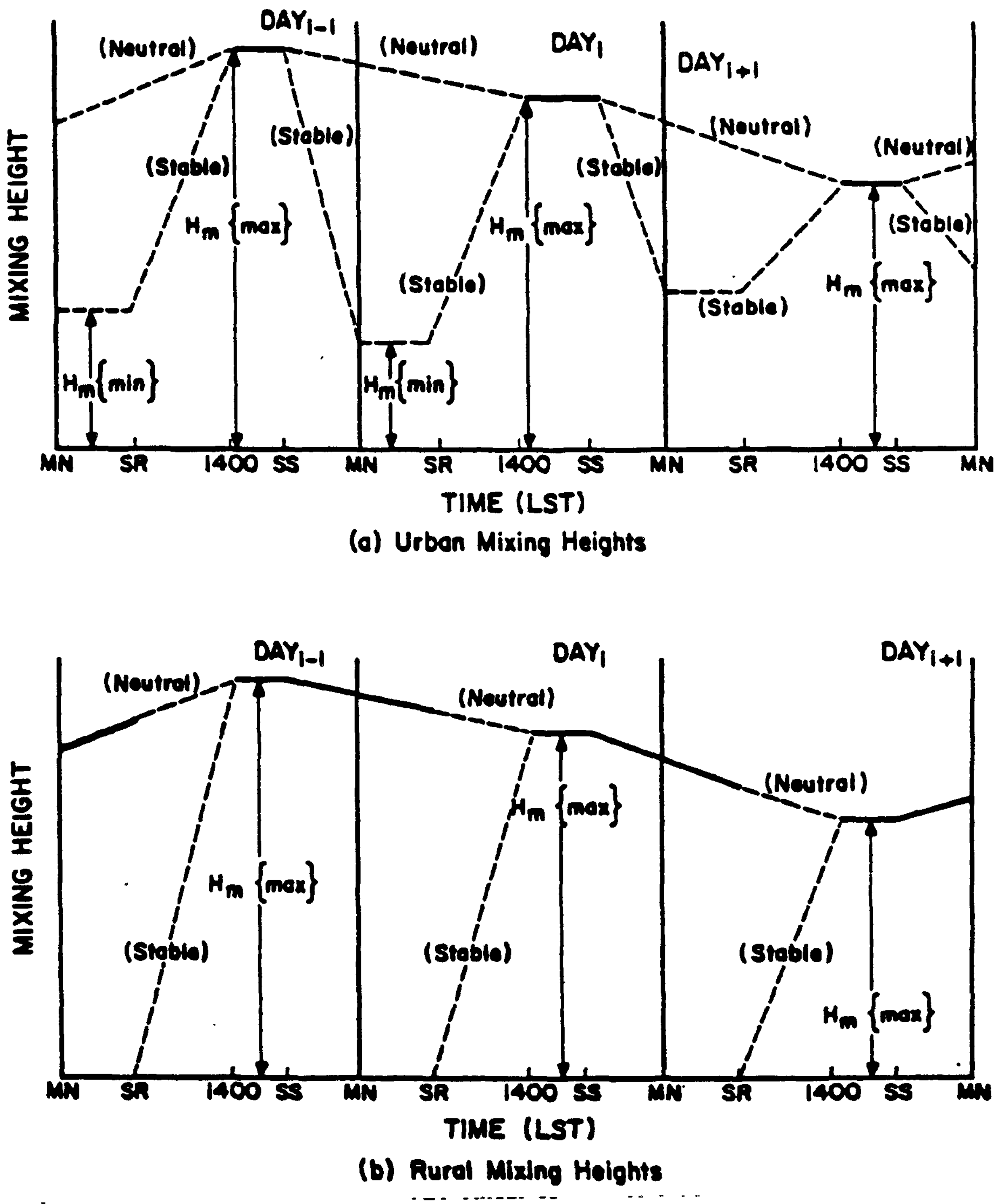


FIGURE 1-4. SCHEMATIC ILLUSTRATION OF (a) URBAN AND (b) RURAL MIXING HEIGHT INTERPOLATION PROCEDURES

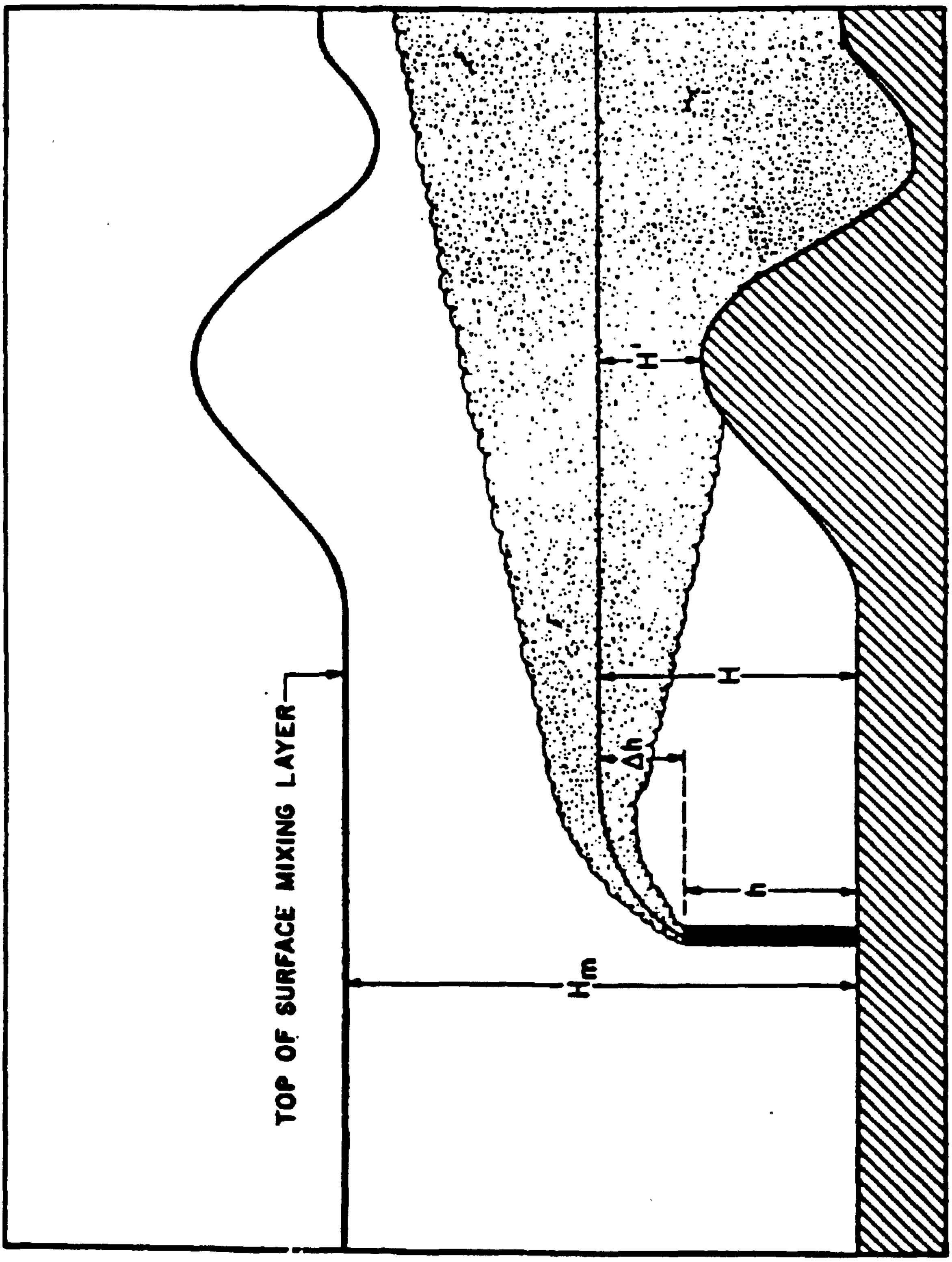


