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Screening Procedures for Estimating the Air Quality Impact of Stationary Sources

by

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PREFACE

This document presents current EPA guidance on the use of screening procedures to estimate the air quality impact of stationary sources. The document is an update and revision of the original Volume 10 of the "Guidelines for Air Quality Maintenance Planning and Analysis", and the later Volume 10 (Revised), and is intended to replace Volume 10R as the standard screening procedures for regulatory modeling of stationary sources. An important advantage of the current document is the availability of the SCREEN model as a computerized version of the short-term procedures. While EPA encourages use of the current document for making screening estimates, it is being issued as a draft for public comment until such time as a final version can be incorporated into a future supplement to the "Guideline on Air Quality Models (Revised)."

Although attempts are made to thoroughly check computer programs with a wide variety of input data, errors are occasionally found. Any suspected errors and technical questions regarding the use of the SCREEN model should be directed to (919) 541-5681 or (FTS) 629-5681. Copies of the SCREEN model in diskette form may be obtained from the National Technical Information Service (NTIS), Springfield, VA 22161. Purchasers of the SCREEN model from NTIS may obtain future revisions to the model from NTIS. Revisions will also be made available on the UNAMAP Electronic Bulletin Board, which may be accessed through (919) 541-1325 or (FTS) 629-1325.

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LIST OF SYMBOLS

Symbol	Definition
A	Parameter used in building cavity calculations and TIBL height factor
A_p	Cross-sectional area of building normal to the wind (m^2)
B	Parameter used in building cavity calculations
C	Contribution to pollutant concentration (g/m^3)
F_b	Bouyancy flux parameter (m^4/s^3)
H	Total heat release rate from flare (cal/s)
L	Alongwind horizontal building dimension (length) (m)
L_b	Lesser of building height or maximum projected width (m)
M	Merged stack parameter
Q	Pollutant emission rate (g/s)
Q_H	Sensible heat release rate from flare (cal/s)
R	Net rate of sensible heating by the sun (67 $cal/m^2/s$)
S	Length of side of square area source (m)
T_a	Ambient temperature (K)
T_s	Stack gas exit temperature (K)
V	Stack gas volume flow rate (m^3/s)
W	Crosswind horizontal building dimension (width) (m)
c_p	Specific heat of air at constant pressure (0.24 cal/gK)
d_s	Stack inside diameter (m)
f	Frequency of occurrence of a wind speed and stability category combination
g	Acceleration due to gravity (9.806 m/s^2)
h	Height of release above terrain = $h_s - h_t$ (m)
h_b	Building height (m)
h_e	Plume (or effective stack) height (m)

LIST OF SYMBOLS (CONT.)

Symbol	Definition
h_i	Height of the top of the plume ($h_e + 2\sigma_z$) (m)
h_s	Physical stack height (m)
h_T	Height of the Thermal Internal Boundary Layer (TIBL) (m)
h_t	Height of terrain above stack base (m)
h_{se}	Effective stack release height for flare (m)
h_e'	Plume height modified for stack tip downwash (m)
m	Multiplicative factor to account for effects of limited mixing
p	Wind speed power law profile exponent
r	Factor to adjust 1-hour concentration to longer averaging time
t_m	Time required for inversion break-up to extend from stack top to top of plume (s)
u	Wind speed (m/s)
u_c	Critical wind speed (m/s)
u_s	Wind speed at stack height (m/s)
u_1	Wind speed at a height of z_1 (m/s)
u_*	Friction velocity (m/s)
u_{10}	Wind speed at a height of 10m (m/s)
$u\Delta h$	Normalized plume rise (m^2/s)
v_s	Stack gas exit velocity (m/s)
x	Downwind distance (m)
x_{max}	Downwind distance to maximum ground-level concentration (m)
x_r	Length of cavity recirculation region (m)
x_s	Distance from source to shoreline (m)
x_y	Virtual point source distance (m)
z_i	Mixing height (m)

Symbol	Definition
z_m	Mechanically driven mixing height (m)
Δh	Plume rise (m)
$\Delta\theta/\Delta z$	Potential temperature gradient with height (K/m)
Δx	Length of side of urban area (m)
π	pi = 3.14159
σ_y	Horizontal (lateral) dispersion parameter (m)
σ_{yo}	Initial horizontal dispersion parameter for area source (m)
σ_z	Vertical dispersion parameter (m)
χ_B	Concentration contributions from other (background) sources (g/m^3)
χ_f	Maximum ground-level concentration due to fumigation (g/m^3)
χ_{max}	Maximum ground-level concentration (g/m^3)
χ_p	Maximum concentration for period greater than 1 hour (g/m^3)
χ_1	Maximum 1-hour ground-level concentration (g/m^3)
χ_{24}	Maximum 24-hour ground-level concentration (g/m^3)
χ/Q	Relative concentration (s/m^3)
$\chi u/Q$	Normalized relative concentration (m^{-2})

1. INTRODUCTION

This document is an update and revision of an earlier guideline[1,2] for applying screening techniques to estimate the air quality impact of stationary sources. The application of screening techniques is addressed in Section 4.2.1 of the Guideline on Air Quality Models (Revised).[3] The current document incorporates changes and additions to the technical approach. The techniques are applicable to chemically stable, gaseous or fine particulate pollutants. An important advantage of the current doucment is that the single source, short-term techniques can be easily executed on an IBM-PC compatible microcomputer with at least 256K of RAM using the SCREEN model provided with the document. As with the earlier versions, however, many of the techniques can be applied with a pocket or desk calculator.

The techniques described in this document can be used to evaluate the air quality impact of sources pursuant to the requirements of the Clean Air Act,[4] such as those sources subject to the prevention of significant deterioration regulations (PSD - addressed in 40 CFR 52.21). The techniques can also be used, where appropriate, for new major or minor sources or modifications subject to new source review regulations, and existing sources of air pollutants, including toxic air pollutants. This document presents a three-phase approach that is applicable to the air quality analysis:

Phase 1. Apply a simple screening procedure (Section 4.1) to determine if either (1) the source clearly poses no air quality problem or (2) the potential for an air quality problem exists.

Phase 2. If the simplified screening results indicate a potential threat to air quality, further analysis is warranted, and the detailed screening (basic modeling) procedures described in Sections 4.2 through 4.5 should be applied.

Phase 3. If the detailed screening results or other factors indicate that a more refined analysis is necessary, refer to the Guideline on Air Quality Models (Revised).[3]

The simple screening procedure (Phase 1) is applied to determine if the source poses a potential threat to air quality. The purpose of first applying a simple screening procedure is to conserve resources by eliminating from further analysis those sources that clearly will not cause or contribute to ambient concentrations in excess of short-term air quality standards or allowable concentration increments. A relatively large degree of "conservatism" is incorporated in that screening procedure to provide reasonable assurance that maximum concentrations will not be underestimated.

If the results of the simple screening procedure indicate a potential to exceed allowable concentrations, then a detailed screening analysis is conducted (Phase 2). The Phase 2 analysis will yield a somewhat conservative first approximation (albeit less conservative than the simple screening estimate) of the source's maximum impact on air quality. If the Phase 2 analysis indicates that the new source does not pose an air quality problem, further modeling may not be necessary. However, there are situations in which analysis beyond the scope of this document (Phase 3) may be required; for example when:

1. A more accurate estimate of the concentrations is needed (e.g., if the results of the Phase 2 analysis indicate a potential air quality problem).

2. The source configuration is complex.

3. Emission rates are highly variable.

4. Pollutant dispersion is significantly affected by nearby terrain features or large bodies of water.

In most of those situations, more refined analytical techniques, such as computer-based dispersion models,[3] can be of considerable help in estimating air quality impact.

In all cases, particularly for applications beyond the scope of this guideline, the services of knowledgeable, well-trained air pollution meteorologists, engineers and air quality analysts should be engaged. An air quality simulation model applied improperly can lead to serious misjudgments regarding the source impact.

2. SOURCE DATA

In order to estimate the impact of a stationary point or area source on air quality, certain characteristics of the source must be known. The following minimum information should generally be available:

- Pollutant emission rate;
- Stack height for a point source and release height for an area source;
- Stack gas temperature, stack inside diameter, and stack gas exit velocity (for plume rise calculations);
- Location of the point of emission with respect to surrounding topography, and the character of that topography;
- A detailed description of all structures in the vicinity of (or attached to) the stack in question. (See the discussion of aerodynamic downwash in Section 4.5.1); and
- Similar information from other significant sources in the vicinity of the subject source (or air quality data or dispersion modeling results that demonstrate the air quality impact of those sources).

At a minimum, impact estimates should be made with source characteristics representative of the design capacity (100 percent load). In addition, the impacts should be estimated based on source characteristics at loads of 50 percent and 75 percent of design capacity, and the maximum impacts selected for comparison to the applicable air quality standard. Refer to Section 9.1.2 in the Guideline on Air Quality Models (Revised)[3] for a further discussion of source data.

2.1 Emissions

The analysis of air quality impact requires that the emissions from each source be fully and accurately characterized. If the pollutants are not emitted at a constant rate (most are not), information should be obtained on how emissions vary with season, day of the week, and hour of the day. In most cases, emission rates vary with the source production rate or rate of fuel consumption. For example, for a coal-fired power plant, emissions are related to the kilowatt-hours of electricity produced, which is proportional to the tonnage of coal used to produce the electricity. Fugitive emissions from an area source are likely to vary with wind speed and both atmospheric and ground moisture content. If pollutant emission data are not directly available, emissions can be estimated from fuel consumption or production rates by multiplying the rates by appropriate emission factors. Emission factors can be determined using three different methods. They are listed below in decreasing order of confidence:

1. Stack-test results or other emission measurements from an identical or similar source.

2. Material balance calculations based on engineering knowledge of the process.

3. Emission factors derived for similar sources or obtained from a compilation by the U.S. Environmental Protection Agency.[5]

In cases where emissions are reduced by control equipment, the effectiveness of the controls must be accounted for in the emissions analysis. The source operator should be able to estimate control effectiveness in reducing emissions and how this effectiveness varies with changes in plant operating conditions.

2.2 Merged Parameters for Multiple Stacks

Sources that emit the same pollutant from several stacks with similar parameters that are within about 100 meters of each other may be analyzed by treating all of the emissions as coming from a single representative stack. For each stack compute the parameter M:

$$M = (h_s V T_s)/Q \tag{2.1}$$

where M = merged stack parameter which accounts for the relative influence of stack height, plume rise, and emission rate on concentrations

h_s = stack height (m)

$V = (\pi/4)\, d_s^2\, v_s$ = stack gas volume flow rate (m^3/s)

d_s = inside stack diameter (m)

v_s = stack gas exit velocity (m/s)

T_s = stack gas exit temperature (K)

Q = pollutant emission rate (g/s)

The stack that has the lowest value of M is used as a "representative" stack. Then the sum of the emissions from all stacks is assumed to be emitted from the representative stack; i.e., the equivalent source is characterized by h_{s1}, V_1, T_{s1} and Q, where subscript 1 indicates the representative stack and $Q = Q_1 + Q_2 + \ldots + Q_n$.

The parameters from dissimilar stacks should be merged with caution. For example, if the stacks are located more than about 100 meters apart, or if stack heights, volume flow rates, or stack gas exit temperatures differ by more than about 20 percent, the resulting estimates of concentrations due to the merged stack procedure may be unacceptably high.

2.3 Topographic Considerations

It is important to study the topography in the vicinity of the source being analyzed. Topographic features, through their effects on plume behavior, will sometimes be a significant factor in determining ambient ground-level pollutant concentrations. Important features to note are the locations of large bodies of water, elevated terrain, valley configurations, and general terrain roughness in the vicinity of the source.

Section 4.5.2 provides a screening technique for estimating ambient concentrations due to plume impaction at receptors located on elevated terrain features above stack height. The effects of elevated terrain below stack height can be accounted for in Sections 4.2 and 4.3. A screening technique for estimating concentrations under shoreline fumigation conditions is presented in Section 4.5.3. Any other topographic considerations, such as terrain-induced plume downwash and valley stagnation, are beyond the scope of this guideline.

2.4 Source Building Complex

The downwash phenomenon caused by the aerodynamic turbulence induced by a building may result in high ground-level concentrations in the vicinity of an emission source. It is therefore important to characterize the height and width of structures nearby the source. For purposes of these analyses, "nearby" includes structures within a distance of five times the lesser of the height or width of the structure, but not greater than 0.8 km (0.5 mile).[6] The screening procedure for building downwash is described in Section 4.5.1.

3. METEOROLOGICAL DATA

The computational procedures given in Section 4 for estimating the impact of a stationary source on air quality utilize information on the following meteorological parameters:

- ° Wind speed and direction
- ° Stability class
- ° Mixing height
- ° Temperature

A discussion of each of these parameters follows.

3.1 Wind Speed and Direction

Wind speed and direction data are required to estimate short-term peak and long-term average concentrations. The wind speed is used to determine (1) plume dilution, and (2) the plume rise downwind of the stack. These factors, in turn, affect the magnitude of and distance to the maximum ground-level concentration.

Most wind data are collected near ground level. The wind speed at stack height, u_s, can be estimated from the following power law equation:

$$u_s = u_1 (h_s / z_1)^p \qquad (3.1)$$

where:

u_s = the wind speed (m/s) at stack height, h_s,

u_1 = the wind speed at a reference height, z_1 (such as the anemometer height), and

p = the stability-related power law exponent from Table 3-1.

Table 3-1. Wind Profile Exponent as a Function of Atmospheric Stability for Rural and Urban Sites*

Stability Class	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 power law equation may be used to adjust wind speeds over a height range from about 10 to 300 meters. Adjustments to heights above 300 meters should be used with caution. For release heights below 10 meters the reference wind speed should be used without adjustment. For the procedures in Section 4 the reference height is assumed to be at 10 meters.

The wind direction is an approximation to the direction of transport of the plume. The variability of the direction of transport over a period of time is a major factor in estimating ground-level concentrations averaged over that time period.

Wind speed and direction data from National Weather Service, Air Weather Service, and Naval Weather Service stations are available from the National Climatic Data Center (NCDC), Federal Building, Asheville, North Carolina, 704-259-0682 (FTS 672-0682). Wind data are often also recorded at existing

* The classification of a site as rural or urban should be based on one of the procedures described in Section 8.2.8 of the Guideline on Air Quality Models (Revised).[3]

plant sites and at air quality monitoring sites. It is important that the equipment used to record such data be properly designed, sited, and maintained to record data that are reasonably representative of the direction and speed of the plume. Guidance on collection of on-site meteorological data is contained primarily in Reference 7, but also in References 3 and 8.

3.2 Stability

Stability categories, as depicted in Tables 3-1 and 3-2, are indicators of atmospheric turbulence. The stability category at any given time will depend upon static stability (related to the change in temperature with height), thermal turbulence (caused by heating of the air at ground level), and mechanical turbulence (a function of wind speed and surface roughness). It is generally estimated by a method given by Turner[9], which requires information on solar elevation angle, cloud cover, cloud ceiling height, and wind speed (see Table 3-2). Opaque cloud cover should be used if available, otherwise total cloud cover may be used. The solar elevation angle is a function of the time of year and the time of day, and is presented in charts in the Smithsonian Meteorological Tables.[10] The hourly weather observations of the National Weather Service include cloud cover, ceiling height, and wind speed. These data are available from the NCDC. Methods for estimating atmospheric stability categories from on-site data are presented in Reference 7. For computation of seasonal and annual concentrations, a joint frequency distribution of stability class, wind direction, and wind speed (stability wind rose) is needed. Such distributions, called STAR summaries, can be obtained from the NCDC for National Weather Service stations.

Table 3-2. Key To Stability Categories

Surface Wind Speed at a Height of 10m (m/s)	Day: Incoming Solar Radiation** (Insolation)			Night*	
	Strong	Moderate	Slight	Thinly Overcast or ≥ 4/8 Low Cloud Cover	≤ 3/8 Cloud Cover
< 2	A	A-B	B	F	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

The neutral class (D) should be assumed for all overcast conditions during day or night.

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*Night is defined as the period from 1 hour before sunset to 1 hour after sunrise.

**Appropriate insolation categories may be determined through the use of sky cover and solar elevation information as follows:

Sky Cover (Opaque or Total)	Solar Elevation Angle > 60°	Solar Elevation Angle ≤ 60° But > 35°	Solar Elevation Angle ≤ 35° But > 15°
4/8 or Less or Any Amount of High Thin Clouds	Strong	Moderate	Slight
5/8 to 7/8 Middle clouds (7000 feet to 16,000 foot base	Moderate	Slight	Slight
5/8 to 7/8 Low Clouds (less than 7,000 foot base)	Slight	Slight	Slight

3.3 Mixing Height

The mixing height is the distance above the ground to which relatively unrestricted vertical mixing occurs in the atmosphere. When the mixing height is low (but still above plume height) ambient ground-level concentrations will be relatively high because the pollutants are prevented from dispersing upward. For estimating long-term average concentrations, it is generally adequate to use an annual-average mixing height rather than daily values.

Mixing height data are generally derived from surface temperatures and from upper air soundings which are made at selected National Weather Service stations. The procedure used to determine mixing heights is one developed by Holzworth.[11] Tabulations and summaries of mixing height data can be obtained from the NCDC.

For the purposes of calculations made in Section 4.2 and for use in the SCREEN model, a mechanically driven mixing height is estimated to provide a lower limit to the mixing height used during neutral and unstable conditions. The mechanical mixing height is calculated from:[12]

$$z_m = 0.3\ u_*/f \qquad (3.2)$$

where: u_* = friction velocity (m/s)

f = Coriolis parameter ($9.374 \times 10^{-5} s^{-1}$ at 40° latitude)

Using a log-linear vertical profile for the wind speed, and assuming a surface roughness length of about 0.3m, u_* may be estimated from the 10 meter wind speed, u_{10}, as

$$u_* = 0.1\ u_{10}$$

Substituting for u_* in (3.2) yields

$$z_m = 320\ u_{10} \qquad (3.3)$$

If the plume height is calculated to be above the mixing height determined from Equation 3.3, then the mixing height is set at 1 meter above the plume height for conservatism in the SCREEN model.

3.4 Temperature

Ambient air temperature must be known in order to calculate the amount of rise of a buoyant plume. Plume rise is proportional to a fractional power of the temperature difference between the stack gases and the ambient air (see Section 4.2). Ambient temperature data are collected hourly at National Weather Service stations, and are available from the NCDC. For the procedures in Section 4, a default value of 293K is used for ambient temperature if no data are available.

4. ESTIMATING SOURCE IMPACT ON AIR QUALITY

A three-phase approach, as discussed in the Introduction, is recommended for estimating the air quality impact of a stationary source:*

Phase 1. Simple screening analysis

Phase 2. Detailed screening (basic modeling) analysis

Phase 3. Refined modeling analysis

The Phase 3 analysis is beyond the scope of this guideline, and the user is referred to the Guideline on Air Quality Models (Revised).[3] This section presents the simple screening procedure (Section 4.1) and the detailed screening procedures (Sections 4.2 through 4.5). All of the procedures, with the partial exception of the procedures in Sections 4.5.2 and 4.5.3, are based upon the bi-variate Gaussian dispersion model assumptions described in the Workbook of Atmospheric Dispersion Estimates.[9] A consistent set of units (meters, grams, seconds) is used throughout:

Distance (m)

Pollutant Emission Rate (g/s)

Pollutant Concentration (g/m^3)

Wind Speed (m/s)

To convert pollutant concentration to micrograms per cubic meter ($\mu g/m^3$) for comparison with air quality standards, multiply the value in g/m^3 by 1×10^6.

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*The techniques described in this section can be used, where appropriate, to evaluate sources subject to the prevention of significant deterioration regulations (PSD - addressed in 40 CFR 52.21), new major or minor sources subject to new source review regulations, and existing sources of air pollutants, including toxic air pollutants.

4.1 Simple Screening Procedure

The simple screening procedure is the "first phase" that is recommended when assessing the air quality impact of a new point source. The purpose of this screening procedure is to eliminate from further analysis those sources that clearly will not cause or contribute to ambient concentrations in excess of short-term air quality standards.

The scope of the procedure is confined to elevated point sources with plume heights of 10 to 300 meters, and concentration averaging times of 1 to 24 hours. The procedure is particularly useful for sources where the short-term air quality standards are "controlling"; i.e., in cases where meeting the short-term standards provides good assurance of meeting the annual standard for that pollutant. Elevated point sources (i.e., sources for which the emission points are well above ground level) are often in that category, particularly when they are isolated from other sources.

When applying the screening procedure to elevated point sources, the following assumptions must apply:

1. No aerodynamic downwash of the effluent plume by nearby buildings occurs. (Refer to Section 4.5.1 to determine if building downwash is a potential problem.)
2. The plume does not impact on elevated terrain. (Refer to Section 4.5.2 to determine if elevated terrain above stack height may be impacted.)

If the potential for building downwash exists, then the SCREEN model should be used to estimate air quality impact and the simple screening procedure is not applicable. If the potential for plume impaction on elevated terrian exists, then the calculation procedure described in the indicated section should also be applied, and the higher concentration from the terrain impaction procedure and the simple screening procedure should be selected to estimate the maximum ground-level concentration. The effects of elevated terrain below stack height should also be accounted for by reducing the computed plume heights by the maximum terrain height above stack base.

The screening procedure utilizes the Gaussian dispersion equation to estimate the maximum 1-hour ground-level concentration for the source in question (Computations 1-6 below). To obtain concentrations for other averaging times up to 24 hours, multiply the 1-hour value by an appropriate factor (Computation 7). Then account for background concentrations (Computation 8) to obtain a total concentration estimate. That estimate is then used, in conjunction with any elevated terrain estimates, to determine if further analysis of the source impact is warranted (Computation 9):

Step 1. Estimate the normalized plume rise ($u\Delta h$) that is applicable to the source during neutral and unstable atmospheric conditions. (Stable atmospheric conditions are not treated explicitly since this simple screening procedure does not apply to stack heights less than 10 meters or cases with terrain intercepts.) First, compute the buoyancy flux parameter, F_b:

$$F_b = (g/4)v_s d_s^2[(T_s-T_a)/T_s] \quad (4.1)$$

$$= 3.12\ V\ [(T_s-T_a)/T_s]$$

where: g = acceleration due to gravity (9.806 m/s^2)

v_s = stack gas exit velocity (m/s)*

d_s = stack inside diameter (m)

T_s = stack gas exit temperature (K)*

T_a = ambient air temperature (K) (If no ambient temperature data are available, assume that T_a = 293K.)

$V = (\pi/4)d_s^2 v_s$ = actual stack gas volume flow rate (m^3/s)

Normalized plume rise ($u\Delta h$) is then given by:

$$u\Delta h = 21.4F_b^{3/4} \text{ when } F_b < 55 \text{ m}^4/\text{s}^3$$
$$u\Delta h = 38.7F_b^{3/5} \text{ when } F_b \geq 55 \text{ m}^4/\text{s}^3 \quad (4.2)$$

Step 2. Divide the $u\Delta h$ value obtained from Equation 4.2 by each of five wind speeds (u = 1.0, 2.0, 3.0, 5.0 and 10 m/s) to estimate the actual plume rise (Δh) for each wind speed:

$$\Delta h = (u\Delta h)/u$$

Step 3. Compute the plume height (h_e) that will occur during each wind speed by adding the respective plume rises to the stack height (h_s):

$$h_e = h_s + \Delta h$$

If the effects of elevated terrain below stack height are to be accounted for, then reduce each plume height by the maximum terrain height above stack base.

Step 4. For each plume height computed in (3), estimate a $\chi u/Q$ value from Figure 4-1.[14]

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*If stack gas temperature or exit velocity data are unavailable, they may be approximated from guidelines that present typical values for those parameters for existing plants.[13]

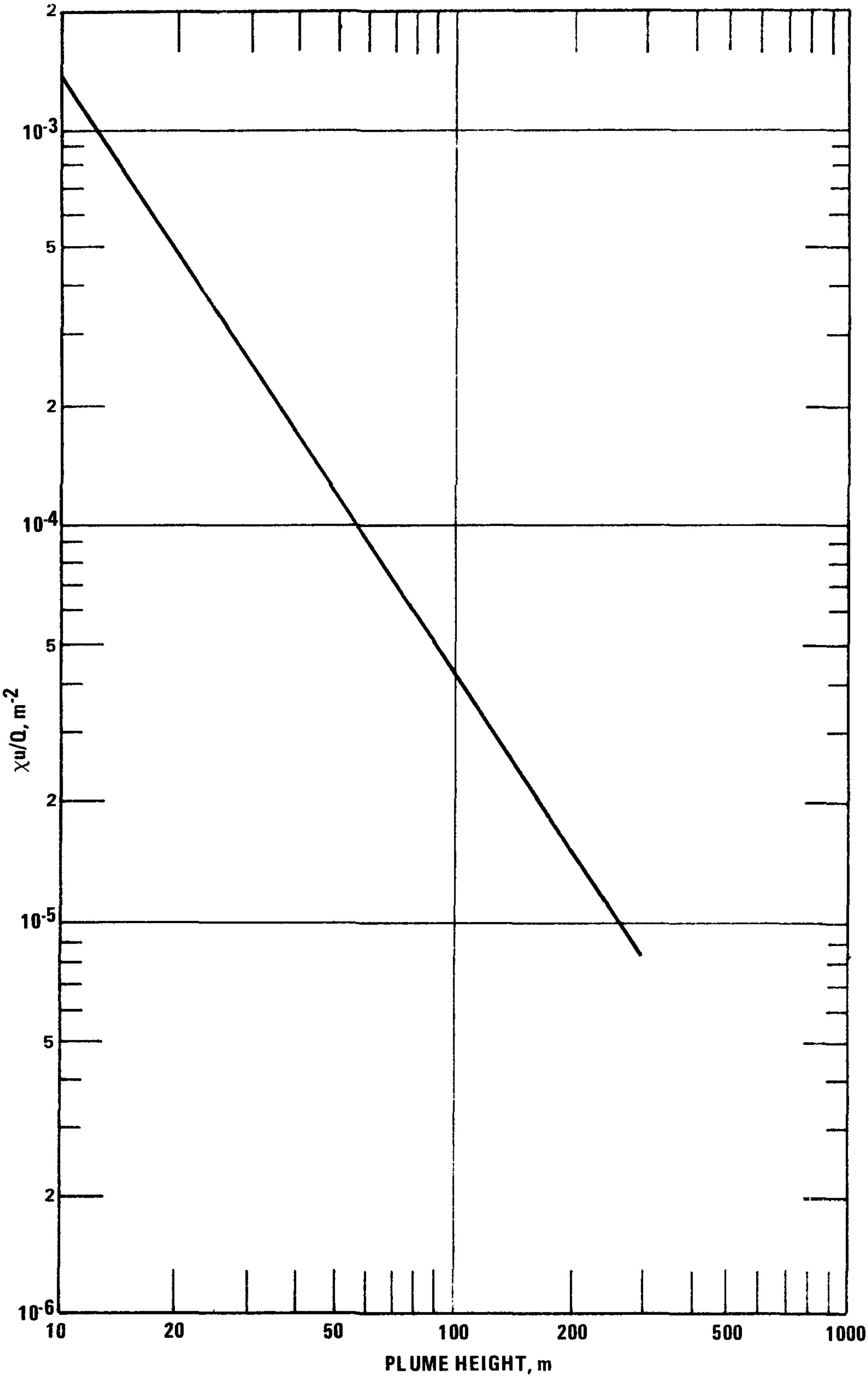

Figure 4-1. Maximum $\chi u/Q$ as a function of plume height, H (for use only with the simple screening procedure).

Step 5. Divide each $\chi u/Q$ value by the respective wind speed to determine the corresponding χ/Q values:

$$\chi/Q = (\chi u/Q)/u$$

Step 6. Multiply the maximum χ/Q value obtained in (5) by the emission rate Q (g/s), and incorporate a factor of 2 margin of safety, to obtain the maximum 1-hour ground-level concentration χ_1 (g/m^3) due to emissions from the stack in question:

$$\chi_1 = 2Q(\chi/Q)$$

The margin of safety is incorporated in the screening procedure to account for the potential inaccuracy of concentration estimates obtained through calculations of this type.

