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IMPROVEMENTS TO SINGLE-SOURCE MODEL VOLUME 2: TESTING AND EVALUATION OF MODEL IMPROVEMENTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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Research Triangle Park, North Carolina 27711

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IMPROVEMENTS TO SINGLE-SOURCE MODEL VOLUME 2: TESTING AND EVALUATION OF MODEL IMPROVEMENTS

by

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ACKNOWLEDGMENTS

The key data used in carrying out this study were made available to GCA/Technology Division by the New England Gas and Electric System and the Ohio Power Company. Project direction and guidance were given by Mr. Russell Lee of the Source-Receptor Analysis Branch, Monitoring and Data Analysis Division, EPA, Durham, North Carolina, who served as project officer.

SECTION I

INTRODUCTION

The purpose of this study is to test a number of suggested improvements to the EPA Single Source Model (CRSTER). In particular three alternate methods for the parameterization of vertical and horizontal dispersion coefficients with distance will be evaluated along with two additional stability class selection algorithms. The predictions of each modified version of the Single Source Model will be compared with actual concentration measurements so that these potential model improvements can be evaluated. Another objective of this study was to determine whether the use of a variable buoyancy flux in the plume rise equation in the model would yield better predictions.

During two previous EPA sponsored projects[1,2] GCA carried out validation studies for the Single Source 24-Hour Model at four separate power plant sites. Model predictions of 1-hour and 24-hour SO_2 concentration frequency distributions were carried out based upon emission parameters and hourly meteorological data and compared with the corresponding frequency distributions of SO_2 concentration measurements corrected for background contributions.

In the first validation exercise, which was performed for the Canal Power Plant in southeastern Massachusetts, concentration predictions were made for a variety of emissions and meteorological data bases ranging in degree of resolution from monthly average emission rates taken from FPC Form-67 and hourly meteorological data from the nearest weather station to actual hourly emissions and on-site wind speed and direction

data in conjunction with hourly stabilities and mixing heights extracted from the weather station observations. Regardless of the choice of input data sets the model was found to underpredict both 1-hour and 24-hour SO_2 concentrations. With the exception of one receptor location, the ratios of measured minus background to predict second highest yearly SO_2 concentrations fell between 1.0 and 2.0. The corresponding ratios for the 24-hour concentrations, again neglecting one receptor location, ranged from 1.2 to 6.4 with an arithmetic mean of 3.2.

To determine whether the underprediction found for the Canal Plant was due to the coastal location of the plant site or some weakness in the model itself, three power plant sites were chosen in Ohio for additional tests of the model. Source characteristics and emission rates for the J. M. Stuart, Muskingum and Philo power plants were used in conjunction with surface and upper air meteorological data from nearby weather stations to generate model estimates of SO_2 concentrations for the 1-hour and 24-hour averaging times employed in the Canal plant study. With the exception of the Philo plant the predicted 1-hour SO_2 concentrations were in much better agreement with measurements than for the Canal plant study. The average ratio of second highest measured to predicted 1-hour SO_2 concentrations was 1.02 and 1.10 for the Stuart and Muskingum plants respectively. One-hour SO_2 concentrations for the Philo plant were overpredicted by a factor of 2, a circumstance due in large part to the inadequacy of the Single Source Model to handle the dispersion effects associated with complex terrain, particularly for those receptor locations with elevations comparable to that of the stack top. The predicted second highest 24-hour SO_2 concentrations for the J. M. Stuart and Muskingum plants were in better agreement with the measured values than in the case of the Canal plant with the measured to predicted ratios of 1.5 and 2.0 for the J. M. Stuart and Muskingum plants respectively.

Based upon these model validation studies two problems areas could be identified. The first concerned the underprediction of second highest 24-hour concentrations at three of the four plants studied. To a large degree

this tendency to underpredict 24-hour concentrations may be traced to the method by which 24-hour predictions are obtained from 1-hour concentration calculations. For the calculation of 1-hour concentrations the Single Source Model requires that the wind flow vector remain constant for the entire hour so that no mechanism exists for a smooth transition from one hourly flow direction to the next. While this assumption does not seriously affect the quality of the peak 1-hour concentration predictions, the resulting deficiency in low and intermediate concentrations (i.e., large number of zero concentration predictions) may lead to an underestimate in the associated 24-hour concentrations. An alternate method for the estimation of peak 24-hour concentrations is through the application of peak to mean ratio distribution statistics. In each of the model validation studies distributions of peak 1-hour to average 24-hour SO_2 concentration ratios were constructed from actual hourly SO_2 concentration measurements corrected for background. For the four plants studied the geometric means of these distributions ranged from 7.3 to 7.9 and the standard geometric deviations from 1.5 to 1.7. If the second highest predicted 1-hour SO_2 concentration were found to be accurate, then an estimated second highest 24-hour SO_2 concentration obtained by dividing the 1-hour value by the geometric mean of the 1-hour to 24-hour peak to mean ratio should be accurate to at least a factor of 2. Volume I of this study was devoted to a further examination of these ratio distributions to determine their sensitivity to the use of successively higher threshold values of peak 1-hour SO_2 concentrations.

The second area of concern dealt with the theoretical bases for the model predictions, namely, the plume rise formulation, stability class selection procedure and the choice of parameters for the calculation of vertical and horizontal plume dispersion coefficients. The basic question was whether the use of alternate techniques would improve the agreement between predicted and measured 1-hour SO_2 concentrations, particularly at the Canal plant. The Briggs[3,4,5] plume rise estimates currently incorporated in the Single Source Model represent the best fit to currently existing data. For the Canal plant study, a modification was made to the plume rise

computation in the model to include the effect of stack downwash but this modification did not improve the quality of the predictions to a significant degree. On the other hand, there are a number of techniques different from the Pasquill-Turner method which is currently in use for the classification of stabilities and the calculation of dispersion coefficients. In Section II we shall describe some of these techniques and describe the manner in which they were included in the Single Source Model. Section III will deal with the source and meteorological input data bases to be used in the test of potential model improvements. In Secion IV we shall present the model validation results for the alternate dispersion calculation techniques and draw a conclusion as to the adequacy of the existing model formulation. Also, in Section IV we shall investigate the utility of incorporating a variable volume flux in the Single Source Model.

SECTION II

SURVEY OF DISPERSION CALCULATION METHODS

DESCRIPTION OF THE EXISTING MODEL

We shall begin our discussion of dispersion calculation methods with a description of the EPA Single Source Model as it currently exists. The program, which was developed by the EPA Meteorology and Assessment Division, calculates hourly and daily concentrations for an array of receptor locations and maximum hourly and daily pollutant concentrations for a year along with the meteorological conditions which can lead to these maxima. These concentrations are written on magnetic tape for the 252 receptor positions situated at each of 36 directions from the source and seven different distance ranges. The normal version of the model has five distances and 180 receptors. The seven distances and 252 receptors occur only in the special GCA adaptation. The model can handle from 1 to 19 sources but treats all of them as if they were at the same physical location. The expression used for evaluation of 1-hour pollutant concentrations downwind of a point source is the Gaussian plume equation[6,7] given by

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

where

x = distance along plume axis (m)

y = horizontal distance from plume axis (m)

z = distance above surface (m)

$\chi(x,y,z)$ = concentration of pollutant (g/m^3)

Q = effective emission rate of pollutant distance x (g/sec)

$\sigma_y(x)$, $\sigma_z(x)$ = horizontal and vertical dispersion coefficients for a particular atmospheric stability (A,B,C,D,E,F) and distance x

u = wind speed at source height (m/sec)

h(x) = effective emission height at distance x (m)

The variation of σ_y and σ_z with distance was first parameterized by Gifford[6] as shown in Figures 1 and 2. These curves represent a fit to a number of concentration field measurements including those made during the Prairie Grass study[8] conducted during the summer of 1956. Although these plume dispersion estimates were based largely upon ground level releases they are also generally applied to elevated point sources. Criteria for selection of a particular stability class were first suggested by Pasquill[9] and Meade[10] and are listed in Table 1. The measurements upon which these curves were based were taken within 1 km of the source, the shape of the σ_z curves beyond this distance is somewhat uncertain especially for the A and B stability classes. For the σ_z curves used for the Single Source Model the variation of dispersion with distance for the A and B stabilities is represented by a simple power law beyond 500 m and 700 m, respectively, as shown in Figure 3.[7] A more detailed stability class assignment algorithm than the one given in Table 1 was suggested by Turner[11] and is currently incorporated in the meteorological preprocessor program used in conjunction with the Single Source Model. The details of this method are presented in Appendix A. The Single Source Model makes use of an additional stability class, G, for which the assumption is made that the plume never reaches the ground.

Surface meteorological input to the model consists of hourly surface observations of wind speed (knots), wind direction sector (1-36), temperature (^{o}F), and total cloud cover (tenths). The format for these data is that used by the National Climatic Center for WBAN-144 hourly surface observations. These data along with twice daily mixing heights are input into a preprocessor program which in turn writes a tape containing hourly values of stability index, mixing height, temperature, windspeed, flow

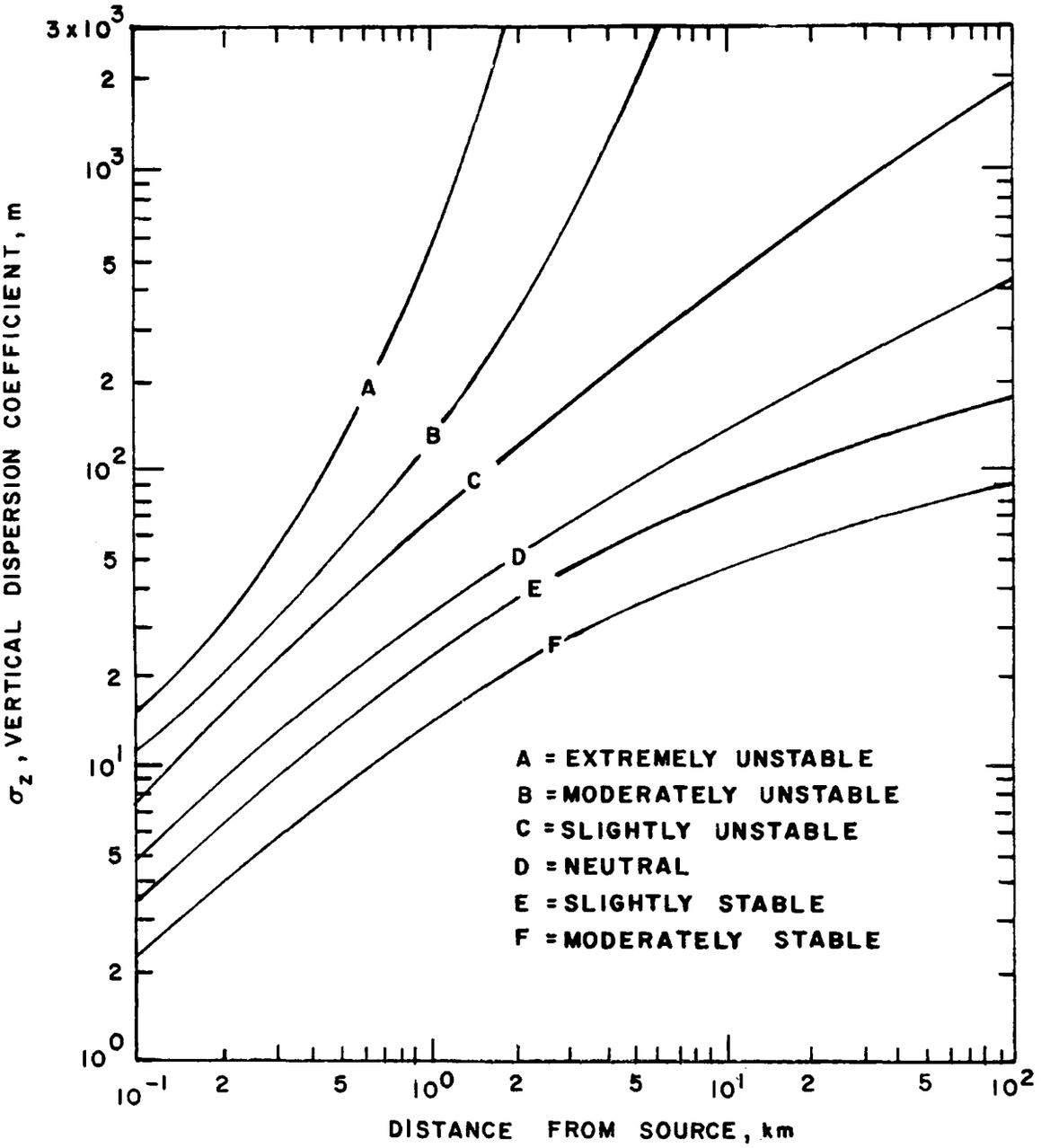

Figure 1. Vertical dispersion coefficient as a function of distance according to Gifford[6]

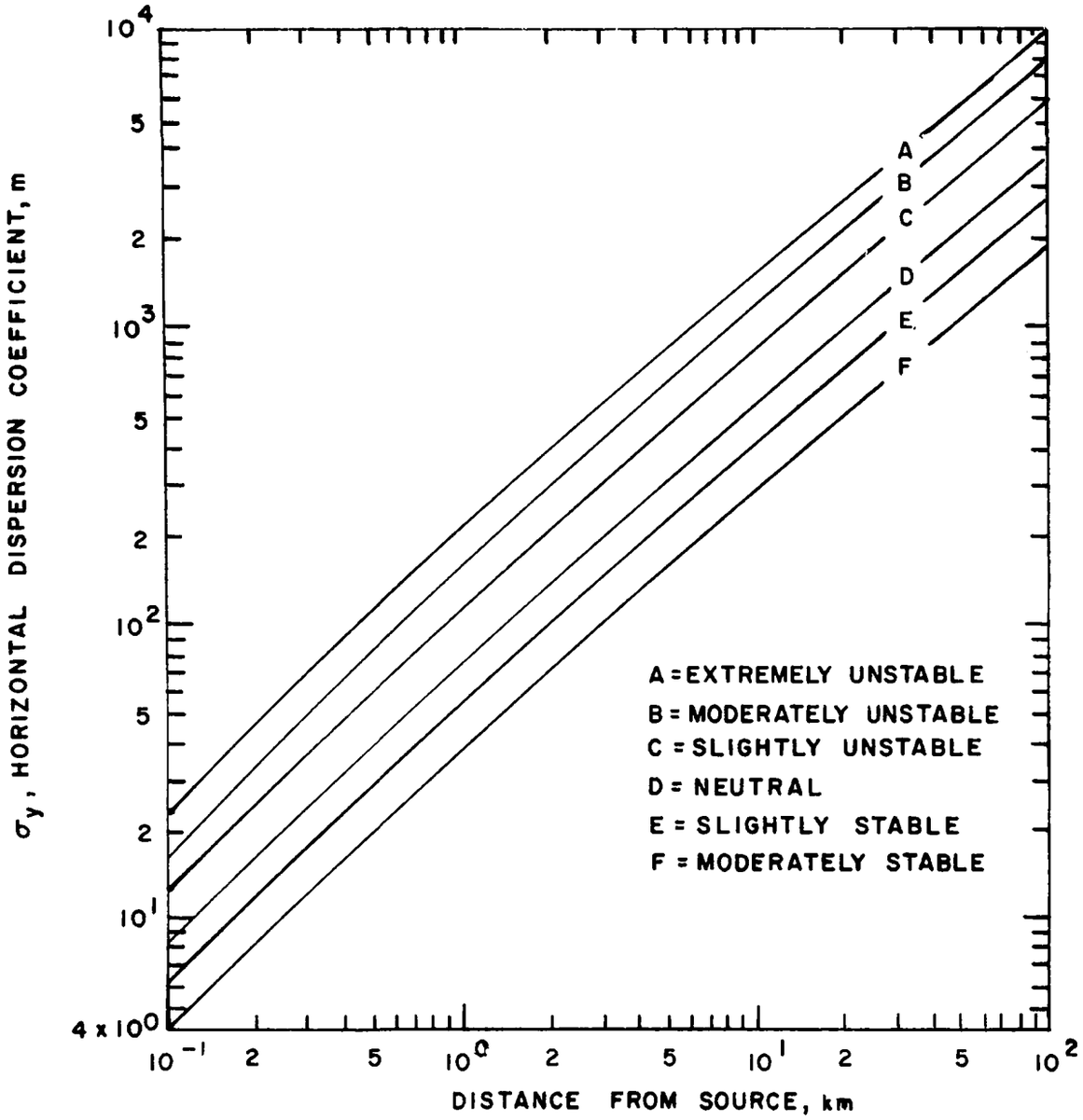

Figure 2. Horizontal dispersion coefficient as a function of distance according to Gifford[6]

Table 1. METEOROLOGICAL CATEGORIES ACCORDING TO PASQUILL[9] AND MEADE[10]

Surface wind speed, m/sec	Daytime insolation			Thin overcast or ≥ 4/8 cloudiness	≥ 3/8 cloudiness
	Strong	Moderate	Slight		
< 2	A	A-B	B		
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
> 6	C	D	D	D	D

A - Extremely unstable conditions

B - Moderately unstable conditions

C - Slightly unstable conditions

D - Neutral conditions (Applicable to heavy overcast, day or night)