FIGURE 1-5. ILLUSTRATION OF PLUME BEHAVIOR IN COMPLEX TERRAIN ASSUMED BY THE ISC2 MODEL

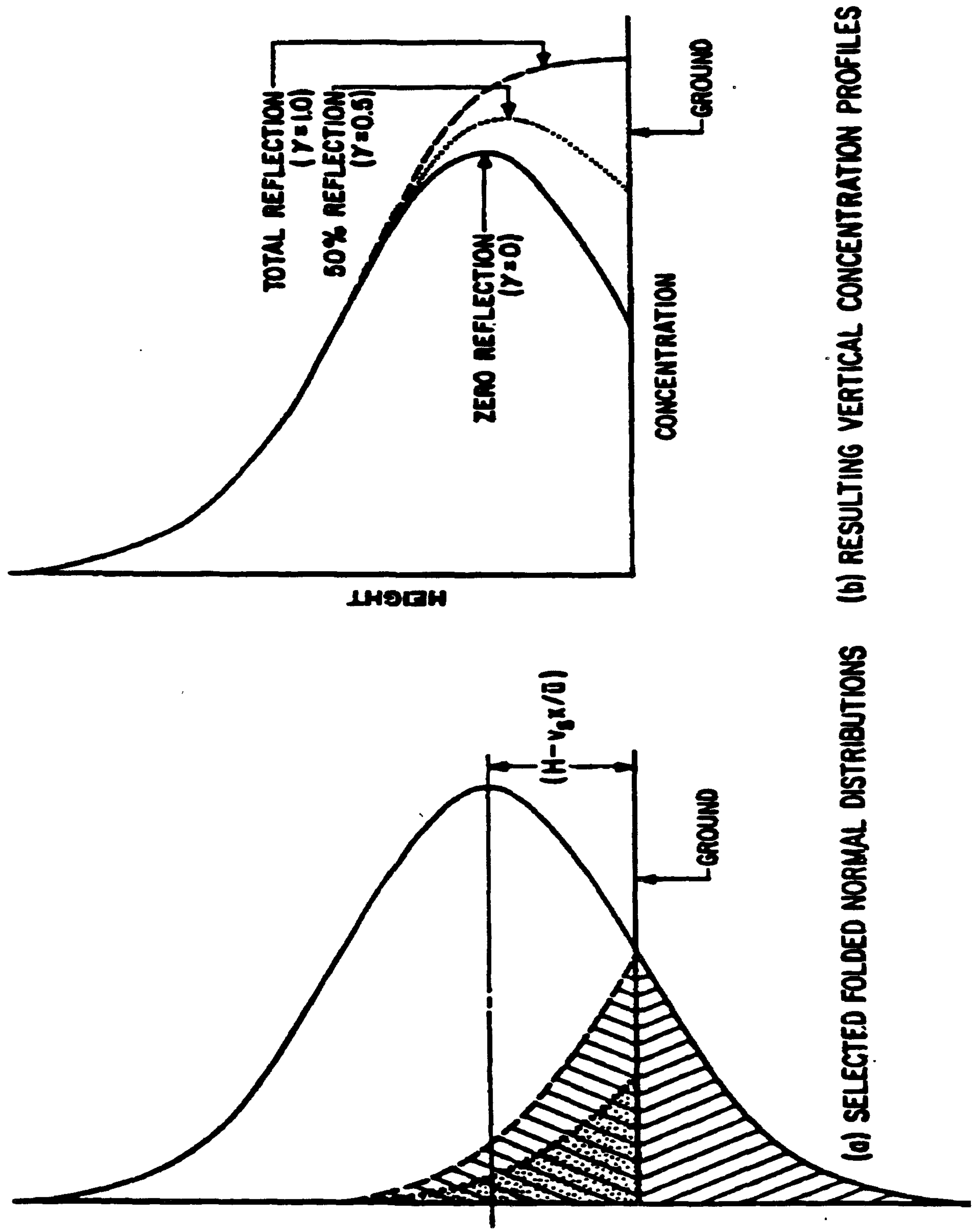


FIGURE 1-6. ILLUSTRATION OF VERTICAL CONCENTRATION PROFILES FOR REFLECTION COEFFICIENTS OF 0., 0.5, AND 1.0