If more than one stack is being considered, and the procedure for merging parameters for multiple stacks is not applicable (Section 2.2), (1) through (6) must be applied for each stack separately. The maximum values (χ_1) found for each stack are then added together to estimate the total maximum 1-hour concentration.

Step 7. To obtain a concentration estimate (χ_p) for an averaging time greater than one hour, multiply the one-hour value by an appropriate factor, r. (See the discussion in Step 5 of Section 4.2 which addresses multiplication factors for averaging times longer than 1 hour).

$$\chi_p = r\chi_1$$

Step 8. Next, contributions from other sources (χ_B) should be taken into account, yielding the final screening procedure concentration estimate χ_{max} (g/m^3):

$$\chi_{max} = \chi_p + \chi_B.$$

Procedures on estimating concentrations due to other sources are provided in Section 4.5.5.

Step 9. Based on the estimate of χ_{max} and (if applicable) estimate of concentrations due to terrain impaction problems, determine if further analysis of the source is warranted. If any of the estimated concentrations exceeds the air quality level of concern (e.g., an air quality standard), proceed to Section 4.2 for further analysis. If the concentrations are below the level of concern, the source can be safely assumed to pose no threat to that air quality level, and no further analysis is necessary.

4.2 Estimating Maximum Short-Term Concentrations

The basic modeling procedures described in the remainder of this document comprise the recommended "second phase" (or detailed screening) that may be used in assessing air quality impacts. The procedures are intended for application in those cases where the simple screening procedure (first phase) indicates a potential air quality problem.

As with the first phase (simple screening) analysis in Section 4.1, if elevated terrain above stack height occurs within 50 km of the source, then the procedure in Section 4.5.2 should be applied in addition to the procedures in this section. The highest concentration from all applicable procedures should then be selected to estimate the maximum ground-level concentration. Even if the plume is not likely to impact on elevated terrain, the user should account for the effects of elevated terrain below stack height. If the terrain is relatively uniform around the source, then a procedure to account for terrain effects is to reduce the computed plume height, h_e (for all stabilities), by the maximum terrain elevation above stack base within a 50 km radius from the source. The adjusted plume height can then be used in conjunction with the "flat terrain" procedures described in this section.

If there are only a few isolated terrain features in otherwise flat terrain, then the flat terrain estimates from this section should be expanded to include the procedures of Section 4.3 applied to the locations with elevated terrain. For the additional calculations the computed plume height, h_e, should be reduced by the terrain height above stack base corresponding to the specific terrain features.

The procedures in this section can be applied without the aid of a computer (a pocket or desk calculator will suffice). However, they are subject to the same limitations as the simple screening procedure, i.e., no building downwash occurs (see Section 4.5.1), no terrain impaction occurs (Section 4.5.2), and plume heights do not exceed 300m. An alternative approach is to use the SCREEN computer program that has been made available by EPA for use on an IBM-PC compatible microcomputer with at least 256K of RAM. The SCREEN model replaces the PTPLU, PTMAX, and PTDIS codes previously used in conjunction with Volume 10R.[2] It is applicable to all of the procedures contained in this section and Section 4.3, but also includes calculations for the special cases of building downwash, fumigation, elevated terrain, area sources and long-range transport described in Section 4.5. A complete user's guide for the SCREEN model is provided in Appendix A.

This section (4.2) presents the basic procedures for estimating maximum short-term concentrations for specific meteorological situations. If building downwash occurs (see Section 4.5.1), then the SCREEN model must be used in lieu of these procedures. In Steps 1-3, plume rise[15,16,17] and a critical wind speed are computed. In Step 4, maximum 1-hour concentrations are estimated. In Step 5, the 1-hour concentrations are used to estimate concentrations for averaging times up to 24 hours. Contributions from other sources are accounted for in Step 6.

Step 1. Estimate the normalized plume rise ($u\Delta h$) that is applicable to the source during neutral and unstable atmospheric conditions. First, compute the buoyancy flux term, F_b, using Equation 4.1 (repeated here for convenience):

$$F_b = (g/4)v_s d_s^2[(T_s-T_a)/T_s] \tag{4.1}$$
$$= 3.12\ V\ [(T_s-T_a)/T_s]$$

where: g = acceleration of gravity (9.806 m/s^2)

v_s = stack gas exit velocity (m/s)*

d_s = inside stack diameter (m)

T_s = stack gas temperature (K)*

T_a = ambient air temperature (K) (If no ambient temperature data are available, assume that T_a = 293 K.)

$V = (\pi/4)d_s^2 v_s$ = actual stack gas flow rate (m^3/s)

Normalized plume rise is then given by Equation 4.2:

$$u\Delta h = 21.4F_b^{3/4} \text{ when } F_b < 55\ m^4/s^3$$
$$u\Delta h = 38.7F_b^{3/5} \text{ when } F_b \geq 55\ m^4/s^3 \tag{4.2}$$

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*If stack gas temperature or exit velocity data are unavailable, they may be approximated from guidelines that present typical values for those parameters for existing plants.[13]

If the emissions are from a flare, then the normalized plume rise and an effective release height may be determined with the following procedure:

(a) Calculate the total heat release rate, H (cal/s), of the flared gas based on the heat content and the gas consumption rate.

(b) Calculate the buoyancy flux term, F_b, for the flare:*

$$F_b = 1.66 \times 10^{-5} \times H \qquad (4.3)$$

(c) Calculate the normalized plume rise ($u\Delta h$) from Equation 4.2.

(d) Calculate the vertical height of the flame, h_f (m), assuming the flame is tilted 45° from the vertical:[19]

$$h_f = 4.56 \times 10^{-3} \times H^{0.478} \qquad (4.4)$$

(e) Calculate an effective release height for the tip of the flame:

$$h_{se} = h_s + h_f.$$

Use h_{se} in place of h_s along with the value of $u\Delta h$ calculated from (c) in determining plume heights in the following procedures.

Step 2. Estimate the critical wind speed (u_c) applicable to the source during neutral and near-neutral atmospheric conditions. The critical wind speed is a function of two opposing effects that occur with increasing wind speed; namely, increased dilution of the effluent as it leaves the stack (which tends to decrease the maximum impact on ground-level concentration) and suppression of plume rise (tending to increase the impact). The wind speed at which the interaction of those opposing effects results in the highest ground-level concentration is the critical wind speed.

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* This formula was derived from: $F_b = (gQ_H)/(\pi\rho c_p T_a)$ (Eqn. 4.20, Briggs[15]), assuming T_a = 293 K, ρ = 1205 g/m^3, and c_p = 0.24 cal/gK, and that the sensible heat release rate, $Q_H = (0.45)H$.[18]

The critical wind speed can be estimated through the following approximation:

$$u_c = (u\Delta h)/h_s \qquad (4.5)$$

Assume that the value of u_c from Equation 4.5 corresponds to the stack height wind speed. If the value of u_c calculated from Equation 4.5 is less than 1.0 m/s, then use u_c = 1.0 m/s. If the value of u_c calculated from Equation 4.5 is greater than 15.0 m/s, then use u_c = 15.0 m/s.

Step 3. Stable atmospheric conditions may be critical if the emission height is less than 50 meters. The stable case plume rise (Δh) should be estimated as follows:

$$\Delta h = 2.6[(F_b T_a)/(ug\Delta\theta/\Delta z)]^{1/3} \qquad (4.6)$$

The value $\Delta\theta/\Delta z$ is the change in potential temperature with height. Values of 0.02 K/m for E stability (applicable to urban sites), and 0.035 K/m for F stability (rural sites) should be used. The classification of a site as rural or urban should be based on one of the procedures described in Section 8.2.8 of the Guideline on Air Quality Models (Revised).[3]

Step 4. Estimate maximum 1-hour concentrations that will occur during various dispersion situations. First, using Table 4-1 as a guide, determine the dispersion situations and corresponding calculation procedures applicable to the source being considered. Then apply the applicable calculation procedures, which are described on the following pages, in order to estimate maximum 1-hour concentrations. Then proceed to Step 5.

As discussed earlier and as noted in Table 4-1, the hand calculation procedures presented in this step are limited by certain assumptions,

Table 4-1. Calculation Procedures To Use With Various Release Heights

Height of Release Above Terrain, h	Applicable Calculation Procedures
$h \geq 50$ meters	(a) Unstable/Limited Mixing (b) Near-neutral/High Wind
$10 \leq h < 50$ meters	(a) Unstable/Limited Mixing (b) Near-neutral/High Wind (c) Stable
$h < 10$ meters and ground-level sources	(b) Near-neutral/High Wind (c) Stable

NOTE:

If $h_s < h_b + 1.5L_b$, refer to Section 4.5.1 on building downwash and use the SCREEN Model.

If elevated terrain above stack height occurs within 50 km, refer to Section 4.5.2.

If fumigation is potentially a problem (for rural sources with $h_s \geq 10m$), refer to Section 4.5.3.

If the plume height, $h_e = h_s + (u\Delta h/u_s)$ is greater than 300m, then the procedures in this section are not applicable (the SCREEN model may be used without this restriction).

$h = h_s - h_t$

h_s = stack height

h_t = terrain height above stack base

h_b = height of nearby structure

L_b = lesser of height or maximum projected width of nearby structure namely that no building downwash occurs (Section 4.5.1), no terrain impaction occurs (Section 4.5.2), and that plume heights are below 300m. For cases involving building downwash or plume heights above 300m, the SCREEN model should be used. A detailed user's guide for the SCREEN model is provided in Appendix A.

Procedure (a): Unstable/Limited Mixing

During very unstable conditions, the plume from a stack will be mixed to ground level relatively close to the source, resulting in high short-term concentrations. These concentrations can be significantly increased when the unstable conditions occur in conjunction with a limited mixing condition. Limited mixing (also called plume trapping) occurs when a stable layer aloft limits the vertical mixing of the plume. The highest concentrations occur when the mixing height is at or slightly above the plume height.

Calculation Procedure:

1. Compute the plume height, h_e, that will occur during A stability and 10-meter wind speeds of 1 and 3 m/s. Adjust the wind speeds from 10 meters to stack height using Equation 3.1 and the exponent for stability class A. Use the $u\Delta h$ value computed in Step 1.

$$h_e = h_s + (u\Delta h/u_s)$$
$$= h_s + \Delta h$$

If $v_s < 1.5u_s$, account for stack tip downwash as follows:

$$h_e = h_s + \Delta h + 2(v_s/u_s - 1.5)d_s \quad (4.7)$$

If elevated terrain is to be accounted for, then reduce the computed plume height for each wind speed by the maximum terrain elevation above stack base.

2. For both wind speeds considered in (1), determine the maximum 1-hour $\chi u/Q$ using the curve for stability A on Figure 4-2 (rural)[9] or A-B on Figure 4-3 (urban).[20]

3. Compute the maximum 1-hour concentration, χ_1, for both cases using:

$$\chi_1 = mQ(\chi u/Q)/u_s \qquad (4.8)$$

where m is a conservative factor to account for the increase in concentration expected due to reflections of the plume off the top of the mixed layer. The value of m depends on the plume height as follows:*

m = 2.0	for	$290m \le h_e$
m = 1.8	for	$270m \le h_e < 290m$
m = 1.5	for	$210m \le h_e < 270m$
m = 1.2	for	$180m \le h_e < 210m$
m = 1.1	for	$160m \le h_e < 180m$
m = 1.0	for	$h_e < 160m$

Select the highest concentration computed.

<u>Procedure(b): Near-neutral/High Wind</u>

Some buoyant plumes will have their greatest impact on ground-level concentrations during neutral or near-neutral conditions, often in conjunction with high wind speeds.

Calculation procedure:

1. Compute the plume height, h_e, that will occur during C stability with a stack height wind speed of $u_s = u_c$, the value of the critical

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* The values of m are based on an assumed minimum daytime mixing height of about 320m (see Section 3.3).

wind speed computed in Step 2. If $u_c < 10$ m/s, then also compute the plume height that will occur during C stability with a 10-meter wind speed of 10 m/s. Adjust the 10 m/s wind speed from 10 meters to stack height using Equation 3.1 and the exponent for stability class C. Use the $u\Delta h$ value computed in Step 1.

$$h_e = h_s + (u\Delta h)/u_s$$

If $v_s < 1.5u_s$, account for stack tip downwash using Equation 4.7. If elevated terrain is to be accounted for, then reduce the computed plume height for each wind speed by the maximum terrain elevation above stack base.

2. For the wind speed(s) considered in (1), determine the maximum 1-hour $\chi u/Q$ using the curve for stability C on Figure 4-2 (rural)[9] or Figure 4.3 (urban).[20]

3. Compute the maximum 1-hour concentration χ_1 for each case using:

$$\chi_1 = Q(\chi u/Q)/u_s$$

and select the highest concentration computed.

Procedure (c): Stable

Low-level sources (i.e., sources with stack heights less than about 50m) sometimes produce the highest concentrations during stable atmospheric conditions. Under such conditions, the plume's vertical spread is severely restricted and horizontal spreading is also reduced. This results in what is called a fanning plume.

Calculation procedures:

A. For low-level sources with some plume rise, calculate the concentration as follows:

1. Compute the plume height (h_e) that will occur during F stability (for rural cases) and 10-meter wind speeds of 1, 3, and 4 m/s,* or E stability (for urban cases) and 10-meter wind speeds of 1, 3, and 5 m/s. Adjust the wind speeds from 10 meters to stack height, using Equation 3.1 and the appropriate exponent. Use the stable plume rise (Δh) computed from Equation 4.6 in Step 3:

$$h_e = h_s + \Delta h$$

If $v_s < 1.5u_s$, account for stack tip downwash using Equation 4.7. If elevated terrain is to be accounted for, then reduce the computed plume height for each wind speed by the maximum terrain elevation above stack base.

2. For each wind speed and stability considered in (1), find the maximum 1-hour $\chi u/Q$ from Figure 4-2 (rural)[9] or 4-3 (urban).[20] Compute the maximum 1-hour concentration for each case, using

$$\chi 1 = Q(\chi u/Q)/u_s$$

and select the highest concentration computed.

B. For low-level sources with no plume rise ($h_e = h_s$), find the maximum 1-hour $\chi u/Q$ from Figure 4-2 (rural case--assume F stability) or 4-3 (urban case--assume E stability). Compute the maximum 1-hour concentration, assuming a 10-meter wind speed of 1 m/s. Adjust the wind speed from 10 meters to stack height using Equation 3.1 and the appropriate exponent.

$$\chi 1 = Q(\chi u/Q)/u_s$$

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*Refer to the discussion on worst case meteorological conditions in Appendix A, Section A3, for an explanation of the use of F stability with a 4 m/s wind speed.

Step 5. Obtain concentration estimates for the averaging times of concern. The maximum 1-hour concentration (χ_1) is the highest of the concentrations estimated in Step 4, Procedures (a) - (c). For averaging times greater than 1-hour, the maximum concentration will generally be less than the 1-hour value. The following discussion describes how the maximum 1-hour value may be used to make an estimate of maximum concentrations for longer averaging times.

The ratio between a longer-term maximum concentration and a 1-hour maximum will depend upon the duration of the longer averaging time, source characteristics, local climatology and topography, and the meteorological conditions associated with the 1-hour maximum. Because of the many ways in which such factors interact, it is not practical to categorize all situations that will typically result in any specified ratio between the longer-term and 1-hour maxima. Therefore, ratios are presented here for a "general case" and the user is given some flexibility to adjust those ratios to represent more closely any particular point source application where actual meteorological data are used. To obtain the estimated maximum concentration for a 3, 8, or 24-hour averaging time, multiply the 1-hour maximum (χ_1) by the given factor:

Averaging Time	Multiplying Factor
3 hours	0.9 (±0.1)
8 hours	0.7 (±0.2)
24 hours	0.4 (±0.2)

The numbers in parentheses are recommended limits to which one may diverge from the multiplying factors representing the general case. For example, if aerodynamic downwash or terrain is a problem at the facility, or if the emission height is very low, it may be necessary to increase the factors (within the limits specified in parentheses). On the other hand, if the stack is relatively tall and there are no terrain or downwash problems, it may be appropriate to decrease the factors. Agreement should be reached with the Regional Office prior to modifying the factors.

The multiplying factors listed above are based upon general experience with elevated point sources. The factors are only intended as a rough guide for estimating maximum concentrations for averaging times greater than one hour. A degree of conservatism is incorporated in the factors to provide reasonable assurance that maximum concentrations for 3, 8, and 24 hours will not be underestimated.

Step 6. Add the expected contribution from other sources to the concentration estimated in Step 5. Concentrations due to other sources can be estimated from measured data, or by computing the effect of existing sources on air quality in the area being studied. Procedures for estimating such concentrations are given in Section 4.5.5.

At this point in the analysis, a first approximation of maximum short-term ambient concentrations (source impact plus contributions from other sources) has been obtained. If concentrations at specified locations, long-term concentrations, or other special topics must be addressed, refer to applicable portions of Sections 4.3 to 4.5.

4.3 Short-Term Concentrations at Specified Locations

In Section 4.2, maximum concentrations are generally estimated without specific attention to the location(s) of the receptor(s). In some cases, however, it is particularly important to estimate the impact of a source on air quality in <u>specified</u> (e.g., critical) areas. For example, there may be nearby locations at which high pollutant concentrations already occur due to other sources, and where a relatively small addition to ambient concentrations might cause ambient standards to be exceeded. Another example would be where an isolated terrain feature occurs in otherwise flat terrain, and concentrations at the elevated terrain location may exceed those estimated for flat terrain. These procedures assume that no building downwash occurs (Section 4.5.1), no terrain impaction occurs (Section 4.5.2), and that plume heights do not exceed 300m.

Each of the sources affecting a given location can be expected to produce its greatest impact during certain meteorological conditions. The composite maximum concentration at that location due to the interaction of all the sources may occur under different meteorological conditions than those which produce the highest impact from any one source. Thus, the analysis of this problem can be difficult, and may require substantial use of high-speed computers.

Despite the potential complexity of the problem, some preliminary calculations can be made that will at least indicate whether or not a more detailed study is needed. For example, if the preliminary analysis indicates that the estimated concentrations are near or above the air quality standards of concern, a more detailed analysis will probably be required.

Calculation procedure: (If the SCREEN model is used, refer to the discrete distance option described in Appendix A.)

<u>Step 1</u>. Compute the normalized plume rise ($u\Delta h$) for neutral and unstable conditions, utilizing the procedure described in Step 1 of Section 4.2.

Step 2. Compute the plume rise, Δh, that will occur during C stability (to represent neutral and unstable conditions) with 10-meter wind speeds of 1, 3, 5, 10, and 20 m/s. Adjust the wind speeds from 10 meters to stack height using Equation 3.1 and the exponent for stability class C.

$$\Delta h = (u\Delta h)/u_s$$

Step 3. Compute the plume height (h_e) that will occur during each wind speed by adding the respective plume rises to the stack height (h_s):

$$h_e = h_s + \Delta h$$

If $v_s < 1.5\ u_s$, account for stack tip downwash using Equation 4.7. If elevated terrain is to be accounted for, then reduce the computed plume height for each wind speed by the terrain elevation above stack base for the specified location.

Step 4. For each stability class-wind speed combination listed below, at the downwind distance of the "specified location," determine the $\chi u/Q$ value from Figures 4-4 through 4-7 (rural) or Figures 4-10 through 4-12 (urban). Note that in those figures (see the captions) very restrictive mixing heights are assumed, resulting in trapping of the entire plume within a shallow layer.

Stability Class	10 Meter Wind Speed (m/s)
A	1, 3
B	1, 3, 5
C	1, 3, 5, 10
D	1, 3, 5, 10, 20

Step 5. (If the physical stack height is greater than 50 meters and flat terrain is being assumed, Steps 5 and 6 may be skipped.) Compute plume

heights (h_e) that will occur for stability class E and 10-meter wind speeds of 1, 3, and 5 m/s, and for stability class F (rural sources only) and 10-meter wind speeds of 1 and 3 and 4 m/s.* Adjust the wind speeds from 10 meters to stack height using Equation 3.1 and the appropriate exponent. Use the stable plume rise (Δh) computed from Equation 4.6 in Step 3 of Section 4.2:

$$h_e = h_s + \Delta h$$

If $v_s < 1.5u_s$, account for stack tip downwash using Equation 4.7. If elevated terrain is to be accounted for, then reduce the computed plume height for each case by the terrain elevation above stack base for the specified location.

Step 6. For each stability class-wind speed combination considered in Step 5, at the downwind distance of the specified location, determine a $\chi u/Q$ value from Figures 4-8 and 4-9 (or Figure 4-13 for the urban case).

Step 7. For each $\chi u/Q$ value obtained in Step 4 (and Step 6 if applicable), compute χ/Q:

$$\chi/Q = (\chi u/Q)/u_s$$

Step 8. Select the largest χ/Q and multiply by the source emission rate (g/s) to obtain a 1-hour concentration value (g/m^3):

$$\chi_1 = Q(\chi/Q)_{max}$$

Step 9. To estimate concentrations for averaging time greater than 1 hour, refer to the averaging time procedure described earlier (Step 5 of Section 4.2). To account for contributions from other sources, see Section 4.5.5.

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* Refer to the discussion on worst case meteorological conditions in Appendix A, Section A3, for an explanation of the use of F stability with a 4m/s wind speed.

4.4 Annual Average Concentrations

This section presents procedures for estimating annual average ambient concentrations caused by a single point source. The procedure for estimating the annual concentration at a specified location is presented first, followed by a suggestion of how that procedure can be expanded to estimate the overall maximum annual concentration (regardless of location).

The procedures assume that the emissions are continuous and at a constant rate. The data required are emission rate, stack height, stack gas volume flow rate (or diameter and exit velocity), stack gas temperature, average afternoon mixing height, and a representative stability wind rose.* Refer to Sections 2 and 3 for a discussion of such data.

4.4.1 Annual Average Concentration at a Specified Location

Calculation procedure:

Step 1. (Applicable to stability categories A through D). Using the procedure described in Step 1 of Section 4.2 (Equations 4.1 and 4.2) obtain a normalized plume rise value, $u\Delta h$.

Step 2. (Applicable to stability categories E and F). Use Equation 4.6 from Step 3 of Section 4.2 to estimate the plume rise (Δh) as a function of wind speed for both stable categories (E and F) using values of $\Delta\theta/\Delta z$ = 0.02 K/m for category E and $\Delta\theta/\Delta z$ = 0.035 K/m for category F.

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*The stability wind rose is a joint frequency distribution of wind speed, wind direction and atmospheric stability for a given locality. Stability wind roses for many locations are available from the National Climatic Data Center, Asheville, North Carolina.

Step 3. Compute plume rise (Δh) for each stability-wind speed category in Table 4-2 by (1) substituting the corresponding wind speed for u in the appropriate equations referenced in Step 1 or 2 above and (2) solving the equation for Δh. The wind speeds listed in Table 4-2 are derived from the wind speed intervals used by the National Climatic Data Center (Table 4-3) in specifying stability-wind roses. The wind speeds may be adjusted from 10 meters to stack height using Equation 3.1.

Step 4. Compute plume height (h_e) for each stability-wind speed category in Table 4-2 by adding the physical stack height (h_s) to each of the plume rise values computed in Step 3:

$$h_e = h_s + \Delta h$$

Step 5. Estimate the contribution to the annual average concentration at the specified location for each of the stability-wind speed categories in Table 4-2. First, determine the vertical dispersion coefficient (σ_z) for each stability class for the downwind distance (x) between the source and the specified location, using Figure 4-14. (Note: For urban F stability cases, use the σ_z for stability E.) Next, determine the mixing height (z_i) applicable to each stability class. For stabilities A to D, use the average afternoon mixing height for the area (Figure 4-15). For urban stability E use the average morning mixing height (Figure 4-16). For rural stabilities E and F, mixing height is not applicable. Then, use that information as follows: For all stability-wind conditions when the plume height (h_e) is greater than the mixing height (z_i), assume a zero contribution to the annual concentration at the specified location. For each condition when $\sigma_z \leq 0.8z_i$, and for all rural stability E and F cases, apply the following equation[9] to estimate the contribution C (g/m^3):

Table 4-2. STABILITY-WIND SPEED COMBINATIONS THAT ARE CONSIDERED IN ESTIMATING ANNUAL AVERAGE CONCENTRATIONS

Atmospheric Stability Categories	Wind Speed (m/s)					
	1.5	2.5	4.5	7	9.5	12.5
A	*	*				
B	*	*	*			
C	*	*	*	*	*	
D	*	*	*	*	*	*
E	*	*	*			
F	*	*				

*It is only necessary to consider the stability-wind speed conditions marked with an asterisk.

Table 4-3. WIND SPEED INTERVALS USED BY THE NATIONAL CLIMATIC DATA CENTER FOR JOINT FREQUENCY DISTRIBUTIONS OF WIND SPEED, WIND DIRECTION AND STABILITY

Class	Speed Interval, m/s	(knots)	Representative Wind Speed m/s
1	0 to 1.8	(0 to 3)	1.5
2	1.8 to 3.3	(4 to 6)	2.5
3	3.3 to 5.4	(7 to 10)	4.5
4	5.4 to 8.5	(11 to 16)	7.0
5	8.5 to 11.0	(17 to 21)	9.5
6	>11.0	(>21)	12.5

$$C = [(2.032\ Q\ f)/(\sigma_z\ u\ x)]\ \exp[-1/2[h_e/\sigma_z]^2] \quad (4.9)$$

For each condition during which $\sigma_z > 0.8z_i$, the following equation[9] is applied:

$$C = (2.55\ Q\ f)/(z_i\ u\ x) \quad (4.10)$$

In these equations:

Q = pollutant emission rate (g/s)

u = wind speed (m/s)

f = frequency of occurrence of the particular wind speed-stability combination (obtained from the stability-wind rose (STAR) summary available from the National Climatic Data Center) for the wind direction of concern. Only consider the wind speed-stability combinations for the wind direction that will bring the plume closest to the specified location.

Step 6. Sum the contributions (C) computed in Step 5 to estimate the annual average concentration at the specified location.

4.4.2 Maximum Annual Average Concentration

To estimate the overall maximum annual average concentration (the maximum concentration regardless of location) follow the procedure for the annual average concentration at a specified location, repeating the procedure for each of several receptor distances, and for all directions. Because of the large number of calculations required, it is recommended that a computer model such as ISCLT be used.[21] The ISCLT model is a part of the UNAMAP series, which is discussed in Appendix B.

4.5 Special Topics

4.5.1 Building Downwash

In some cases, the aerodynamic turbulence induced by a nearby building will cause a pollutant emitted from an elevated source to be mixed rapidly toward the ground (downwash), resulting in higher ground-level concentration immediately to the lee of the building than would otherwise occur. Thus, when assessing the impact of a source on air quality, the possibility of downwash problems should be investigated. For purposes of these analyses, "nearby" includes structures within a distance of five times the lesser of the height or width of the structure, but not greater than 0.8 km (0.5 mile).[6] If downwash is found to be a potential problem, its effect on air quality should be estimated. Also when Good Engineering Practice (GEP) analysis indicates that a stack is less than the GEP height, the following screening procedures should be applied to assess the potential air quality impact.

The best approach to determine if downwash will be a problem at a proposed facility is to conduct observations of effluent behavior at a similar facility. If this is not feasible, and if the facility has a simple configuration (e.g., a stack adjacent or attached to a single rectangular building), a simple rule-of-thumb[22] may be applied to determine the stack height (h_s) necessary to avoid downwash problems:

$$h_s \geq h_b + 1.5\ L_b \qquad (4.11)$$

where h_b is building height and L_b is the lesser of <u>either</u> building height or maximum projected building width. In other words, if the stack height is equal to or greater than $h_b + 1.5\ L_b$, downwash is unlikely to be a problem.

If there is more than one stack at a given facility, the above rule must be successively applied to each stack. If more than one building is involved the rule must be successively applied to each building. Tiered structures and groups of structures should be treated according to Reference 6. For relatively complex source configurations the rule may not be applicable, particularly when the building shapes are much different from the simple rectangular building for which the above equation was derived. For these cases, refined modeling techniques[3] or a wind tunnel study is recommended.

If it is determined that the potential for downwash exists, then the SCREEN model should be used to estimate the maximum ground-level pollutant concentrations that occur as a result of the downwash. The building downwash screening procedure is divided into the following two major areas of concern:

A. Cavity Region; and
B. Wake Region

Generally, downwash has its greatest impact when the effluent is caught in the cavity region. However, the cavity may not extend beyond the plant boundary, and, in some instances, impacts in the wake region may exceed impacts in the cavity region. Therefore, impacts in both regions must be considered if downwash is potentially a problem.