E - Slightly stable conditions

F - Moderately stable conditions

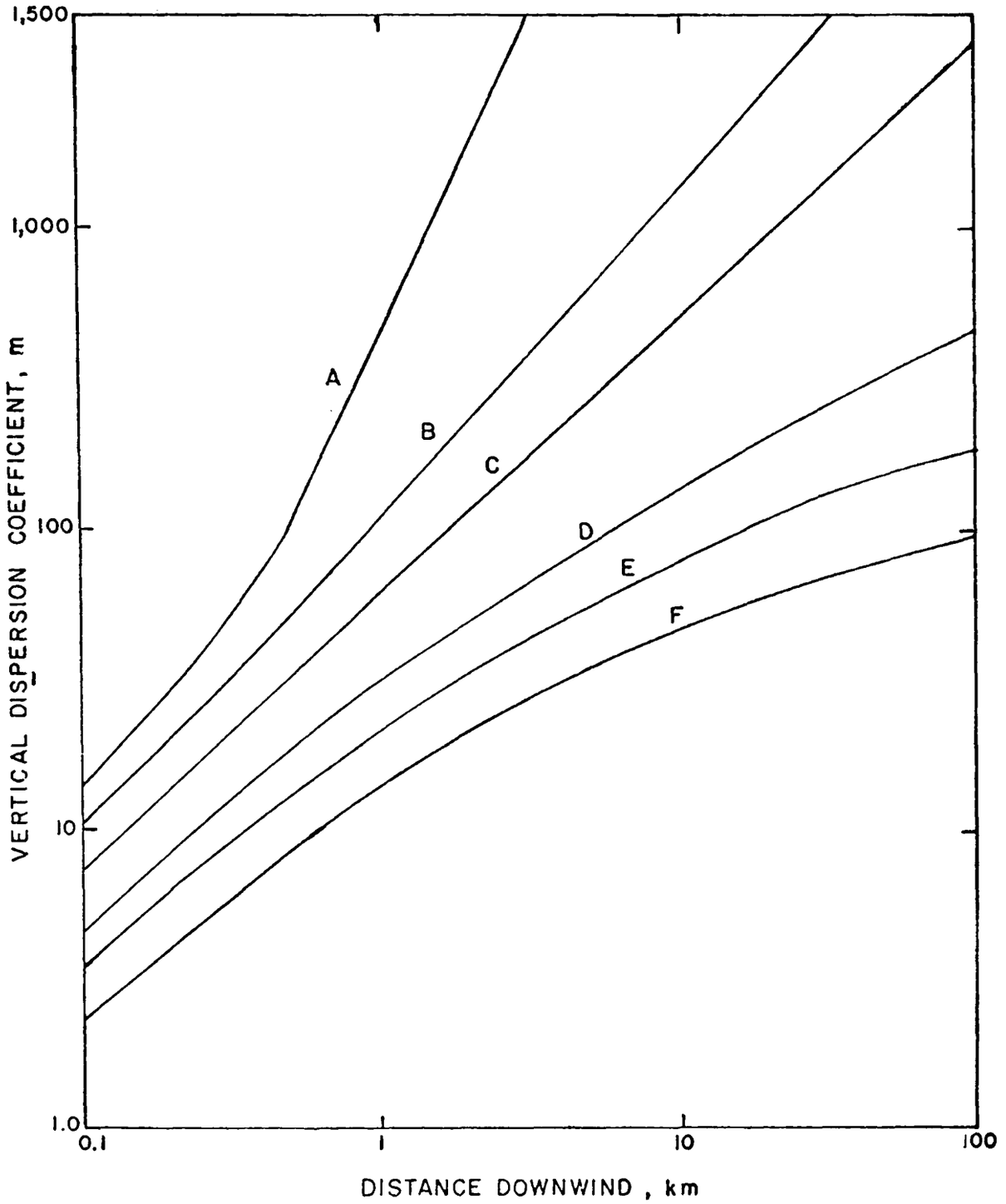

Figure 3. Vertical dispersion coefficient as a function of downwind distance from the source as currently employed in the Single Source Model[7]

vector (wind direction plus 180°), and randomized flow vector. The randomized flow vector is equal to the flow vector minus 4 degrees plus a random number between 0 and 9 degrees. The preprocessor output tape is then read by the Single Source Model which performs the actual concentration calculations. The twice daily mixing height data can be obtained from the National Climatic, Asheville, North Carolina. Missing data were filled in through interpolation.

Two different sets of hourly mixing heights are calculated by the preprocessor. One is for rural surroundings; the other is for urban locations. The way in which hourly mixing heights are determined from maximum mixing heights (MXDP) for yesterday (i-1), today (i) and tomorrow (i + 1) and minimum mixing heights (MNDP) for today (i) and tomorrow (i + 1) is depicted in Figure 4. For urban mixing height between midnight and sunrise the following procedure is used: if the stability is neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ (1), if stability is stable use $MNDP_i$ (2). For hours between sunrise and 1400, if the hour before sunrise was neutral, interpolate between $MXDP_{i-1}$ and $MXDP_i$ (3). For sunrise to 1400, if the hour before sunrise was stable, interpolate between $MNDP_i$ and $MXDP_i$ (4). For 1400 to sunset, use $MXDP_i$ (5). For hours between sunset and midnight, if stability is neutral interpolate between $MXDP_i$ and $MXDP_{i+1}$ (6), if stability is stable interpolate between $MXDP_i$ and $MNDP_{i+1}$ (7).

For rural mixing height between midnight and sunrise, interpolate between $MXDP_{i-1}$ and $MXDP_i$ (8). For hours between sunrise and 1400, if the hour before sunrise was neutral interpolate between $MXDP_{i-1}$ and $MXDP_i$ (9). For sunrise to 1400, if the hour before sunrise was stable, interpolate between 0 and $MXDP_i$ (10). For 1400 to sunset, use $MXDP_i$ (11). For sunset to midnight, interpolate between $MXDP_i$ and $MXDP_{i-1}$ (12).

Wind sppeds u_o measured at instrument height h_o (7 meters is common for weather stations) are adjusted by means of a stability dependent power

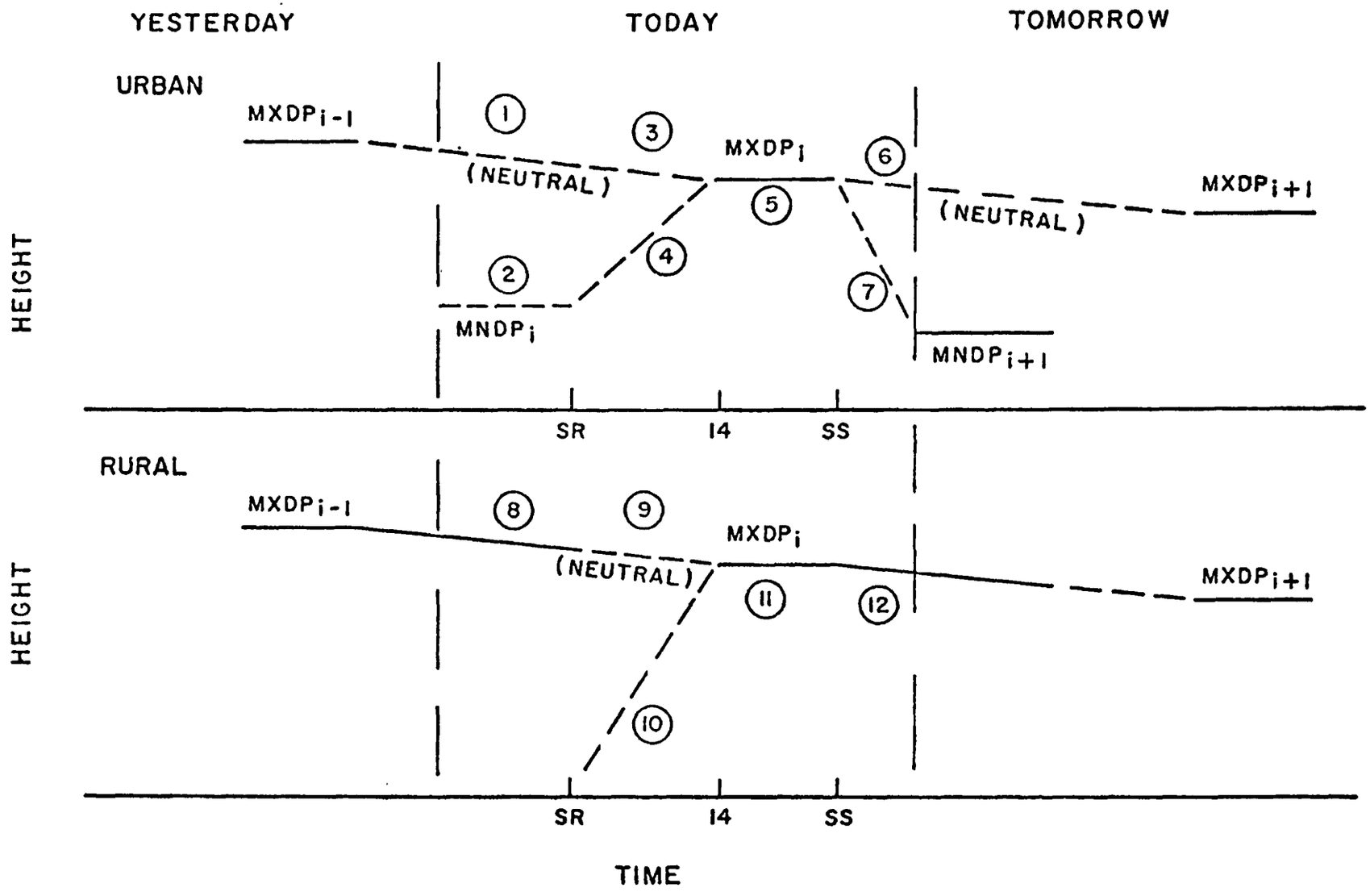

Figure 4. Determination of hourly mixing heights

law ($u = u_o (h/h_o)^{\alpha}$) to correspond to values one would expect at the actual stack height h. The variation of the exponent α with stability is shown in Table 2. Plume rise is calculated on an hourly basis using the method of Briggs.[3-5] The effective stack height h(x) will be greater than the actual stack height h_s due to the buoyancy of the plume. The expression for h(x) for stabilities A through D is given by

$$h(x) = h_s + \Delta h \tag{2}$$

where $\Delta h = 1.6F^{1/3} u^{-1} x^{2/3}$ for $x \leq 3.5x^*$

$\Delta h = 1.6F^{1/3} u^{-1} (3.5x^*)^{2/3}$ for $x > 3.5x^*$

$x^* = 14F^{5/8}$ when $F < 55\ m^4/sec^3$

$x^* = 34F^{2/5}$ when $F \geq 55\ m^4/sec^3$

$$F = gwr^2 \left(\frac{T_s - T_a}{T_s}\right)$$

g = gravitational acceleration (m/sec^2)

w = stack gas exit velocity (m/sec)

T_s = stack gas temperature (^oK)

T_a = ambient temperature (^oK)

Table 2. WIND PROFILE EXPONENTS (α) FOR DIFFERENT STABILITIES

Stability class	α
A	0.1
B	0.15
C	0.2
D	0.25
E	0.3
F	0.3

For stability classes E and F the plume rise becomes

$$\Delta h = 2.9\left(\frac{F}{us}\right)^{1/3} \tag{3}$$

where $s = \frac{g}{T_e}\frac{d\theta}{dz}$

θ = potential temperature (^{o}K)

$\frac{d\theta}{dz}$ = 0.02 ^{o}K/m for stability E

$\frac{d\theta}{dz}$ = 0.035 ^{o}K/m for stability F

If the plume rise calculation indicates that the plume axis will rise above the mixing layer, then a zero concentration contribution is specified. If the final height plume is below the top of the mixing layer, the presence of the mixing boundary is accounted for in the Single Source Model by the incorporation of multiple image sources as was done to satisfy the zero flux condition at ground level. With this assumption Equation (1) is generalized to give

$$\chi(x,y,z) = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma_y^2(x)}\right)}{2\pi\,\sigma_y(x)\,\sigma_z(x)} \left\{ \exp\left(-\frac{(z - h(x))^2}{2\,\sigma_z^2(x)}\right) \right.$$

$$+ \exp\left(-\frac{(z + h(x))^2}{2\,\sigma_z^2(x)}\right) + \sum_{j=1}^{n} \exp\left(-\frac{(z - h(x) - 2jL)^2}{2\,\sigma_z^2(x)}\right)$$

$$+ \exp\left(-\frac{(z + h(x) - 2jL)^2}{2\,\sigma_z^2(x)}\right) + \exp\left(-\frac{(z - h(x) + 2jL)^2}{2\,\sigma_z^2(x)}\right)$$

$$\left. + \exp\left(-\frac{(z + h(x) + 2jL)^2}{2\,\sigma_z^2(x)}\right)\right] \right\} \qquad (4)$$

where L = depth of the mixing layer (m)

n = number of images considered

In practice only the first few image terms contribute significantly to the overall ambient concentration. For distances greater than 2 x_L, where x_L is given by $\sigma_z(x_L) = 1.6$, Equation (5) was approximated by

$$\chi(x,y,z) = \frac{Q \exp\left(\frac{-y^2}{2\,\sigma_y^2(x)}\right)}{\sqrt{2\pi}\,\sigma_y(x)\,u\,L} \qquad x > 2\,x_L \qquad (5)$$

Source input to the Single Source Model may possess several degrees of temporal resolution. In the seasonal version of the model an annual average SO_2 source strength is specified along with monthly variation factors. In addition to the seasonal factors, the diurnal version of the model employs hourly emission variation factors for each month of the year. A modification made to the model used in our validation studies allowed actual hourly source strengths to be utilized. A second modification made to the model allowed actual receptor elevations to be accounted for. In Section IV of this report we shall present the results of a validation of a version of the Single Source Model which allows the stack exit velocity to vary with the fuel consumption rate.

DESCRIPTIONS OF OTHER DISPERSION COEFFICIENTS TO BE TESTED

The stability selection algorithm and the dispersion calculation technique currently used within the Single Source Model will henceforth be referred to as the Pasquill-Turner method. During the next three parts of this section we shall discuss three other methods: (1) Smith-Singer, (2) Gifford Briggs and (3) F. B. Smith and the manner in which they were included in modified versions of the Single Source Model.

SMITH SINGER DISPERSION COEFFICIENTS

The Smith-Singer method for determining the horizontal and vertical dispersion coefficients is based upon a series of atmospheric diffusion experiments conducted over a period of 15 years at the Brookhaven National Laboratory. These included oil fog studies for an elevated source, monitoring of reactor emissions by A^{41} and low level uranine dye releases. The choice of a particular stability assignment (A, B2, B1, C or D) for a given hour is related to a subjective estimate of the lateral turbulence intensity determined from analogue wind direction recordings (Figure 5). A more quantitative explanation of the classification scheme shown in Figure 5 is presented below:

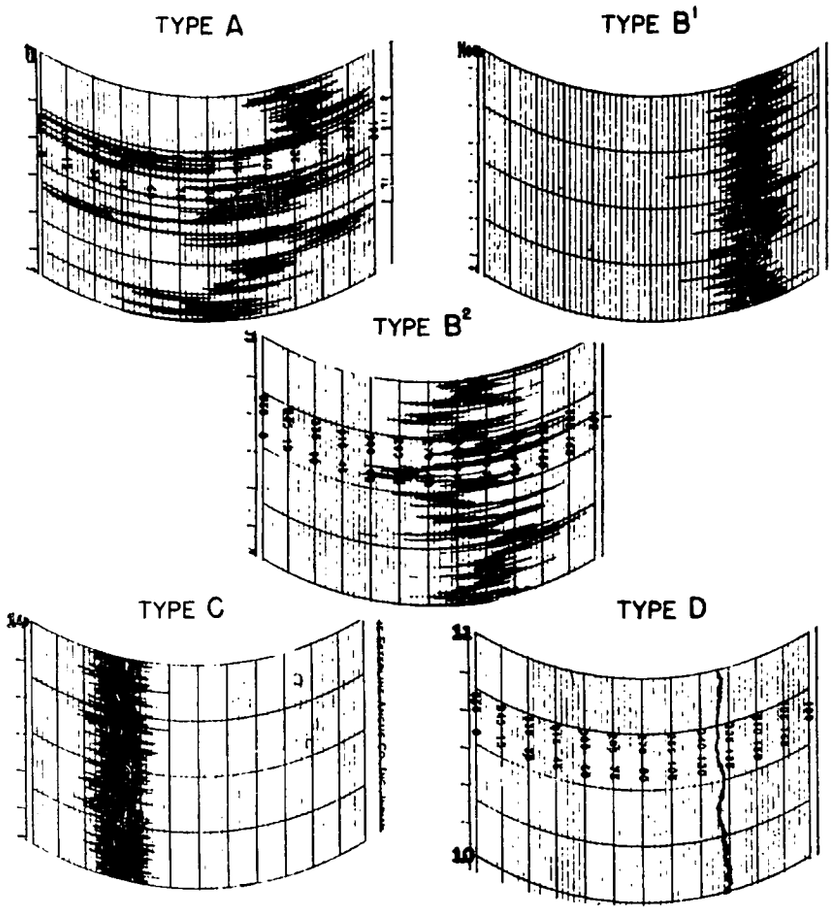

Figure 5. Wind direction trace types used to determine atmospheric stability by the Smith-Singer method[14]

A = fluctuations of the wind direction exceeding 90^{o};

B2 = fluctuations ranging from 40^{o} to 90^{o};

B1 = similar to A and B2, with fluctuations confined to 15 and 45^{o} limits;

C = distinguished by the unbroken solid core of the trace, through which a straight line can be drawn for the entire hour, without touching "open space"; and

D = the trace approximates a line - short-term fluctuations do not exceed 15^{o}.

Power law expressions describing the variation of σ_y and σ_z with distance from the source are specified[12] in Table 3 for four of the five "gustiness classes" (B2, B1, C, and D).

Table 3. SMITH-SINGER POWER LAW PARAMETERS a,b FOR HORIZONTAL AND VERTICAL DISPERSION PARAMETERS $\sigma_{y,z} = ax^{b}$ WHERE x IS IN METERS[13]

	Stability class							
	B2		B1		C		D	
	a	b	a	b	a	b	a	b
σ_y	0.40	0.91	0.36	0.86	0.32	0.78	0.31	0.71
σ_z	0.41	0.91	0.33	0.86	0.22	0.78	0.06	0.71

The dispersion curves described by these parameters are shown in Figures 6 and 7.