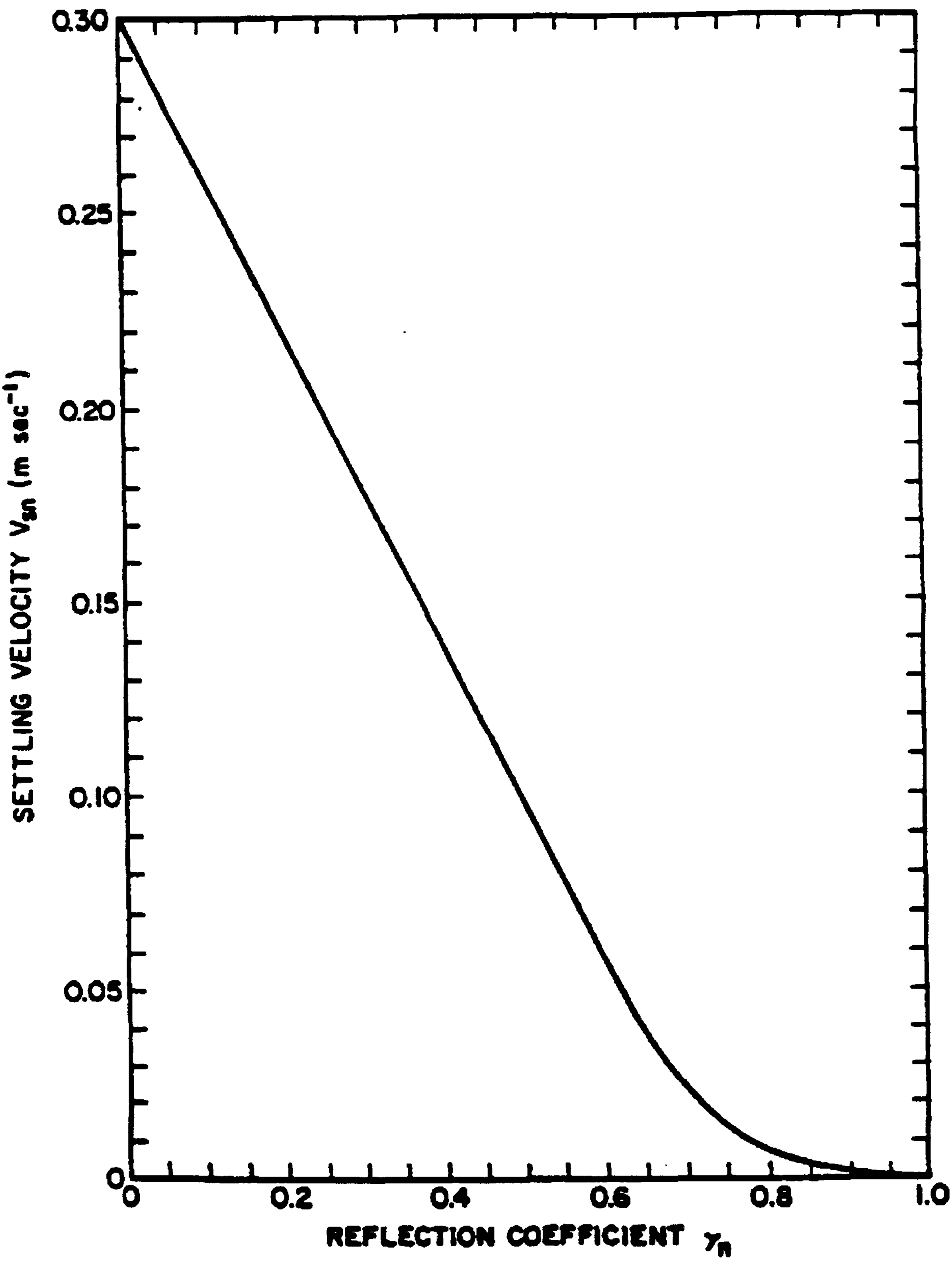


FIGURE 1-7. RELATIONSHIP BETWEEN THE GRAVITATIONAL SETTLING VELOCITY, V_{sn} AND THE REFLECTION COEFFICIENT, γ_N, SUGGESTED BY DUMBAULD, et al. (1976)