When the SCREEN model is run for building downwash calculations, the program prompts the user for the building height, the minimum horizontal building dimension, and the maximum horizontal building dimension.

A. Cavity Region

The cavity calculations are made using methods described by Hosker.[23] Cavity calculations are based on the determination of a critical (i.e., minimum) wind speed required to cause entrainment of the plume in the cavity (defined as being when the plume centerline height equals the cavity height). Two cavity calculations are made, the first using the minimum horizontal dimension alongwind, and the second using the maximum horizontal dimension alongwind. The SCREEN output provides the cavity concentration, cavity length (measured from the lee side of the building), cavity height and critical wind speed for each orientation. The highest concentration value that potentially affects ambient air should be used as the maximum 1-hour cavity concentration for the source.

A more detailed description of the cavity effects screening procedure is contained in Appendix A, Section A3. For situations significantly different from the worst case, and for complex source configurations, a more detailed analysis is required.[24,25] If this estimate proves unacceptable, one may also wish to consider a field study or fluid modeling demonstration to show maintenance of the NAAQS or PSD increments within the cavity. If such options are pursued, prior agreement on the study plan and methodology should be reached with the Regional Office.

B. Wake Region

Wake effects screening can also be performed with the SCREEN model. The SCREEN model uses the downwash procedures contained in the Industrial Source Complex (ISC) Model, Second Edition (Revised)[21], of UNAMAP, and applies them to the full range of meteorological conditions described in Appendix A. The SCREEN model accounts for downwash effects within the "near" wake region (out to ten times the lesser of the building height or projected building width, $10L_b$), and also accounts for the effects of enhanced dispersion of the plume within the "far" wake region (beyond $10L_b$). The same building dimensions as described above for the cavity calculations are used, and SCREEN calculates the maximum projected width from the values input for the minimum and maximum horizontal dimensions. The wake effects procedures are described in more detail in the ISC manual.[21]

4.5.2 Plume Impaction on Elevated Terrain

There is growing acceptance of the hypothesis that greater concentrations can occur on elevated than on flat terrain in the vicinity of an elevated source.* That is particularly true when the terrain extends well above the effective plume height.

A procedure is presented here to (1) determine whether or not an elevated plume may impact on elevated terrain and, (2) estimate the maximum 24-hour concentration if terrain impaction is likely. The procedure is based largely upon the 24-hour mode of the EPA VALLEY model.[26] A similar procedure that accounts for terrain heights above plume height using the VALLEY model, and compares results from the VALLEY model to simple terrain calculations for terrain between stack height and plume height, is included in the SCREEN program (see Appendix A). A concentration estimate obtained through the procedure in this section will likely be somewhat greater than provided by the VALLEY model or by the SCREEN program, primarily due to the relatively conservative plume height that is used in Step 1:

Step 1. Determine if the plume is likely to impact on elevated terrain in the vicinity of the source:

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*An exception may be certain flat terrain situations where building downwash is a problem. (See Section 4.5.1).

(1) Compute one-half the plume rise that can be expected during F stability and a stack height wind speed (u_s) of 2.5 m/s. (The reason for using only one-half the normally computed plume rise is to provide a margin of safety in determining both if the plume may intercept terrain and the resulting ground-level concentration. This assumption is necessary because actual plume heights will be lower with higher stack height wind speeds, and because impacts on intervening terrain above stack height but below the full plume height might otherwise be missed.)

$$\Delta h = 2.6[(F_b T_a)/(u_s g \Delta\theta/\Delta z)]^{1/3}/2 \qquad (4.12)$$

Refer to Steps 1 and 3 of Section 4.2 for a definition of terms.

(2) Compute a conservative plume height (h_e) by adding the physical stack height (h_s) to Δh:

$$h_e = h_s + \Delta h$$

(3) Determine if any terrain features in the vicinity of the source are as high as h_e. If so, proceed with Step 2. If that is <u>not</u> the case, the plume is not likely to intercept terrain, and Step 2 is not applicable.*

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*Even if the plume is not likely to impact on elevated terrain (and for <u>all</u> concentration averaging times of concern) the user should account for the effects of elevated terrain on maximum concentrations. A procedure to account for elevated terrain below stack height is described in Section 4.2 and consists of reducing the computed plume height, h_e (for all stabilities), by the elevation difference between stack base and location of the receptor(s) in question. The adjusted plume heights can then be used in conjunction with the "flat-terrain" modeling procedures described earlier.

Step 2. Estimate the maximum 24-hour ground-level concentration on elevated terrain in the vicinity of the source:

(1) Using a topographic map, determine the distance from the source to the nearest ground-level location at the height h_e.

(2) Using Figure 4-17 and the distance determined in (1), estimate a 24-hour χ/Q value.

(3) Multiply the $(\chi/Q)_{24}$ value by the emission rate Q (g/s) to estimate the maximum 24-hour concentration, χ_{24}, due to plume impaction on elevated terrain:

$$\chi_{24} = Q(\chi/Q)_{24}$$

4.5.3 Fumigation

Fumigation occurs when a plume that was originally emitted into a stable layer is mixed rapidly to ground-level when unstable air below the plume reaches plume level. Fumigation can cause very high ground-level concentrations.[27] Typical situations in which fumigation occurs are:

1. Breaking up of the nocturnal radiation inversion by solar warming of the ground surface;
2. Shoreline fumigation caused by advection of pollutants from a stable marine environment to an unstable inland environment; and
3. Advection of pollutants from a stable rural environment to a turbulent urban environment.

The following procedure can be used for estimating concentrations due to inversion break-up and shoreline fumigation in rural areas. Sources located within 3 km of a large body of water should be evaluated for shoreline fumigation. Procedures for estimating concentrations during the third type, rural/urban, are beyond the scope of this document.

Calculation procedures:

Step 1. Compute the plume height (h_e) that will occur during F stability and a stack height wind speed of 2.5 m/s:

$$h_e = h_s + \Delta h$$

To obtain a value for Δh, use the procedure described in Step 3 of Section 4.2 with u = 2.5 m/s. If $v_s < 1.5u_s$, account for stack tip downwash using Equation 4.7.

Step 2. Estimate the downwind distance to maximum ground-level concentration using (a) for inversion break-up and (b) for shoreline fumigation.

(a) For inversion break-up fumigation, use Table 4-4 (derived from Equation (5.5) of Turner's Workbook)[9] to estimate the downwind distance at which the maximum fumigation concentration is expected to occur, which is based on the time required for the mixed layer to develop from the top of the stack to the top of the plume. If this distance is less than about 2 kilometers, then fumigation concentrations are not likely to exceed the limited mixing concentrations estimated in Step 4, Procedure (a), of Section 4.2, and may be ignored.

(b) For shoreline fumigation, the maximum fumigation concentration is expected to occur where the top of the stable plume intercepts the top of the thermal internal boundary layer (TIBL). The distance to this location, measured from the shoreline, may be estimated from Table 4-5. The distances in Table 4-5 are based on the assumption of a parabolic TIBL shape.[28] Subtract the distance from the source to the shoreline from the value in Table 4-5 in order to obtain the downwind distance to the maximum from the source. If the distance obtained is less than 0.2 km, then the shoreline fumigation screening procedure should not be applied since the plume/TIBL interaction

Table 4-4. Downwind Distance (km) to the Maximum Ground-Level Concentration for Inversion Break-Up Fumigation … Function of Stack Height (h_s) and Plume Height (h_e) (Assume Stability Class F and Wind Speed = 2.5 …

h_s \ h_e	<60	60	70	80	90	100	125	150	175	200	225	250	275	[illegible]
10	(< 2)	2.6	3.6	4.7	5.9	7.2	11	16	20	26	32	38	46	[illegible]
20	(< 2)	2.3	3.3	4.3	5.5	6.8	11	15	20	25	31	38	45	[illegible]
30	(< 2)	(< 2)	2.9	3.9	5.1	6.4	10	14	19	24	30	37	44	[illegible]
40	(< 2)	(< 2)	2.5	3.5	4.7	5.9	9.5	14	19	24	30	36	43	[illegible]
50	(< 2)	(< 2)	2.0	3.1	4.2	5.4	9.0	13	18	23	29	35	42	[illegible]
60	-	(< 2)	(< 2)	2.5	3.7	4.9	8.4	12	17	22	28	34	41	[illegible]
70	-	-	(< 2)	(< 2)	3.1	4.3	7.7	12	16	21	27	33	40	[illegible]
80	-	-	-	(< 2)	2.4	3.6	7.1	11	16	21	26	32	39	[illegible]
90	-	-	-	-	(< 2)	2.9	6.3	10	15	20	25	31	38	[illegible]
100	-	-	-	-	-	(< 2)	5.5	9.4	14	19	24	30	37	[illegible]
125	-	-	-	-	-	-	3.2	7.2	12	17	22	28	34	[illegible]
150	-	-	-	-	-	-	-	4.5	9.0	14	19	25	31	[illegible]
175	-	-	-	-	-	-	-	-	5.9	11	16	22	28	[illegible]
200	-	-	-	-	-	-	-	-	-	7.5	13	18	24	[illegible]
225	-	-	-	-	-	-	-	-	-	-	9.1	15	21	[illegible]
250	-	-	-	-	-	-	-	-	-	-	-	11	17	[illegible]
275	-	-	-	-	-	-	-	-	-	-	-	-	13	[illegible]
[illegible]	-	-	-	-	-	-	-	-	-	-	-	[illegible]	[illegible]	[illegible]

Table 4-5. Downwind Distance (km) to the Maximum Ground-Level Concentration for Shoreline Fumigation as a Function of Stack Height (h_s) and Plume Height (h_e) (Assume Stability Class F and Wind Speed = 2.5 m/s)

h_s \ h_e	<60	60	70	80	90	100	125	150	175	200	225	250	275	300
10	(<0.2)	0.22	0.31	0.42	0.54	0.67	1.1	1.6	2.2	2.9	3.6	4.5	5.4	6.5
20	(<0.2)	(<0.2)	0.28	0.38	0.49	0.62	1.0	1.5	2.1	2.8	3.5	4.4	5.3	6.3
30	(<0.2)	(<0.2)	0.25	0.34	0.45	0.58	0.96	1.4	2.0	2.7	3.4	4.2	5.2	6.2
40	(<0.2)	(<0.2)	0.22	0.31	0.41	0.53	0.90	1.4	1.9	2.6	3.3	4.1	5.0	6.0
50	(<0.2)	(<0.2)	(<0.2)	0.28	0.38	0.49	0.85	1.3	1.8	2.5	3.2	4.0	4.9	5.9
60	-	(<0.2)	(<0.2)	0.25	0.34	0.45	0.79	1.2	1.8	2.4	3.1	3.9	4.8	5.8
70	-	-	(<0.2)	0.23	0.31	0.42	0.75	1.2	1.7	2.3	3.0	3.8	4.7	5.6
80	-	-	-	0.22	0.29	0.39	0.70	1.1	1.6	2.2	2.9	3.7	4.5	5.5
90	-	-	-	-	0.28	0.36	0.66	1.1	1.5	2.1	2.8	3.6	4.4	5.4
100	-	-	-	-	-	0.35	0.62	1.0	1.5	2.1	2.7	3.5	4.3	5.2
125	-	-	-	-	-	-	0.57	0.89	1.3	1.9	2.5	3.2	4.0	4.9
150	-	-	-	-	-	-	-	0.85	1.2	1.7	2.3	3.0	3.8	4.6
175	-	-	-	-	-	-	-	-	1.2	1.6	2.2	2.8	3.5	4.4
200	-	-	-	-	-	-	-	-	-	1.6	2.0	2.6	3.3	4.1
225	-	-	-	-	-	-	-	-	-	-	2.0	2.5	3.2	3.9
250	-	-	-	-	-	-	-	-	-	-	-	2.5	3.0	3.7
275	-	-	-	-	-	-	-	-	-	-	-	-	3.0	3.6
300	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6

may be influenced by transitional plume rise effects.

Step 3. At the distance estimated in (2), determine the value of σ_y from Figure 4-18 and of σ_z from Figure 4-14 for F stability. Since the effects of buoyancy-induced dispersion (BID) have been incorporated in the distances determined in (2) above, it is recommended that the values for σ_y and σ_z be adjusted for BID effects as follows:

$$\sigma_y' = [\sigma_y^2 + (\Delta h/3.5)^2]^{1/2} ,$$
$$\sigma_z' = [\sigma_z^2 + (\Delta h/3.5)^2]^{1/2} \qquad (4.13)$$

where Δh is the plume rise determined in (1) above. The maximum fumigation estimate, particularly for shoreline fumigation, is sensitive to the inclusion of BID since it effects the distance to the maximum as well as the actual concentration calculation.

Step 4. Compute the maximum fumigation concentration (χ_f), using the following equation:[9]

$$\chi_f = Q/[\sqrt{2\pi}u(\sigma_y'+h_e/8)(h_e+2\sigma_z')] \qquad (4.14)$$

For the inversion break-up case, the concentration χ_f can be expected to persist for about 30 to 90 minutes. For shoreline fumigation, the high ground-level concentrations can persist as long as the stable onshore flow persists, up to several hours, although the location may shift as the direction of the onshore flow shifts.

Step 5. If the estimated fumigation concentration, χ_f, is less than the maximum 1-hour concentration, χ_1, estimated from Step 4 of Section 4.2, then the effects of fumigation may be ignored. If the estimated fumigation concentration exceeds the maximum 1-hour concentration estimated from Step 4 of Section 4.2, then the effect of fumigation on longer averaging periods may be accounted for as follows. The value of χ used with the multiplying factors in Step 5 (Section 4.2) should be adjusted using a weighted average of χ_1 and χ_f, assuming that χ_f persists for 90 minutes. The weighted average should be calculated as follows:

Averaging Time	Adjustment of χ_1 for Fumigation
3 hours	$\chi_1' = (\chi_1 + \chi_f)/2$
8 hours	$\chi_1' = (13\chi_1 + 3\chi_f)/16$
24 hours	$\chi_1' = (15\chi_1 + \chi_f)/16$

The adjusted value, χ_1', should then be used with the multiplying factors in Step 5 of Section 4.2.

4.5.4 Estimated Concentrations from Area Sources

Fugitive emissions from simple area sources may be modeled as virtual point sources in order to obtain pollutant concentration estimates,[9] using the procedure in this section. This procedure should only be applied to approximately square area sources of at least 50 meters on a side and with effective release heights of less than 10 meters. The SCREEN model may also be used to estimate concentrations for area sources without these restrictions on size and height (refer to Appendix A). Because of the simplifying assumptions used in this procedure, the results should be used with extreme caution, especially for receptors close to the area source where there may be a bias toward over prediction. An area source approximation for estimating contributions from multiple point sources is presented in Section 4.5.5(C).

Step 1. Define the area source by approximating it as a square area. (For complex area sources that cannot be approximated by a square, the Industrial Source Complex (ISC) model[21] of the UNAMAP series may be used if the area can be broken down into a group of adjacent squares).

Step 2. Determine the distance to the virtual point source corresponding to stability classes C and F for rural sources and classes C and E for urban sources.

(1) Estimate the initial horizontal dispersion parameter, σ_{yo}, by dividing the length of the side of the area source, S, by 4.3:

$$\sigma_{yo} = S/4.3 \qquad (4.15)$$

(2) For rural sites, use Figure 4-18 to determine the virtual point source distance, x_y, that corresponds with the value of σ_{yo} for both stability classes (C and E or F).

For urban sites, calculate the virtual point source distance, x_y, that corresponds with the value of σ_{yo} from the following:

$$x_y = [0.0004\sigma_{yo}{}^2+(1.6x10^{-7}\sigma_{yo}{}^4+4a^2\sigma_{yo}{}^2)^{1/2}]/(2a^2) \qquad (4.16)$$

with a = 0.22 for stability class C and a = 0.11 for stability class E.

Step 3. Determine the effective release height, h_e. In general, this will be the physical height of the source for fugitive emissions. For a slag pile, use one half the height of the pile. If the effective release height cannot be determined, assume a release height of 0 m.

Step 4. Estimate maximum short term (1-hour) concentrations by following the procedure for point sources outlined in Step 4 of Section 4.2, assuming no plume rise, $\Delta h = 0$. Do not use the multiplying factors in Step 5 of Section 4.2 to correct for averaging times greater than 1-hour. Concentrations close to an area source will not vary as much as those for point sources in response to varying wind directions, and the meteorological conditions which are likely to give maximum 1-hour concentrations (Procedures

(b) and (c) of Section 4.2) can persist for several hours. Therefore it is recommended that the maximum 1-hour concentration be conservatively assumed to apply for averaging periods out to 24 hours.

Step 5. Determine the downwind distance to the maximum concentration, measured from the downwind edge of the area source, by subtracting the virtual point source distance, x_y, from the distance obtained from Figure 4-2 (rural) or Figure 4-3 (urban) in Step 4 of Section 4.2. For ground-level sources (h_e = 0m), the maximum concentration will be at the downwind edge of the source.

4.5.5 Contributions from Other Sources

To assess the significance of the air quality impact of a proposed source, the impact of nearby sources and "background" must be specifically determined. (Background includes those concentrations due to natural sources, and distant or unspecified man-made sources.) The impact of the proposed source can be separately estimated, applying the techniques presented elsewhere in Section 4, and then superimposed upon the impact of the nearby sources and background to determine total concentrations in the vicinity of the proposed source.

This section addresses the estimation of concentrations due to nearby sources and background. Three situations are considered:

A. A proposed source relatively isolated from other sources.

B. A proposed source in the vicinity of a few other sources.

C. A proposed source in the vicinity of an urban area or other large number of sources.

It must be noted that in all references to air quality monitoring in the following discussion, it is assumed that the source in question is not yet operating. If the source is emitting pollutants during the period of air quality data collection, care must be taken not to use monitoring data influenced by the impact of the source. Additional guidance on determining background concentrations is provided in Section 9.2 of the Guideline on Air Quality Models (Revised).[3]

A. Relatively Isolated Proposed Source

A proposed source may be considered to be isolated if it is expected that background will be the only other significant contributor to ambient pollutant concentrations in its vicinity. In that case, it is recommended that air quality data from monitors in the vicinity of the proposed source be used to estimate the background concentrations. If monitoring data are not available from the vicinity of the source, use data from a "regional" site; i.e., a site that characterizes air quality across a broad area, including that in which the source is located.

Annual average concentrations should be relatively easy to determine from available air quality data. For averaging times of about 24 hours or less, meteorology should be accounted for; i.e., the combined source/ background concentration must be calculated for several meteorological conditions to ensure that the maximum total concentration is determined.

B. Proposed Source in the Vicinity of a Few Other Sources

If there already are a few sources in the vicinity of the proposed facility, the air quality impact of these sources should be accounted for. As long as the number of nearby sources is relatively small, the recommended procedure is to use (1) air quality monitoring data to estimate background concentrations and (2) dispersion modeling to estimate concentrations due to the nearby source(s). Then superimpose those estimates to determine total concentrations in the vicinity of the proposed source.

To estimate background concentrations, follow the same basic procedure as in the case of an isolated source. In this case, however, there is one added complication. Wind direction must be accounted for in order to single out the air quality data that represent background only (i.e., data that are not affected by contributions from nearby sources).

Concentrations due to the nearby sources will normally be best determined through dispersion modeling. The modeling techniques presented in this guideline may be used. If the user has access to UNAMAP, the modeling effort can be considerably simplified. If UNAMAP can not be used, the user should model each source separately to estimate concentrations due to each source during various meteorological conditions and at an array of receptor locations (e.g., see Sections 4.3 and 4.4.1) where interactions between the effluents of the proposed source and the nearby sources can occur. Significant locations include (1) the area of expected maximum impact of the proposed source, (2) the area of maximum impact of the nearby sources, and (3) the area where all sources will combine to cause maximum impact. It may be necessary to identify those locations through a trial and error analysis.

C. Proposed Source Within an Urban Area or in the Vicinity of a Large Number of Sources

For more than a very small number of nearby sources, it may be impractical to model each source separately. Two possible alternatives for estimating ambient concentrations due to the other sources are to use air quality monitoring data or a multisource dispersion model.

If data from a comprehensive air monitoring network are available, it may be possible to rely entirely on the measured data. The data should be adequate to permit a reliable assessment of maximum concentrations, particularly in (1) the area of expected maximum impact of the proposed source, (2) the area of maximum impact of the existing sources and (3) the area where all sources will combine to cause maximum impact.

In some cases, the available air quality monitor data will only be adequate to estimate general area-wide background concentrations. In such cases, there is no choice but to use dispersion modeling to estimate concentrations due to the nearby sources. If possible, a multisource dispersion model should be used. If the user has access to UNAMAP the ISCLT model can be applied for long-term concentration estimates, and the MPTER or ISCST model for short-term estimates (MPTER can handle up to 250 point sources but cannot handle building downwash effects).

If it is not feasible to apply a multisource model, and there is a considerable number of nearby sources, a rough estimate of maximum concentrations due to those sources can be made by arbitrarily grouping the sources into an area source through the following equation.[29] (The estimate is primarily applicable to receptor locations near the center of the area source, defined below, although it may be considered a reasonable first-approximation for any location within the area):

$$C = 18\ Q\ (\Delta x)^{1/4}/u \qquad (4.17)$$

where:

C = maximum short term (1 - 24 hours) contribution to ground-level concentrations from the area source (g/m^3)

Q = average emission rate ($g/m^2/s$) within the area defined by Δx

u = assumed average wind speed (m/s) for the averaging time of concern (use 2 m/s if no data are available)

Δx = length (m) of one side of the smallest square area that will contain the nearby sources, ignoring relatively small outlying sources or any source that is considerably removed from the other sources.

The best results will be obtained with the above equation when emissions are uniformly distributed over the defined area. Any large point sources in the vicinity should be modeled separately, and the estimated concentrations manually superimposed upon that computed for the area source. Because this is an area source approximation, the adjustment factors for averaging times greater than an hour should not be used.

4.5.6 Long Range Transport

In certain instances it will be necessary to estimate the air quality impact of a proposed source at locations beyond its vicinity (beyond roughly 30-50 km). To estimate seasonal or annual average concentrations (out to about 100 km) the procedures of Section 4.4 provide a rough estimate. The procedures are limited to plume heights greater than 50m, and should not be applied beyond 100 km.

For short-term estimates (concentration averaging times up to about 24 hours) beyond the vicinity of the source and out to 100 km downwind, the following procedure is recommended. The procedure accounts for the meteorological situations with the greatest persistence that are likely to result in the highest concentrations at large distances; viz., neutral/high wind conditions (Steps 1-4) and stable conditions (Steps 5-7):

Step 1. Estimate the normalized plume rise ($u\Delta h$) applicable to neutral and unstable atmospheric conditions. Use the procedure described in Step 1 of Section 4.2.

Step 2. Compute plume height, h_e, that will occur during D stability with a 10-meter wind speed of 5 m/s. Adjust the wind speed from 10 meters to stack height, using Equation 3.1 and the exponent for stability class D.

$$h_e = h_s + (u\Delta h)/u_s$$

Step 3. Using Figure 4-19, obtain a $\chi u/Q$ value for the desired downwind distance (D stability case). (If the plume height is greater than 300m, then the value corresponding to h_e = 300m may be used for conservatism.)

Step 4. Compute the maximum 1-hour D stability concentration, χ_{max}, using the $\chi u/Q$ value obtained in Step 3.

$$\chi_{max} = Q(\chi u/Q)/u_s$$

For Q, substitute the source emission rate (g/s), and use the value of u_s determined in Step 2.

Step 5. Compute the plume height $h_e = h_s + \Delta h$ that will occur during E stability with a 10-meter wind speed of 2 m/s. Adjust the wind speed from 10 meters to stack height using Equation 3.1 and the exponent for stability class E. Use the stable plume rise (Δh) computed from Equation 4.6 in Step 3 of Section 4.2.

$$h_e = h_s + \Delta h$$

Step 6. From Figure 4-20, obtain a $\chi u/Q$ value for the same distance considered in Step 3 above. (If the plume height is greater than 300m, then the value corresponding to h_e = 300m may be used for conservatism).

Step 7. Compute the maximum 1-hour E stability concentration, χ_{max}, using the $\chi u/Q$ value obtained in Step 6:

$$\chi_{max} = Q(\chi u/Q)/u_s$$

where u_s was determined in Step 5.

Step 8. Select the higher of the χ_{max} values computed in Steps 4 and 7. The selected value represents the highest 1-hour concentration likely to occur at the specified distance.

Step 9. To estimate concentrations for averaging times up to 24 hours, multiply the 1-hour value by the factors presented in Step 5 of Section 4.2.

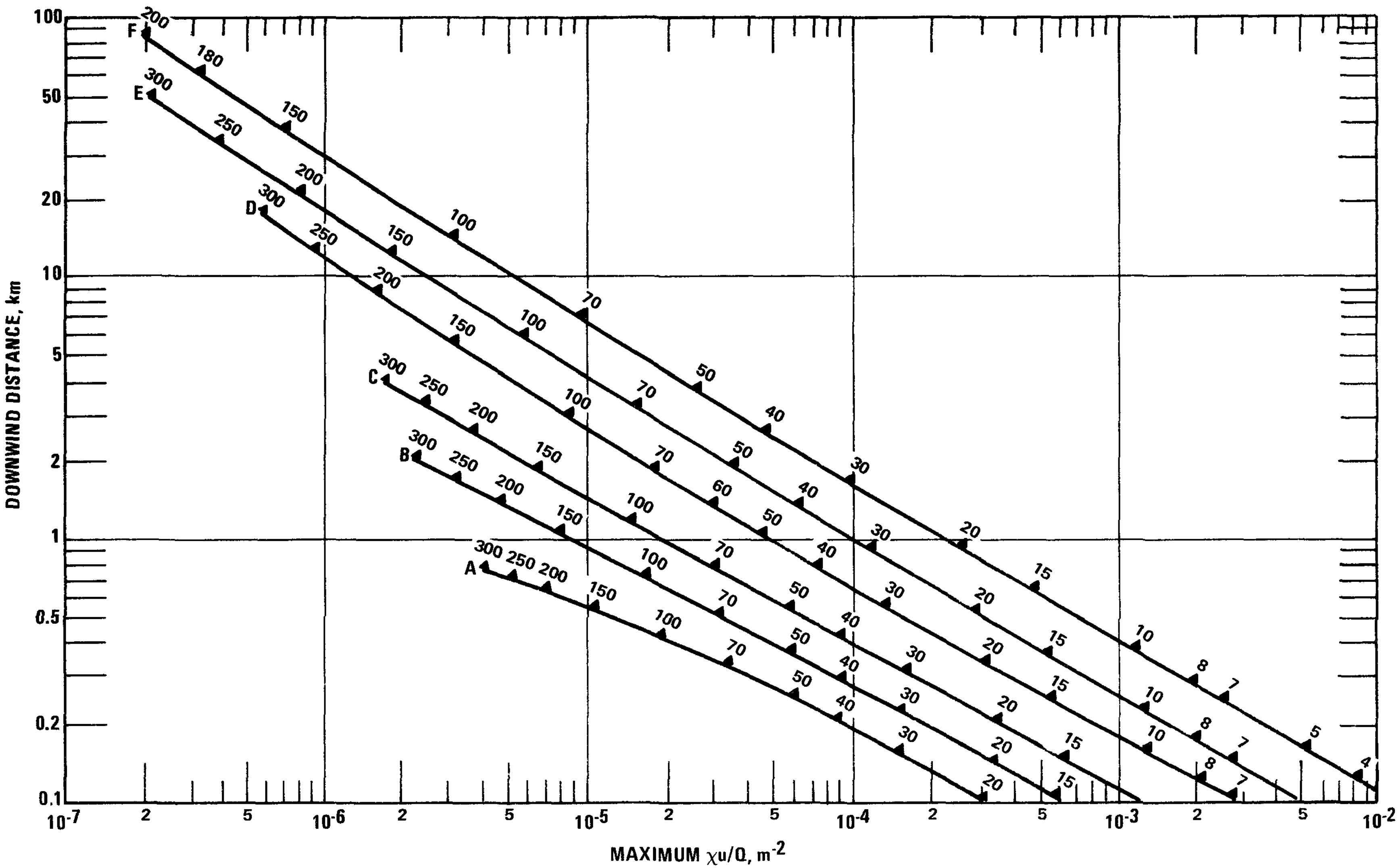

Figure 4-2. Downwind distance to maximum concentration and maximum $\chi u/Q$ as a function of stability class and plume height (m); rural terrain.