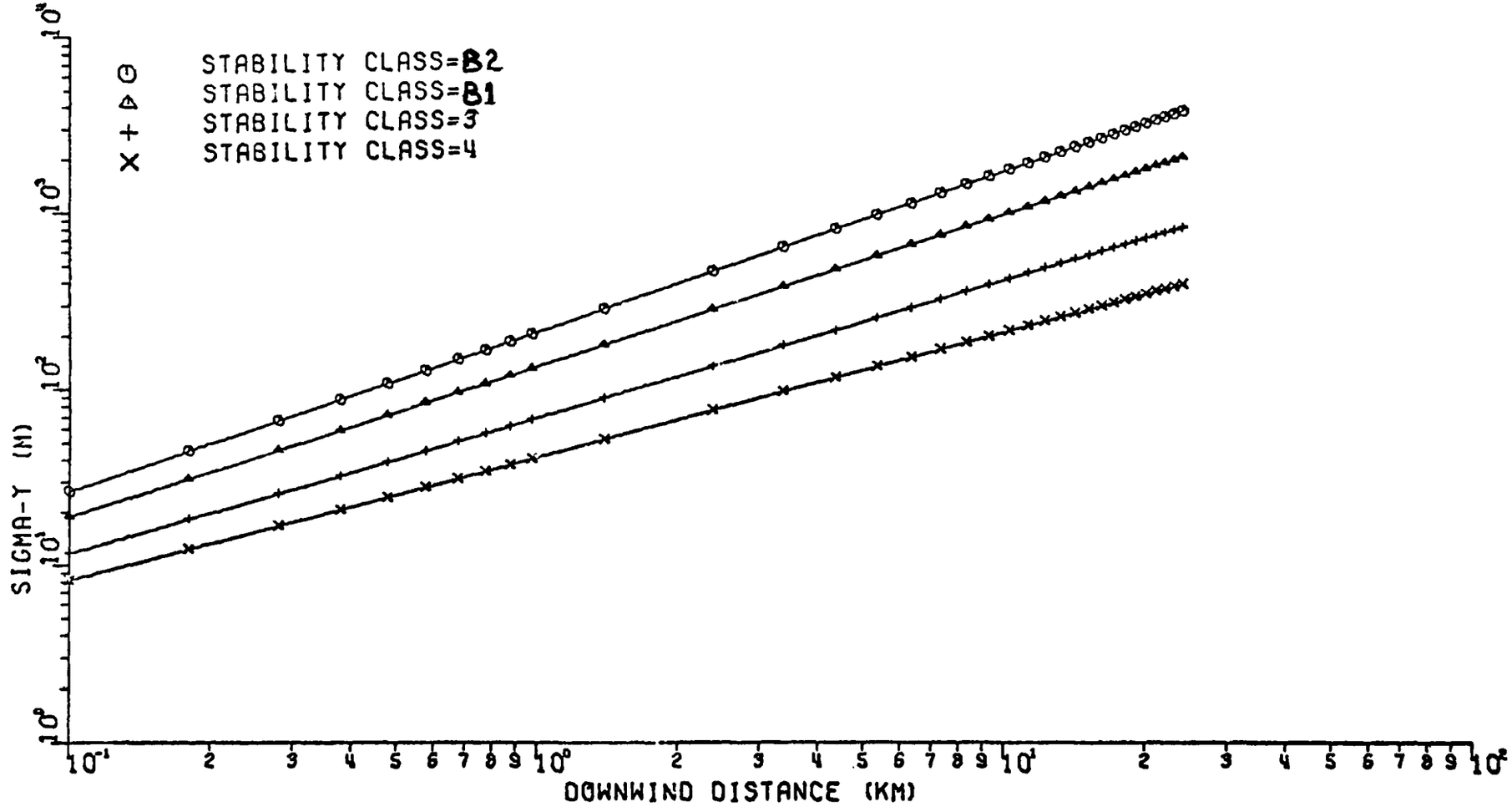

Figure 6. Variation of σ_y with distance for the Smith-Singer stability classes

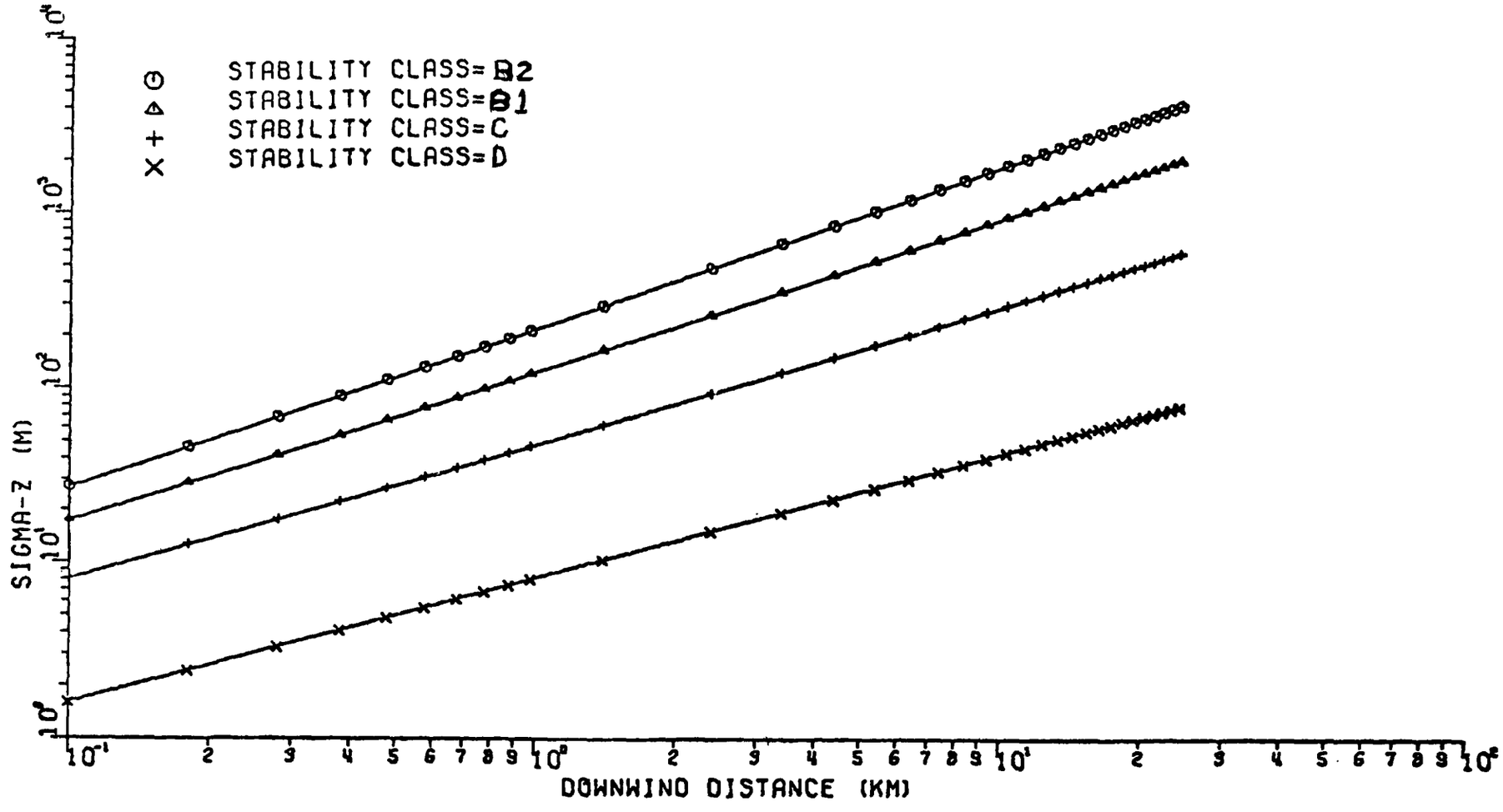

Figure 7. Variation of σ_z with distance for each of the Smith-Singer stability classes

No dispersion parameters are given for stability A since this condition is characterized by no organized horizontal wind flow so that the resultant ground level concentrations may only be described in a qualitative manner. Stability A cases were therefore not included in our validation studies to be described later in this report. As in the case of the Pasquill-Turner scheme the wind speed is assumed to increase with height according to a power law with the exponent α assigned the values 0.16, 0.25, 0.32, and 0.50 for atmospheric stabilities B2 through D.[13]

In the application of these dispersion curves to the prediction of concentrations downwind of large elevated point sources M.E. Smith calculates the effective stack height by use of the following formula presented in the ASME Guide[15] Second Edition, 1973:

$$h = h_s + 7.4 \left(\frac{F^{1/3} \, h_s^{2/3}}{u} \right) \tag{6}$$

Since we were primarily interested in the comparison of different dispersion calculation methods we continued to employ the Briggs formulae, with Equation (2) used for stabilities B2, B1 and C and Equation (3) used for stability D. For power plant diffusion modeling Smith modifies his estimate of σ_y by adding a term to allow for the presence of directional wind shear:

$$\sigma_y = ax^b + x \tan \phi \tag{7}$$

where ϕ = wind direction change

Since no rule is given for the selection of ϕ as a function of stability or plume height, the term was not included in our analysis. Had the term been included, it would have effectively lowered the predictions of ground level air concentrations especially for the more stable conditions.

GIFFORD-BRIGGS DISPERSION COEFFICIENTS

A method for the determination of plume standard deviations has recently been developed by Briggs[16] using a wide range of experimental data including the TVA and Prairie Grass measurements mentioned earlier. The selection of an appropriate stability class is called out according to the Pasquill-Turner method but the corresponding curves for σ_y and σ_z are chosen to represent a wider range of source elevations and source-receptor distances. Analytical expressions for σ_y and σ_z applicable to rural areas are given in Table 4. The utilization of the Gifford-Briggs method in the Single Source Model required only that the dispersion calculation subroutine be modified. The plume rise and the wind profile equations were left unchanged.

Table 4. VARIATION OF σ_y AND σ_z WITH DISTANCE x (METERS) FOR RURAL AREAS

Stability	σ_y (meters)	σ_z (meters)
A	$0.224\ x/\sqrt{1 + 0.0001\ x}$	$0.20\ x$
B	$0.16\ x/\sqrt{1 + 0.0001\ x}$	$0.12\ x$
C	$0.112\ x/\sqrt{1 + 0.0001\ x}$	$0.080\ x/\sqrt{1 + 0.0002\ x}$
D	$0.080\ x/\sqrt{1 + 0.0001\ x}$	$0.056\ x/\sqrt{1 + 0.0015\ x}$
E	$0.056\ x/\sqrt{1 + 0.0001\ x}$	$0.032\ x/(1 + 0.0003x)$
F	$0.040\ x/\sqrt{1 + 0.0001\ x}$	$0.016\ x/(1 + 0.0003x)$

F.B. SMITH DISPERSION COEFFICIENTS

Recently the Pasquill-Turner scheme for stability classification for vertical dispersion coefficients has been modified and extended by Pasquill's colleague, F.B. Smith,[17] to include the effect of surface

roughness and provide for the fractional assignment of stability classes. This latter development was especially significant since the variation of ground level air concentration with stability class can be an order of magnitude or more.

The scheme utilizes numerical solutions of the diffusion equation up to 100 km downwind with profiles of wind, u(z), and diffusivity, (K(z), suggested by actual measurements in unstable, neutral and stable conditions. The horizontal dispersion coefficients are chosen to be the same as the Pasquill-Turner. The reason for this is that F. B. Smith does not recommend any specific σ_y curve, but rather advises the use of wind fluctuation data, with an adjustment for downwind distance. At larger distances, this adjustment makes $\sigma_y \propto x^{1/2}$ where x is downwind distance. Since the required wind fluctuation data are not available, the Pasquill-Turner σ_y data were used. It should be pointed out, however, that the Pasquill-Turner curves show σ_y to be approximately proportional to $x^{0.9}$ at all distances, and not $x^{1/2}$. The method for fractional stability assignment is illustrated in Figure 8. F.B. Smith presented Figure 9 as a guide for choosing a value for incoming solar radiation as a function of solar elevation angle. He recommends that this value be multiplied by an appropriate factor to account for the presence of cloud cover (see Table 5).

Table 5. MULTIPLICATION FACTORS FOR INCOMING SOLAR RADIATION INTENSITY FOR DIFFERENT AMOUNTS OF CLOUD COVER

Cloud amount (eights)	Multiplier
0	1.07
1	0.89
2	0.81
3	0.76
4	0.72
5	0.67
6	0.59
7	0.45
8	0.23

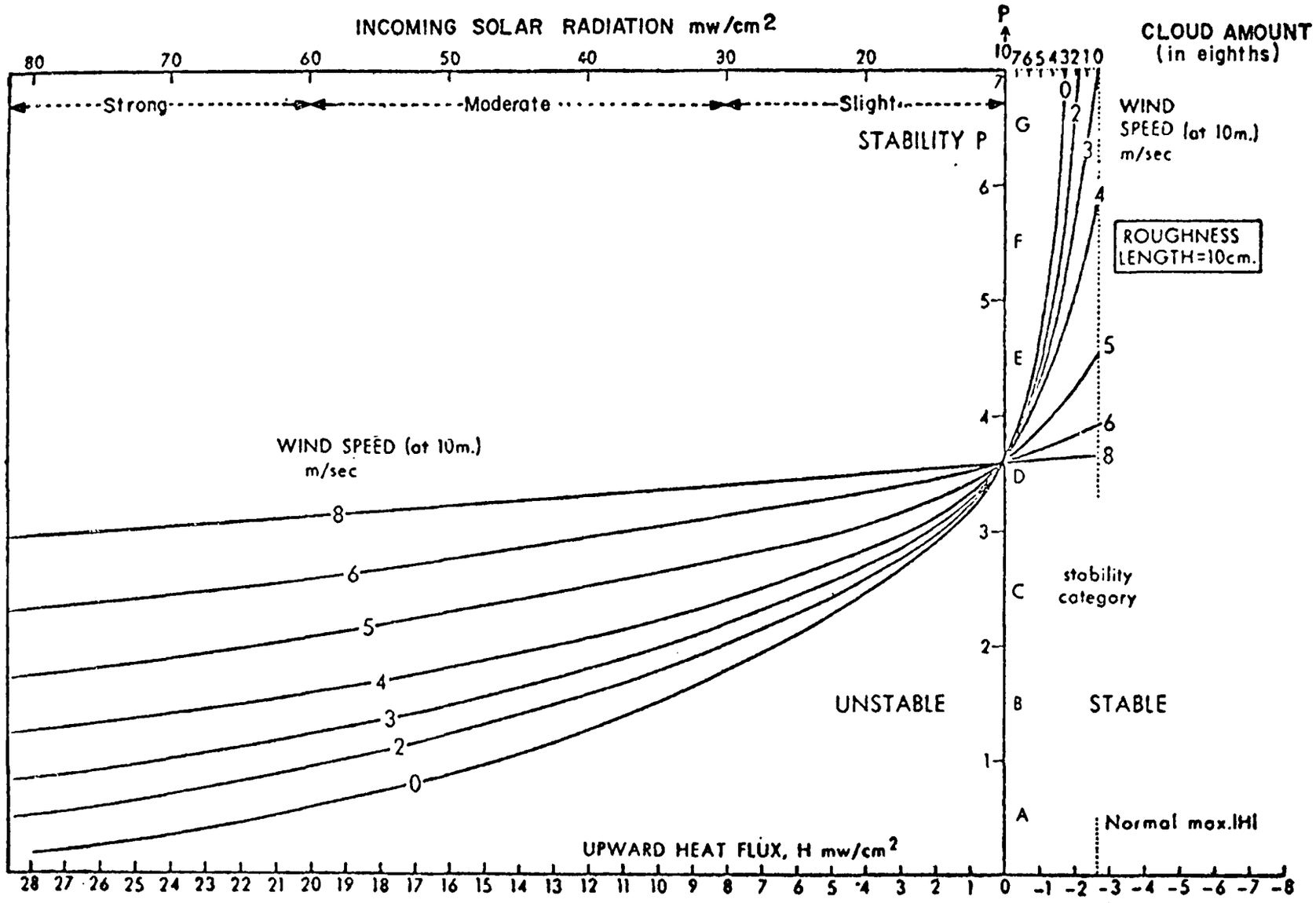

Figure 8. F.B. Smith scheme for assignment of fractional stability classes[17]

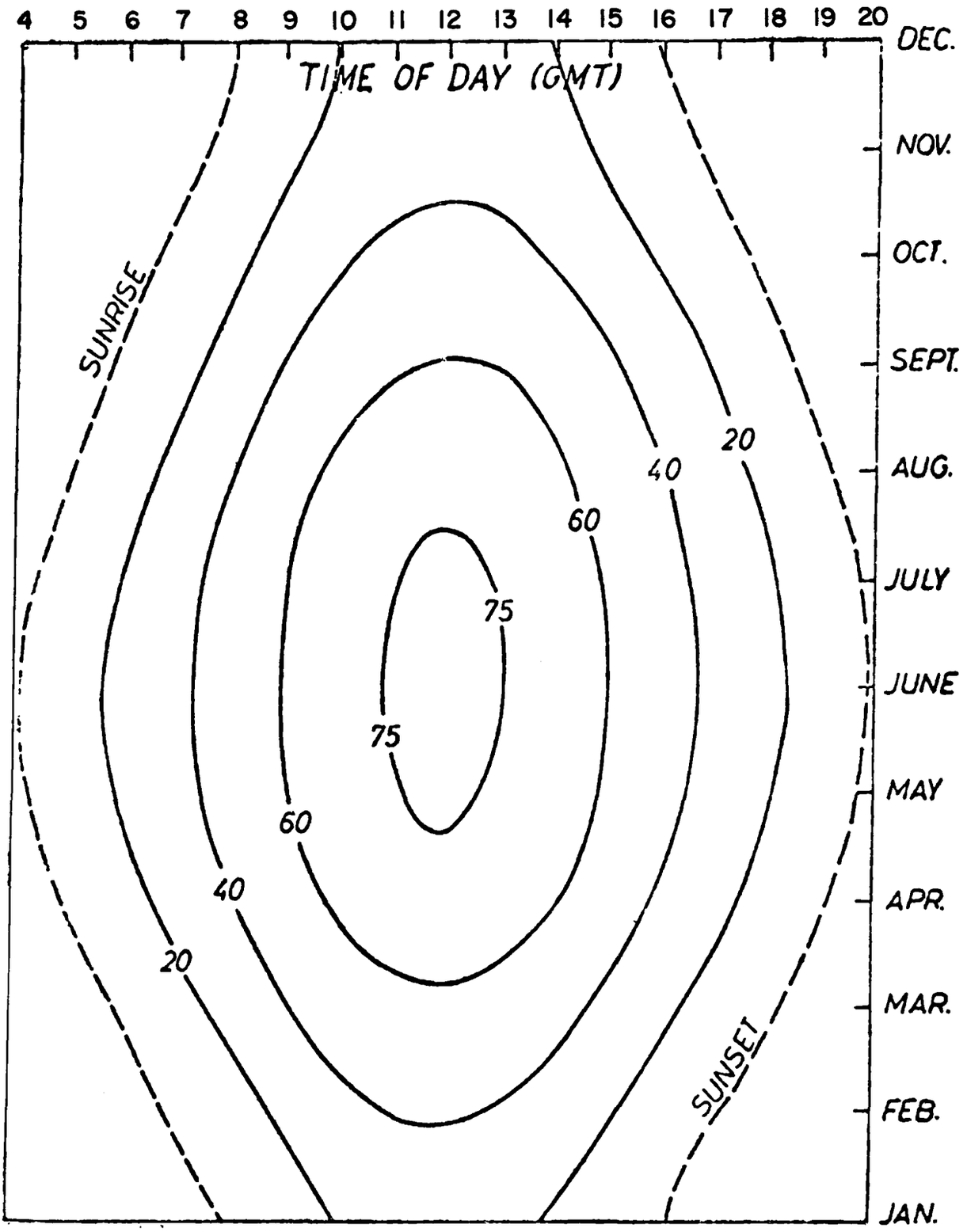

Figure 9. Incoming solar radiation (mW/cm^2) measured at Cambridge, England on a cloudless day[17]

To obtain a relationship between solar angle and incident solar radiation, we sought to describe the data presented in Figure 9 for Cambridge, England in terms of the following equation:[18]

$$I = \frac{J_o}{r^2} \, a^{\sec\theta} \cos\theta \tag{8}$$

where I = solar radiation intensity

J_o = 135.3 milliwatts/cm^2

a = transmission factor

θ = solar zenith angle (90^o - solar elevation angle)

r = "radius vector" of earths orbit (≈ 1)

For a specific latitude and longitude the angle θ may be determined based upon the time zone classification, hour of the day (standard time) and day of the year. When the data were analyzed it was found that the diurnal and seasonal variation of the radiation intensity, I, could not be reproduced by use of a constant transmission factor a. The best fit was obtained for the following variation of the transmission factor, a, with zenith angle θ.

$$a = 0.57 + 0.0045\,\theta \tag{9}$$

where θ is measured in degrees. The fitted solar radiation intensity as a function of zenith angle is shown in Figure 10.