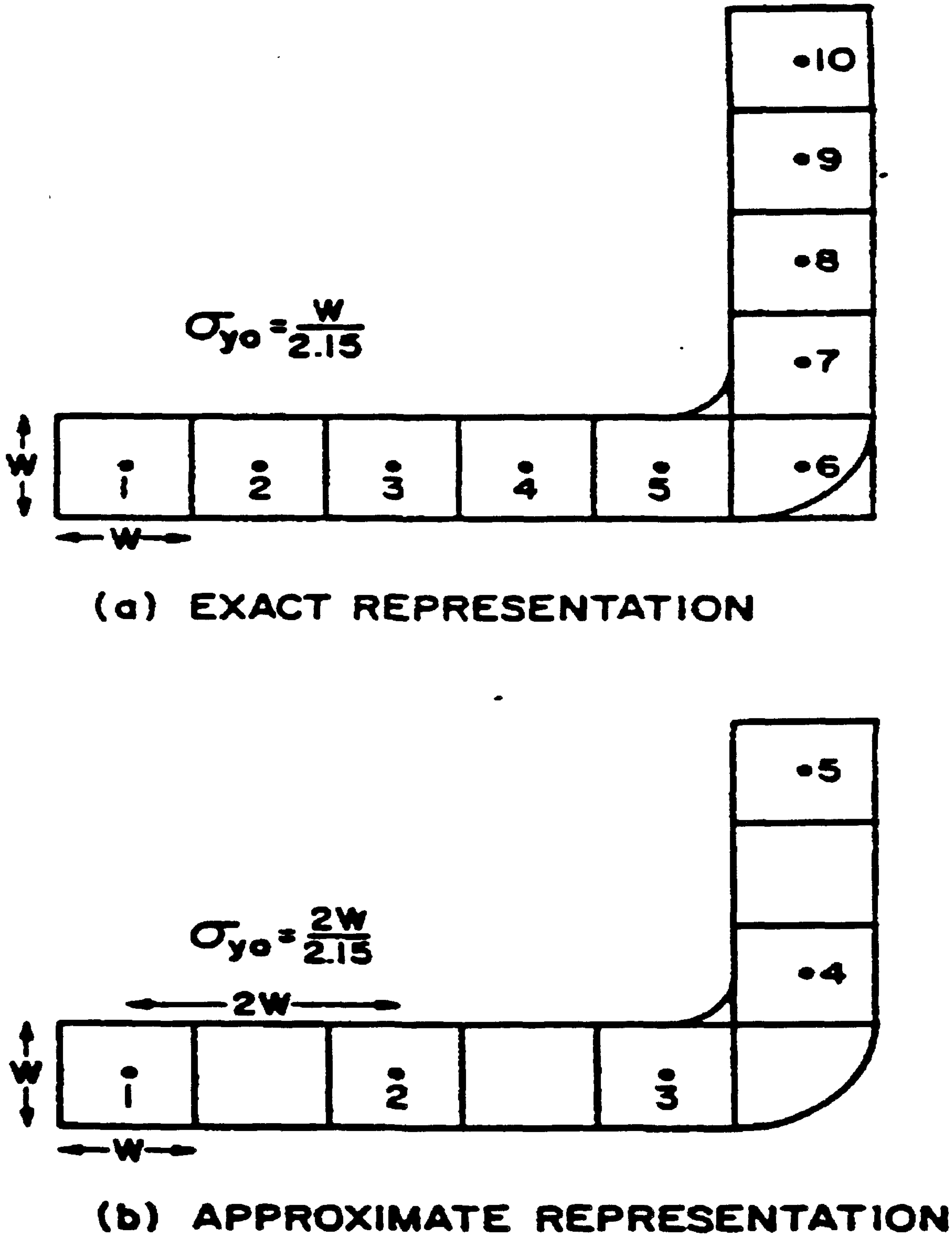


FIGURE 1-8. EXACT AND APPROXIMATE REPRESENTATIONS OF A LINE SOURCE BY MULTIPLE VOLUME SOURCES

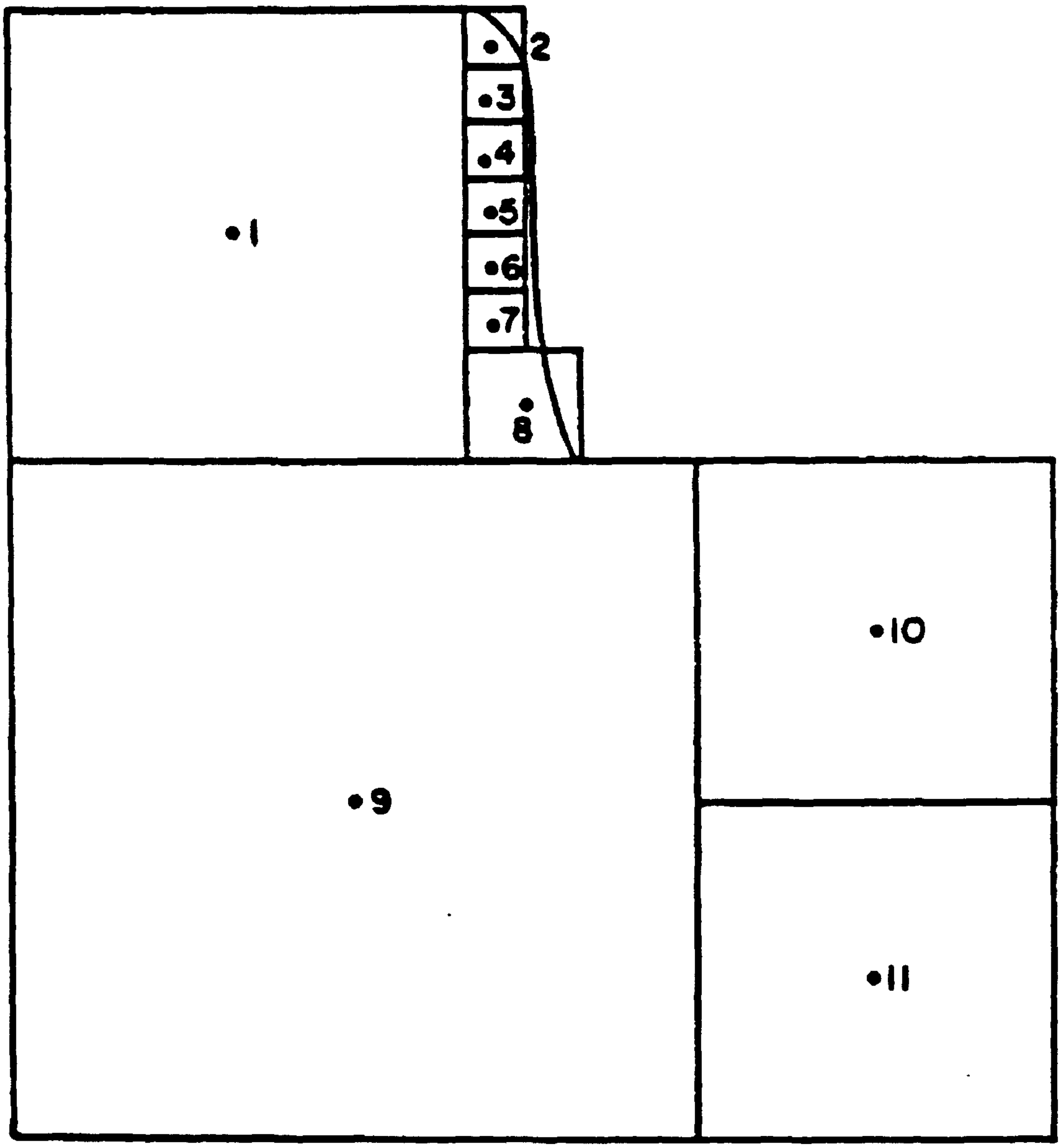


FIGURE 1-9. REPRESENTATION OF AN IRREGULARLY SHAPED AREA SOURCE BY 11 SQUARE AREA SOURCES

2.0 THE ISC2 LONG-TERM DISPERSION MODEL EQUATIONS

This section describes the ISC2 Long-Term dispersion model equations. Where the technical information is the same, this section refers to the ISC2 Short-Term model description in Section 1 for details. The long-term model provides options for modeling the same types of sources as provided by the short-term model. The information provided below follows the same order as used for the short-term model equations.

The ISC2 long-term model uses input meteorological data that have been summarized into joint frequencies of occurrence for particular wind speed classes, wind direction sectors, and stability categories. These summaries, called STAR summaries for STability ARray, may include frequency distributions over a monthly, seasonal or annual basis. The long term model has the option of calculating concentration or deposition values for each separate STAR summary input and/or for the combined period covered by all available STAR summaries. Since the wind direction input is the frequency of occurrence over a sector, with no information on the distribution of winds within the sector, the ISC2 long-term model uses a Gaussian sector-average plume equation as the basis for modeling pollutant emissions on a long-term basis.

2.1 POINT SOURCE EMISSIONS

2.1.1 The Gaussian Sector Average Equation