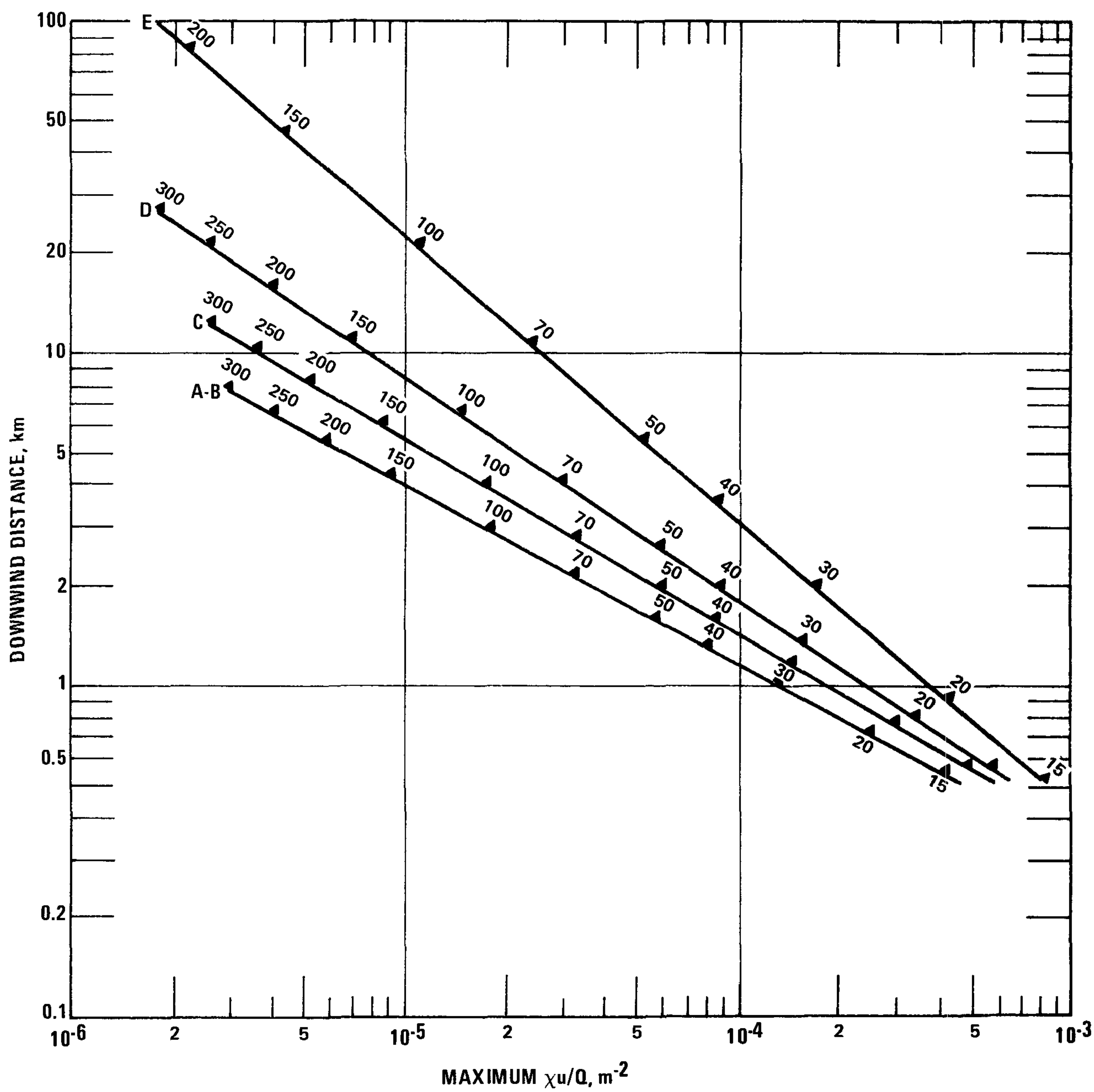

Figure 4-3. Downwind distance to maximum concentration and maximum χu/Q as a function of stability class and plume height (m); urban terrain.

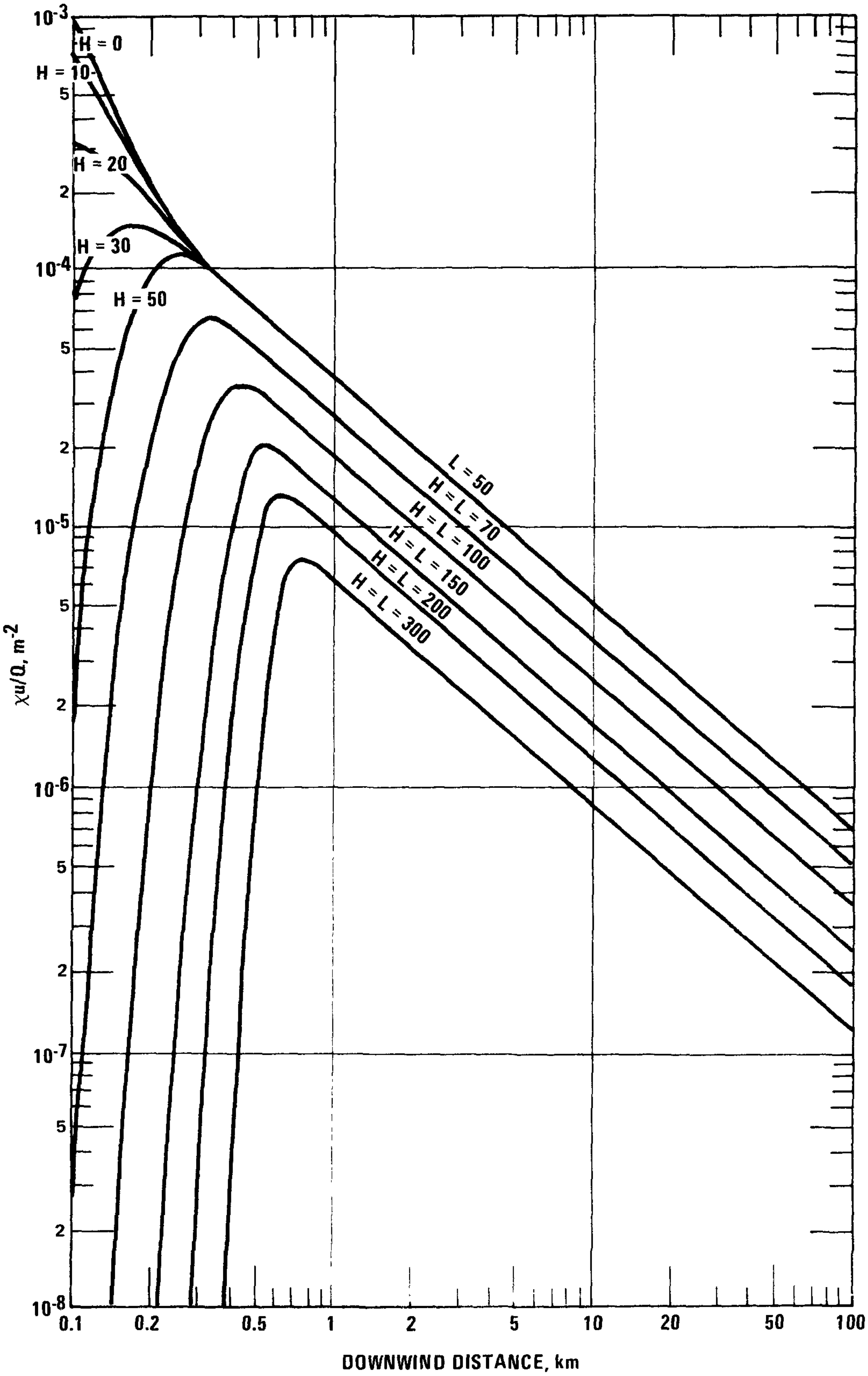

Figure 4-4. Stability class A; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m

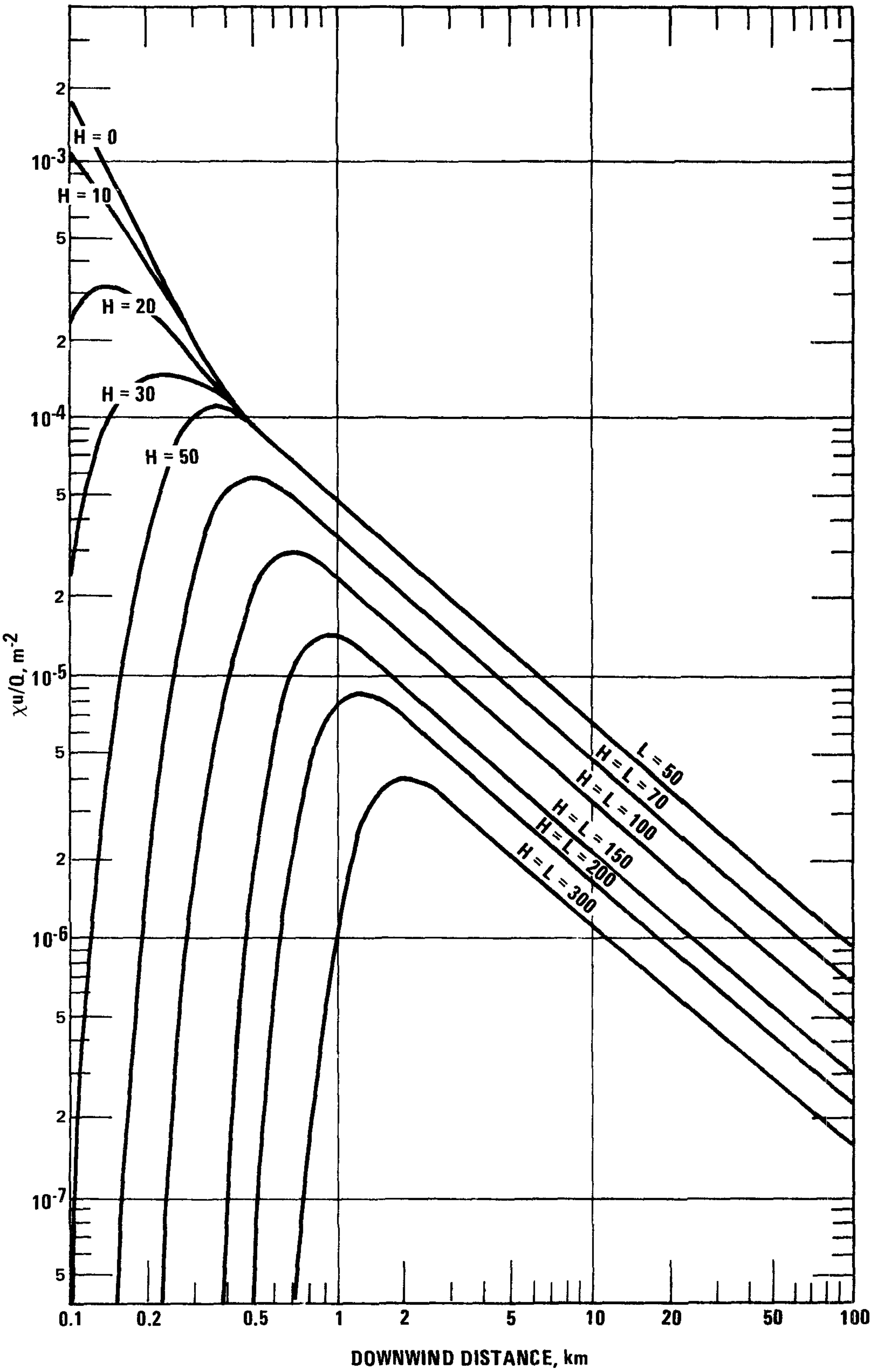

Figure 4-5 Stability class B; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m.

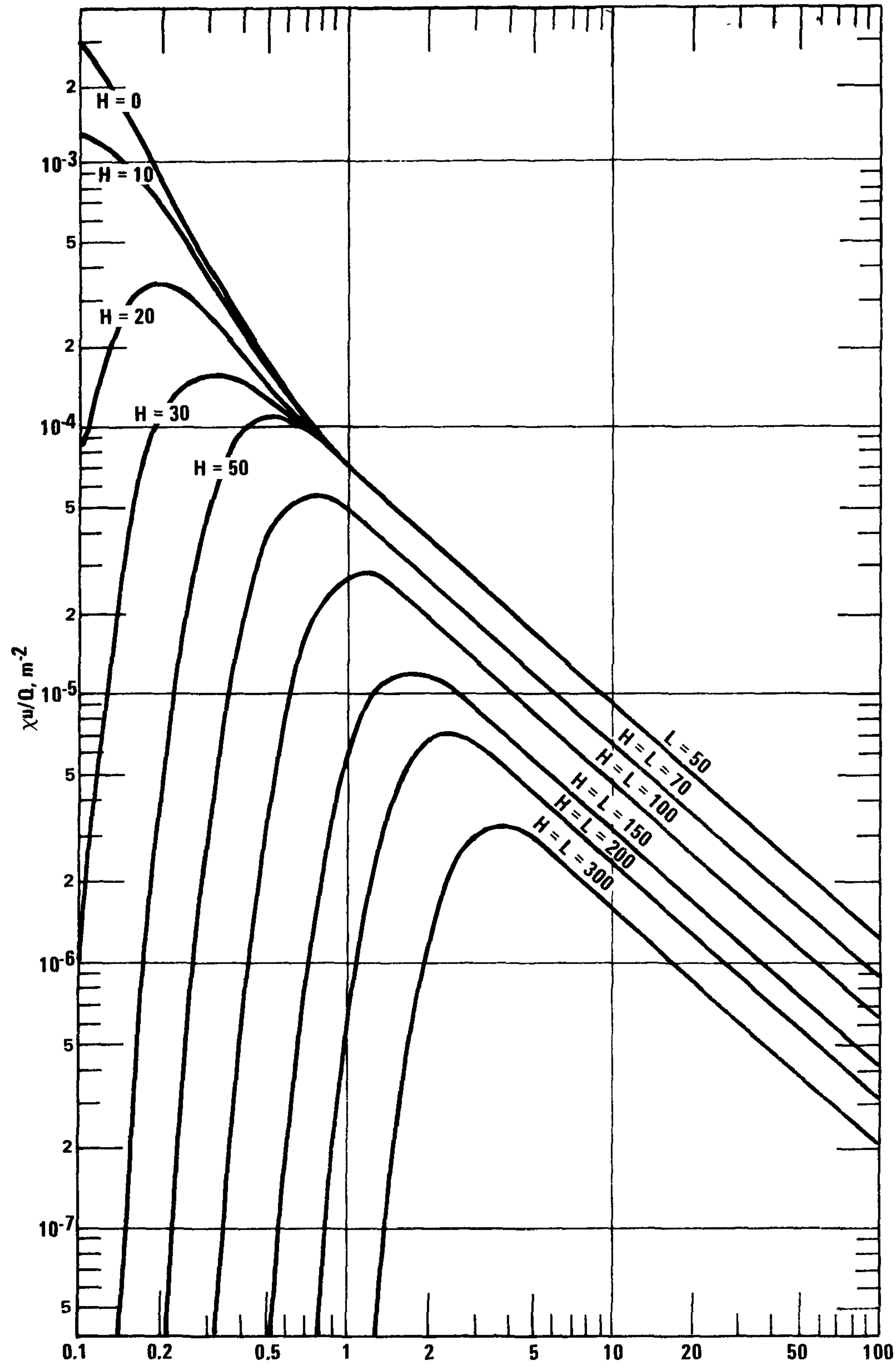

Figure 4-6. Stability class C; rural terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ⩽ 50 m; L = H for H > 50 m.

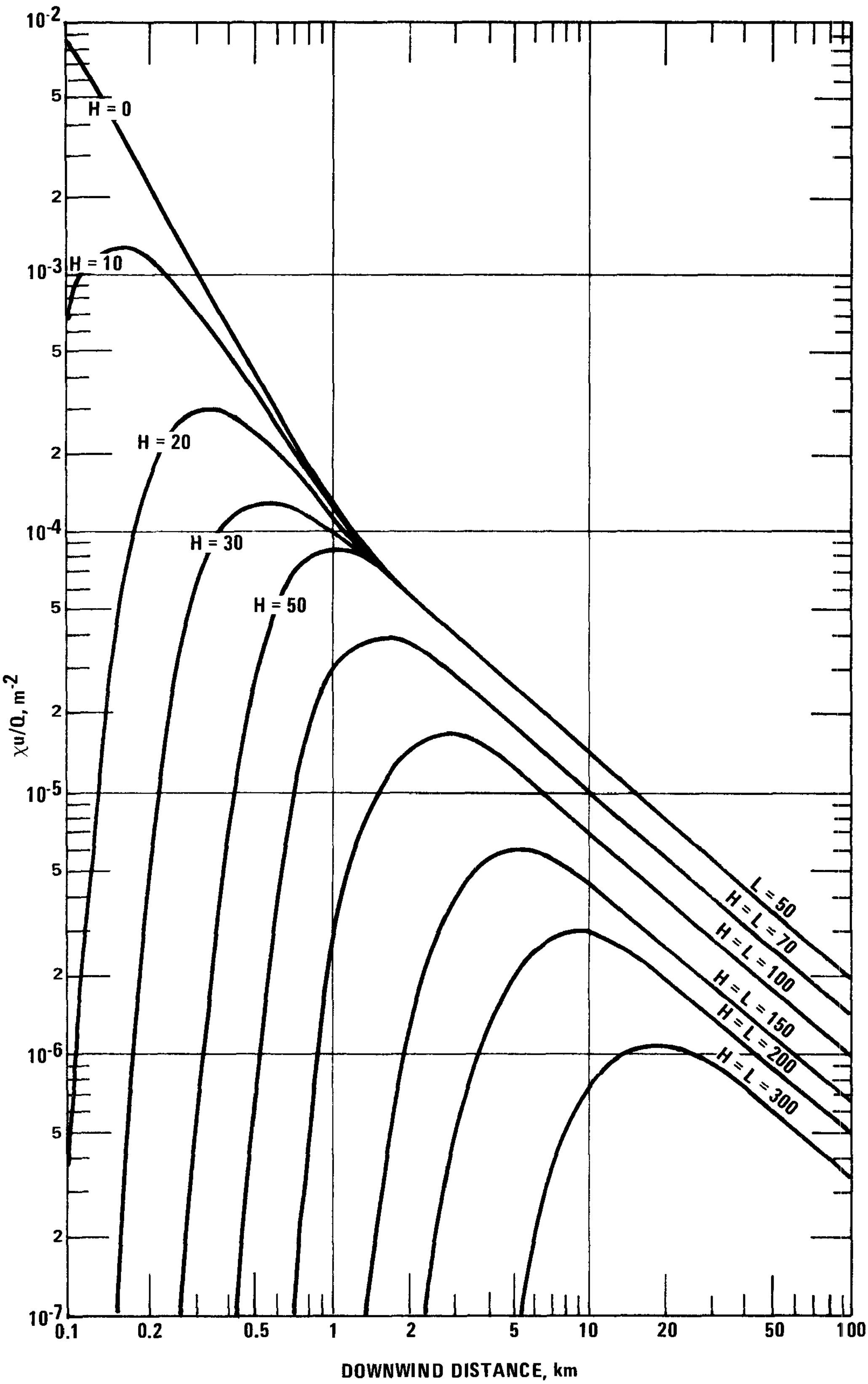

Figure 4-7. Stability class D; rural terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m.

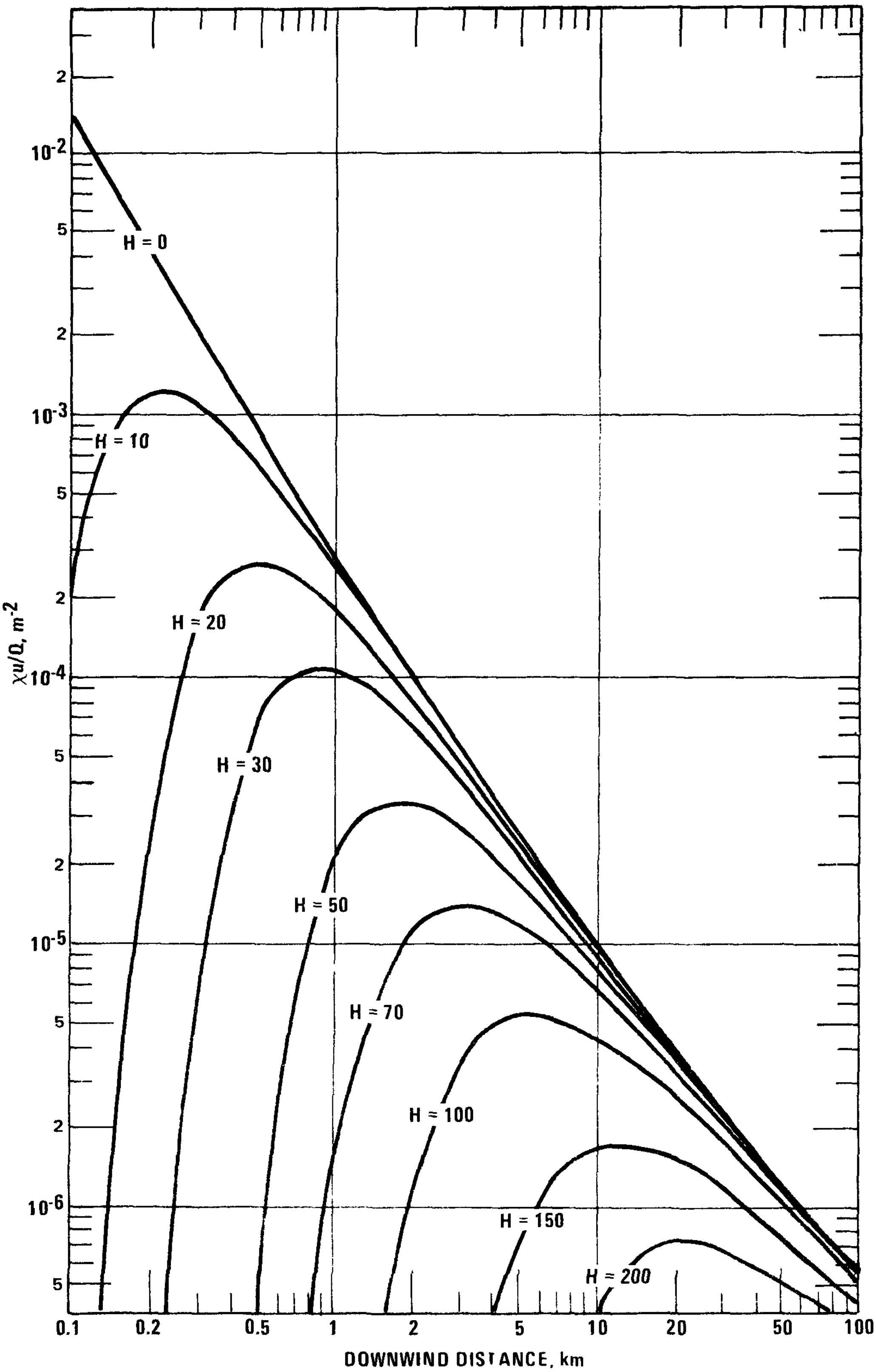

Figure 4-8 Stability class E; rural terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m

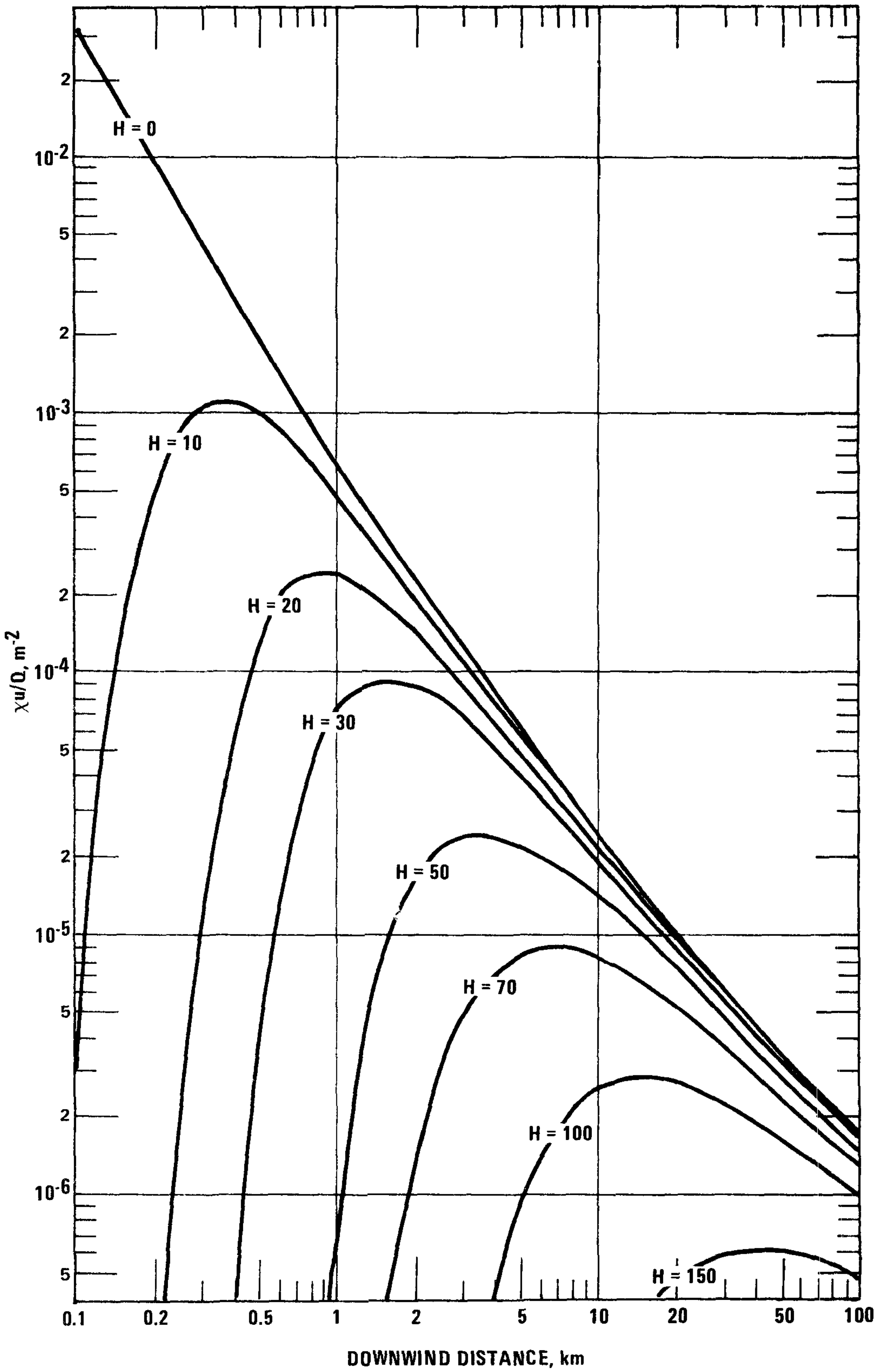

Figure 4-9 Stability class F; rural terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m.