With the relationships given by Equations (8) and (9) the fractional stability index, P, may be determined from the curves shown in Figure 8 once the windspeed and cloud cover have been specified. In his article F. B. Smith identifies a P value of 3.6 with a D stability index (i.e., stability 4) which would have been determined according to the Turner scheme presented in Appendix A. The relationship between the fractional stability P and the Turner stability S_T should then be given by

$$S_T = (P + 0.4) \text{ rounded} \tag{10}$$

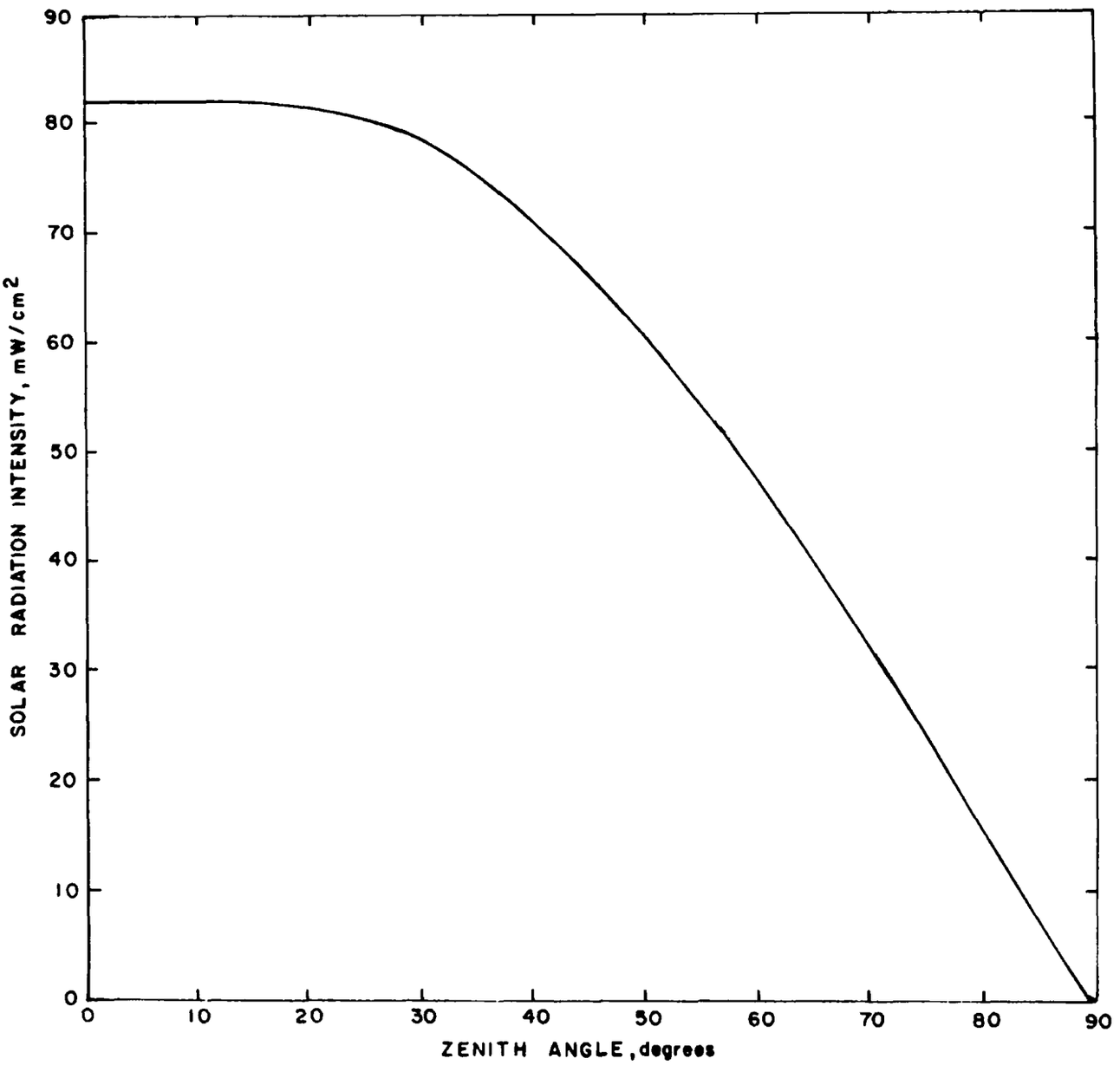

Figure 10. Solar radiation intensity as a function of zenith angle. Relationship based upon data presented in Figure 9

To determine the validity of this assumption we carried out a polynomial fit to the curves given in Figure 8 so that, based upon the solar elevation angle, cloud cover and wind speed, a comparison between the F. B. Smith and Turner assignment schemes could be made for a wide range of meteorological configurations. Based upon this comparison we found that the Turner stability class assignment was higher during the middle part of the day, especially during the summer months when the difference could be greater than an entire stability class. The polynomial fits used for this comparison formed the basis of the fractional stability of the Single Source Model Preprocessor Program which is presented in Appendix B.

Once the stability parameter P has been selected the corresponding vertical dispersion coefficient σ_z is determined for a particular downwind distance x by use of the curves presented in Figures 11 and 12. These results have been fitted by R. P. Hosker[19] to analytical expressions of the form

$$\sigma_z(x) = \frac{a_1 x^{b_1}}{1 + a_2 x^{b_2}} \qquad (11)$$

A list of the numerical values of the parameters used in Equation (11) is given in Table 6.

Table 6. FIT PARAMETERS FOR DISPERSION COEFFICIENTS

Stability category	a_1	b_1	a_2	b_2
A (P = 0.6)	0.112	1.06	5.38×10^{-4}	0.815
B (P = 1.6)	0.130	0.950	6.52×10^{-4}	0.750
C (P = 2.6)	0.112	0.920	9.05×10^{-4}	0.718
D (P = 3.6)	0.098	0.889	1.35×10^{-3}	0.688
E (P = 4.6)	0.0609	0.895	1.96×10^{-3}	0.684
F (P = 5.6)	0.0638	0.783	1.36×10^{-3}	0.672

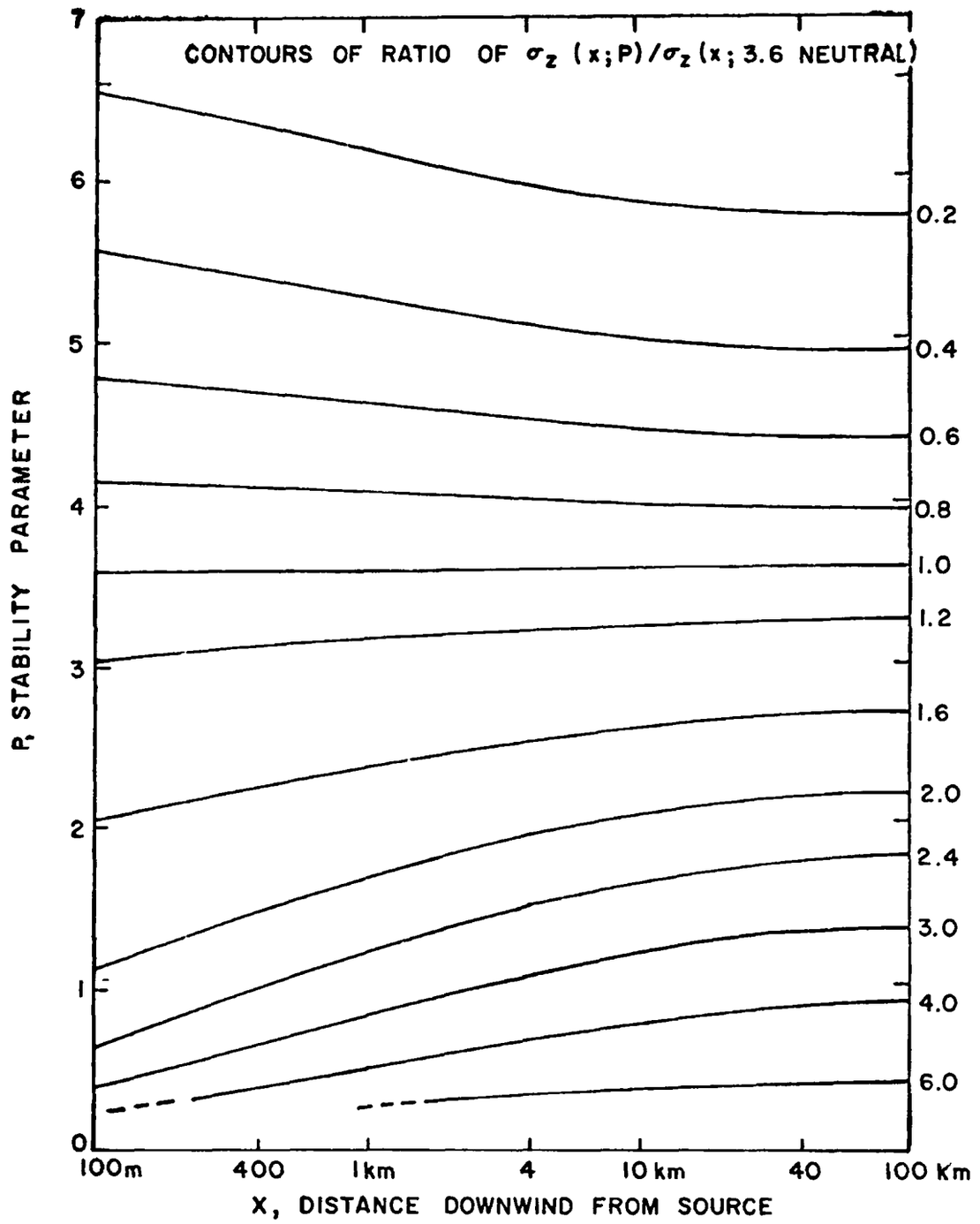

Figure 11. Variation with distance of the vertical dispersion parameter σ_z (normalized with respect to the neutral stability value) for different values of P[17]

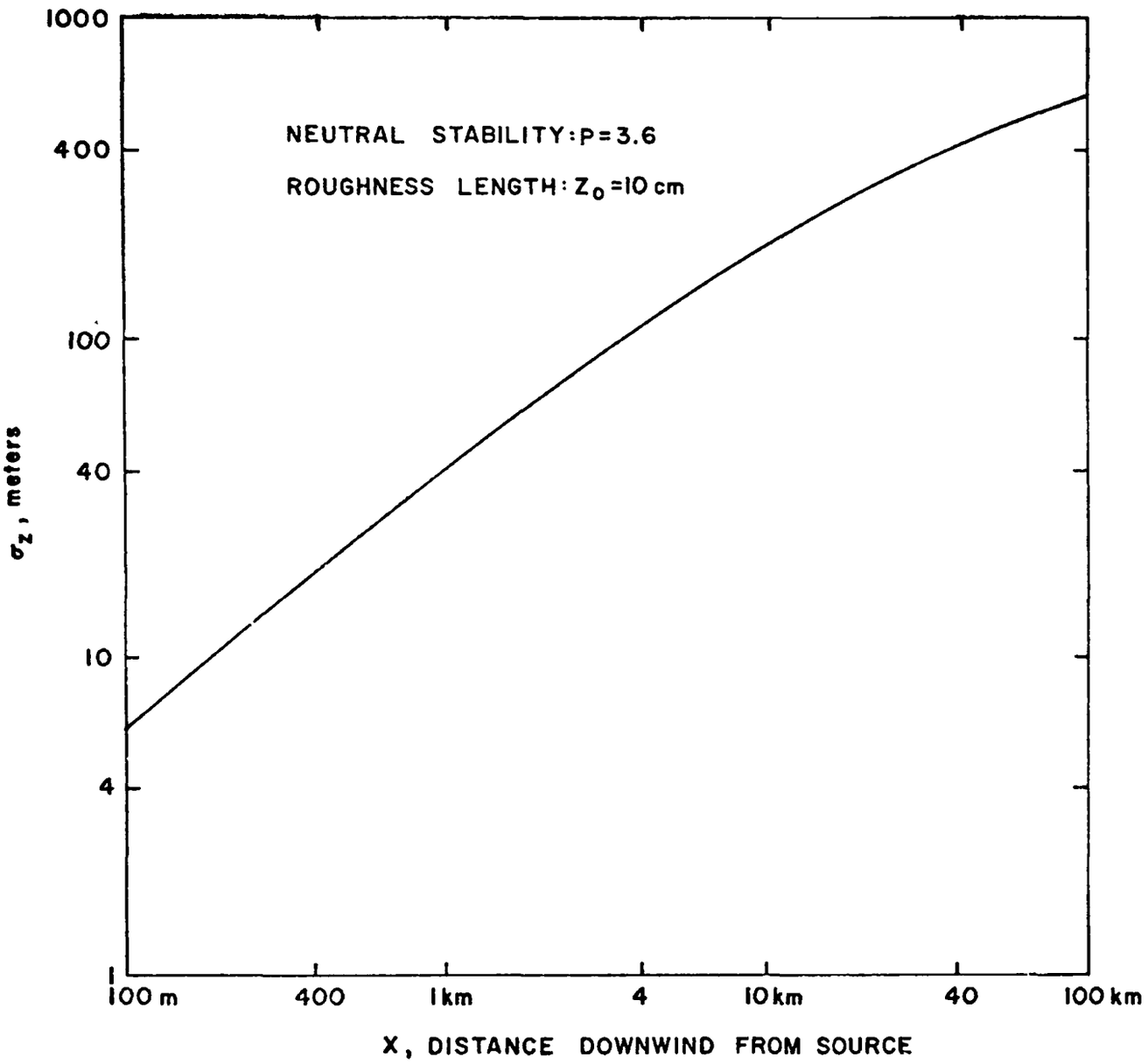

Figure 12. Variation of σ_z with distance for stability D (P = 3.6)[17]

According to the F.B. Smith method the dispersion curves may be modified to account for the effect of surface roughness z_o. These correction factors are shown in Figure 13. As parameterized by Hosker,[19] this correction factor $F(z_o, x)$ takes the following forms:

$$F(z_o,x) = \ell n \left\{ c_1 x^{d_1} \left[1 + \left(c_2 x^{d_2} \right)^{-1} \right] \right\}, \quad z_o > 10 \text{ cm} \tag{12}$$

$$= \ell n \left\{ c_1 x^{d_1} \left[1 + c_2 x^{d_2} \right]^{-1} \right\}, \quad z_o < 10 \text{ cm} \tag{13}$$

The corrected dispersion coefficient $\sigma_z(z_o, x)$ may be written as

$$\sigma_z(z_o,x) = F(z_o,x)\ \sigma(10 \text{ cm}, x) \tag{14}$$

where the $\sigma(10 \text{ cm}, x)$ are the σ_z values given by the curves in Figures 11 and 12. The parameters required to evaluate Equations (12a) and (12b) are presented in Table 7.