The ISC2 long-term concentration model makes the same basic assumption as the short-term model. In the long-term model, the area surrounding a continuous source of pollutants is divided into sectors of equal angular width corresponding to the sectors of the seasonal and annual frequency distributions of wind direction, wind speed, and stability. Seasonal or annual emissions from the source are partitioned among the sectors according to the frequencies of wind blowing toward the sectors. The concentration fields calculated for each source are translated to a common coordinate system (either polar or Cartesian as specified by the user) and summed to obtain the total due to all sources.

For a single stack, the mean seasonal concentration at a point ($r > 1m$, θ) with respect to the stack is given by:

$$\chi_l = \frac{K}{\sqrt{2\pi}\, R \Delta\theta'} \sum_{i,j,k} \frac{QfSVD}{u_s \sigma_z} \qquad (2\text{-}1)$$

where:

K = units scaling coefficient (see Equation 1-1)

Q = pollutant emission rate (mass per unit time), for the i^{th} wind-speed category, the k^{th} stability category and the l^{th} season

f = frequency of occurrence of the i^{th} wind-speed category, the j^{th} wind-direction category and the k^{th} stability category for the l^{th} season

$\Delta\theta'$ = the sector width in radians

R = radial distance from lateral virtual point source (for building downwash) to the receptor = $[(x+x_y)^2 + y^2]^{1/2}$

x = downwind distance from source center to receptor, measured along the plume axis

y = lateral distance from the plume axis to the receptor

x_y = lateral virtual distance (see Equation (1-33)), equals zero for point sources without building downwash, and for downwash sources that do not experience lateral dispersion enhancement

S = a smoothing function similar to that of the AQDM (see Section 2.1.8)

u_s = mean wind speed (m/sec) at stack height for the i^{th} wind-speed category and k^{th} stability category