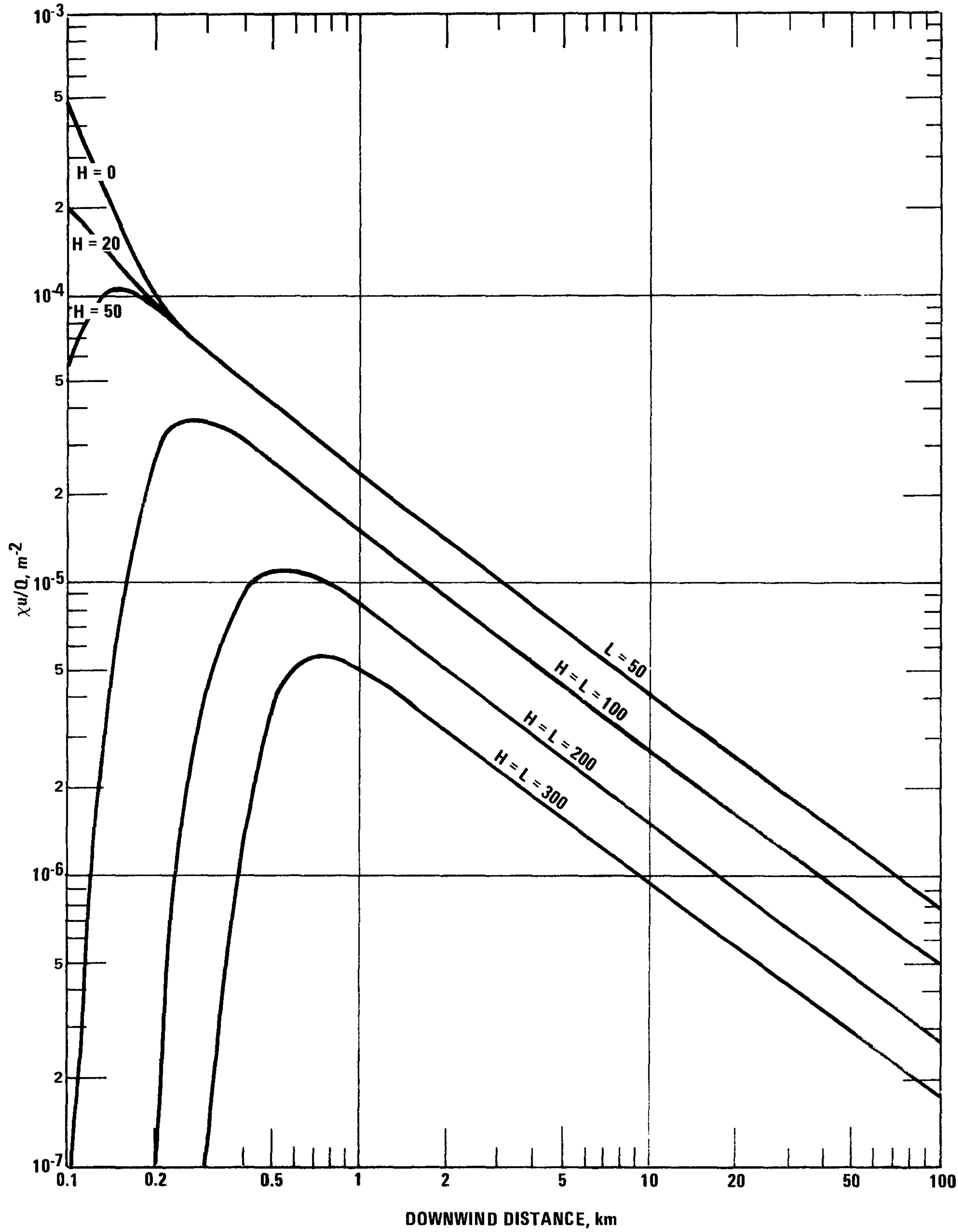

Figure 4-10. Stability classes A and B; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leq$ 50 m; L = H for H $>$ 50 m.

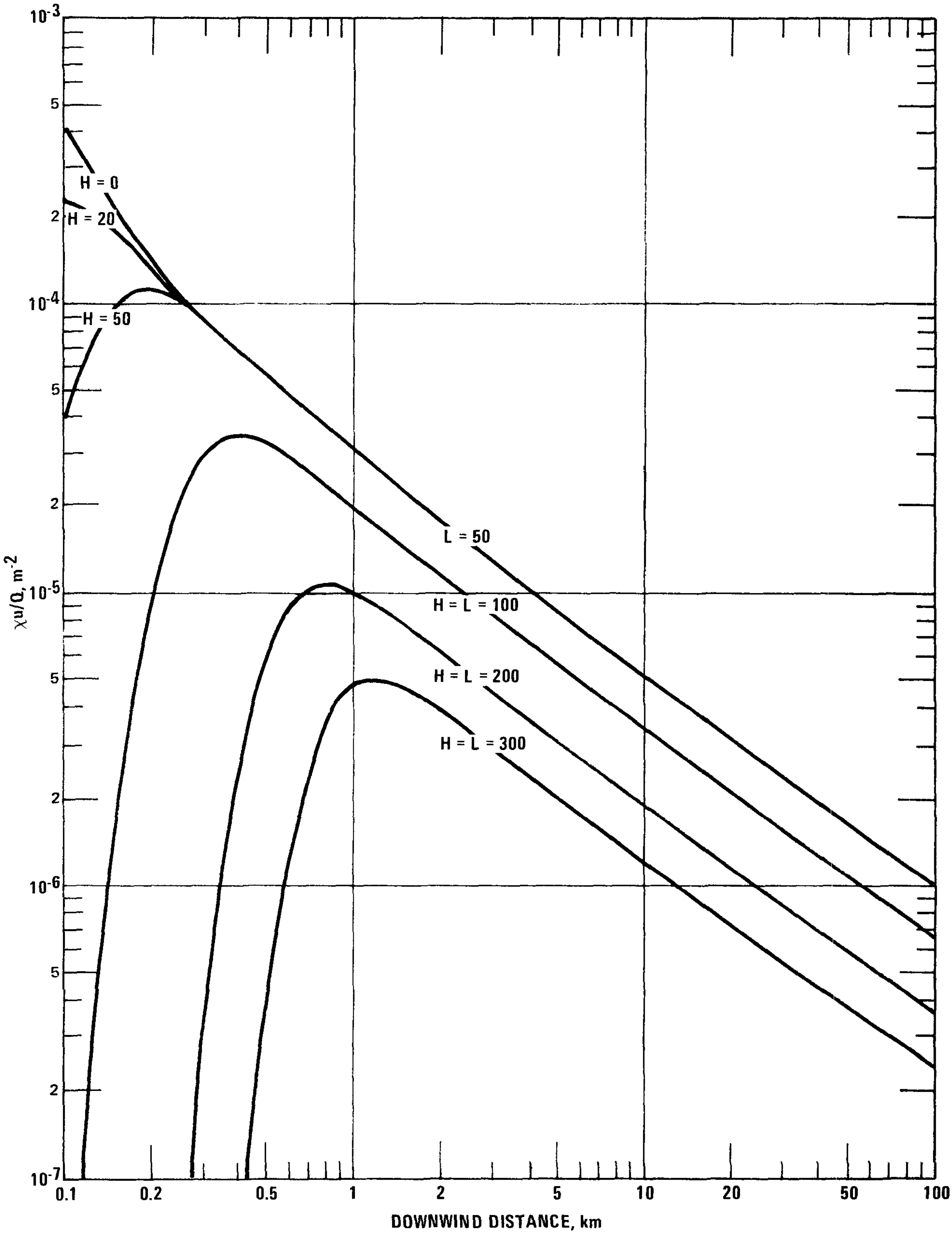

Figure 4-11. Stability class C; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H $\leqslant$ 50 m; L = H for H > 50 m.

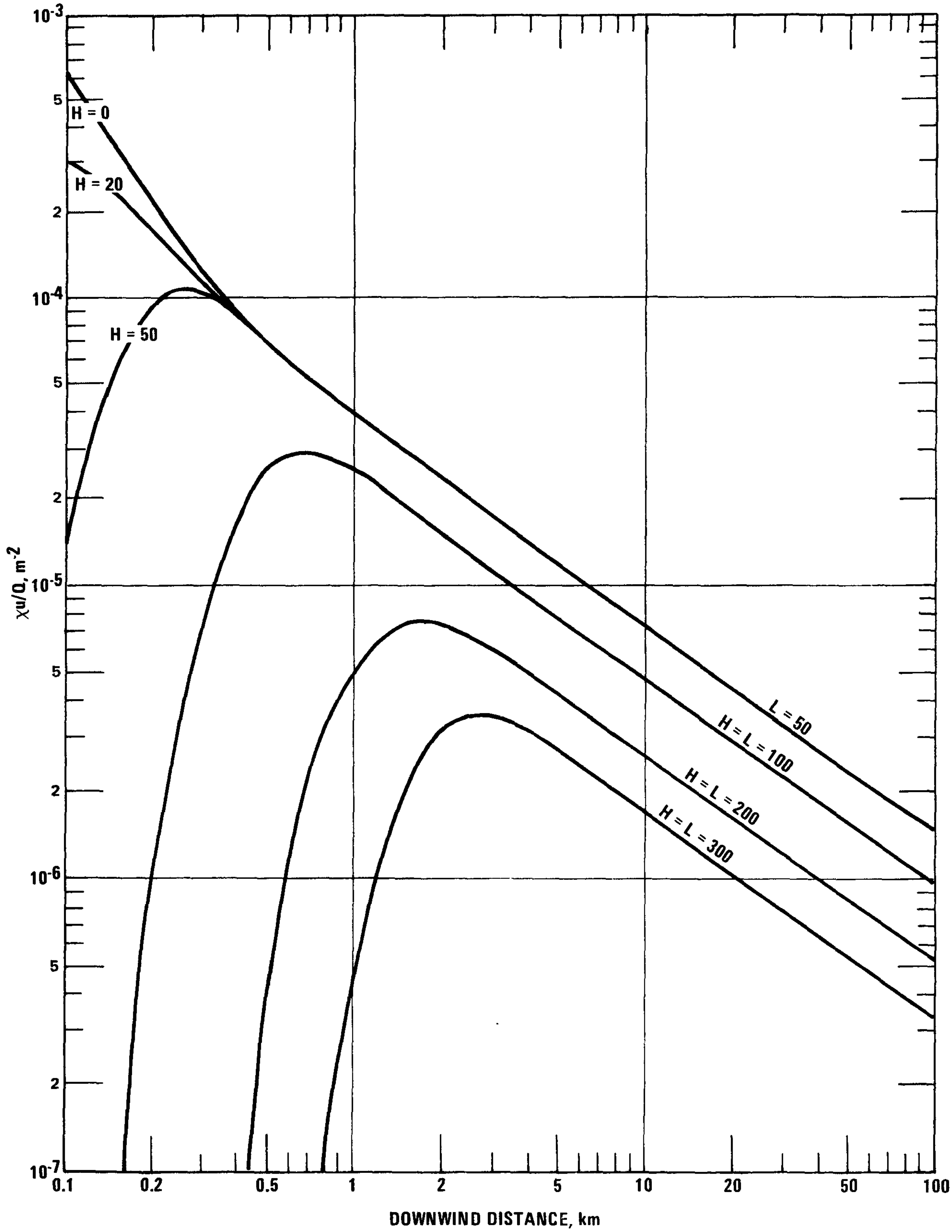

Figure 4-12. Stability class D; urban terrain $\chi u/Q$ versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ≤ 50 m; L = H for H > 50 m

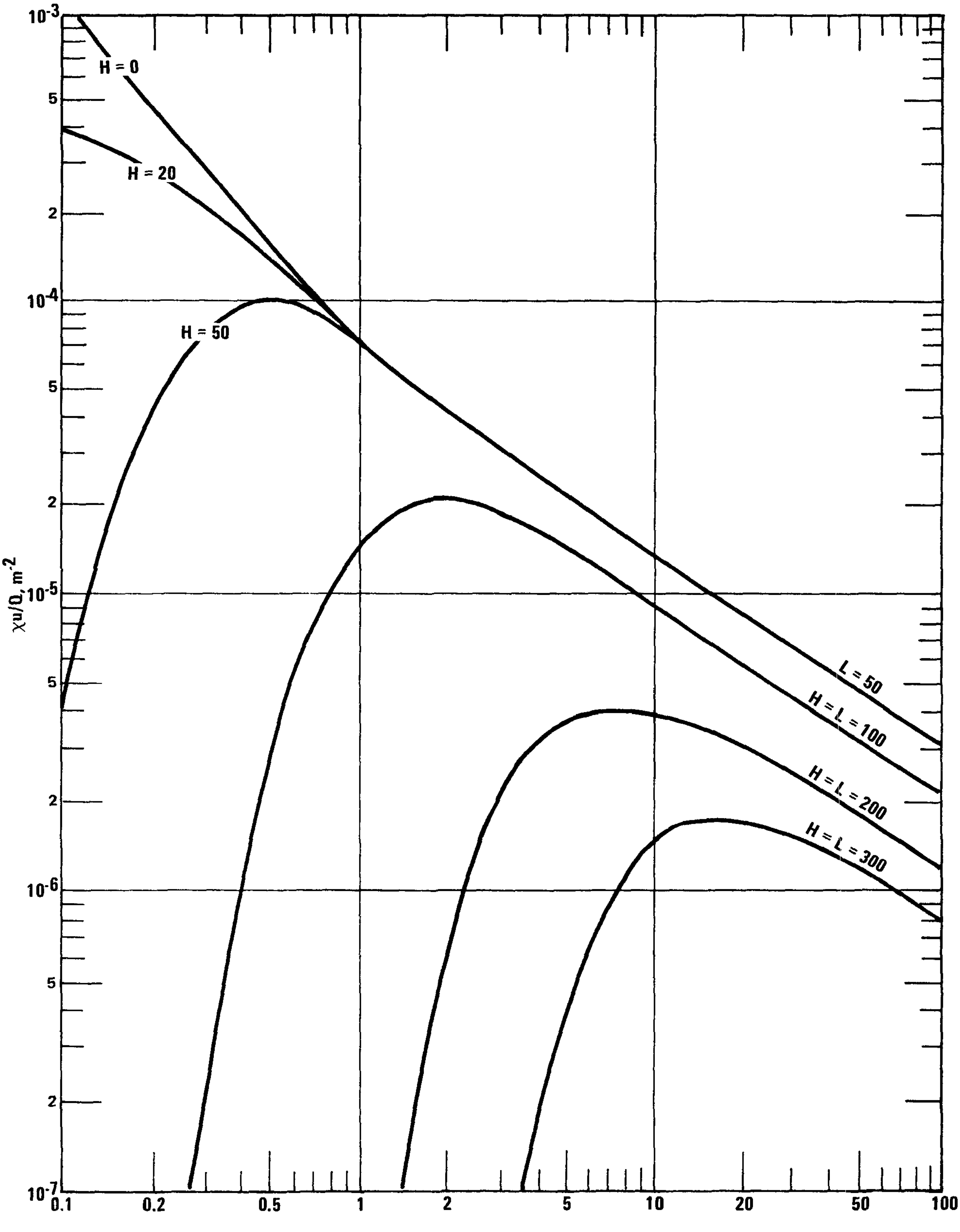

Figure 4-13. Stability class E; urban terrain χu/Q versus distance for various plume heights (H), assuming very restrictive mixing heights (L): L = 50 m for H ⩽ 50 m; L = H for H > 50 m.

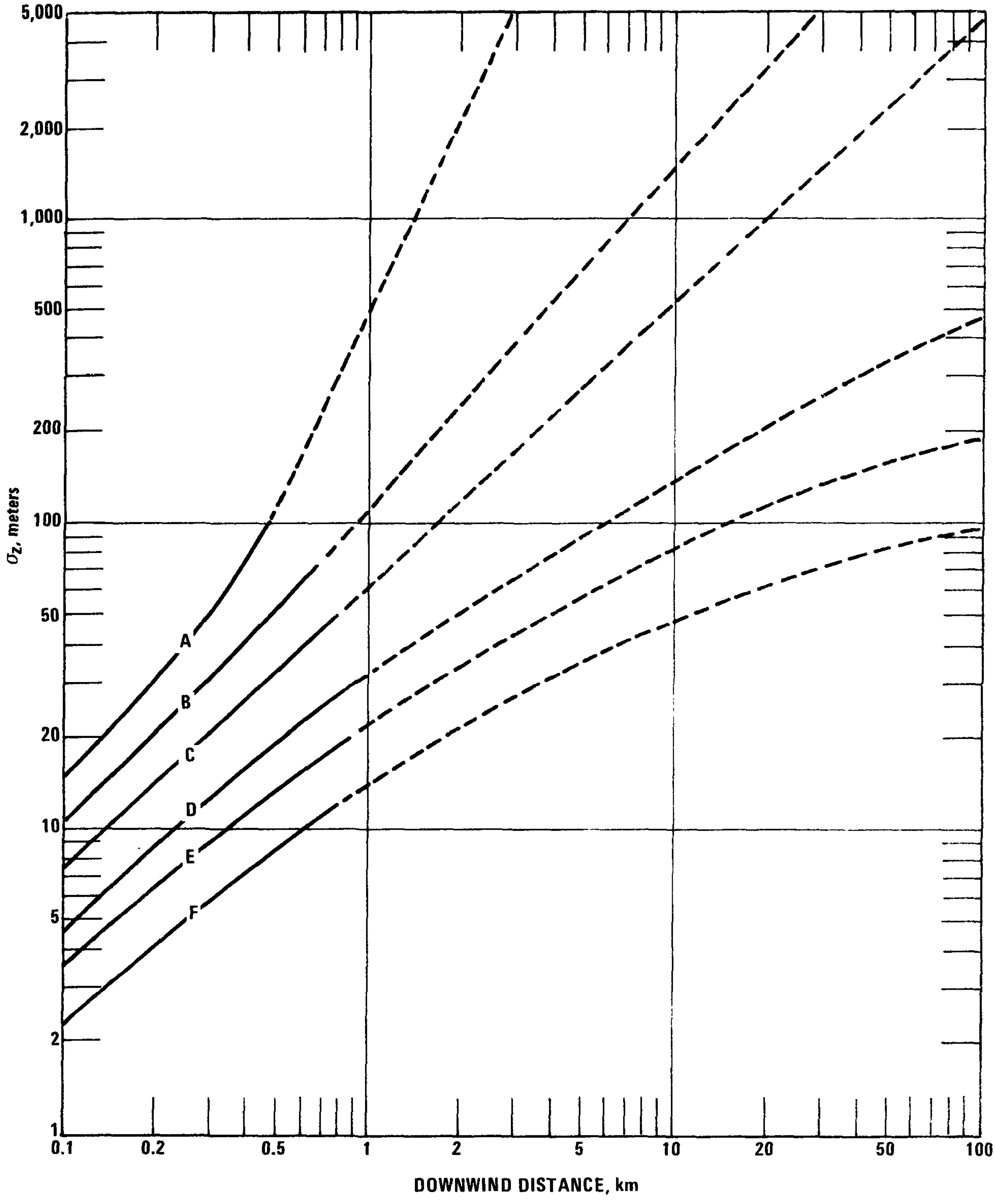

Figure 4-14. Vertical dispersion parameter (σ_Z) as a function of downwind distance and stability class; rural terrain.

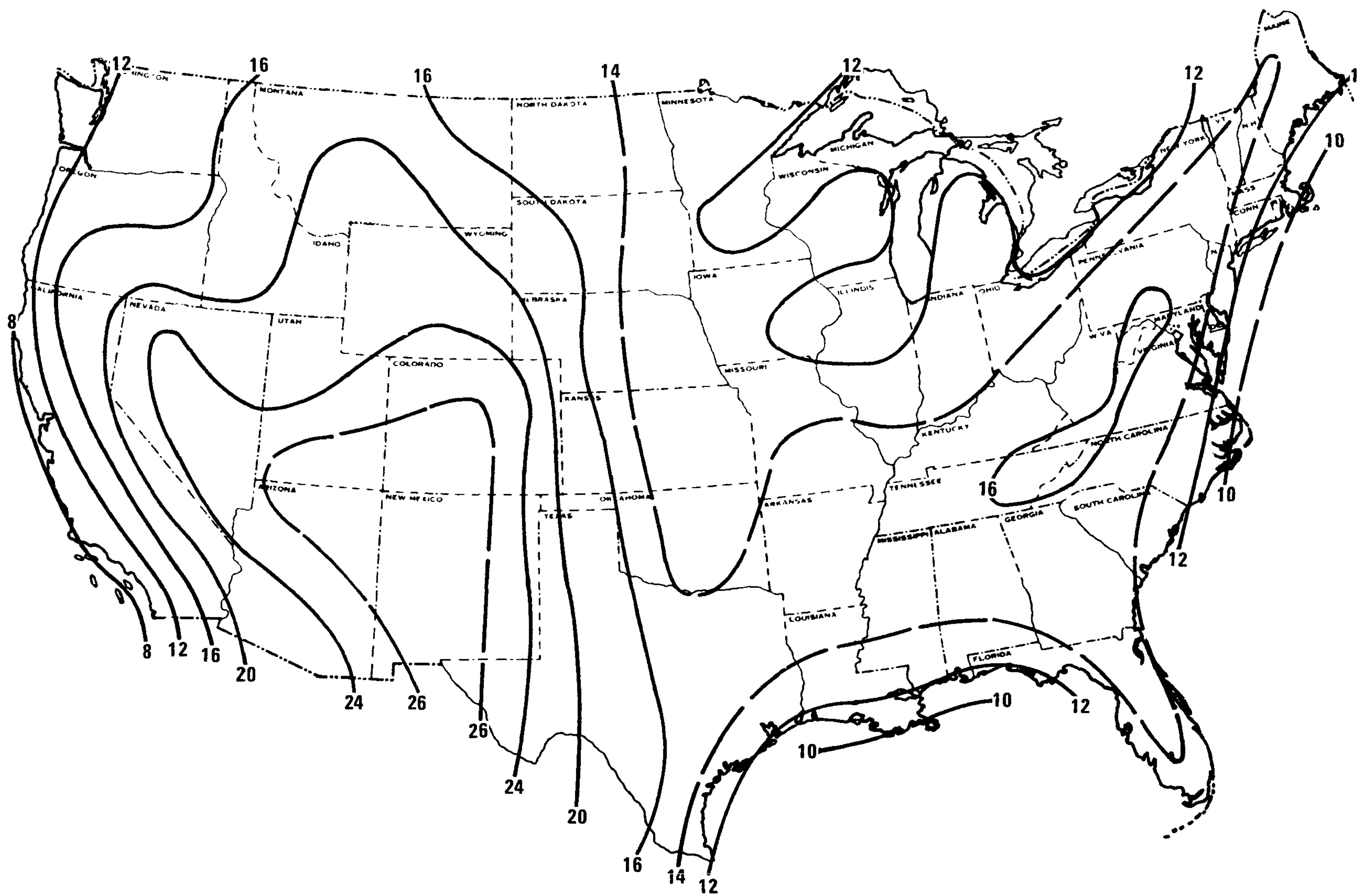

Figure 4-15. Isopleths (hundreds of meters) of mean annual afternoon mixing heights

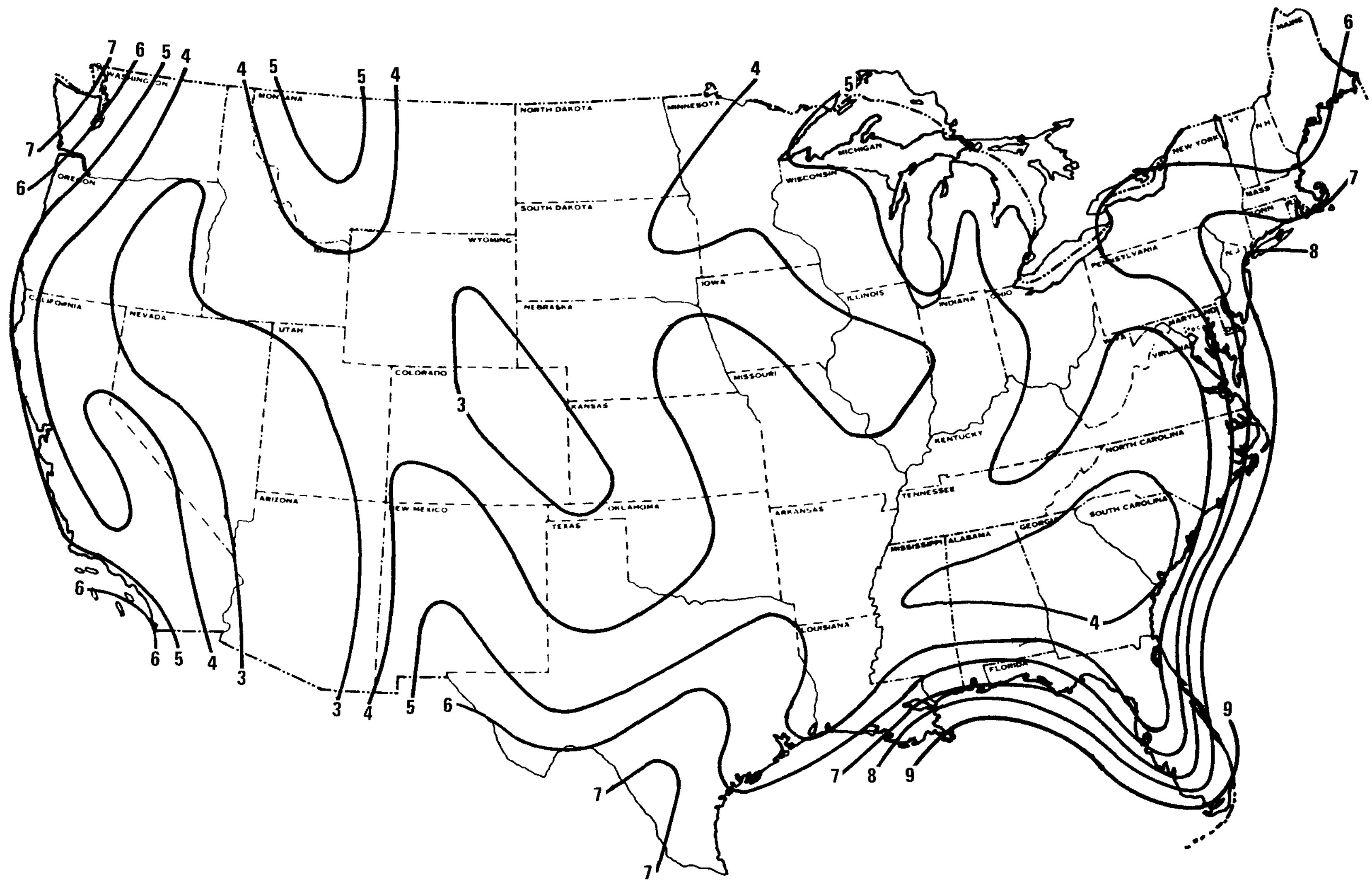

Figure 4-16. Isopleths (hundreds of meters) of mean annual morning mixing heights

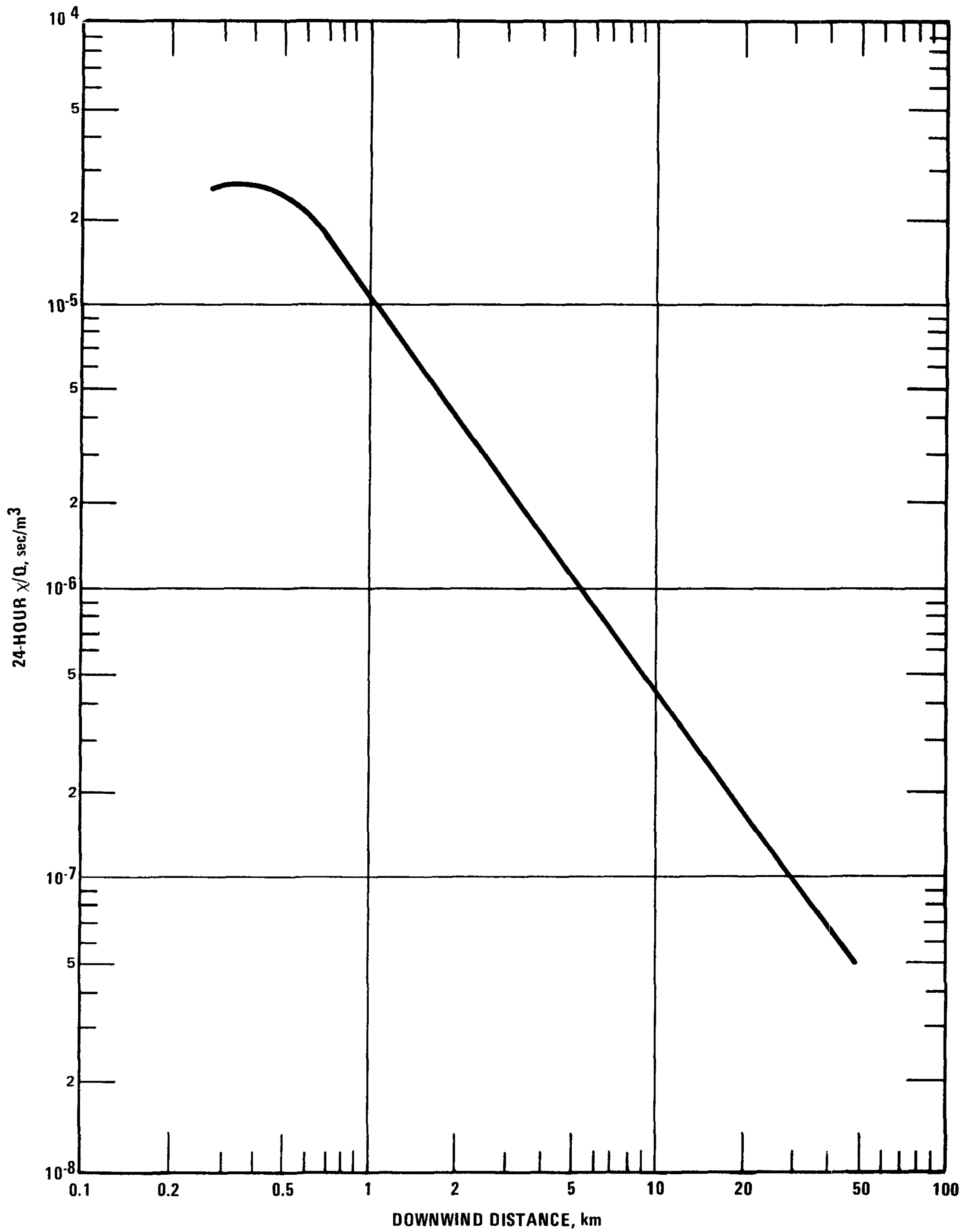

Figure 4-17. 24 hour χ/Q versus downwind distance, obtained from the valley model Assumptions include stability class F, a wind speed of 2.5 m/sec, and plume height 10 meters above terrain.