Table 7. COEFFICIENTS OF THE ROUGHNESS CORRECTION FACTOR USED IN CALCULATING $\sigma_z(x)$ FOR VARIOUS ROUGHNESS LENGTHS (x IS GIVEN IN METERS)

Roughness length	c_1	d_1	c_2	d_2
1 cm	1.56	0.0480	6.25×10^{-4}	0.45
4 cm	2.02	0.0269	7.76×10^{-4}	0.37
40 cm	5.16	-0.098	18.6	-0.225
100 cm	7.37	-0.0957	4.29×10^{3}	-0.60
400 cm	11.7	-0.128	4.59×10^{4}	-0.78

In Section IV of this report we will describe three types of model validation studies based upon the F.B. Smith dispersion coefficients. The first test will combine the Turner stability class assignment scheme with the F.B. Smith dispersion curves for the point stabilities (A, B, C, D, E and F). The second test will involve the calculation and use of fractional

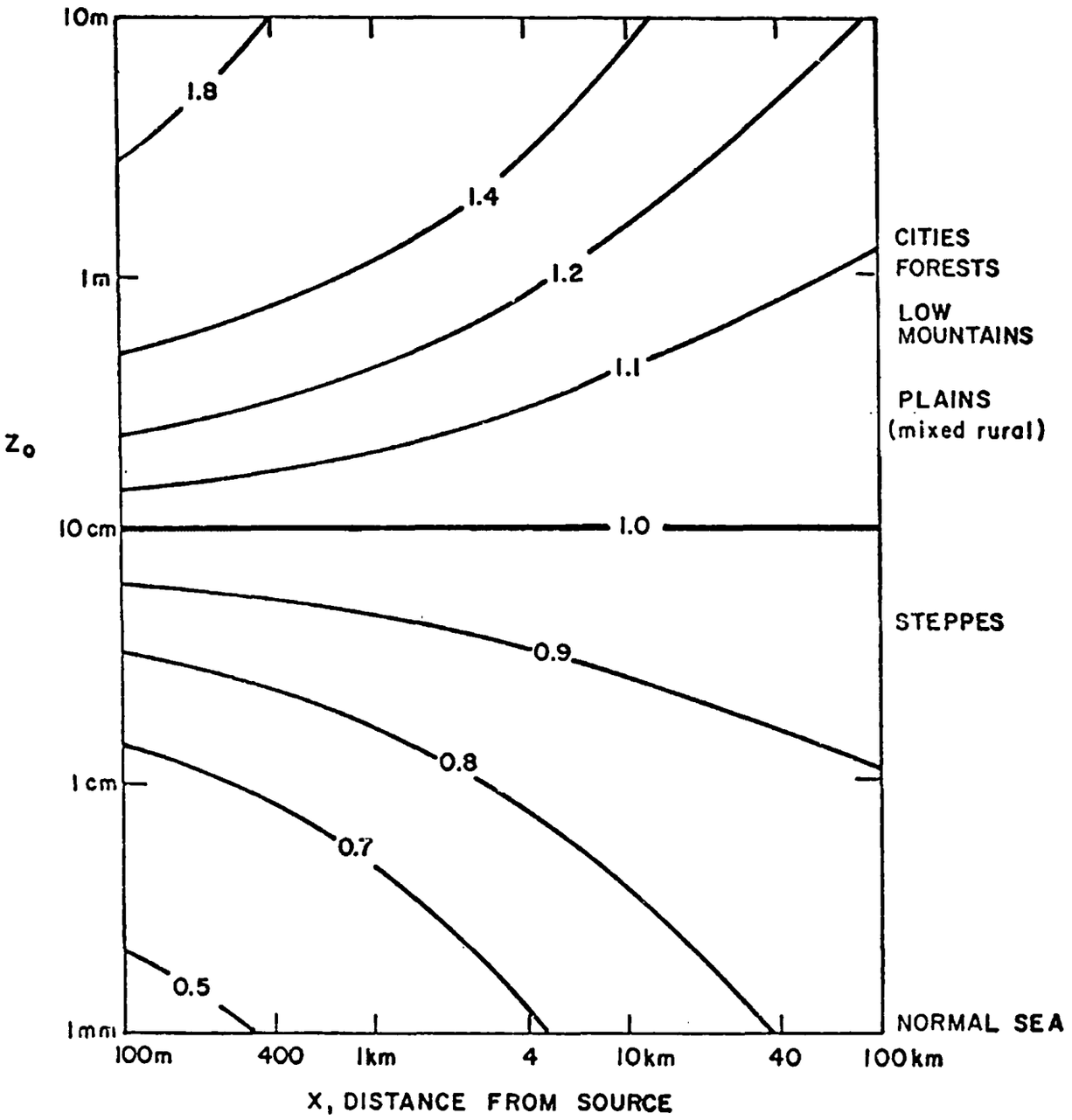

Figure 13. Contours of the vertical dispersion coefficient correction factor $F(z_o,x)$

stabilities. Finally the effect of incorporating surface roughness will be investigated.

COMPARISON OF THE DISPERSION COEFFICIENTS

A comparison of the dispersion curves we have just discussed will prove useful in our analysis of the model validation results which will be presented in Section IV. In Figures 14(a) through (f), vertical dispersion coefficients according to Briggs, F.B. Smith, and Pasquill-Turner are plotted as a function of downwind distance for stabilities A through F. The following observations may be made based upon an examination of these curves:

1. The Briggs and Pasquill-Turner curves are quite close to one another except in the case of stability A.

2. The F.B. Smith vertical dispersion curve falls below the other two curves for stabilities A, B and C and above the other curves for stabilities D, E and F.

3. The worst agreement between all three of the curves is seen for stability A with the best agreement for stabilities D, E and F.

In Figures 15(a) through (f) we have plotted the horizontal dispersion curves according to Briggs and Pasquill-Turner by stability class. The Pasquill-Turner horizontal dispersion curves are used in conjunction with the F.B. Smith vertical dispersion curves, so that no F.B. Smith horizontal curves have been presented. An obvious feature of these plots is that the Briggs and Pasquill curves are virtually identical. The horizontal and vertical dispersion curves according to Smith-Singer were presented in Figures 6 and 7 for the four Smith-Singer stability classes B2, B1, C and D. The most striking feature of these plots is the identical slope for σ_z and σ_y curves for the same stability. Finally the effect of surface roughness upon the F. B. Smith vertical dispersion curves is illustrated in Figures 16(a) through (f).

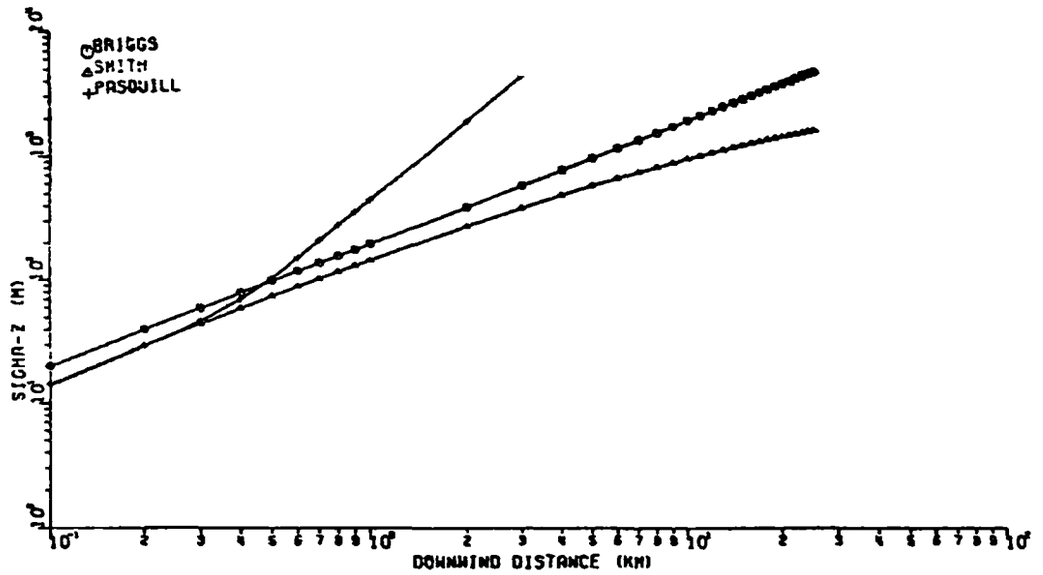

Figure 14a. Vertical dispersion coefficient as a function of downwind distance for Stability Class A according to Briggs, F.B. Smith and Pasquill-Turner

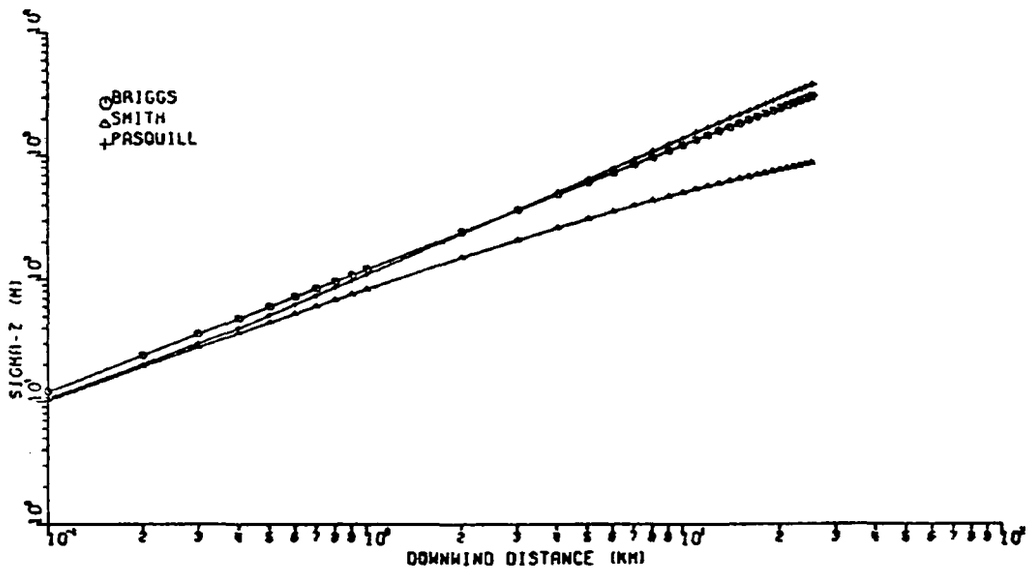

Figure 14b. Vertical dispersion coefficient as a function of downwind distance for Stability Class B according to Briggs, F.B. Smith and Pasquill-Turner

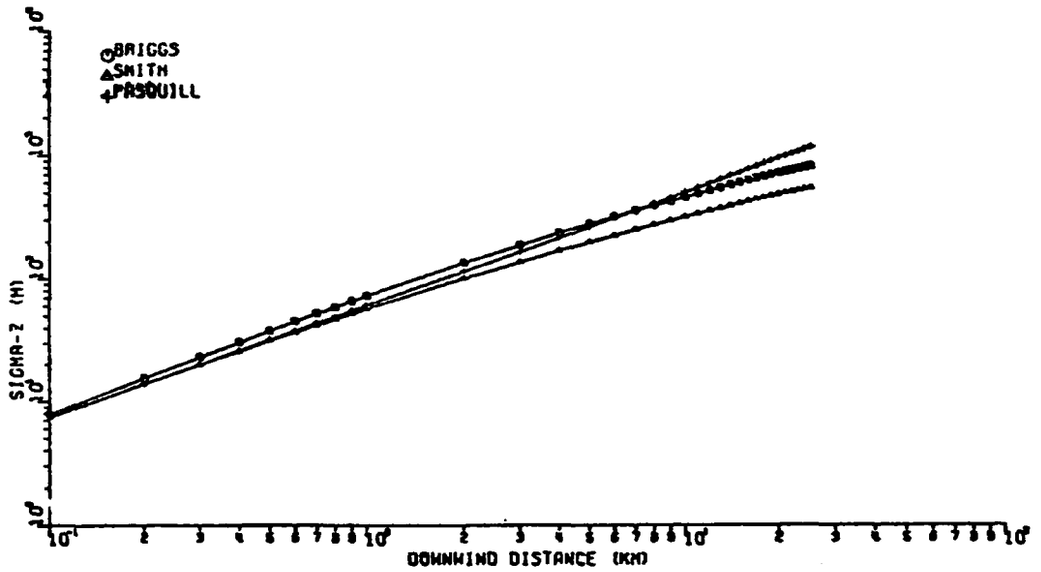

Figure 14c. Vertical dispersion coefficient as a function of downwind distance for Stability Class C according to Briggs, F.B. Smith and Pasquill-Turner

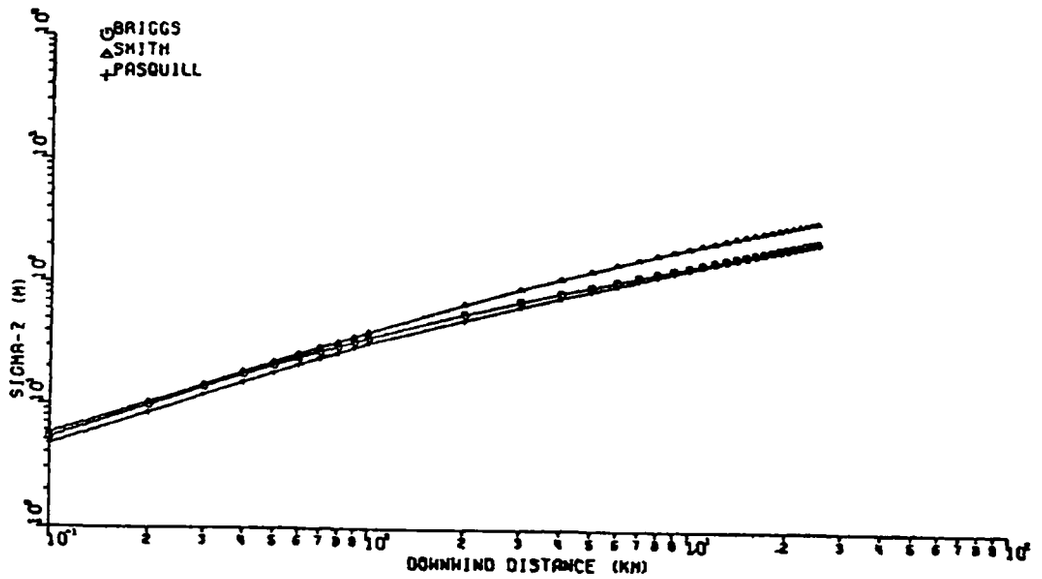

Figure 14d. Vertical dispersion coefficient as a function of downwind distance for Stability Class D according to Briggs, F.B. Smith and Pasquill-Turner

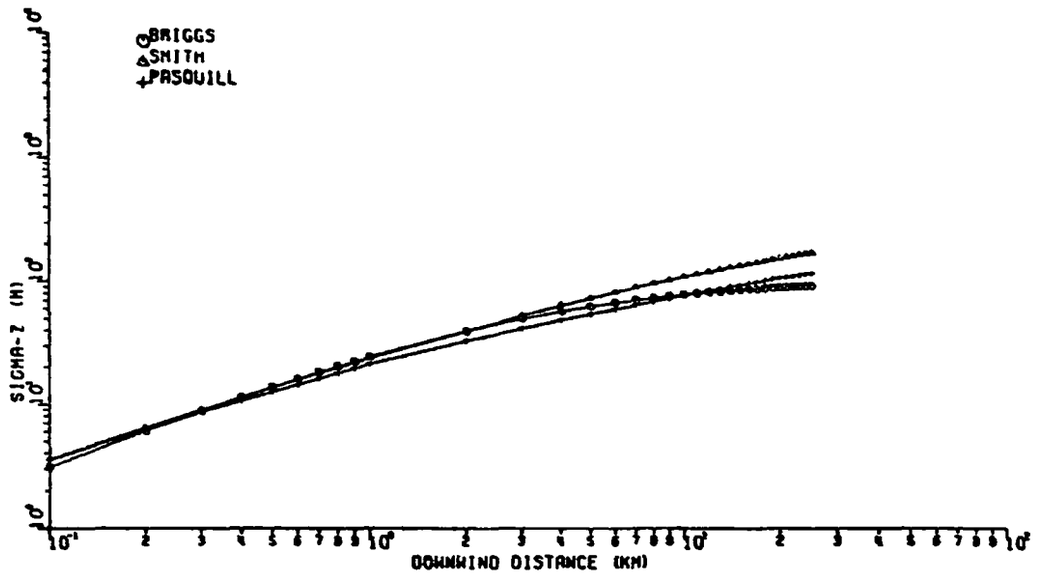

Figure 14e. Vertical dispersion coefficient as a function of downwind distance for Stability Class E accordings to Briggs, F.B. Smith and Pasquill-Turner

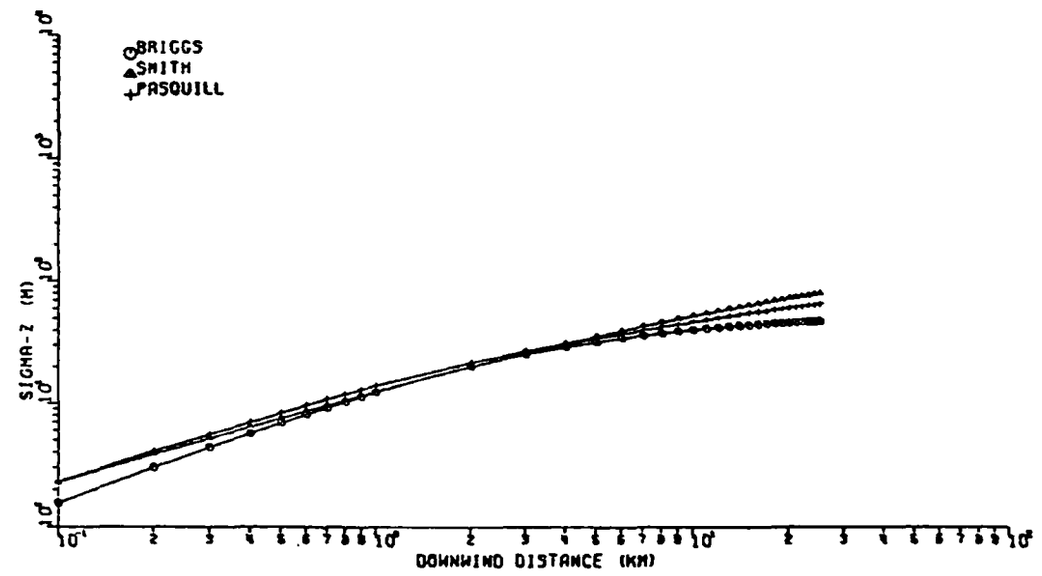

Figure 14f. Vertical dispersion coefficient as a function of downwind distance for Stability Class F according to Briggs, F.B. Smith and Pasquill-Turner