σ_z = standard deviation of the vertical concentration distribution (m) for the k^{th} stability category

V = the Vertical Term for the i^{th} wind-speed category, k^{th} stability category and l^{th} season

D = the Decay Term for the i^{th} wind speed category and k^{th} stability category

The mean annual concentration at the point (r,θ) is calculated from the seasonal concentrations using the expression:

$$\chi_a = 0.25 \sum_{l=1}^{4} \chi_l \quad (2\text{-}2)$$

The terms in Equation (2-1) correspond to the terms discussed in Section 1.1 for the short-term model except that the parameters are defined for discrete categories of wind-speed, wind-direction, stability and season. The various terms are briefly discussed in the following subsections. In addition to point source emissions, the ISC2 long-term concentration model considers emissions from volume and area sources. These model options are discussed in Section 2.2. The optional algorithms for calculating dry deposition are discussed in Section 2.3.

2.1.2 Downwind and Crosswind Distances

See the discussion given in Section 1.1.2.

2.1.3 Wind Speed Profile

See the discussion given in Section 1.1.3.

2.1.4 Plume Rise Formulas

See the discussion given in Section 1.1.4.

2.1.5 The Dispersion Parameters

2.1.5.1 Point Source Dispersion Parameters.

See Section 1.1.5.1 for a discussion of the procedures use to calculate the standard deviation of the vertical concentration distribution σ_z for point sources (sources without initial dimensions). Since the long term model assumes a uniform lateral distribution across the sector width, the model does not use the standard deviation of the lateral dispersion, σ_y (except for use with the Schulman-Scire plume rise formulas described in Section 1.1.4.11).