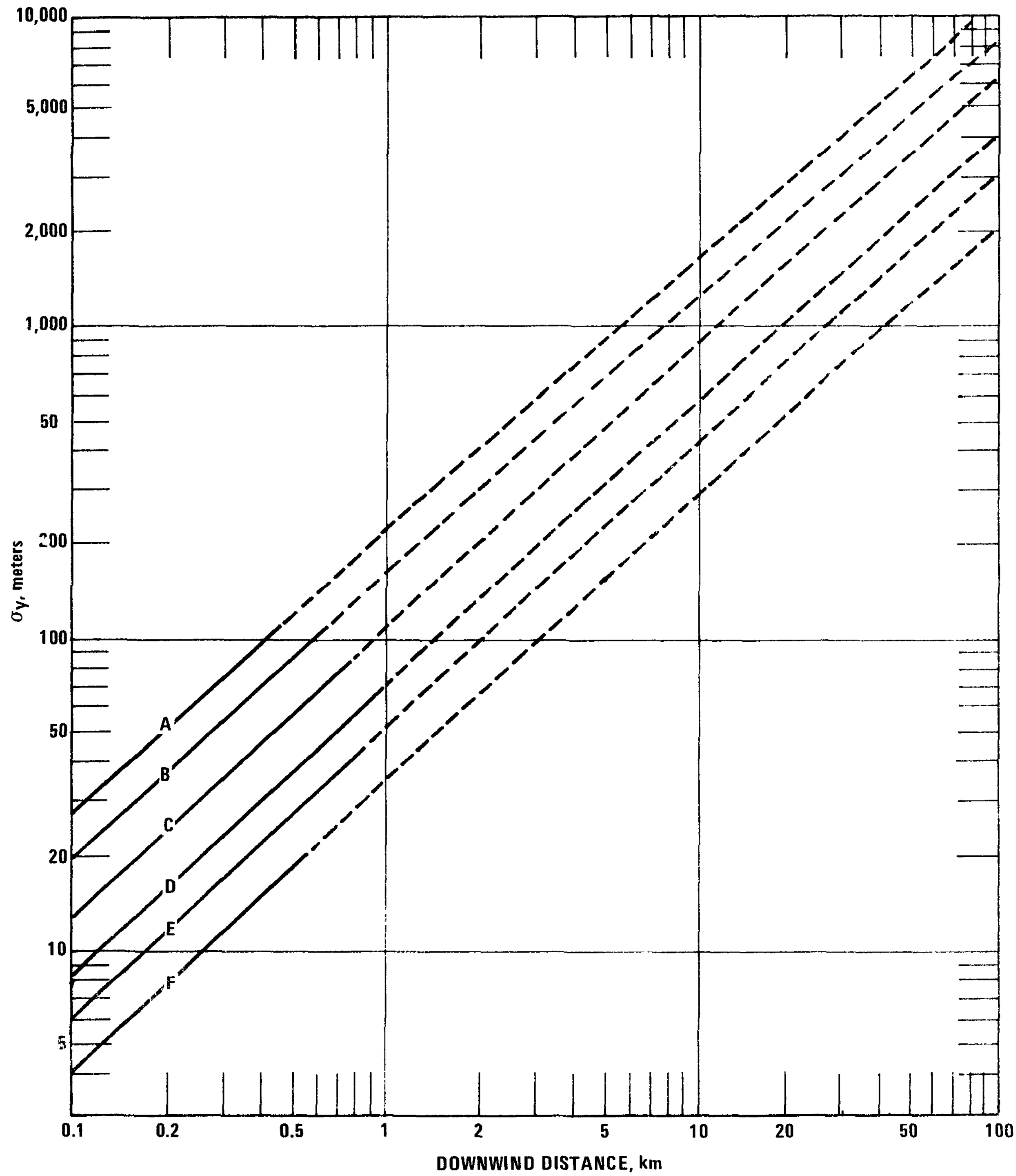

Figure 4-18. Horizontal dispersion parameter (σ_y) as a function of downwind distance and stability class; rural terrain.

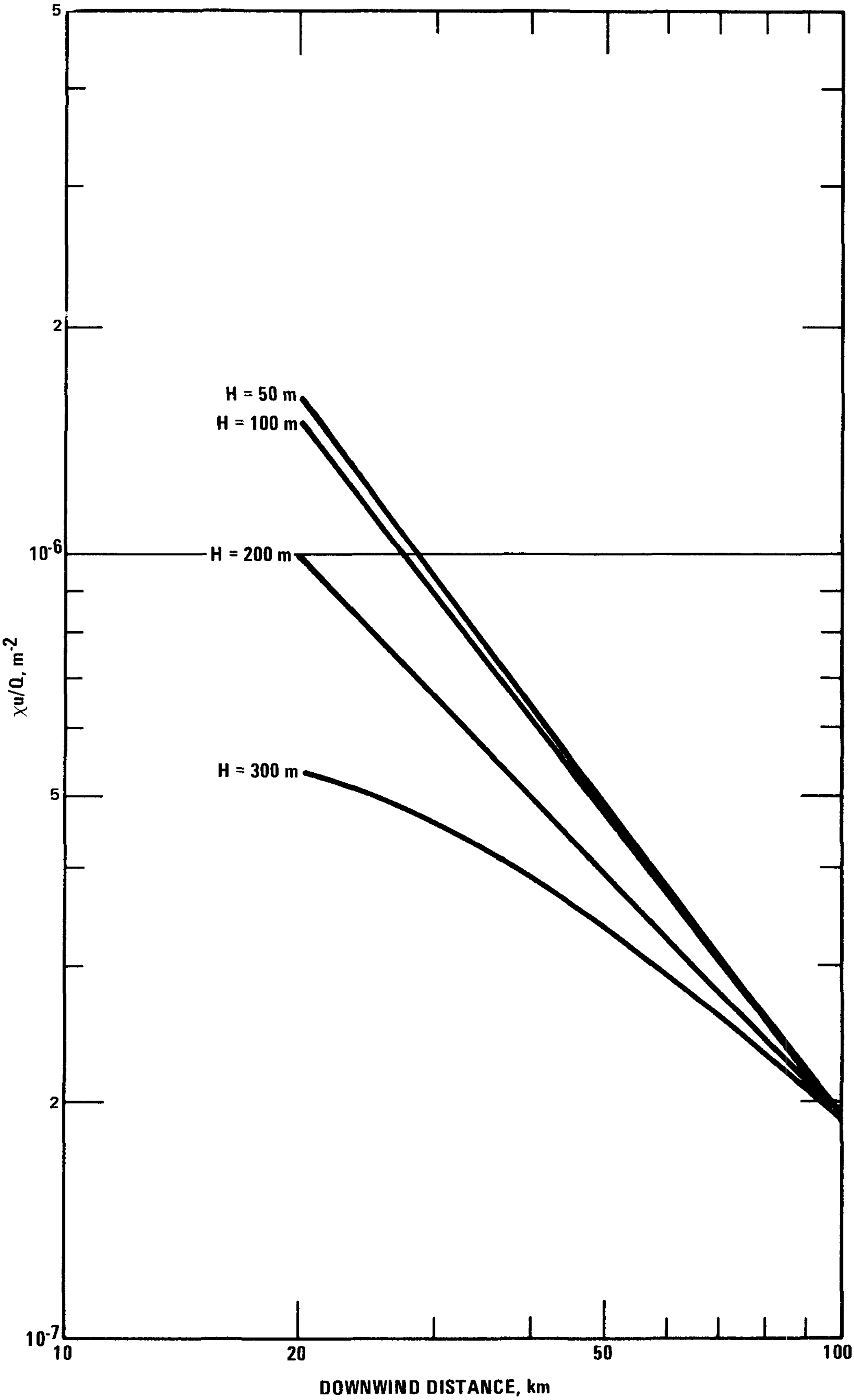

Figure 4-19. Maximum $\chi u/Q$ as a function of downwind distance and plume height (H), assuming a mixing height of 500 meters; D stability.

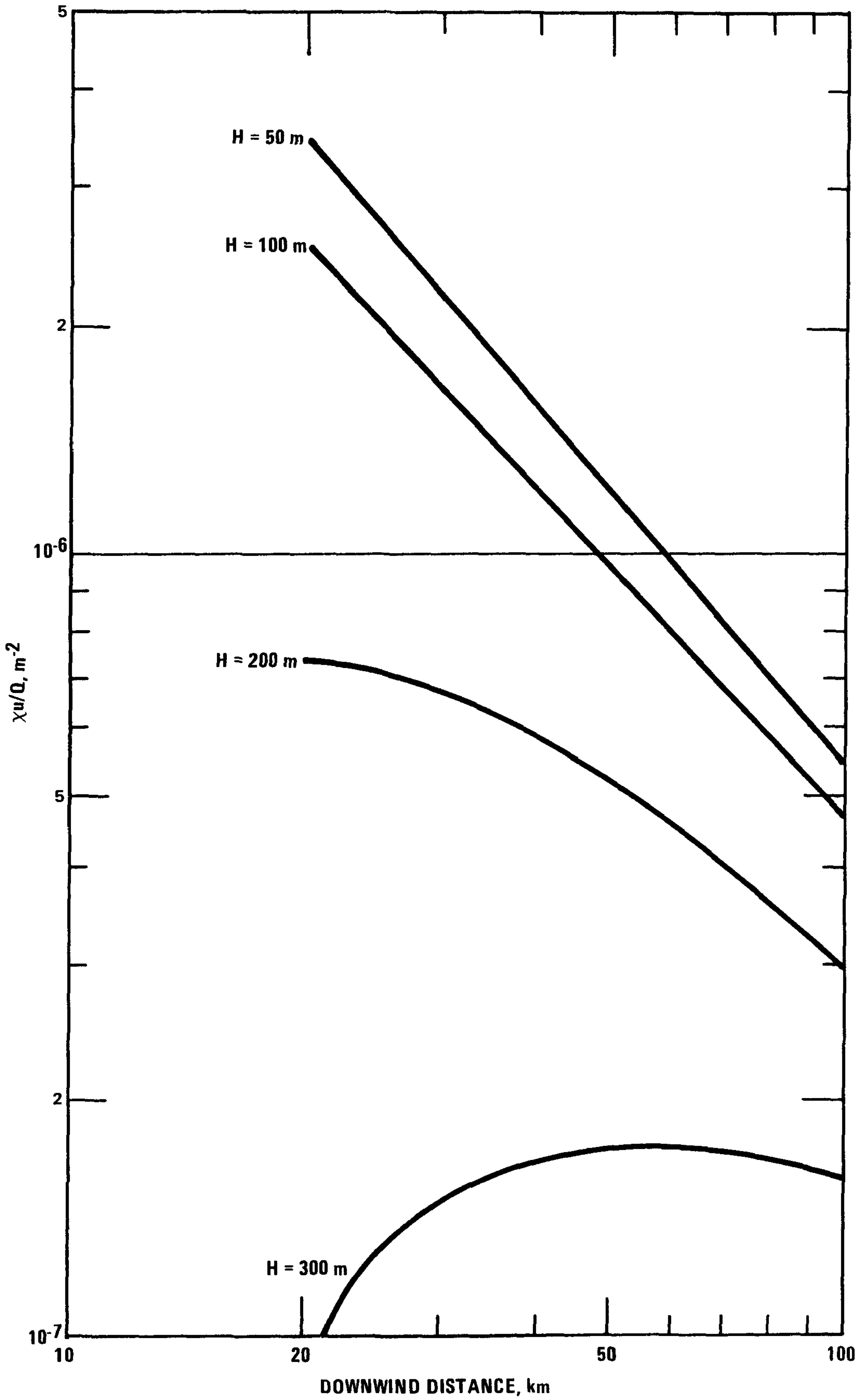

Figure 4-20. Maximum $\chi u/Q$ as a function of downwind distance and plume height (H); E stability.

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APPENDIX A

SCREEN Model User's Guide

A1. INTRODUCTION

Overview of User's Guide

It will be easier to understand this user's guide and the SCREEN model if you are already familiar with the screening procedures, especially those described in Section 4.2.

This introduction should answer most of your general questions about what the SCREEN model can (and cannot) do, and explain its relationship to the screening procedures document.

Section A2 provides several examples of how to run the SCREEN model and will also help the novice user get started. The point source example provides the most detailed description and should be read before the other examples. If you are already familiar with personal computers and with the screening procedures, you probably won't have much trouble simply running SCREEN and "experimenting" with it. It runs interactively, and the prompts should be self explanatory.

Section A3 provides background technical information as a reference for those who want to know more about how SCREEN makes certain calculations. The discussion in Section A3 is intended to be as brief as possible, with reference to other documents for more detailed descriptions.

Purpose of SCREEN

The SCREEN model was developed to provide an easy-to-use method of obtaining pollutant concentration estimates based on the new screening procedures document. By taking advantage of the rapid growth in the availability and use of personal computers (PCs) the SCREEN model makes screening calculations accessible to a wide range of users.

What is needed in order to use SCREEN?

SCREEN will run on an IBM-PC compatible personal computer with at least 256K of RAM. You will need at least one 5 1/4" double-sided, double-density (360K) or a 5 1/4" high density (1.2MB) disk drive. The program will run with or without a math coprocessor chip. Execution time will be greatly enhanced with a math coprocessor chip present (about a factor of 5 in runtime) and will also benefit from the use of a hard disk drive. SCREEN will write a date and time to the output file, provided that a real time clock is available.

What will SCREEN do?

SCREEN runs interactively on the PC, meaning that the program asks the user a series of questions in order to obtain the necessary input data, and to determine which options to exercise. SCREEN can perform all of the single source, short-term calculations in the screening procedures document, including estimating maximum ground-level concentrations and the distance to the maximum (Step 4 of Section 4.2), incorporating the effects of building downwash on the maximum concentrations for both the near wake and far wake regions (Section 4.5.1), estimating concentrations in the cavity recirculation zone (Section 4.5.1), estimating concentrations due to inversion break-up and shoreline fumigation (Section 4.5.3), and determining plume rise for flare releases (Step 1 of Section 4.2). The model can incorporate the effects on maximum concentrations of elevated terrain below stack height (Section 4.2), and can also estimate 24-hour average concentrations due to plume impaction in complex terrain using the VALLEY model 24-hour screening procedure (Section 4.5.2). Simple area sources can be modeled with SCREEN using a virtual point source procedure (Section 4.5.4). The SCREEN model can also calculate the maximum concentration at any number of user-specified distances in flat or elevated simple terrain (Section 4.3), including distances out to 100 km for long-range transport (Section 4.5.6).

What will SCREEN not do?

SCREEN can not explicitly determine maximum impacts from multiple sources, except for the procedure to handle multiple nearby stacks by merging emissions into a single "representative" stack (Section 2.2). The user is directed to the MPTER or ISCST models in the UNAMAP series to model short-term impacts for multiple sources. With the exception of the 24-hour estimate for complex terrain impacts, the results from SCREEN are estimated maximum 1-hour concentrations. To handle longer period averages, the screening procedures document contains recommended adjustment factors to estimate concentrations out to 24 hours from the maximum 1-hour value (Section 4.2, Step 5). For seasonal or annual averages, Section 4.4 of the screening procedures document contains a procedure using hand calculations, but the use of ISCLT or another long-term model of UNAMAP is recommended.

How will SCREEN results compare to hand calculations from the document?

The SCREEN model is based on the same modeling assumptions that are incorporated into the screening procedures and nomographs, and for many sources the results will be very comparable, with estimated maximum concentrations differing by less than about 5 percent across a range of source characteristics. However, there are a few differences that the user should be aware of. For some sources, particularly taller sources with greater buoyancy, the differences in estimated concentrations will be larger, with the hand calculation exceeding the SCREEN model result by as much as 25 percent. These differences are described in more detail below.

The SCREEN model can provide estimated concentrations for distances less than 100 meters (down to one meter as in other regulatory models), whereas the nomographs used in the hand calculations are limited to distances greater than or equal to 100 meters. The SCREEN model is also not limited to plume heights of 300 meters, whereas the nomographs are. In both cases, caution should be used in interpreting results that are outside the range of the nomographs.

In addition, SCREEN examines a full range of meteorological conditions, including all stability classes and wind speeds (see Section A3) to find maximum impacts, whereas to keep the hand calculations tractable only a subset of meteorological conditions (stability classes A, C, and E or F) likely to contribute to the maximum concentration are examined. The use of full meteorology is required in SCREEN because maximum concentrations are also given as a function of distance, and because A, C, and E or F may not be controlling for sources with building downwash (not included in the hand calculations). SCREEN explicitly calculates the effects of multiple reflections of the plume off the elevated inversion and off the ground when calculating concentrations under limited mixing conditions. To account for these reflections, the hand calculation screening procedure (Procedure (a) of Step 4 in Section 4.2) increases the calculated maximum concentrations for A stability by a factor ranging from 1.0 to 2.0. The factor is intended to be a conservative estimate of the increase due to limited mixing, and may be slightly higher (about 5 to 10 percent) than the increase obtained from SCREEN using the multiple reflections, depending on the source. Also, SCREEN handles the near neutral/high wind speed case (Procedure (b)) by examining a range of wind speeds for stability class C and selecting the maximum, whereas the hand calculations are based on the maximum concentration estimated using stability class C with a calculated critical wind speed and a 10 meter wind speed of 10 m/s. stability class C. This difference should result in differences in maximum concentrations of less than about 5 percent for those sources where the near neutral/high wind speed case is controlling.

The SCREEN model results also include the effects of buoyancy-induced dispersion (BID), which are not accounted for by the hand calculations (except for fumigation). The inclusion of BID in SCREEN may either increase or decrease the estimated concentrations, depending on the source and distance. For sources with plume heights below the 300 meter limit of the hand calculations, the effect of BID on estimated maximum concentrations will usually be less than about $\pm$ 10 percent. For elevated sources with relatively large buoyancy, the inclusion of BID may be expected to decrease the estimated maximum concentration by as much as 25 percent.

How does SCREEN differ from PTPLU, PTMAX and PTDIS?

The PT-series of models have been used in the past to obtain results for certain screening procedures in Volume 10R. The SCREEN model is designed specifically as a computerized implementation of the revised screening procedures, and is much more complete than the earlier models, as described above. The SCREEN model also requires less manual "postprocessing" than the earlier models by listing the maximum concentrations in the output. However, many of the algorithms in SCREEN are the same as those contained in PTPLU-2.0. For the same source parameters and for given meteorological conditions, the two models will give comparable results. SCREEN also incorporates the option to estimate concentrations at discrete user-specified distances, which was available with PTDIS, but is not included in PTPLU.

A2. TUTORIAL

What is needed?

- o IBM-PC compatible with at least 256K bytes of RAM, and a 5 1/4" double-sided, double-density or high density disk drive.
- o Diskette provided with SCREEN software.
- o Hard disk drive (Optional but recommended).
- o Math coprocessor chip (Optional but recommended).
- o Blank diskette for use in making a backup copy of software.

Setup on the PC

Using the DISKCOPY command of DOS (Disk Operating System) or similar routine, make a backup copy of the SCREEN software. Store the original SCREEN software diskette in a safe location. The DISKCOPY command will also format the blank disk if needed.

The following set-up instructions assume that the user has a system with a hard disk drive. Examine the contents of the READ.ME file on the SCREEN diskette (e.g., by using the DOS TYPE command) for instructions on the set-up of SCREEN for a system with no hard disk drive.

Insert the SCREEN diskette in floppy drive A: and enter the following commands at the DOS prompt from drive C: (either from the root directory or a subdirectory):

```
COPY A:*.*
ARC521
ARC E SCREEN
```

These commands will copy the three files from the SCREEN diskette, SCREEN.ARC, ARC521.COM, and READ.ME, to the hard disk; "unpack" the archiving program, ARC521; and extract the SCREEN files from archive. The hard disk will now contain the executable file of SCREEN, called SCREEN.EXE, as well as the FORTRAN source file, SCREEN.FOR, a listing file, SCREEN.LST, an example input file, EXAMPLE.DAT, and associate output file EXAMPLE.OUT.

Executing the Model

The SCREEN model is written as an interactive program for the PC, as described earlier. Therefore, SCREEN is normally executed by simply typing SCREEN from any drive and directory that contains the SCREEN.EXE file, and responding to the prompts provided by the program. However, a mechanism has been provided to accommodate for the fact that for some applications of SCREEN the user might want to perform several runs for the same source changing only one or a few input parameters. This mechanism takes advantage of the fact that the Disk Operating System (DOS) on PCs allows for the redirection of input that is normally provided via the keyboard to be read from a file instead. As an example, to run the sample problem provided on the disk one would type:

```
SCREEN <EXAMPLE.DAT
```

at the DOS prompt. The SCREEN model will then read the responses to its prompts from the EXAMPLE.DAT file rather than from the keyboard. The output from this run will be stored in a file called SCREEN.OUT, which can then be compared with the EXAMPLE.OUT file provided on the program disk. The file containing the redirected input data may be given any valid DOS pathname. To facilitate the creation of the input file for the SCREEN model, SCREEN has been programmed to write out all inputs provided to a file called SCREEN.DAT during execution. Therefore, at the completion of a run, if the user types SCREEN <SCREEN.DAT, the last run will be duplicated exactly. Alternatively, the SCREEN.DAT file may be edited as an ASCII file using a text or line editor, and selected input parameters changed before rerunning the model. Since the original SCREEN.DAT file will be overwritten each time the model is run, it is advisable to save the modified inputs under a different file name.

Some cautions are needed regarding the use of redirected input with SCREEN. Because of the way some input errors are handled by SCREEN, the SCREEN.DAT file may contain some of the errors from the original input. While SCREEN.DAT should still reproduce the correct results, it will be easier to work with the file if the original input does not contain any errors. More importantly, since the inputs requested by SCREEN depend on the options selected, it is not advisable to edit the SCREEN.DAT file and try to change the options selected. An experienced user may be able to do this, especially with the help of the input flow charts provided later in this section, but it may be easier simply to rerun SCREEN with the new options.

Point Source Example

When running SCREEN for a point source, or for flare releases and area sources discussed below, the user is first asked to provide a one line title (up to 79 characters) that will appear on the output file. The user will then be asked to identify the source type, and should enter P for a point source, F for a flare release, or A for an area source (the model will identify either upper or lower case letters and will repeat the prompt until a valid response is given).

For a point source, the user will be asked to provide the following inputs:

Point Source Inputs

Emission rate (g/s)
Stack height (m)
Stack inside diameter (m)
Stack gas exit velocity (m/s)
Stack gas temperature (K)
Ambient temperature (K) (use default of 293K if not known)
Receptor height above ground (may be used to define flagpole receptors) (m)
Urban/rural option (1=urban, 2=rural)

The SCREEN model uses free format to read the numerical input data.

Figure A-1 presents the order of options within the SCREEN model for point sources and is annotated with the corresponding sections from the screening procedures document. In order to obtain results from SCREEN corresponding to the procedures in Step 4 of Section 4.2, the user should select the full meteorology option, the automated distance array option, and, if applicable for the source, the simple elevated terrain option. These, as well as the other options in Figure A-1, are explained in more detail below.

Building Downwash Option

Following the basic input of source characteristics SCREEN will first ask if building downwash is to be considered, and if so, asks for the building height, minimum horizontal dimension, and maximum horizontal dimension in meters. The downwash screening procedure assumes that the building

Order of Options in SCREEN	Corresponding Section in Screening Procedures Document
Input Source Characteristics	
Building Downwash Option	Section 4.5.1
Complex Terrain Option	Section 4.5.2
Simple Elevated or Flat Terrain Option*	Section 4.2
Choice of Meteorology*	Section 4.2, Step 4
Automated Distance Array Option*	Section 4.2, Step 4
Discrete Distance Option*	Section 4.3 for Distances $\leq$ 50km Section 4.5.6 for Distances > 50km
Fumigation Option (Rural Only)	Section 4.5.3

*These options also apply to Area Sources, Section 4.5.4

Figure A-1. Point Source Options in SCREEN can be approximated by a simple rectangular box. Wake effects are included in any calculations made using the automated distance array or discrete distance options (described below). Cavity calculations are made for two building orientations - first with the minimum horizontal building dimension alongwind, and second with the maximum horizontal dimension alongwind. The cavity calculations are summarized at the end of the distance-dependent calculations.

Complex Terrain Option

The complex terrain option of SCREEN allows the user to estimate impacts for cases where terrain elevations exceed stack height. If the user elects this option, then SCREEN will calculate and print out a final stable plume height and distance to final rise for the VALLEY model 24-hour screening technique. This technique assumes stability class F (E for urban) and a stack height wind speed of 2.5 m/s. For complex terrain, maximum impacts are expected to occur for plume impaction on the elevated terrain under stable conditions. The user is therefore instructed to enter minimum distances and terrain heights for which impaction is likely, given the plume height calculated, and taking into account complex terrain closer than the distance to final rise. If the plume is at or below the terrain height for the distance entered, then SCREEN will make a 24-hour concentration estimate using the VALLEY screening technique. If the terrain is above stack height but below plume centerline height for the distance entered, then SCREEN will make a VALLEY 24-hour estimate (assuming E or F and 2.5 m/s), and also estimate the maximum concentration across a full range of meteorological conditions using simple terrain procedures with terrain "chopped off" at physical stack height. The higher of the two estimates is selected as controlling for that distance and terrain height (both estimates are printed out for comparison). The simple terrain estimate is adjusted to represent a 24-hour average by multiplying by a factor of 0.40, while the VALLEY 24-hour estimate incorporates the 0.25 factor used in the VALLEY model. Calculations continue for each terrain height/distance combination entered until a terrain height of zero is entered. The user will then have the option to continue with simple terrain calculations or to exit the program. It should be noted that SCREEN will not consider building downwash effects in either the VALLEY or the simple terrain component of the complex terrain screening procedure, even if the building downwash option is selected. SCREEN also uses a receptor height above ground of 0.0m (i.e. no flagpole receptors) in the complex terrain option even if a non-zero value is entered. The original receptor height is saved for later calculations. Refer to Section A3 for more details on the complex terrain screening procedure.