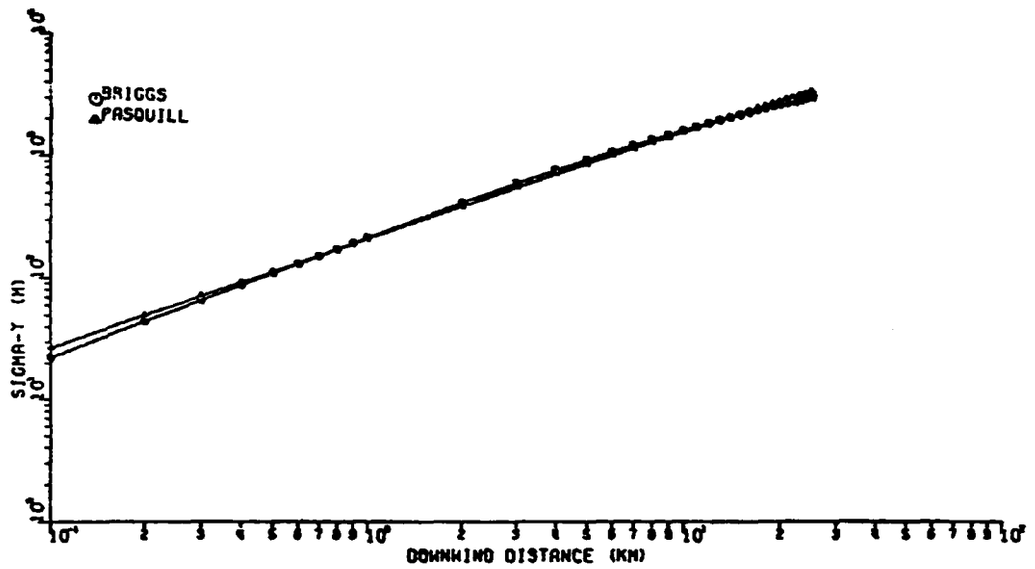

Figure 15a. Horizontal dispersion coefficient as a function of downwind distance for Stability Class A according to Briggs and Pasquill-Turner

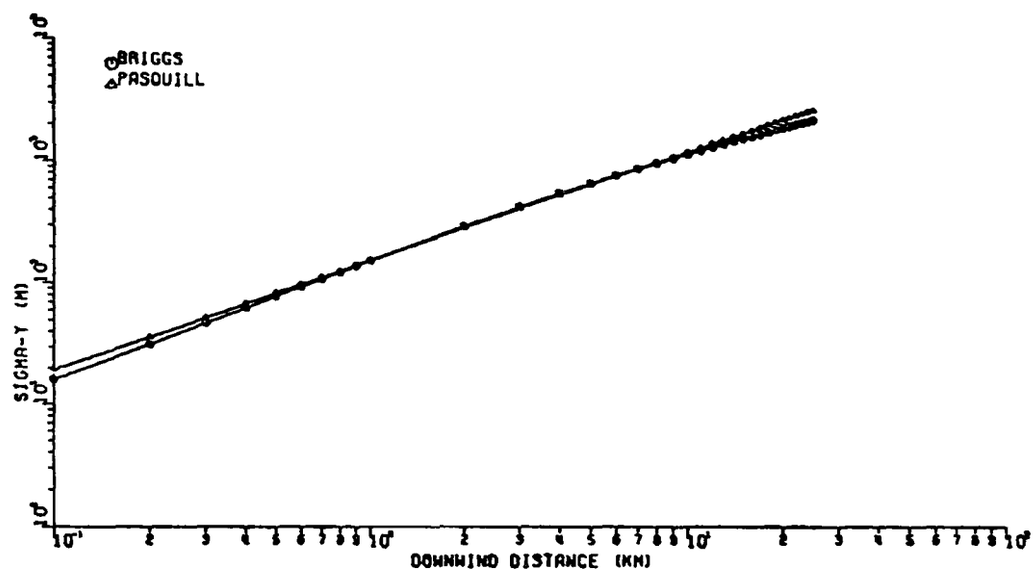

Figure 15b. Horizontal dispersion coefficient as a function of downwind distance for Stability Class B according to Briggs and Pasquill-Turner

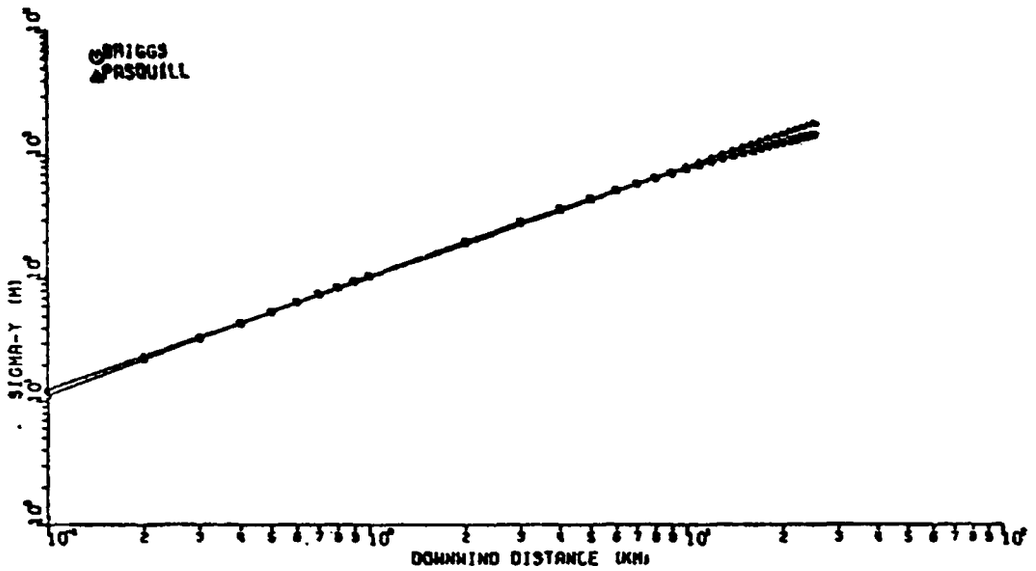

Figure 15c. Horizontal dispersion coefficient as a function of downwind distance for Stability Class C according to Briggs and Pasquill-Turner

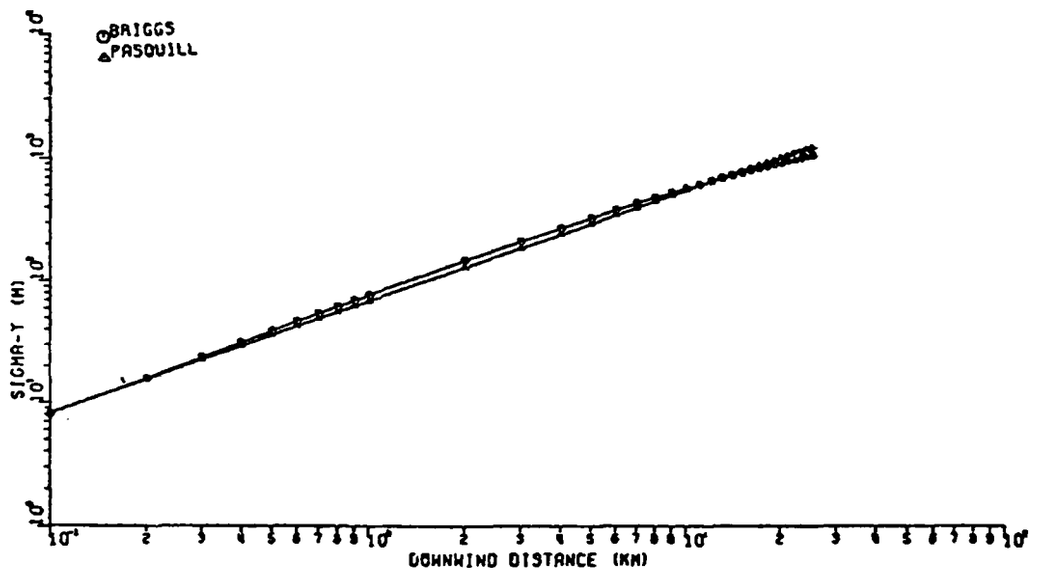

Figure 15d. Horizontal dispersion coefficient as a function of downwind distance for Stability Class D according to Briggs and Pasquill-Turner

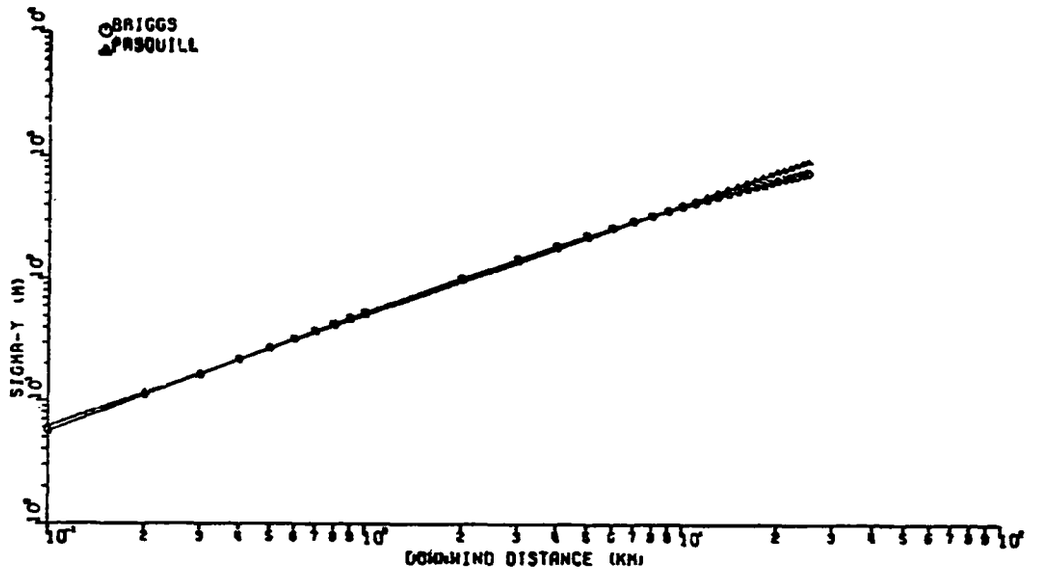

Figure 15e. Horizontal dispersion coefficient as a function of downwind distance for Stability Class E according to Briggs and Pasquill-Turner

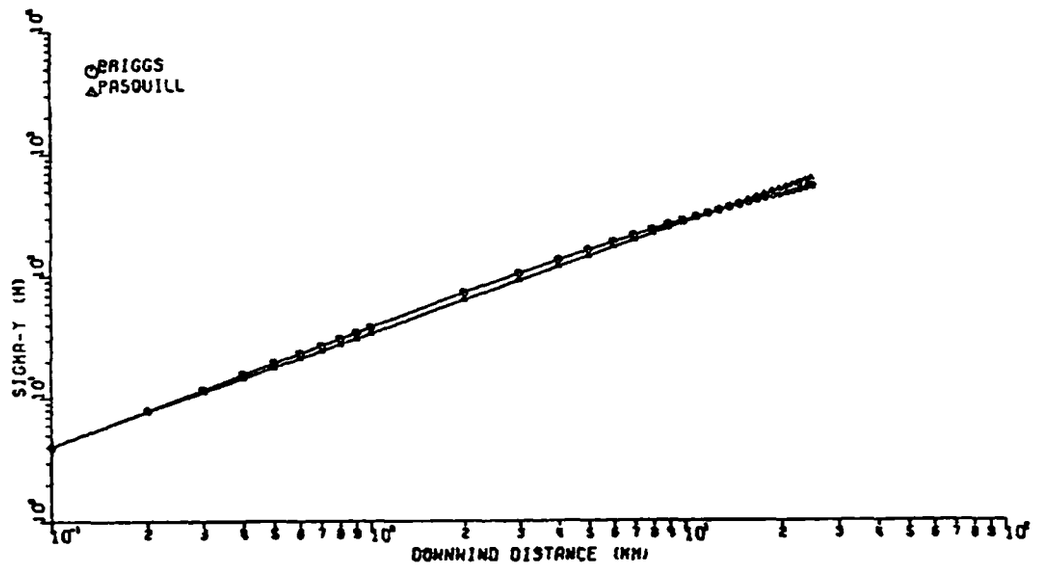

Figure 15f. Horizontal dispersion coefficient as a function of downwind distance for Stability Class F according to Briggs and Pasquill-Turner

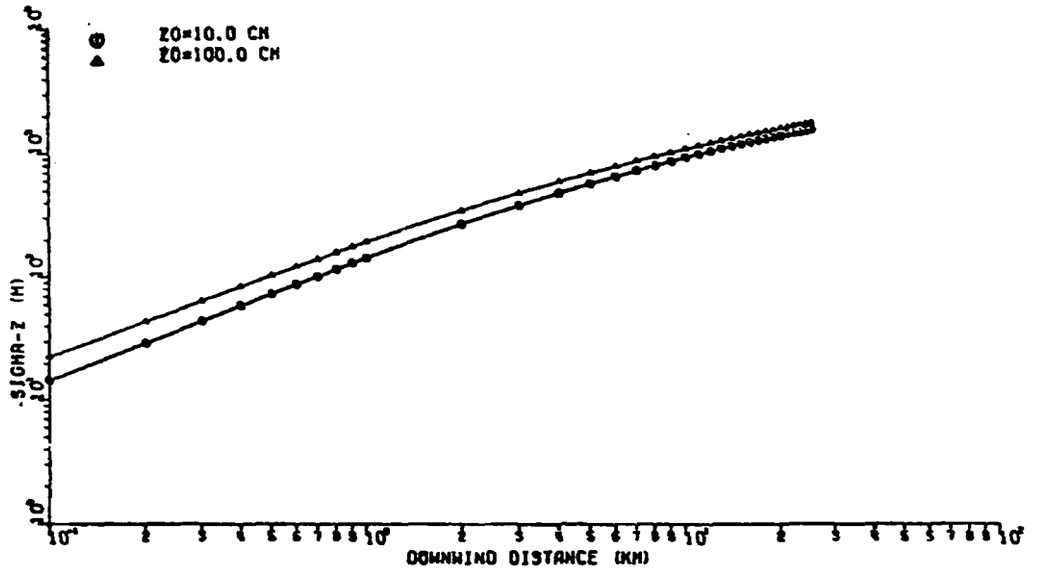

Figure 16a. Vertical dispersion coefficient as a function of downwind distance for Stability Class A and surface roughness of 10 cm and 100 cm according to F.B. Smith

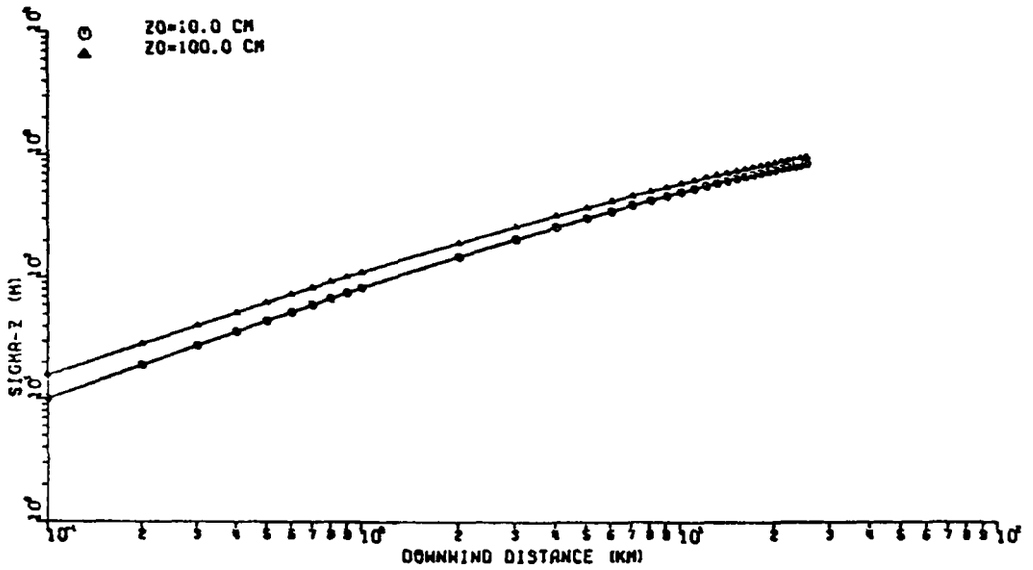

Figure 16b. Vertical dispersion coefficient as a function of downwind distance for Stability Class B and surface roughness of 10 cm and 100 cm according to F.B. Smith

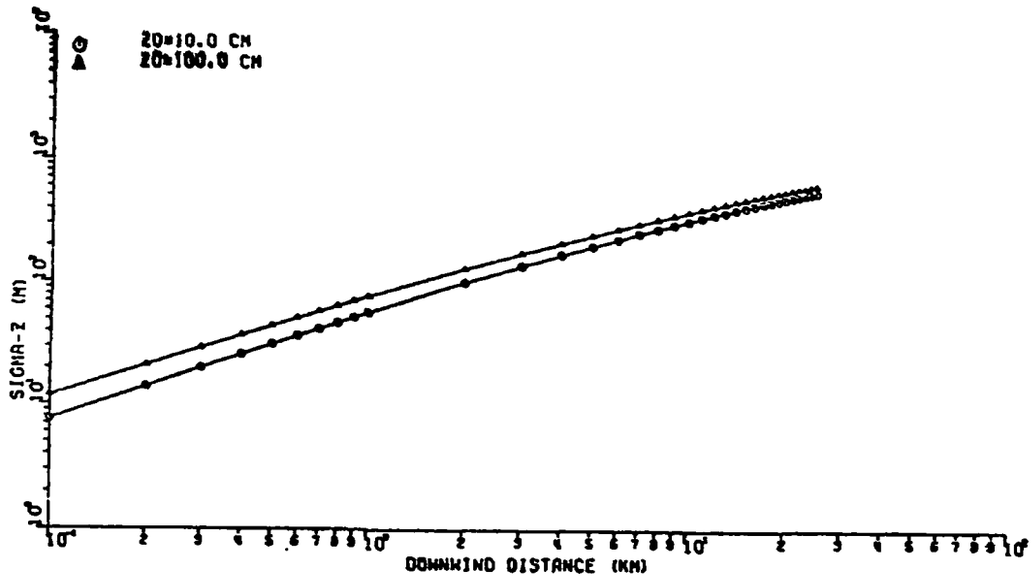

Figure 16c. Vertical dispersion coefficient as a function of downwind distance for Stability Class C and surface roughness of 10 cm and 100 cm according to F.B. Smith