2.1.5.2 Lateral and Vertical Virtual Distances.

See Section 1.1.5.2 for a discussion of the procedures used to calculate vertical virtual distances. The lateral virtual distance is given by:

$$\chi_y = r_o \cot\left(\frac{\Delta\theta'}{2}\right) \quad (2\text{-}3)$$

where r_o is the effective source radius. For volume sources (see Section 2.2.2), the program sets r_o equal to $2.15\sigma_{yo}$, where σ_{yo} is the initial lateral dimension. For area sources (see Section 2.2.3), the program sets r_o equal to $x_o/\sqrt{\pi}$ where x_o is the length of the side of the area source. For plumes affected by building wakes (see Section 1.1.5.2), the program sets r_o equal to 2.15 σ_y' where σ_y' is given for squat buildings by Equation (1-41), (1-42), or (1-43) for downwind distances between 3 and 10 building heights and for tall buildings by Equation (1-44) for downwind distances between 3 and 10 building widths. At downwind distances greater than 10 building heights for Equation (1-41), (1-42), or (1-43), σ_y' is held constant at the value of σ_y' calculated at a downwind distance of 10 building heights. Similarly, at downwind distances greater than 10 building widths for Equation (1-44),

σ_y' is held constant at the value of σ_y' calculated at a downwind distance of 10 building widths.

2.1.5.3 Procedures Used to Account for the Effects of Building Wakes on Effluent Dispersion.

With the exception of the equations used to calculate the lateral virtual distance, the procedures used to account for the effects of building wake effects on effluent dispersion are the same as those outlined in Section 1.1.5.3 for the short-term model. The calculation of lateral virtual distances by the long-term model is discussed in Section 2.1.5.2 above.

2.1.5.4 Procedures Used to Account for Buoyancy-Induced Dispersion.

See the discussion given in Section 1.1.5.4.

2.1.6 The Vertical Term

2.1.6.1 The Vertical Term for Gases and Small Particulates.

Except for the use of seasons and discrete categories of wind-speed and stability, the Vertical Term for gases and small particulates corresponds to the short term version discussed in Section 1.1.6. The user may assign a separate mixing height z_i to each combination of wind-speed and stability category for each season.

As with the short-term model, the Vertical Term is changed to the form:

$$V = \frac{\sqrt{2\pi}\sigma_z}{z_i} \qquad (2\text{-}4)$$

at downwind distances where the σ_z/z_i ratio is greater than or equal to 1.6. Additionally, the ground-level concentration is set equal to zero if the effective stack height h_e exceeds the mixing height z_i. As explained in Section 1.1.6.1, the ISC2 model currently assumes unlimited mixing for the E and F stability categories.

2.1.6.2 The Vertical Term in Elevated Terrain.

See the discussion given in Section 1.1.6.2.

2.1.6.3 The Vertical Term for Large Particulates.

Section 1.1.6.3 discusses the differences in the dispersion of large particulates and the dispersion of gases and small particulates and provides the guidance on the use of this option. The Vertical Term for large particulates is given by Equation (1-53).

2.1.7 The Decay Term

See the discussion given in Section 1.1.7.

2.1.8 The Smoothing Function

As shown by Equation (2-1), the rectangular concentration distribution within a given angular sector is modified by the function $S\{\theta\}$ which smooths discontinuities in the concentration at the boundaries of adjacent sectors. The centerline concentration in each sector is unaffected by contribution from adjacent sectors. At points off the sector centerline, the concentration is a weighted function of the concentration at the centerline and the concentration at the centerline of the nearest adjoining sector. The smoothing function is given by:

$$S = \frac{(\Delta\theta' - |\theta_j' - \theta'|)}{\Delta\theta'} \quad \text{for} \quad |\theta_j' - \theta'| \leq \Delta\theta'$$

(2-5)

or

$$= 0 \quad \text{for} \quad |\theta_j' - \theta'| > \Delta\theta'$$

where:

θ_j' = the angle measured in radians from north to the centerline of the j^{th} wind-direction sector

θ' = the angle measured in radians from north to the receptor point (R, θ) where R, defined above for equation 2-1, is measured from the lateral virtual source.

2.2 VOLUME AND AREA SOURCE EMISSIONS

2.2.1 General

As explained in Section 1.2.1, the ISC2 volume and area sources are used to simulate the effects of emissions from a wide variety of industrial sources. Section 1.2.2 provides guidance on the use of the volume source model and Section 1.2.3 provides guidance on the use of the area source model. The volume source model may also be used to simulate line sources. The following subsections give the volume and area source equations used by the long-term model.