Simple Elevated or Flat Terrain Option

The user is given the option in SCREEN of modeling either simple elevated terrain, where terrain heights exceed stack base but are below stack height, or simple flat terrain, where terrain heights are assumed not to exceed stack base elevation. If the user elects not to use the option for simple terrain screening with terrain above stack base, then flat terrain is assumed and the terrain height is assigned a value of zero. If the simple elevated terrain option is used, SCREEN will prompt the user to enter a terrain height above stack base. If terrain heights above physical stack height are entered by the user for this option, they are chopped off at the physical stack height.

The simple elevated terrain screening procedure assumes that the plume elevation above sea level is not affected by the elevated terrain. Concentration estimates are made by reducing the calculated plume height by the user-supplied terrain height above stack base. Neither the plume height nor terrain height are allowed to go below zero. The user can model simple elevated terrain using either or both of the distance options described below, i.e., the automated distance array or the discrete distance option. When the simple elevated terrain calculations for each distance option are completed, the user will have the option of continuing simple terrain calculations for that option with a new terrain height. (For flat terrain the user will not be given the option to continue with a new terrain height). For conservatism and to discourage the user from modeling terrain heights that decrease with distance, the new terrain height for the automated distances cannot be lower than the previous height for that run. The user is still given considerable flexibility to model the effects of elevated terrain below stack height across a wide range of situations.

For relatively uniform elevated terrain, or as a "first cut" conservative estimate of terrain effects, the user should input the maximum terrain elevation (above stack base) within 50 km of the source, and exercise the automated distance array option out to 50 km. For isolated terrain features a separate calculation can be made using the discrete distance option for the distance to the terrain feature, with the terrain height input as the maximum height of the feature above stack base. Where terrain heights vary with distance from the source, then the SCREEN model can be run on each of several concentric rings using the minimum and maximum distance inputs of the automated distance option to define each ring, and using the maximum terrain elevation above stack base within each ring for terrain height input. As noted above, the terrain heights are not allowed to decrease with distance in SCREEN. If terrain decreasing with distance (in all directions) can be justified for a particular source, then the distance rings would have to modeled using separate SCREEN runs, and the results combined. The overall maximum concentration would then be the controlling value. The optimum ring sizes will depend on how the terrain heights vary with distance, but as a "first cut" it is suggested that ring sizes of about 5 km be used (i.e., 0-5km, 5-10km, etc.). The application of SCREEN to evaluating the effects of elevated terrain should be done in consultation with the permitting agency.

Choice of Meteorology

For simple elevated or flat terrain screening, the user will be given the option of selecting from three choices of meteorology: (1) full meteorology (all stability classes and wind speeds); (2) specifying a single stability class; or (3) specifying a single stability class and wind speed. Generally, the full meteorology option should be selected. The other two options were originally included for testing purposes only, but may be useful when particular meteorological conditions are of concern. See Section A3 for more details on the determination of worst case meteorological conditions by SCREEN.

Automated Distance Array Option

The automated distance array option of SCREEN gives the user the option of using a pre-selected array of 50 distances ranging from 100m out to 50 km. Increments of 100m are used out to 3,000m, with 500m increments from 3,000m to 10 km, 5 km increments from 10 km to 30 km, and 10 km increments out to 50 km. When using the automated distance array, SCREEN prompts the user for a minimum and maximum distance to use, which should be input in free format, i.e., separated by a comma or a space. SCREEN then calculates the maximum concentration across a range of meteorological conditions for the minimum distance given ($\geq$ 1 meter), and then for each distance in the array larger than the minimum and less than or equal to the maximum. Thus, the user can input the minimum site boundary distance as the minimum distance for calculation and obtain a concentration estimate at the site boundary and beyond, while ignoring distances less than the site boundary.

If the automated distance array is used, then the SCREEN model will use an iteration routine to determine the maximum value and associated distance to the nearest meter. Note: SCREEN assumes that the overall maximum concentration occurs for the same stability class that is associated with the maximum concentration from the automated distance array, and begins interating from that value, examining a range of wind speeds for that stability (unless Option 3 for choice of meteorology is selected). If the minimum and maximum distances entered do not encompass the true maximum concentration, then the maximum value calculated by SCREEN may not be the true maximum. Therefore, it is recommended that the maximum distance be set sufficiently large initially to ensure that the maximum concentration is found. This distance will depend on the source, and some "trial and error" may be necessary, however, the user can input a distance of 50,000m to examine the entire array. The iteration routine stops after 50 iterations and prints out a message if the maximum is not found. Also, since there may be several local maxima in the concentration distribution associated with different wind speeds, it is possible that SCREEN will not identify the overall maximum in its iteration. This is not likely to be a frequent occurrence, but will be more likely for stability classes C and D due to the larger number of wind speeds examined.

Discrete Distance Option

The discrete distance option of SCREEN allows the user to input specific distances. Any number of distances ($\geq$ 1 meter) can be input by the user and the maximum concentration for each distance will be calculated. The user will always be given this option whether or not the automated distance array option is used. The option is terminated by entering a distance of zero (0). SCREEN will accept distances out to 100 km for long-range transport estimates with the discrete distance option. However, for distances greater than 50 km, SCREEN sets the minimum 10 meter wind speed at 2 m/s to avoid unrealistic transport times.

Fumigation Option

Once the distance-dependent calculations are completed, SCREEN will give the user the option of estimating maximum concentrations and distance to the maximum associated with inversion break-up fumigation, and shoreline fumigation. The option for fumigation calculations is applicable only for rural sites with stack heights greater than or equal to 10 meters (within 3,000m of a large body of water for shoreline.)

Once all calculations are completed, SCREEN summarizes the maximum concentrations for each of the calculation procedures considered. Before execution is stopped, whether it is after complex terrain calculations are completed or at the end of the simple terrain calculations, the user is given the option of printing a hardcopy of the results. Whether or not a hardcopy is printed, the results of the session, including all input data and concentration estimates, are stored in a file called SCREEN.OUT. This file is opened by the model each time it is run. If a file named SCREEN.OUT already exists, then its contents will be overwritten and lost. Thus, if you wish to save results of a particular run, then change the name of the output file using the DOS RENAME command, e.g., type 'REN SCREEN.OUT SAMPLE1.OUT', or print the file using the option at the end of the program. If SCREEN.OUT is later printed using the DOS PRINT command, the FORTRAN carriage controls will not be observed. (Instructions are included in Section A4 for simple modifications to the SCREEN code that allow the user to specify an output filename for each run.)

Figure A-2 shows an example using the complex terrain screen only. Figure A-3 shows an example for an urban point source which uses the building downwash option. In the DWASH column of the output, 'NO' indicates that no downwash is included, 'HS' means that Huber-Snyder downwash is included, 'SS' means that Schulman-Scire downwash is included, and 'NA' means that downwash is not applicable since the downwind distance is less than $3L_b$. A blank in the DWASH column means that no calculation was made for that distance because the concentration was so small.

Figure A-4 presents a flow chart of all the inputs and various options of SCREEN for point sources. Also illustrated are all of the outputs from SCREEN. If a cell on the flow chart does not contain the words "Enter" or "Print out", then it is an internal test or process of the program, and is included to show the flow of the program.

```
                                                                          10-26-88
                                                                          12:00:00
 *** SCREEN-1.1 MODEL RUN ***
 *** VERSION DATED  88300 ***

POINT SOURCE EXAMPLE WITH COMPLEX TERRAIN

COMPLEX TERRAIN INPUTS:
   SOURCE TYPE            =     POINT
   EMISSION RATE (G/S) =     100.0
   STACK HT (M)           =    100.00
   STACK DIAMETER (M)     =      2.50
   STACK VELOCITY (M/S)=     25.00
   STACK GAS TEMP (K)    =    450.00
   AMBIENT AIR TEMP (K)=    293.00
   RECEPTOR HEIGHT (M) =       .00
   IOPT (1=URB,2=RUR)    =      2


BUOY. FLUX =  133.64 M**4/S**3;  MOM. FLUX =  635.35 M**4/S**2.


FINAL STABLE PLUME HEIGHT (M) =  192.9
DISTANCE TO FINAL RISE (M)    =  151.3

                                  *VALLEY 24-HR CALCS*   **SIMPLE TERRAIN 24-HR CALCS**
 TERR           MAX 24-HR                     PLUME HT              PLUME HT
  HT    DIST     CONC           CONC       ABOVE STK     CONC      ABOVE STK      U10M USTK
 (M)     (M)    (UG/M**3)     (UG/M**3)    BASE (M)   (UG/M**3)   HGT (M)   SC    (M/S)
-----  -------  ----------    ----------    ------    ----------   ------   --  ----  ----
 150.    1000.  243.4          243.4          192.9    161.1     [illegible].9    4  15.0  21.2
 200.    2000.  284.3          284.3          132.9    .0000          .0    0    .0    .0
 200.    5000.  91.39          91.39          192.9    .0000          .0    0    .0    .0
 200.   10000.  37.36          37.36          192.9    .0000          .0    0    .0    .0

     ***************************************
     *** SUMMARY OF SCREEN MODEL RESULTS ***
     ***************************************

 CALCULATION           MAX CONC       DIST TO     TERRAIN
  PROCEDURE           (UG/M**3)       MAX (M)      HT (M)
--------------       -----------      -------     -------
COMPLEX TERRAIN        284.3           2000.        200.  (24-HR CONC)


***************************************************
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
***************************************************
```

Figure A-2. SCREEN Point Source Example for Complex Terrain

10-26-88
12.00:00

*** SCREEN-1.1 MODEL RUN ***
*** VERSION DATED 88300 ***

POINT SOURCE EXAMPLE WITH BUILDING DOWNWASH

SIMPLE TERRAIN INPUTS:

SOURCE TYPE	=	POINT
EMISSION RATE (G/S)	=	100.0
STACK HEIGHT (M)	=	100.00
STK INSIDE DIAM (M)	=	2.00
STK EXIT VELOCITY (M/S)	=	15.00
STK GAS EXIT TEMP (K)	=	450.00
AMBIENT AIR TEMP (K)	=	293.00
RECEPTOR HEIGHT (M)	=	.00
IOPT (1=URB,2=RUR)	=	1
BUILDING HEIGHT (M)	=	80.00
MIN HORIZ BLDG DIM (M)	=	80.00
MAX HORIZ BLDG DIM (M)	=	100.00

BUOY. FLUX = 51.32 M**4/S**3; MOM. FLUX = 146.50 M**4/S**2.

*** FULL METEOROLOGY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
100.	.0000	0	.0	.0	.0	.0	.0	.0	NA
200.	.0000	0	.0	.0	.0	.0	.0	.0	NA
300.	601.1	1	2.0	2.8	640.0	111.5	90.7	82.1	SS
400.	479.9	1	2.0	2.8	640.0	119.5	118.8	113.6	SS
500.	412.5	3	2.0	3.2	640.0	133.1	100.4	100.0	SS
600.	403.8	5	2.0	4.0	5000.0	110.1	59.3	59.2	SS
700.	459.3	5	1.0	2.0	5000.0	121.5	68.1	58.3	SS
800.	547.9	5	1.0	2.0	5000.0	121.5	76.6	64.5	SS
900.	549.7	5	1.0	2.0	5000.0	121.5	84.9	67.4	SS
1000.	547.5	5	1.0	2.0	5000.0	121.5	93.0	70.3	SS
MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 100. M:									
274.	611.3	1	2.0	2.8	640.0	109.8	83.5	74.5	SS

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

*** CAVITY CALCULATION - 1 ***

CONC (UG/M**3)	=	2793.
CRIT WS @10M (M/S)	=	3.76
CRIT WS @ HS (M/S)	=	5.97
DILUTION WS (M/S)	=	2.98
CAVITY HT (M)	=	114.88
CAVITY LENGTH (M)	=	142.41
ALONGWIND DIM (M)	=	80.00

*** CAVITY CALCULATION - 2 ***

CONC (UG/M**3)	=	1600.
CRIT WS @10M (M/S)	=	8.22
CRIT WS @ HS (M/S)	=	13.02
DILUTION WS (M/S)	=	6.51
CAVITY HT (M)	=	105.20
CAVITY LENGTH (M)	=	101.30
ALONGWIND DIM (M)	=	100.00

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)	
SIMPLE TERRAIN	611.3	274.	0.	
BUILDING CAVITY-1	2793.	142.	--	(DIST = CAVITY LENGTH)
BUILDING CAVITY-2	1600.	101.	--	(DIST = CAVITY LENGTH)

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

Figure A-3. SCREEN Point Source Example with Building Downwash

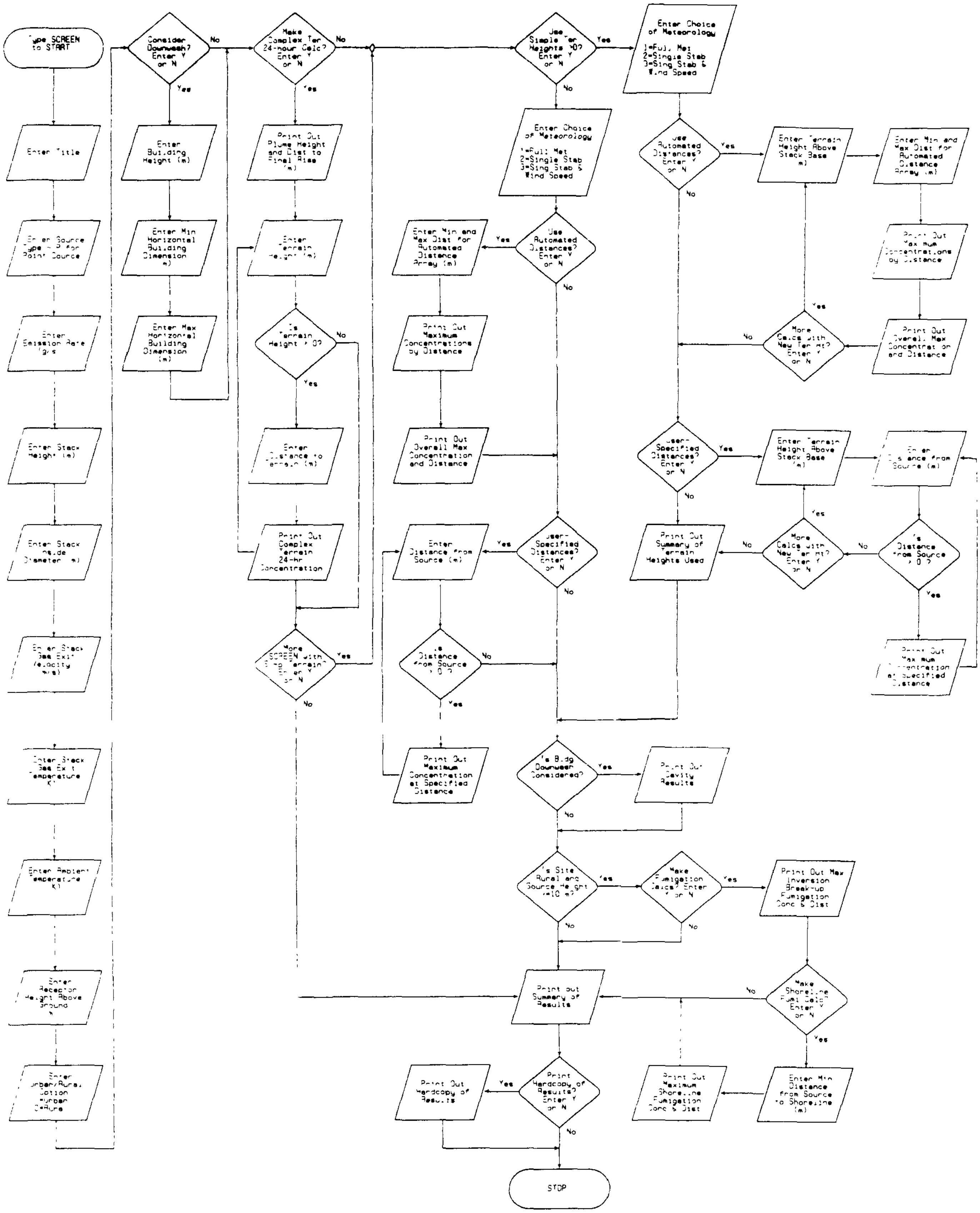

Figure A-4. Flow Chart of Inputs and Outputs for SCREEN Point Source

Flare Release Example

By answering "F" or "f" to the question on source type the user selects the flare release option. This option is similar to the point source described above except for the inputs needed to calculate plume rise. The inputs for flare releases are as follows:

Flare Release Inputs

Emission rate (g/s)
Flare stack height (m)
Total heat release rate (cal/s)
Receptor height above ground (m)
Urban/rural option (1 = urban, 2 = rural)

The SCREEN model calculates plume rise for flares based on an effective buoyancy flux parameter. An ambient temperature of 293K is assumed in this calculation and therefore none is input by the user. It is assumed that 55 percent of the total heat is lost due to radiation. Plume rise is calculated from the top of the flame, assuming that the flame is bent 45 degrees from the vertical. SCREEN calculates and prints out the effective release height for the flare. SCREEN provides the same options for flares as described earlier for point sources, including building downwash, complex and/or simple terrain, fumigation, and the automated and/or discrete distances. The order of these options and the user prompts are the same as described for the point source example.

While building downwash is included as an option for flare releases, it should be noted that SCREEN assumes an effective stack gas exit velocity (v_s) of 20 m/s and an effective stack gas exit temperature (T_s) of 1,273K, and calculates an effective stack diameter based on the heat release rate. These effective stack parameters are somewhat arbitary, but the resulting buoyancy flux estimate is expected to give reasonable final plume rise estimates for flares. However, since building downwash estimates depend on transitional momentum plume rise and transitional buoyant plume rise calculations, the selection of effective stack parameters could influence the estimates. Therefore, building downwash estimates should be used with extra caution for flare releases. If more realistic stack parameters can be determined, then the estimate could alternatively be made with the point source option of SCREEN. In doing so, care should be taken to account for the vertical height of the flame in specifying the release height (see Section A3). Figure A-5 shows an example for a flare release, and Figure A-6 shows a flow chart of the flare release inputs, options, and output.

Area Source Example

The third source type option in SCREEN is for area sources. The area source algorithm in SCREEN is a simple virtual point source procedure that assumes that the area source can be approximated by a simple square area. The inputs requested for area sources are as follows:

Area Source Inputs

Emission rate (g/s)
Source release height (m)
Length of side of the square area (m)
Receptor height above ground (m)
Urban/rural option (1 = urban, 2 = rural)

The user has the same options for handling distances and the same choices of meteorology as described above for point sources, but no complex terrain, elevated simple terrain, building downwash, or fumigation calculations are made for area sources. Figure A-7 shows an example of SCREEN for an area source, using both the automated and discrete distance options. Figure A-8 provides a flow chart of inputs, options, and outputs for area sources.

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12:00:00

*** SCREEN-1.1 MODEL RUN ***
*** VERSION DATED 88300 ***

FLARE RELEASE EXAMPLE

SIMPLE TERRAIN INPUTS:

SOURCE TYPE	=	FLARE
EMISSION RATE (G/S)	=	1000.
FLARE STACK HEIGHT (M)	=	100.00
TOT HEAT RLS (CAL/S)	=	.1000E+08
RECEPTOR HEIGHT (M)	=	.00
IOPT (1=URB,2=RUR)	=	2
EFF RELEASE HEIGHT (M)	=	110.11
BUILDING HEIGHT (M)	=	.00
MIN HORIZ BLDG DIM (M)	=	.00
MAX HORIZ BLDG DIM (M)	=	.00

BUOY. FLUX = 165.80 M**4/S**3. MOM. FLUX = 101.10 M**4/S**2.

*** FULL METEOROLOGY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
250.	.7733E-04	5	1.0	2.3	5000.0	233.5	38.0	36.1	NO
300.	.2501E-03	1	3.0	3.5	960.0	344.3	78.5	57.1	NO
400.	1.283	1	3.0	3.5	960.0	344.3	100.4	80.9	NO
500.	66.54	1	3.0	3.5	960.0	344.3	121.5	113.8	NO
600.	407.0	1	3.0	3.5	960.0	344.3	142.1	162.0	NO
700.	741.2	1	3.0	3.5	960.0	344.3	162.2	220.5	NO
800.	839.8	1	3.0	3.5	960.0	344.3	181.9	289.5	NO
900.	943.3	1	2.0	2.4	640.0	461.4	214.4	376.4	NO
1000.	1030.	1	2.0	2.4	640.0	461.4	231.6	464.8	NO
1100.	1165.	1	1.0	1.2	813.6	812.6	302.0	590.5	NO
1200.	1239.	1	1.0	1.2	813.6	812.6	316.8	697.1	NO
1300.	1236.	1	1.0	1.2	813.6	812.6	330.8	815.9	NO
1400.	1198.	1	1.0	1.2	813.6	812.6	345.0	946.7	NO
1500.	1153.	1	1.0	1.2	813.6	812.6	359.4	1089.3	NO
1600.	1108.	1	1.0	1.2	813.6	812.6	374.0	1240.6	NO
1700.	1067.	1	1.0	1.2	813.6	812.6	388.6	1409.7	NO
1800.	1028.	1	1.0	1.2	813.6	812.6	403.3	1587.5	NO
1900.	991.5	1	1.0	1.2	813.6	812.6	419.1	1777.1	NO
2000.	957.5	1	1.0	1.2	813.6	812.6	433.0	1978.4	NO

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 250. M:

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
1241.	1244.	1	1.0	1.2	813.6	812.6	322.3	743.2	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	1244.	1241.	0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

Figure A-5. SCREEN Flare Release Example

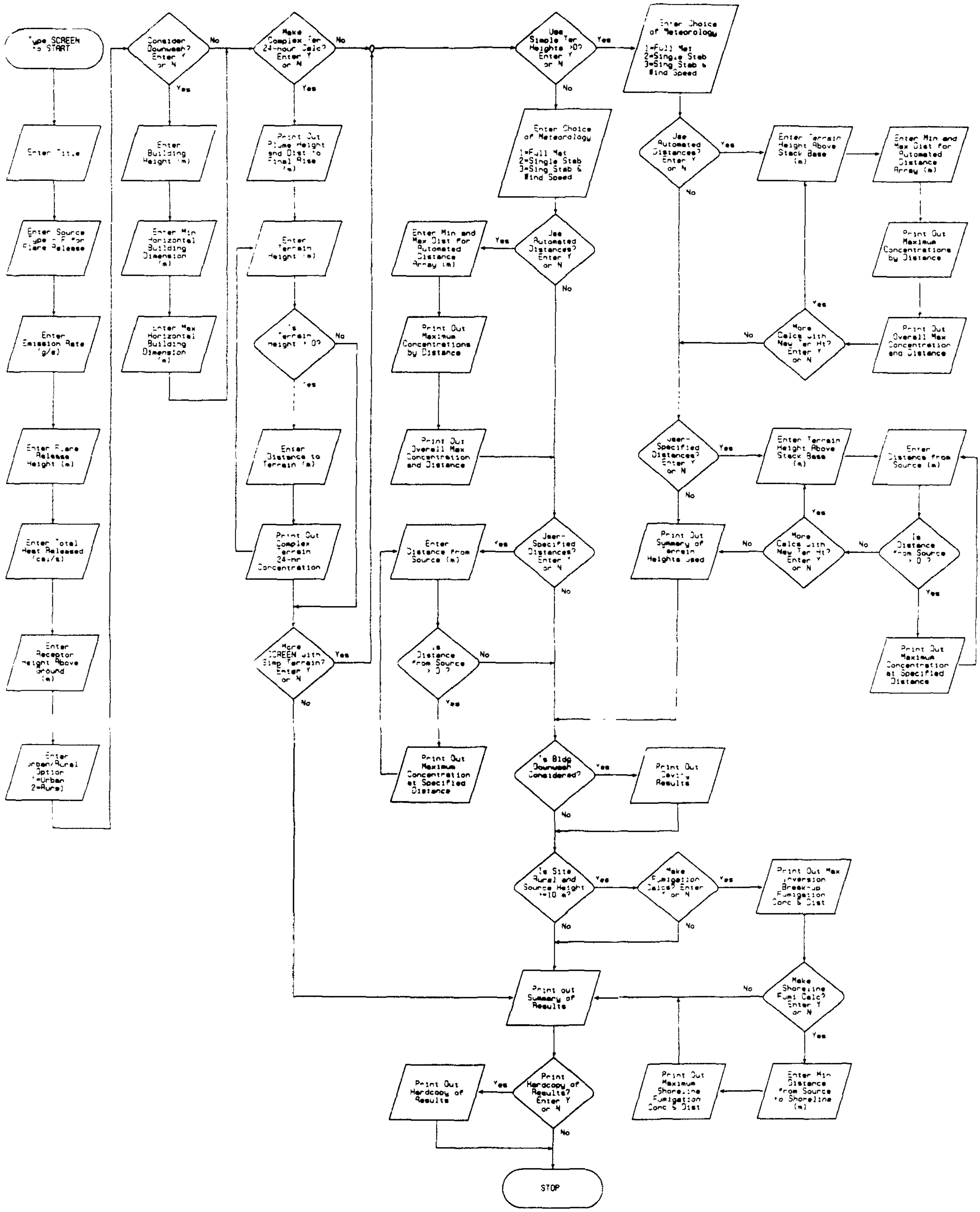

Figure A-4. Flow Chart of Inputs and Outputs for SCREEN Flare Release

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12:00.00

*** SCREEN-1.1 MODEL RUN ***
*** VERSION DATED 88300 ***

AREA SOURCE EXAMPLE

SIMPLE TERRAIN INPUTS:

SOURCE TYPE	=	AREA
EMISSION RATE (G/S)	=	100.0
SOURCE HEIGHT (M)	=	5.00
LENGTH OF SIDE (M)	=	200.00
RECEPTOR HEIGHT (M)	=	.00
IOPT (1=URB,2=RUR)	=	1

BUOY. FLUX = .00 M**4/S**3; MOM. FLUX = .00 M**4/S**2.