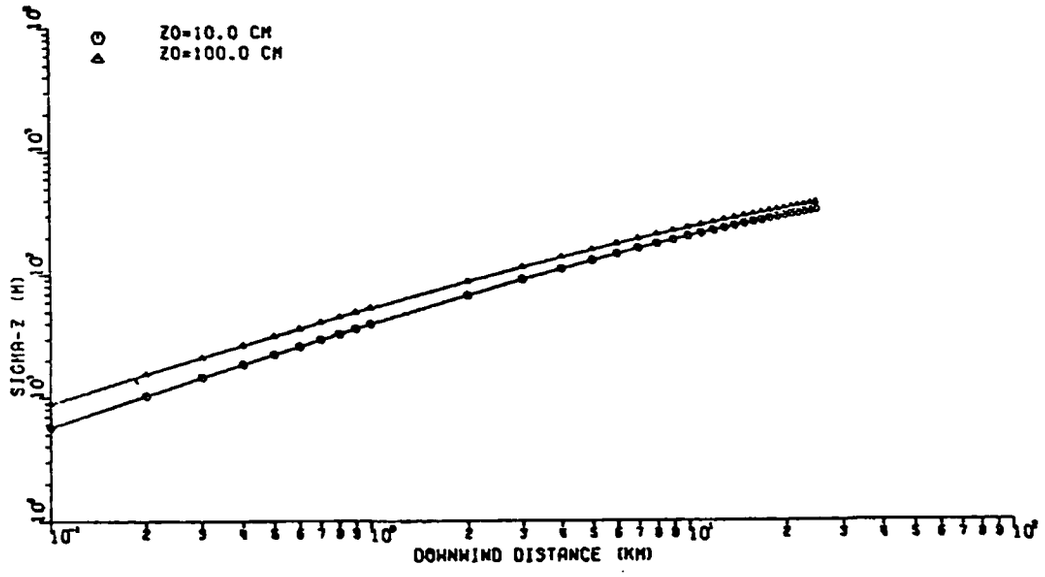

Figure 16d. Vertical dispersion coefficient as a function of downwind distance for Stability Class C and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

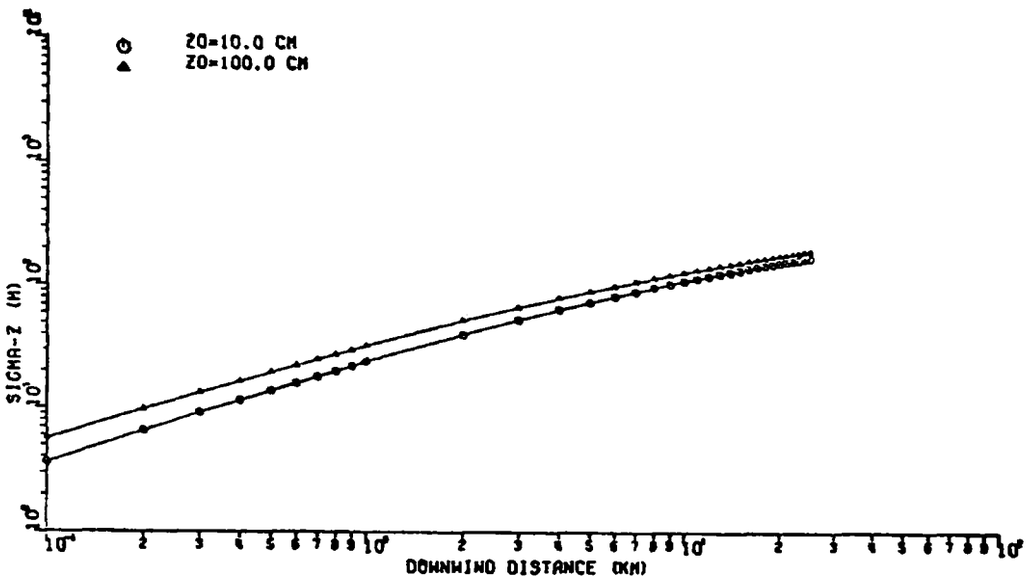

Figure 16e. Vertical dispersion coefficient as a function of downwind distance for Stability Class E and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

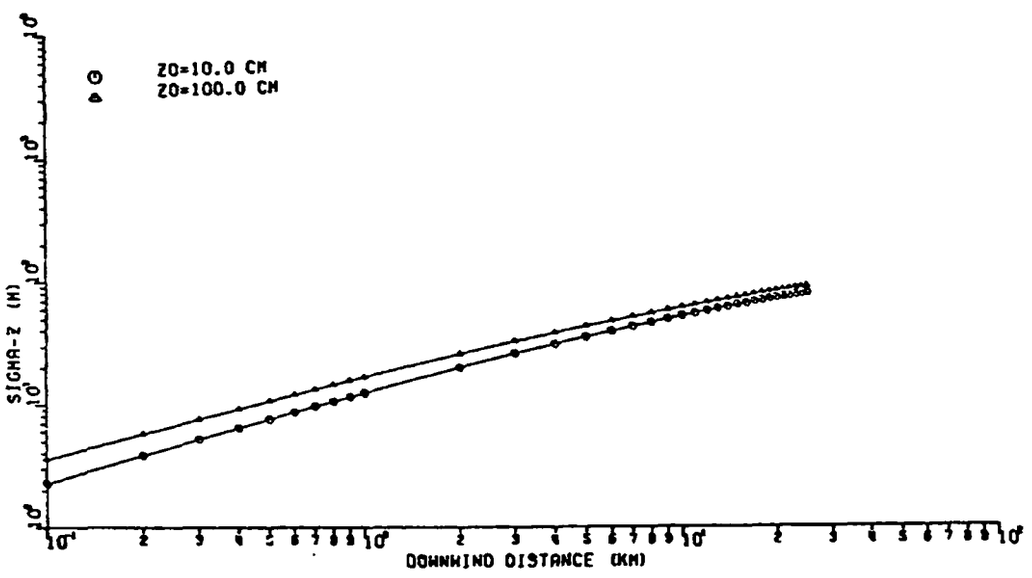

Figure 16f. Vertical dispersion coefficient as a function of downwind distance for Stability Class F and surface roughnesses of 10 cm and 100 cm according to F.B. Smith

DISCUSSION OF THE PROCEDURE FOR VARYING THE PLUME RISE

Another objective of this study was to determine whether the requirement of a constant stack gas exit velocity was adversely affecting the model predictions. To study the effect of a variable stack tas exit velocity, the hourly velocity was calculated according to the following expression:

$$w_h = w_a \frac{f_h}{f_a}$$

where w_a = stack gas exit velocity obtained from form FPC-67

f_h = hourly fuel consumption for all boilers feeding into the stack

f_a = average hourly fuel consumption for all boilers feeding into the stack

SECTION III

SITE AND DATA BASE DESCRIPTIONS FOR MODEL IMPROVEMENT STUDY

In this section we shall describe the site characteristics, SO_2 monitoring program and meteorological data base for the two power plants included in the model improvement study. Each topic will be covered on a plant-by-plant basis. Much of this material has already been covered in three previous EPA reports but is presented again for the sake of completeness. Also the description of the meteorological data base is somewhat different for this study since for a large number of cases local wind speed and wind direction data were used for model input as well as for background subtraction.

At the outset of this study we planned to include the J.M. Stuart Plant in our test of the Smith-Singer Dispersion Coefficients, but we subsequently found that the angular resolution of the local wind direction data did not permit a meaningful comparison between measurements and model predictions. The Philo Power Plant was also excluded from our analysis of model improvements due to the complications of terrain mentioned in Section I. The tests of different dispersion calculation methods were, therefore, carried out for the Canal and Muskingum River Plants.

CANAL PLANT

Site Description

The Canal Plant is located on the south side of the Cape Cod Canal about 1.6 kilometers from the entrance on Cape Cod Bay (Figure 17) The

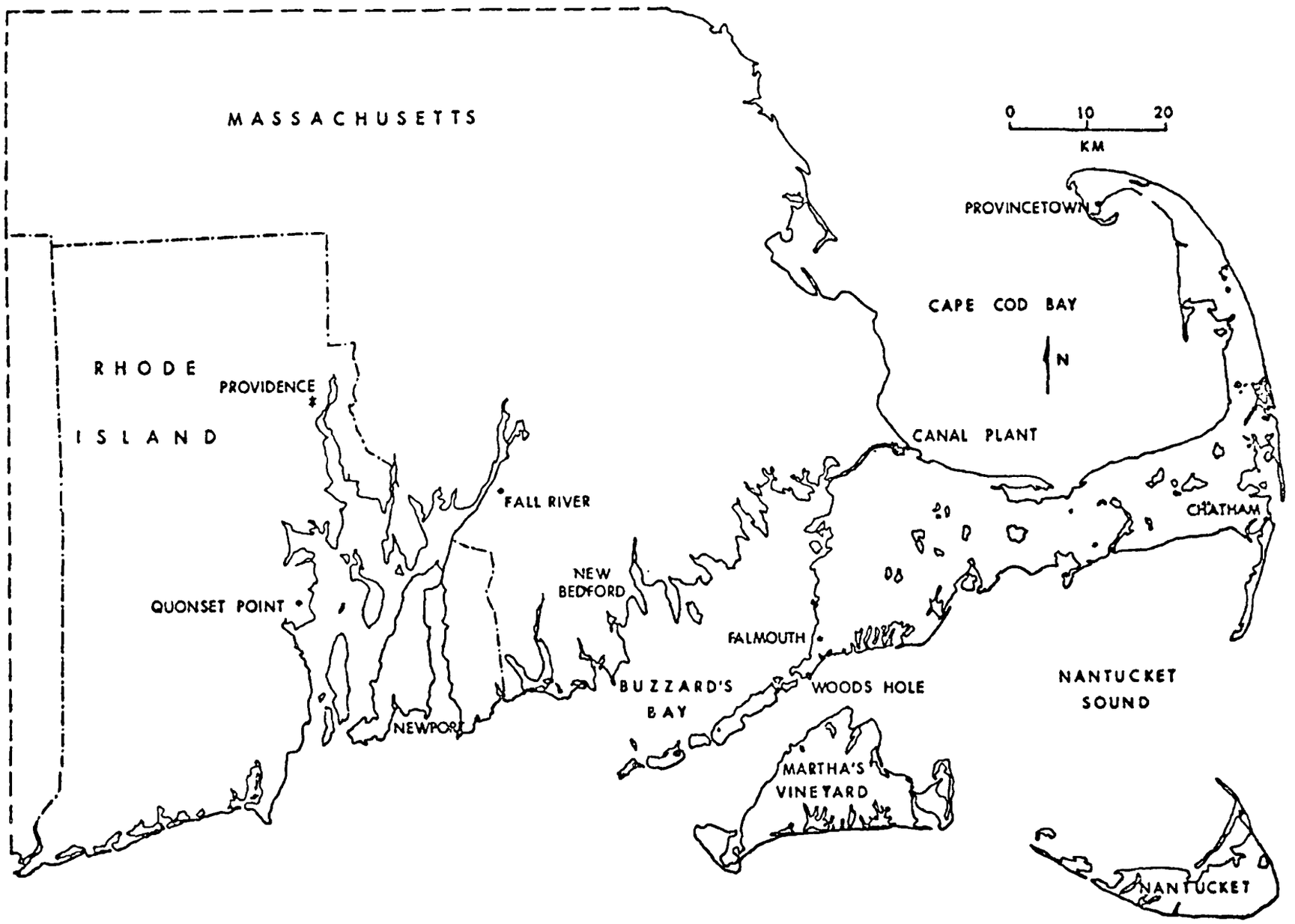

Figure 17. Map of eastern Massachusetts and Rhode Island showing locations of the Canal Plant. Meteorological observations were used from Quonset Point Naval Air Station and Chatham

surrounding terrain is gently rolling with elevations generally below 60 meters above mean sea level. The highest elevations in the area are about 90 meters above sea level in the western end of the Cape. Most of the area is covered with scrub pine forests and low vegetation.

Data for the study were collected in 1971. During that year, the plant consisted of a single oil-fired unit with a generating capacity of 560 megawatts. The top of the stack was about 91 meters above grade and 5.6 meters in diameter. The main power plant structure to the north of the stack totally enclosed the turbine generator and boiler. The roofs of the turbine and boiler rooms were about 30 meters and 59 meters above grade respectively. Stack and boiler data are given in Table 8. The 1971 monthly percent sulfur content of the fuel used at the Canal Plant is given in Table 9.

Table 8. PLANT CHARACTERISTICS

Characteristic	Plant		
	Canal	Muskingum	
	Stack 1	Stack 1	Stack 2
Stack height, m	91	251	251
Diameter, m	5.6	7.6	6.7
Velocity, m/sec	-	28.5	24.8
Temperature, ^{o}F	-	430	425
Number of boilers per stack	1	4	1
Maximum generating capacity per stack, MW	560	876	591
Average per stack, MW	-	748	487
Plant total, MW	560	1467	
Plant average, MW	-	1235	

Table 9. MONTHLY PERCENT SULFUR CONTENT OF FUEL

Month	Canal	Muskingum
January	2.0	4.9
February	1.9	4.8
March	2.1	4.8
April	1.9	4.5
May	2.1	4.7
June	2.1	5.0
July	2.1	4.7
August	2.0	4.7
September	1.9	4.3
October	0.9	4.6
November	1.0	4.5
December	0.9	4.4

Overview of Canal Plant Monitoring Program

SO_2 concentrations are measured at four locations on a continuous basis with Ultragas SO_2 Analyzers manufactured in Germany by H. Wosthoff. These instruments measure sulfur dioxide by the increase in conductivity of an acidified hydrogen peroxide solution and have a full scale reading of 0.4 ppm. The instruments do not conform to the reference method for sulfur dioxide or to any of the specified equivalent methods. They have, however, been extensively studied and one comparison noted a correlation coefficient of 0.99 with the West-Gaeke method. The instruments used provide a continuous real-time chart trace and a tape printout giving date, time, and average concentration over consecutive 30 minutes. The sensitivity of the instrument in combination with the chart recorder is approximately 0.005 ppm. The locations of the SO_2 monitors with respect to the Canal Plant are given in Figure 18 and Table 10.

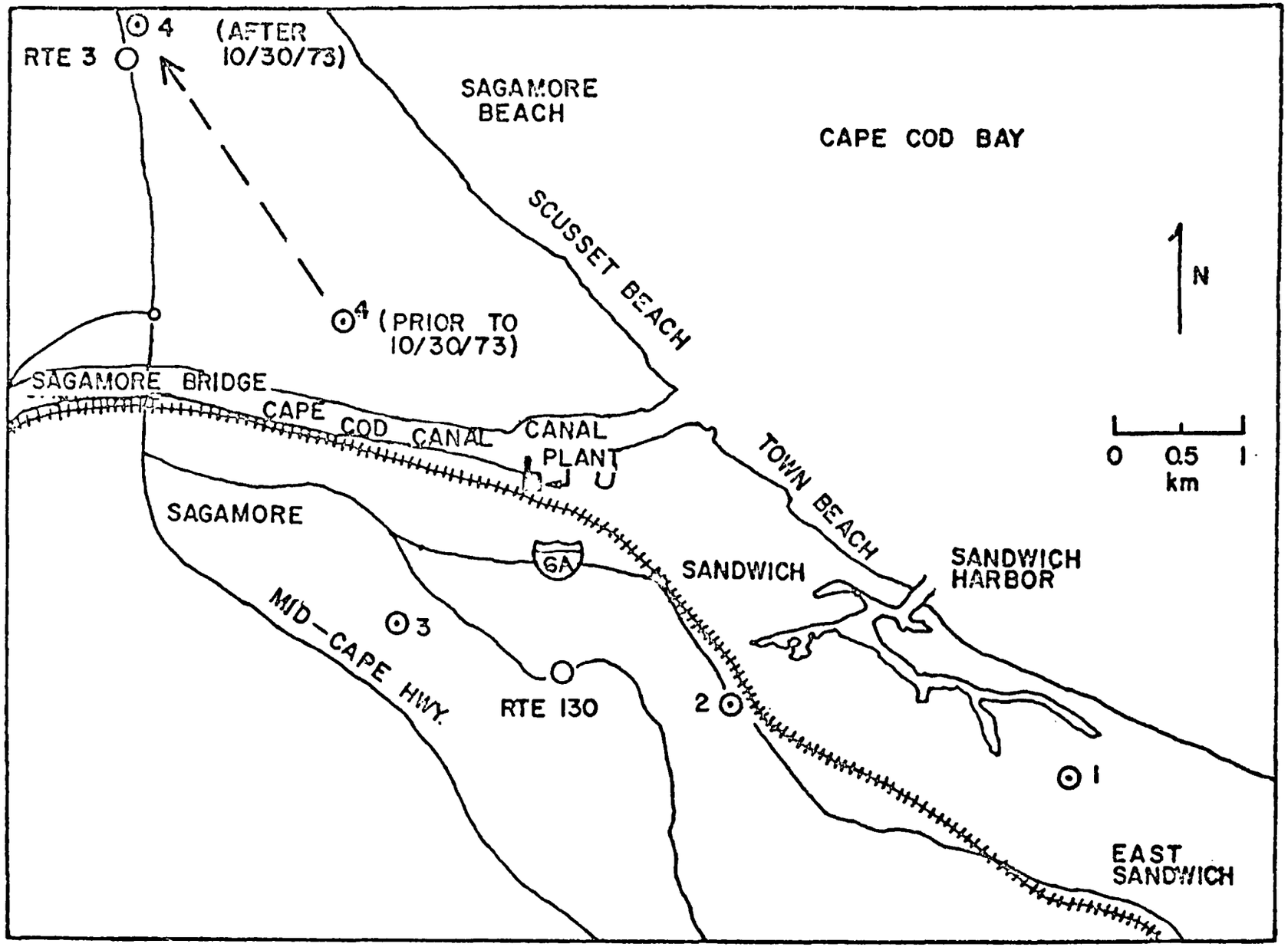

Figure 18. Sketch of the Canal Plant area showing the locations of the four automatic SO_2 stations by the symbol ⊙

Table 10. SULFUR DIOXIDE MONITORING STATIONS FOR THE CANAL AND MUSKINGUM PLANTS

Plant	Station		Distance, km	Heading, degrees	Elevation above stack base, m
	No.	Name			
Canal	1		4.7	119	10
	2		2.3	138	4
	3		1.4	224	40
	4		2.0	312	20
Muskingum	1	Beverly	5.3	140	64
	2	Hackney	4.3	40	82
	3	Rich Valley	8.3	35	101
	4	Caldwell	19.6	35	128
	-	Top of stacks	-	-	251

Meteorological Data for Canal Plant

Bendix-Friez Aeorovanes are used to provide local wind speed and direction data. Through July 1971, the principal source of wind data was the Aerovane mounted on a 12.2 meter mast located on the 58.8 meter boiler-room roof. Since July 1971, wind data are obtained from a second Aerovane installed on a 44 meter tower near the top of Telegraph Hill approximately 5 kilometers south-southeast of the Canal Plant. This hourly wind data was used to define upwind receptor locations for calculation of hourly background concentrations. A station was considered to be a background receptor if it were located outside the boundaries of a 90 degree sector centered about the wind flow vector. The concentrations for these background stations are then averaged and subtracted from the hourly concentratios at all stations. Any resultant negative concentrations were set equal to zero. The on-site wind speed, wind direction and ambient temperature data were also input to the Single Source Model after proper conversion to a wind measurement height of 7 meters. These stability dependent wind speed corrections, which were discussed in Section II, were based upon hourly atmospheric stabilities derived from a Single

Source Model Preprocessor run using surface meteorological data for 1971 collected at Quonset Point Naval Air Station. Hourly mixing heights for 1971 were based upon surface data from Quonset Point, Rhode Island and upper air observations taken at Chatham, Massachusetts. In this way a "hybrid" Preprocessor output file was generated containing on-site wind speed, wind direction and temperature measurements and nonlocal stability and mixing height assignments.