2.2.2 The Long-Term Volume Source Model

The ISC2 Long Term Model uses a virtual point source algorithm to model the effects of volume sources. Therefore, Equation (2-1) is also used to calculate seasonal average ground-level concentrations for volume source emissions. The user must assign initial lateral (σ_{yo}) and vertical (σ_{zo}) dimensions and the effective emission height h_e. A discussion of the application of the volume source model is given in Section 1.2.2.

2.2.3 The Long-Term Area Source Model

The ISC2 Long Term Model also uses a virtual point source algorithm to model the effects of area sources, however the form of the equation is slightly different since the area source emissions, Q_A, are in emissions per unit area. The seasonal average concentration at the point (r, θ) with respect to the center of an area source is given by the expression:

$$\chi_1 = \frac{K x_o^2}{\sqrt{2\pi}\, R \Delta\theta'} \sum_{i,j,k} \frac{Q_A f S V D}{u_s \sigma_z} \qquad (2-6)$$

where:

K = units scaling coefficient (see Equation (1-1))

R = radial distance from the lateral virtual point source to the receptor = $[(x + x_y)^2 + y^2]^{1/2}$

D = decay term = $\exp\left[-\psi \frac{(x - r_o)}{u_s}\right]$

x = downwind distance from source center to receptor, measured along the plume axis

y = lateral distance from the plume axis to the receptor

r_o = effective source radius = $x_o/\sqrt{\pi}$

x_o = length of the side of the area source (m)

x_y = lateral virtual distance (see Equation (2-3))

S = smoothing function (see Equation (2-5))

A vertical virtual distance, equal to x_o, is added to the actual downwind distance x for the σ_z calculations. The vertical terms V for gaseous pollutants and small particulates, and for cases with settling and dry deposition, are given in Section 1.1.6 with the emission height h_e defined by the user.

2.3 THE ISC2 LONG-TERM DRY DEPOSITION MODEL

2.3.1 General

The concepts upon which the ISC2 long-term dry deposition model are based are discussed in Sections 1.1.6.3 and 1.3.

2.3.2 Point and Volume Source Emissions

The seasonal deposition at the point (r, θ) with respect to the base of a stack or the center of a volume source for particulates in the n^{th} settling-velocity category or a gaseous pollutant with zero settling velocity V_{sn} and a reflection coefficient γ_n is given by:

$$DEP_{l,n} = \frac{K(1-\gamma_n)\phi_n}{\sqrt{2\pi}R^2\Delta\theta'} \sum_{i,j,k} \frac{Q_\tau f S V_d D}{\sigma_z} \qquad (2\text{-}7)$$

where the vertical term for deposition, V_d, was defined in Section 1.3.2. K and D are described in Equations (1-1) and (1-56), respectively. Q_τ is the product of the total time during the l^{th} season, of the seasonal emission rate Q for the i^{th} wind-speed category, k^{th} stability category. For example, if the emission rate is in grams per second and there are 92 days in the summer season (June, July, and August), $Q_{\tau,l-3}$ is given by 7.95 x 10^6 Q_{l-3}. It should be noted that the user need not vary the emission rate by season or by wind speed and stability. If an annual average emission rate is assumed, Q_τ is equal to 3.15 x 10^7 Q for a 365-day year. For a plume comprised of N settling velocity categories, the total seasonal deposition is obtained by summing Equation (2-7) over the N settling-velocity categories. The program also sums the seasonal deposition values to obtain the annual deposition.

2.3.3 Area Source Emissions

With slight modifications, Equation (2-7) is applied to area source emissions. The user assigns the effective emission height h_e and Equation (2-7) is changed to:

$$DEP_{l,n} = \frac{K(1-\gamma_n)\phi_n x_o^2}{\sqrt{2\pi}R^2\Delta\theta'} \sum_{i,j,k} \frac{Q_{A\tau} f S V_d D}{\sigma_z} \qquad (2\text{-}8)$$

where

K = units scaling coefficient (Equation (1-1))

Q_{AT} = the product of the total time during the l^{th} season and the emission rate per unit area for the i^{th} wind-speed category and k^{th} stability category

V_d = vertical term for dry deposition (Equation (1-60)

D = decay term (see Equation (2-6))

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16. ABSTRACT

This volume of the User's Guide for the Industrial Source Complex (ISC2) Dispersion Models (Version 2) describes the dispersion algorithms utilized in the ISC2 models. Much of the discussion in this document is based on Section 2.0 of the Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition (Revised), EPA-450/4-88-002a (EPA, 1987). The ISC2 User's Guide has been developed as part of a larger effort to restructure and reprogram the original ISC models, and to improve the "end-user" documentation for the models. Volume II of the ISC2 User's Guide provides a technical description of the dispersion algorithms utilized in the ISC2 models. Volume III provides a guide to programmers, including a description of the structure of the computer code and information about installing and maintaining the code on various computer systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

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