*** FULL METEOROLOGY ***

****
*** SCREEN AUTOMATED DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
50.	.6967E+05	5	1.0	1.0	5000.0	5.0	51.1	3.9	NO
100.	.6121E+05	5	1.0	1.0	5000.0	5.0	55.7	7.5	NO
200.	.3296E+05	5	1.0	1.0	5000.0	5.0	64.6	14.0	NO
300.	.2114E+05	5	1.0	1.0	5000.0	5.0	73.2	19.9	NO
400.	.1512E+05	5	1.0	1.0	5000.0	5.0	81.6	25.3	NO
500.	.1157E+05	5	1.0	1.0	5000.0	5.0	89.8	30.2	NO
600.	9258.	5	1.0	1.0	5000.0	5.0	97.7	34.8	NO
700.	7654.	5	1.0	1.0	5000.0	5.0	105.5	39.1	NO
800.	6483.	5	1.0	1.0	5000.0	5.0	113.0	43.1	NO
900.	5597.	5	1.0	1.0	5000.0	5.0	120.4	47.0	NO
1000.	4906.	5	1.0	1.0	5000.0	5.0	127.6	50.6	NO
MAXIMUM 1-HR CONCENTRATION AT OR BEYOND 50. M:									
62.	.7371E+05	5	1.0	1.0	5000.0	5.0	52.3	4.8	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SCREEN DISCRETE DISTANCES ***
****

*** TERRAIN HEIGHT OF 0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

DIST (M)	CONC (UG/M**3)	STAB	U10M (M/S)	USTK (M/S)	MIX HT (M)	PLUME HT (M)	SIGMA Y (M)	SIGMA Z (M)	DWASH
5000.	688.8	5	1.0	1.0	5000.0	5.0	336.6	137.2	NO
10000.	314.8	5	1.0	1.0	5000.0	5.0	505.4	200.0	NO
20000.	149.1	5	1.0	1.0	5000.0	5.0	742.6	287.4	NO
50000.	71.18	4	1.0	1.0	320.0	5.0	1751.4	1750.0	NO

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	.7371E+05	62.	0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

Figure A-7. SCREEN Area Source Example

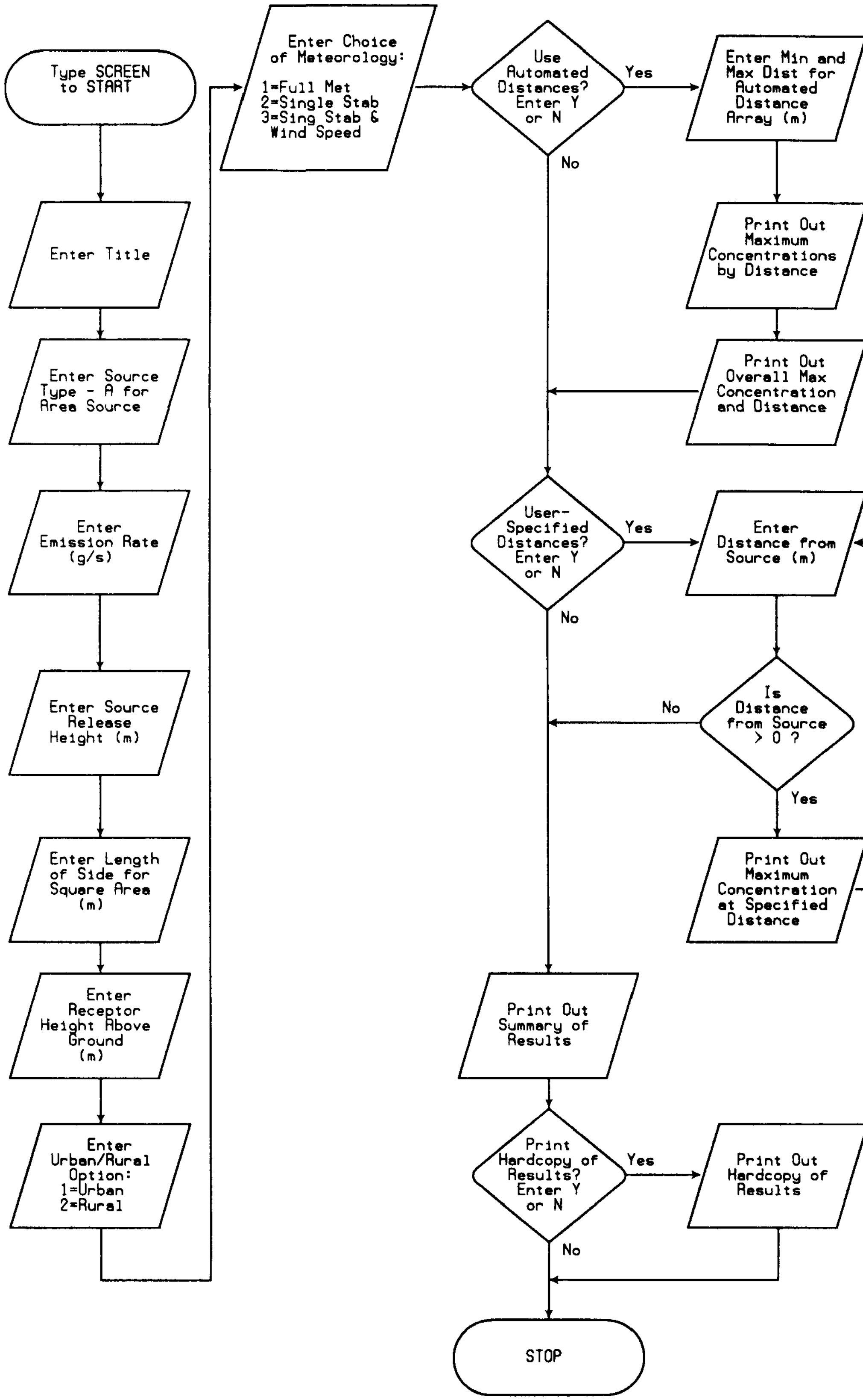

Figure A-8. Flow Chart of Inputs and Outputs for SCREEN Area Source

A3. TECHNICAL DESCRIPTION

Most of the techniques used in the SCREEN model are based on assumptions and methods common to other EPA dispersion models. For the sake of brevity, lengthy technical descriptions that are available elsewhere are not duplicated here. This discussion will concentrate on how those methods are incorporated into SCREEN and on describing those techniques that are unique to SCREEN.

Basic Concepts of Dispersion Modeling

SCREEN uses a Gaussian plume model to estimate pollutant concentration from continuous sources which incorporates source-related factors and meteorological factors. It is assumed that the pollutant does not undergo any chemical reactions, and that no other removal processes, such as wet or dry deposition, act on the plume during its transport from the source. The Gaussian model equations and the interactions of the source-related and meteorological factors are described in the PTPLU user's guide (Pierce, et al, 1982), and in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970).

The basic equation for determining ground-level concentrations under the plume centerline is:

$$
\begin{aligned}
\chi = Q/(2\pi u_s \sigma_y \sigma_z) \{ & \exp[-1/2((z_r-h_e)/\sigma_z)^2] \\
& + \exp[-1/2((z_r+h_e)/\sigma_z)^2] \\
& + \sum_{N=1}^{k} [\exp[-1/2((z_r-h_e-2Nz_i)/\sigma_z)^2] \\
& + \exp[-1/2((z_r+h_e-2Nz_i)/\sigma_z)^2] \\
& + \exp[-1/2((z_r-h_e+2Nz_i)/\sigma_z)^2] \\
& + \exp[-1/2((z_r+h_e+2Nz_i)/\sigma_z)^2]] \} \qquad \text{(A.1)}
\end{aligned}
$$

where

χ = concentration (g/m^3)

Q = emission rate (g/s)

π = 3.14159

u_s = stack height wind speed (m/s)

σ_y = lateral dispersion parameter (m)

σ_z = vertical dispersion parameter (m)

z_r = receptor height above ground (m)

h_e = plume centerline height (m)

z_i = mixing height (m)

k = summation limit for multiple reflections of plume off of the ground and elevated inversion, usually ≤ 4.

Note that for stable conditions and/or mixing heights greater than or equal to 5,000m, unlimited mixing is assumed and the summation term is assumed to be zero.

Worst Case Meteorological Conditions

SCREEN examines a range of stability classes and wind speeds to identify the "worst case" meteorological conditions, i.e., the combination of wind speed and stability that results in the maximum ground level concentrations. The wind speed and stability class combinations used by SCREEN are given in Table A-1. The 10-meter wind speeds given in Table A-1 are adjusted to stack height by SCREEN using the wind profile power law exponents given in Table 3-1 of the screening procedures document. For release heights of less than 10 meters, the wind speeds listed in Table A-1 are used without adjustment. For distances greater than 50 km (available with the discrete distance option), SCREEN sets 2 m/s as the lower limit for the 10-meter wind speed to avoid unrealistic transport times. Table A-1 includes some cases that may not be considered standard stability class/wind speed combinations, namely E with 1 m/s, and F with 4 m/s. The combination of E and 1 m/s is often excluded because the algorithm developed by Turner (1964) to determine stability class from routine National Weather Service (NWS) observations excludes cases of E stability for wind speeds less than 4 knots (2 m/s). The combination of E and 1 m/s is included in SCREEN because it is a valid combination that could appear in a data set using on-site meteorological data with another stability class method. A wind speed of 6 knots (the highest speed for F stability in Turner's scheme) measured at a typical NWS anemometer height of 20 feet (6.1 meters) corresponds to a 10 meter wind speed of 4 m/s under F stability. Therefore the combination of F and 4 m/s has been included for conservatism.

Table A-1. Wind Speed and Stability Class Combinations Used by the SCREEN Model

Stability Class	10-m Wind Speed (m/s)								
	1	2	3	4	5	8	10	15	20
A	*	*	*						
B	*	*	*	*	*				
C	*	*	*	*	*	*	*		
D	*	*	*	*	*	*	*	*	*
E	*	*	*	*	*				
F(rural only)	*	*	*	*					

The user has three choices of meteorological data to examine. The first choice, which should be used in most applications, is to use "Full Meteorology" which examines all six stability classes (five for urban sources) and their associated wind speeds. Using full meteorology with the automated distance array (described in Section A2), SCREEN prints out the maximum concentration for each distance, and the overall maximum and associated distance. The overall maximum concentration from SCREEN represents the controlling 1-hour value corresponding to the result from Procedures (a) - (c) in Step 4 of Section 4.2. Full meteorology is used instead of the A, C, and E or F subset used by the hand calculations because SCREEN provides maximum concentrations as a function of distance, and stability classes A, C and E or F may not be controlling for all distances. The use of A, C, and E or F may also not give the maximum concentration when building downwash is considered. The second choice is to input a single stability class (1 = A, 2 = B, ..., 6 = F). SCREEN will examine a range of wind speeds for that stability class only. Using this option the user is able to determine the maximum concentrations associated with each of the individual procedures, (a) - (c), in Step 4 of Section 4.2. The third choice is to specify a single stability class and wind speed. The last two choices were originally put into SCREEN to facilitate testing only, but they may be useful if particular meteorological conditions are of concern. However, they are not recommended for routine uses of SCREEN.

The mixing height used in SCREEN for neutral and unstable conditions (classes A-D) is based on an estimate of the mechanically driven mixing height. The mechanical mixing height, z_m (m), is calculated (Randerson,

1984) as

$$z_m = 0.3\ u*/f \qquad (A.2)$$

where: $u*$ = friction velocity (m/s)

f = Coriolis parameter ($9.374 \times 10^{-5}\ s^{-1}$ at 40^o latitude)

Using a log-linear profile of the wind speed, and assuming a surface roughness length of about 0.3m, $u*$ is estimated from the 10-meter wind speed, u_{10}, as

$$u* = 0.1\ u_{10} \qquad (A.3)$$

Substituting for $u*$ in Equation A.2 we have

$$z_m = 320\ u_{10}. \qquad (A.4)$$

The mechanical mixing height is taken to be the minimum daytime mixing height. To be conservative for limited mixing calculations, if the value of z_m from Equation A.3 is less than the plume height, h_e, then the mixing height used in calculating the concentration is set equal to $h_e + 1$. For stable conditions, the mixing height is set equal to 5000m to represent unlimited mixing.

Plume Rise for Point Sources

The use of the methods of Briggs to estimate plume rise are discussed in detail in the PTPLU user's guide (Pierce, et al, 1982). These methods are also incorporated in the SCREEN model.

Stack tip downwash is estimated following Briggs (1973, p.4) for all sources except those employing the Schulman-Scire downwash algorithm. Buoyancy flux for non-flare point sources is calculated from

$$F_b = g\ v_s\ d_s^2\ (T_s - T_a)/(4T_s), \qquad (A.5)$$

which is described in Section 4 of the screening procedures document and is equivalent to Briggs' (1975, p. 63) Equation 12.

Buoyancy flux for flare releases is estimated from

$$F_b = 1.66 \times 10^{-5} \times H \qquad (A.6)$$

where H is the total heat release rate of the flare (cal/s). This formula was derived from Equation 4.20 of Briggs (1969), assuming T_a = 293K, ρ = 1205 g/m, c_p = 0.24 cal/gK, and that the sensible heat release rate, Q_H = (0.45) H. The sensible heat rate is based on the assumption that 55 percent of the total heat released is lost due to radiation (Leahey and Davies, 1984). The buoyancy flux for flares is calculated in SCREEN by assuming effective stack parameters of v_s = 20 m/s, T_s = 1,273K, and solving for an effective stack diameter, $d_s = 9.88 \times 10^{-4} Q_H$.

The momentum flux, which is used in estimating plume rise for building downwash effects, is calculated from,

$$F_m = v_s^2 \, d_s^2 T_a/(4T_s) \qquad (A.7)$$

The PTPLU-2.0 user's guide (Pierce, et al 1982) describes the equations used to estimate buoyant plume rise and momentum plume rise for both unstable/neutral and stable conditions. Also described are transitional plume rise and how to estimate the distance to final rise. Final plume rise is used in SCREEN for all cases with the exception of the complex terrain screening procedure and for building downwash effects.

The buoyant line source plume rise formulas that are used for the Schulman-Scire downwash scheme are described in Section 2.3.12 of the revised ISC manual (EPA, 1987a). These formulas apply to sources where $h_s \leq h_b + 0.5L_b$. For sources subject to downwash but not meeting this criterion, the downwash algorithms of Huber and Snyder (EPA, 1987a) are used, which employ the Briggs plume rise formulas referenced above.

Dispersion Parameters

The formulas used for calculating vertical (σ_z) and lateral (σ_y) dispersion parameters for rural and urban sites are described in Section 2.4.1.1 of the revised ISC manual (EPA, 1987a).

Bouyancy Induced Dispersion

Throughout the SCREEN model, with the exception of the Schulman-Scire downwash algorithm, the dispersion parameters, σ_y and σ_z, are adjusted to account for the effects of buoyancy induced dispersion as follows:

$$\sigma_{ye} = (\sigma_y^2 + (\Delta h/3.5)^2)^{1/2}$$
$$\sigma_{ze} = (\sigma_z^2 + (\Delta h/3.5)^2)^{1/2} \qquad (A.8)$$

where Δh is the distance-dependent plume rise. (Note that for inversion break-up and shoreline fumigation, distances are always beyond the distance to final rise, and therefore Δh = final plume rise).

Building Downwash

Cavity Recirculation Region

The cavity calculations are a revision of the procedure described in the Regional Modelers Workshop Report, Appendix C (EPA, 1983), and are based largely on results published by Hosker (1984).

If non-zero building dimensions are input to SCREEN for either point or flare releases, then cavity calculations will be made as follows. The cavity height, h_c (m), is estimated based on the following equation from Hosker (1984):

$$h_c = h_b\ (1.0 + 1.6\ \exp\ (-1.3L/h_b)) \qquad (A.9)$$

where: h_b = building height (m)

L = alongwind dimension of the building (m)

Using the plume height based on momentum rise at two building heights downwind, including stack tip downwash, a critical (i.e. minimum) stack height wind speed is calculated that will just put the plume into the cavity (defined by plume centerline height = cavity height). The critical wind speed is then adjusted from stack height to 10-meter using a power law with an exponent of 0.2 to represent neutral conditions (no attempt is made to differentiate between urban or rural sites or different stability classes). If the critical wind speed (adjusted to 10-meters) is less than or equal to 20 m/s, then a cavity concentration is calculated, otherwise the cavity concentration is assumed to be zero. Concentrations within the cavity, χ_c, are estimated by the following approximation (Hosker, 1974):

$$\chi_c = Q/(1.5\ A_p\ u) \quad (A.10)$$

where: Q = emission rate (g/s)

$A_p = h_b \cdot W$ = cross-sectional area of the building normal to the wind (m^2)

W = crosswind dim ension of the building (m)

u = wind speed (m/s).

For u, a value of one-half the stack height critical wind speed is used, but not greater than 10 m/s and not less than 1 m/s. Thus, the calculation of χ_c is linked to the determination of a critical wind speed. The concentration, χ_c, is assumed to be uniform within the cavity.

The cavity length, x_r, measured from the lee side of the building, is estimated by the following (Hosker, 1984):

(1) for short buildings ($L/h_b < 2$);

$$x_r = \frac{(A)(W)}{1.0 + B(W/h_b)} \quad (A.11)$$

(2) for long buildings ($L/h_b \geq 2$);

$$x_r = \frac{1.75\ (W)}{1.0 + 0.25(W/h_b)} \quad (A.12)$$

where: h_b = building height (m)

L = alongwind building dimension (m)

W = crosswind building dimension (m)

$A = -2.0 + 3.7\ (L/h_b)^{-1/3}$, and

$B = -0.15 + 0.305\ (L/h_b)^{-1/3}$

The equations above for cavity height, concentration and cavity length are all sensitive to building orientation through the terms L, W and A_p. Therefore, the entire cavity procedure is performed for two orientations, first with the minimum horizontal dimension alongwind and second with the maximum horizontal dimension alongwind. For screening purposes, this is thought to give reasonable bounds on the cavity estimates. The first case will maximize the cavity height, and therefore minimize the critical wind speed. However, the A_p term will also be larger and will tend to reduce concentrations. The highest concentration that potentially effects ambient air should be used as the controlling value for the cavity procedure.

Wake Region

The calculations for the building wake region are based on the revised ISCST model, UNAMAP 6 Change 7 (EPA, 1987a). The wake effects are divided into two regions, one referred to as the "near wake" extending from $3L_b$ to $10L_b$ (L_b is the lesser of the building height, h_b, and maximum projected width), and the other as the "far wake" for distances greater than $10L_b$. For the SCREEN model, the maximum projected width is calculated from the input minimum and maximum horizontal dimensions as $(L^2 + W^2)^{1/2}$. The remainder of the building wake calculations in SCREEN are based on the ISC manual (EPA, 1987a).

It should be noted that, unlike the cavity calculation, the comparison of plume height (due to momentum rise at two building heights) to wake height to determine if wake effects apply does not include stack tip downwash. This is done for consistency with the ISC model.

Fumigation

Inversion Break-up Fumigation

The inversion break-up screening calculations are based on procedures described in Turner's Workbook of Atmospheric Dispersion Estimates (Turner, 1970). The distance to maximum fumigation is based on an estimate of the time required for the mixing layer to develop from the top of the stack to the top of the plume, using Equation 5.5 of Turner (1970):

$$x_{max} = u\ t_m$$

$$= (u\ \rho_a\ c_p/R)\ (\Delta\theta/\Delta z)\ (h_i - h_s)\ [(h_i + h_s)/2] \qquad (A.13)$$

where

x_{max} = downwind distance to maximum concentration (m)

t_m = time required for mixing layer to develop from top of stack to top of plume (s)

u = wind speed (2.5 m/s assumed)

ρ_a = ambient air density (1205 g/m^3 at 20^oC)

c_p = specific heat of the air at constant pressure (0.24 cal/gK)

R = net rate of sensible heating of an air column by solar radiation (about 67 $cal/m^2/s$)

$\Delta\theta/\Delta z$ = vertical potential temperature gradient (assume 0.035 K/m for F stability)

h_i = height of the top of the plume (m) = $h_e + 2\sigma_z$ (h_e = plume centerline height)

h_s = physical stack height (m).

σ_z' = vertical dispersion parameter (m)

The values of u and $\Delta\theta/\Delta z$ are based on assumed conditions of stability class F and stack height wind speed of 2.5 m/s for the stable layer above the inversion. The value of h_i incorporates the effect of buoyancy induced dispersion on σ_z. The equation above is solved by iteration, starting from an initial guess of x_{max} = 5,000m.

The maximum ground-level concentration due to inversion break-up fumigation, χ_f, is calculated from Equation 5.2 of Turner (1970).

$$\chi_f = Q/[\sqrt{2\pi}u(\sigma_y'+h_e/8)(h_e+2\sigma_z')] \qquad (A.14)$$

where Q is the emission rate (g/s), and other terms are defined above. The dispersion parameters, σ_y' and σ_z', incorporate the effects of buoyancy induced dispersion. If the distance to the maximum fumigation is less than 2000m, then SCREEN sets χ_f = 0 since for such short distances the fumigation concentration is not likely to exceed the unstable/limited mixing concentration estimated by the simple terrain screening procedure.

Shoreline Fumigation

For rural sources within 3000m of a large body of water, maximum shoreline fumigation concentrations can be estimated by SCREEN. A stable onshore flow is assumed with stability class F ($\Delta\theta/\Delta z$ = 0.035 K/m) and stack height wind speed of 2.5 m/s. Similar to the inversion break-up fumigation case, the maximum ground-level shoreline fumigation concentration is assumed to occur where the top of the stable plume intersects the top of the well-mixed thermal internal boundary layer (TIBL).

An evaluation of coastal fumigation models (EPA, 1987b) has shown that the TIBL height as a function of distance inland is well-represented in rural areas with relatively flat terrain by an equation of the form:

$$h_T = A\,[x]^{1/2} \qquad (A.15)$$

where: h_T = height of the TIBL (m)

A = TIBL factor containing physics needed for TIBL parameterization (including heat flux) ($m^{1/2}$)

x = inland distance from shoreline (m).

Studies (e.g. Misra and Onlock, 1982) have shown that the TIBL factor, A, ranges from about 2 to 6. For screening purposes, A is conservatively set equal to 6, since this will minimize the distance to plume/TIBL intersection, and therefore tend to maximize the concentration estimate.

As with the inversion break-up case, the distance to maximum ground-level concentration is determined by iteration. The equation used for the shoreline fumigation case is:

$$x_{max} = [(h_e + 2\,\sigma_z')/6]^2 - x_s \qquad (A.16)$$

where: x_{max} = downwind distance to maximum concentration (m)

x_s = shortest distance from source to shoreline (m)

h_e = plume centerline height (m)

σ_z' = vertical dispersion parameter (m)

Plume height is based on the assumed F stability and 2.5 m/s wind speed, and the dispersion parameter (σ_z') incorporates the effects of buoyancy induced dispersion. If x_{max} is less than 200m, then no shoreline fumigation calculation is made, since the plume may still be influenced by transitional rise and its interaction with the TIBL is more difficult to model.

The maximum ground-level concentration due to shoreline fumigation, χ_f, is also calculated from Turner's (1970) Equation 5.2:

$$\chi_f = Q/[\sqrt{2\pi} u(\sigma_y'+h_e/8)(h_e+2\sigma_z')] \qquad (A.14)$$

with σ_y' and σ_z' incorporating the effects of buoyancy induced dispersion.

Even though the calculation of x_{max} above accounts for the distance from the source to the shoreline in x_s, extra caution should be used in interpreting results as the value of x_s increases. The use of A=6 in Equations A.15 and A.16 may not be conservative in these cases since there will be an increased chance that the plume will be calculated as being below the TIBL height, and therefore no fumigation concentration estimated. Whereas a smaller value of A could put the plume above the TIBL with a potentially high fumigation concentration. Also, this screening procedure considers only TIBLs that begin formation at the shoreline, and neglects TIBLs that begin to form offshore.

Complex Terrain 24-hour Screen

The SCREEN model also contains the option to calculate maximum 24-hour concentrations for terrain elevations above stack height. A final plume height and distance to final rise are calculated based on the VALLEY model screening technique (Burt, 1977) assuming conditions of F stability (E for urban), and a stack height wind speed of 2.5 m/s. Stack tip downwash is incorporated in the plume rise calculation.

The user then inputs a terrain height and a distance (m) for the nearest terrain feature likely to experience plume impaction, taking into account complex terrain closer than the distance to final rise. If the plume height is at or below the terrain height for the distance entered, then SCREEN will make a 24-hour average concentration estimate using the VALLEY screening technique. If the terrain is above stack height but below plume centerline height, then SCREEN will make a VALLEY 24-hour estimate (assuming F or E and 2.5 m/s), and also estimate the maximum concentration across a full range of meteorological conditions using simple terrain procedures with terrain "chopped off" at physical stack height, and select the higher estimate. Calculations continue until a terrain height of zero is entered. For the VALLEY model concentration SCREEN will calculate a sector-averaged ground-level concentration with the plume centerline height (h_e) as the larger of 10.0m or the difference between plume height and terrain height. The equation used is

$$\chi = \frac{2.032\ Q}{\sigma_z' u\ x} \exp[-0.5(h_e/\sigma_z')^2]. \qquad (A.17)$$

Note that for screening purposes, concentrations are not attenuated for terrain heights above plume height. The dispersion parameter, σ_z', incorporates the effects of buoyancy induced dispersion (BID). For the simple terrain calculation SCREEN examines concentrations for the full range of meteorology and selects the highest ground level concentration. Plume heights are reduced by the chopped off terrain height for the simple terrain calculation. To adjust the concentrations to 24-hour averages, the VALLEY SCREEN value is multiplied by 0.25, as done in the VALLEY model, and the simple terrain value is multiplied by the 0.4 factor used in Step 5 of Section 4.2.

A4. NOTE TO PROGRAMMERS

The SCREEN model provided on the diskette was compiled on an IBM PC/AT compatible microcomputer using the Microsoft FORTRAN 4.1 Optimizing Complier. It was compiled with the emulator library, meaning that the executable file (SCREEN.EXE) will run with or without a math coprocessor chip. A minimum of 256 KB of RAM is required to execute the model. Provided in an archive file on the diskette are the executable file, SCREEN.EXE, the FORTRAN source file, SCREEN.FOR, the listing file, SCREEN.LST, a sample input file, EXAMPLE.DAT, and associated output file, EXAMPLE.OUT. Also included on the diskette is a READ.ME file with instructions on extracting SCREEN, and the archiving program ARC521.COM. The listing file contains 99 pages.

The SCREEN model provided was complied with the following Microsoft FORTRAN options:

/4I2	Defines all integer variables as INTEGER*2
/FPi	Causes floating point operations to be processed using in-line instructions rather than library CALLs (used for faster execution)
/Fs	Causes source listing file to be generated
/St"SCREEN-1.1 PROGRAM"	Causes title to be printed at the top of each page of the .LST file

It was also compiled with the following METACOMMAND included in the source file:

$PAGE	Causes new page in .LST file, used at end of each SUBROUTINE or FUNCTION

The $PAGE METACOMMAND has been commented out in the source file provided on the diskette in order to facilitate recompiling SCREEN with a different compiler. SCREEN uses the FORTRAN default unit number of 5 (five) for reading input from the keyboard and 6 (six) for writing to the screen. The unit number for the disk output file, SCREEN.OUT, is set internally to 9, and the unit number for writing to the input data file, SCREEN.DAT, is set to 7. These unit numbers are assigned to the variables IRD, IPRT, IOUT, and IDAT, respectively, beginning on line 86 of the source file. The Microsoft version of SCREEN also uses the GETDAT and GETTIM system routines for retrieving the date and time. These routines require the variables to be INTEGER*2, and they may differ on other compilers.

The following simple change can be made to the SCREEN source file, SCREEN.FOR, in order to create a version that will accept a user-specified output filename, instead of automatically writing to the file SCREEN.OUT. An ASCII editor or a wordprocessor that has an ASCII or nondocument mode may be used to edit the source file. Delete the letter C from Column 1 on lines 128 to 131. They should read as follows:

```
      WRITE(IPRT,*) ' '
94    WRITE(IPRT,*) 'ENTER NAME FOR OUTPUT FILE'
      READ(IRD,95) OUTFIL
95    FORMAT(A12)
```

With this change, if the user-specified filename already exists, it will be overwritten. If desired, the OPEN statement on line 133 may also be changed to read as follows:

```
      OPEN(IOUT,FILE=OUTFIL,STATUS='NEW',ERR=94)
```

With this additional change, the program will continue to prompt for the input filename until a filename that doesn't already exist is entered by the user. Before recompiling, make any other changes that may be necessary for the particular compiler being used, and use the appropriate compile option for defining all integer variables as INTEGER*2. It should be noted that without optimization, the source file may be too large to compile as a single unit. In this case, the SCREEN.FOR file may need to be split up into separate modules that can compiled separately and then linked together.

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APPENDIX B

UNAMAP Dispersion Models

UNAMAP is an acronym for User's Network for Applied Modeling of Air Pollution. Since 1973, UNAMAP has served as a source for air quality simulation models in computer compatible form. UNAMAP has grown from an original six models in 1973 to 23 models as of July 1986 with UNAMAP Version 6. UNAMAP includes the source codes and test cases for the Appendix A models from the Guideline on Air Quality Models (Revised), as well as other models and processors.

The UNAMAP versions are created and maintained by:

Applied Modeling Research Branch
Atmospheric Sciences Modeling Division (MD-80)
Atmospheric Research and Environmental Assessment Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

(919) 541-4564; FTS 629-4564

A magnetic tape containing the current UNAMAP is available from:

Computer Products
National Technical Information Service
U.S. Department of Commerce
Springfield, VA 22161

(703) 487-4763; FTS 737-4763

A more detailed description of UNAMAP (Version 6) including abstracts for all of the models, is provided in the publication Description of UNAMAP (Version 6), by D. B. Turner and L. W. Bender, EPA/600/M-86/027, U. S. Environmental Protection Agency, Research Triangle Park, NC (Dec. 1986).

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(Please read Instructions on the reverse before completing)

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This document is a revision of Volume 10R of the Guidelines for Air Quality Maintenance Planning and Analysis series, EPA-450/4-77-001.

16. ABSTRACT

This document presents current EPA guidance on the use of screening procedures to estimate the air quality impact of stationary sources. It is an update and revision of Volume 10R of the GAQMPA series, and is intended to replace Volume 10R as the standard screening procedures for regulatory modeling of stationary sources. It is being issued as a draft for public comment until such time as a final version can be incorporated into a future supplement to the Guideline on Air Quality Models (Revised). An important advantage of the current document is the availability of the SCREEN model for executing the single source, short-term procedures on a personal computer.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Atmospheric Diffusion Atmospheric Models Meteorology	New Source Review	

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