MUSKINGUM PLANT

Site Description

The Muskingum Plant is located in southeastern Ohio on the Muskingum River about 6 kilometers northwest of the town of Beverly. Figure 19 indicates the location of the plant, the SO_2 monitoring sites, and the surrounding towns. The plant is in the river valley about 500 meters from the valley walls which rise about 75 meters above the valley floor. The two 251 meter stacks are 640 meters apart and extend about 185 meters above the surrounding terrain. During 1973 the plant consisted of five coal-fired units with a total capacity of 1467 megawatts (Table 8). Percent sulfur content of the fuel for 1973 is given in Table 9.

Overview of the Muskingum Monitoring Program

Four sulfur dioxide monitoring stations make up the monitoring network (Figure 19 and Table 10). Data were available from all stations for January 1 to November 21, 1973. During the entire year of 1973, Station 1 missed 57 days and the other three stations missed approximately 41 days. Instruments at Muskingum were Leeds & Northrup Company, Catalog No. 7860-SW, Aeroscan Air Quality Monitors. The sample was obtained by passing ambient air taken from 5 feet above ground level, through an absorption column along with an absorption solution. The sample analysis method was by electrolytic conductivity. Data were taken continuously and listed every hour. Each instrument was automatically zeroed once a day

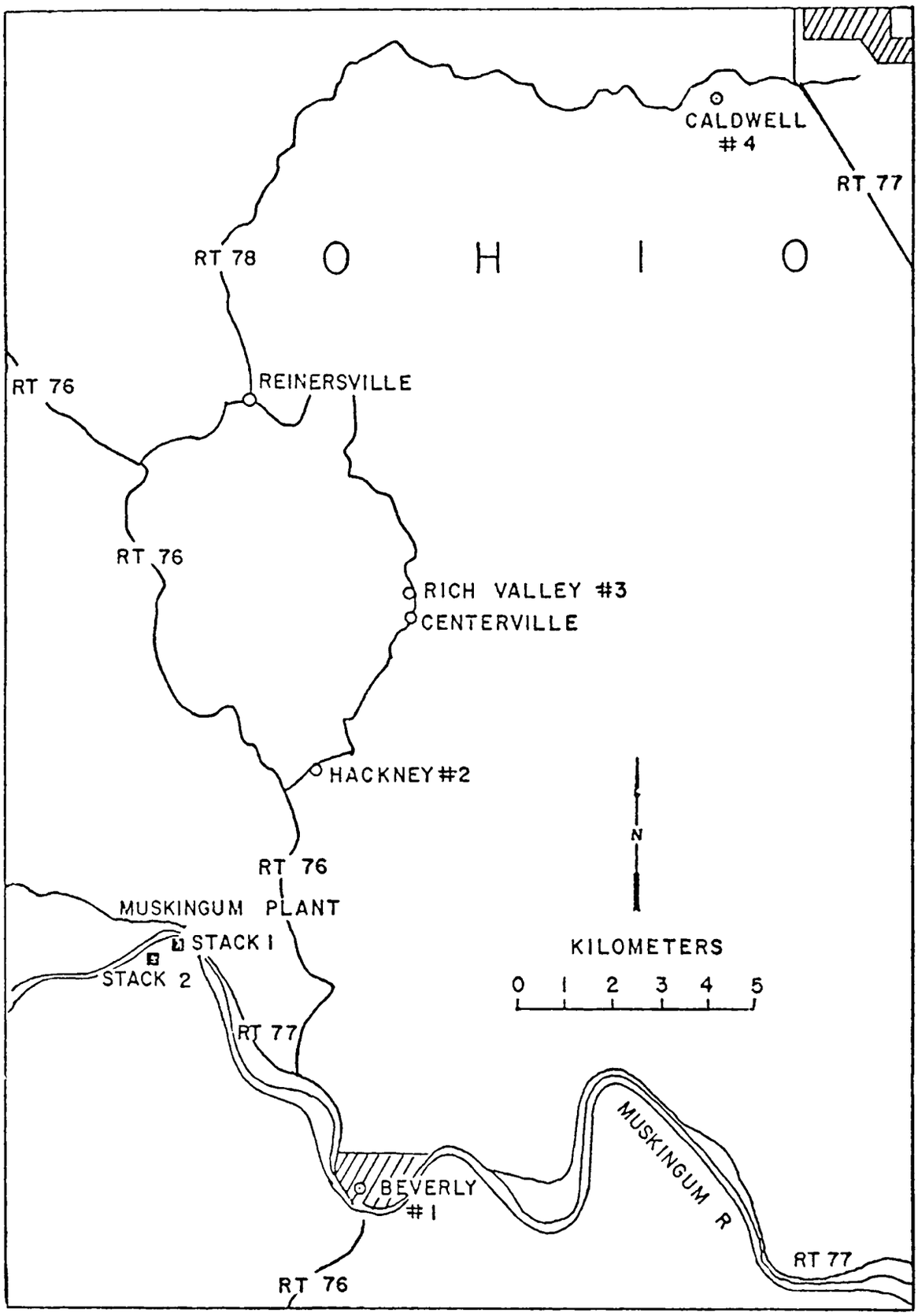

Figure 19. Sketch of the Muskingum Plant area showing locations of four automatic SO_2 monitoring stations

The manufacturer's performance accuracy specifications for this instrument are as follows. In a typical ambient atmosphere which includes the normal interfering gases, this instrument has:

- Zero drift = 2 percent of full scale per week
- Sensitivity drift < 1 percent of full scale per week
- Reproductibility < 1 percent of full scale
- Sensitivity = 0.01 ppm
- Recorder error < 0.5 percent of full scale
- Range = approximately 0 - 1 ppm

Meteorological Data for Muskingum Plant

There were two wind monitoring stations at the Muskingum Plant consisting of Bendix-Friez Aerovane wind speed and direction devices. One station was located 24 meters above ground at Beverly, and the other at the Hackney SO_2 monitoring station, where the wind monitors were also located 24 meters above ground. The data from Hackney was used in this study, as it was higher and common to more stations, but Beverly data was used when the Hackney system was not recording. On-site hourly wind direction data were used for the assignment of upwind receptor locations whose concentrations were then used in a background subtraction procedure identical to the one described for the Canal plant. Wind speeds at these two meteorological stations were adjusted to the 7 meter height by means of the stability dependent power law currently used in the Single Source Model and hourly stabilities based upon Huntington, West Virginia surface observations for 1973. A hybrid Preprocessor output file was then constructed using local wind direction and adjusted windspeed data in conjunction with ambient temperature and stability assignments from Huntington. Hourly mixing heights were based upon surface and upper air data both collected at Huntington. This particular combination of on-site and nonlocal meteorological data were used to test the Pasquill-Turner, Gifford-Briggs and F. B. Smith dispersion parameters at the Muskingum Plant. In our test of the F. B. Smith fractional stabilities, the Preprocessor program was modified to include a two-digit stability class.

For the test of the Smith-Singer dispersion coefficients, local values for wind direction, wind speed (uncorrected) and Smith-Singer stability class (1 - 4) were used with nonlocal values for ambient temperature and mixing height as input to the Single Source Model modified to include Smith-Singer dispersion coefficients and wind speed profile parameters.

SECTION IV

MODEL VALIDATION RESULTS

Our test of the different sets of dispersion coefficients described in Section II was based upon a comparison of cumulative frequency distributions of measured and predicted 1-hour SO_2 concentrations at the Canal and Muskingum Power Plants. The combinations of power plant sites, stability assignment algorithms, dispersion coefficients and meteorological data bases are presented in Table 11 along with the results of each model validation test and the numbers of the figures illustrating each test. The results of the variable plume rise test are also included in Table 11.

The overall conclusion which may be reached based upon the examination of results presented in Table 11 is that the Pasquill-Turner dispersion coefficients and stability assignment algorithm yield the best agreement of the methods tested with the possible exception of the Gifford-Briggs dispersion coefficients. Although in the case of the Canal Plant the Gifford-Briggs coefficients gave slightly better agreement with measurements than the Pasquill-Turner curves, the two schemes worked equally well for the Muskingum Plant. This outcome is reasonable in light of the close agreement between the σ_z curves, except for stability A, for the two different methods (see Figures 15a through 15f).

The most surprising result of the study was the failure of the Smith-Singer dispersion coefficients and stability assignment scheme to predict the upper percentile or even the shape of the 1-hour concentration frequency distribution (see Figures 24a through 24e). One would expect these

coefficients to be better suited to the prediction of short-term SO_2 levels in the vicinity of power plants since they were based upon experiments involving the release of tracers from elevated sources. Since the criteria for selection of a given curve is somewhat qualitative, this may be a factor in their not giving a proper frequency distribution shape.

Since a major portion of our validation efforts involved the testing of the fractional stability scheme of F.B. Smith, we shall examine a number of reasons behind the resulting poor agreement with measured 1-hour SO_2 concentrations. Our first test of the F.B. Smith method involved point stability assignments according to Pasquill-Turner and the corresponding F.B. Smith Dispersion curves for stabilities A through F. Again it should be pointed out that only the F.B. Smith σ_z estimates were used in this model validation test. The Pasquill-Turner σ_y curves (see Figure 2), were used in conjunction with the F.B. Smith σ_z's. The results of this first validation exercise (Run Nos. 6 and 8) indicated a strong tendency for the F.B. Smith point stability dispersion curves to underpredict 1-hour SO_2 concentrations both for the Canal and Muskingum Plants. The only exception to this finding was the result for Muskingum Station 4 which showed slightly improved agreement over the Pasquill-Turner results (Run No. 2). The reason that this station did not follow the trend toward underprediction may have been its location 19.6 km from the plant. At this distance the largest concentrations should be observed during the more stable conditions (D, E and F). For these stability classes the F.B Smith σ_z curves do not differ radically from the Pasquill-Turner curves (see Figures 14c through 14e). When a surface roughness of 100 cm, rather than the standard value of 10 cm, was used for calculation of the F.B. Smith σ_z curves the agreement between predicted and measured 1-hour SO_2 concentrations was somewhat better for the Canal Plant (Run No. 7), although the assumption of 100 cm surface roughness for this site is clearly unrealistic.

To determine whether the F. B. Smith vertical dispersion curves would yield better results when used in conjunction with the F. B. Smith stabilities described in Section II, we rewrote the Single Source Model

Preprocessor Program to include the fractional stability calculation techniques discussed in Section II. Minor modifications to the Single Source Model itself were made to provide for the interpolation of σ_y and σ_z values based upon the fractional stability assignment. A comparison of the Pasquill-Turner and F. B. Smith stabilities for three days in 1973 based upon Huntington, West Virginia surface meteorological data is presented in Table 12. Local windspeed and wind direction data for the Muskingum River Plant were not used in this calculation since the windspeed measurements were obtained at 24.2 m above the ground and not the 10 m height required for use in the F. B. Smith calculation. A stability dependent power law correction could have been used to convert the windspeed to the 10 m height except that the purpose of the exercise was to actually determine the fractional stability. Although the 7 m measurement height assumed for Huntington, W. Va. was not equal to the required 10 m height, the resulting error is negligible.

When the fractional stability versions of the Preprocessor Program and the Single Source Model were run for the Muskingum Plant, an overprediction occurred for stations 2, 3 and 4, compared to the substantial underprediction which resulted when the F. B. Smith dispersion coefficients were used in conjunction with the Pasquill-Turner point stability assignments. The generally lower stability index assignments based upon the F. B. Smith method have overcompensated for the smaller F. B. Smith σ_z values for the A, B and C stability classes. An example of the generally lower stability indices calculated by the F. B. Smith method is shown in Table 12. For the midday hours during the summer months the F. B. Smith stability indices can be more than one stability class lower than the corresponding Pasquill-Turner values.

The final objective of the model improvement study was to determine whether the incorporation of an hourly variation of a stack gas exit velocity, which is directly proportional to the fuel consumption rate, would improve model agreement with measured 1-hour SO_2 concentrations. The procedure for calculating hourly exit velocities was described in

Section II. Although the tests for the Canal and Muskingum River Plants showed no such improvement, the inclusion of a variable buoyancy flux in the model still may be desirable in the case of highly variable fuel consumption.

Table 11. DESCRIPTION OF MODEL VALIDATION RUNS AND RESULTS

Run number	Site	Stability assignment method	Dispersion calculation method	Meteorological data base	Special modifications	Validation results	Figure numbers
1	Canal	Pasquill-Turner	Pasquill-Turner	Local wind speed, wind direction and ambient temperature. Stabilities based upon surface data from Quonset Point, R.I. mixing heights from Chatham, Mass.		All stations underpredicted for the entire distribution, especially stations 2 and 4. Closest agreement for station 3, which had the highest elevation above the stack base. Except for station 3, the calculated distribution shapes are also in error.	20
2	Muskingum	Pasquill-Turner	Pasquill-Turner	Local wind speed and wind direction. Ambient temperature and stability from Huntington, W. Va. surface data. Mixing heights from Huntington, W. Va.		Good agreement for the higher end of the distributions except for station 2 which is overpredicted.	21
3	Canal	Pasquill-Turner	Gifford-Briggs	Same as Run No. 1		In comparison with Run No. 1 slightly better agreement for all stations was obtained, but the entire frequency distribution is still underpredicted.	22
4	Muskingum	Pasquill-Turner	Gifford-Briggs	Same as Run No. 2		Slightly better agreement for stations 2 and 4 when compared with Run No. 1.	23
5	Muskingum	Smith-Singer	Smith-Singer	Local wind speed, wind direction and atmospheric stability. Ambient temperature and mixing height from Huntington, W. Va.	Smith-Singer windspeed profile incorporated. For stabilities B2, B1 and C, plume rise is calculated according to Equation (2) in Section II. For stability D, Equation (3) is used.	Considerable overprediction for stations 1, 2 and 3 even at the lower end of the distributions. Calculated distribution shapes are unrealistic.	24
6	Canal	Pasquill-Turner	F. B. Smith	Same as Run No. 1	Surface roughness of 10 cm.	All stations underpredicted for the entire distribution. For stations 2, 3 and 4 agreement considerably worse than for Run No. 1.	25
7	Canal	Pasquill-Turner	F. B. Smith	Same as Run No. 1	Surface roughness of 100 cm.	Improved agreement over Run No. 6.	26

Table 11 (continued). DESCRIPTION OF MODEL VALIDATION RUNS AND RESULTS

Run number	Site	Stability assignment method	Dispersion calculation method	Meteorological data base	Special modifications	Validation results	Figure numbers
8	Muskingum	Pasquill-Turner	F. B. Smith	Same as Run No. 2		Only station 4 at 19.6 km from the plant showed better agreement than for Run No. 2 All other stations were considerably underpredicted for the entire distribution.	27
9	Muskingum	F. B. Smith (fractional stabilities)	F. B. Smith (values for σ_y and σ_z interpolated based upon fractional stability assignment).	1973 Huntington, W. Va. surface and upper air data.	Preprocessor and single Source Model modified to include a two-digit stability index and provide for the interpolation of dispersion coefficients.	All stations except 1 were overpredicted at the high end of the distributions.	28
10	Muskingum	Same as Run No. 2	Same as Run No. 2	Same as Run No. 2	Variable buoyancy flux.	No improvement over Run No. 2.	29
11	Canal	Same as Run No. 1	Same as Run No. 1	Same as Run No. 1	Variable buoyancy flux.	No improvement over Run No. 2	30

Table 12. COMPARISON OF PASQUILL-TURNER (P-T) AND F. B. SMITH (F.B.S.) STABILITY ASSIGNMENTS FOR THREE DAYS OF HUNTINGTON, W. VA. 1973 SURFACE METEOROLOGICAL DATA[a]

Day No. 64		Day No. 134		Day No. 323	
P-T	F.B.S.	P-T	F.B.S.	P-T	F.B.S.
6	4.1	4	4.1	4	4.1
5	4.1	4	4.1	4	4.0
5	4.1	7	4.1	4	4.1
6	4.1	4	4.1	4	4.1
5	4.1	4	4.1	4	4.1
5	4.1	6	4.8	4	4.1
6	4.1	4	4.1	5	4.5
4	4.1	3	3.1	4	4.1
4	4.1	3	2.2	4	4.1
4	3.8	2	1.7	4	4.1
3	2.6	2	1.4	4	3.6
3	2.8	3	1.5	4	3.4
4	3.4	3	1.8	4	3.4
4	2.4	4	2.7	4	3.3
4	2.4	4	2.9	4	3.4
4	2.5	4	2.4	4	3.8
4	2.6	3	3.0	4	4.3
3	3.3	3	2.5	3	7.0
4	6.2	3	3.3	6	6.9
5	5.0	4	7.0	6	7.0
7	7.0	6	7.0	7	7.0
7	7.0	6	7.0	7	7.0
7	7.0	6	7.0	6	7.0
7	7.0	4	4.3	7	7.0

[a]A value of 0.4 has been added to the F.B. Smith stabilities so that they could be compared with the Pasquill-Turner values.

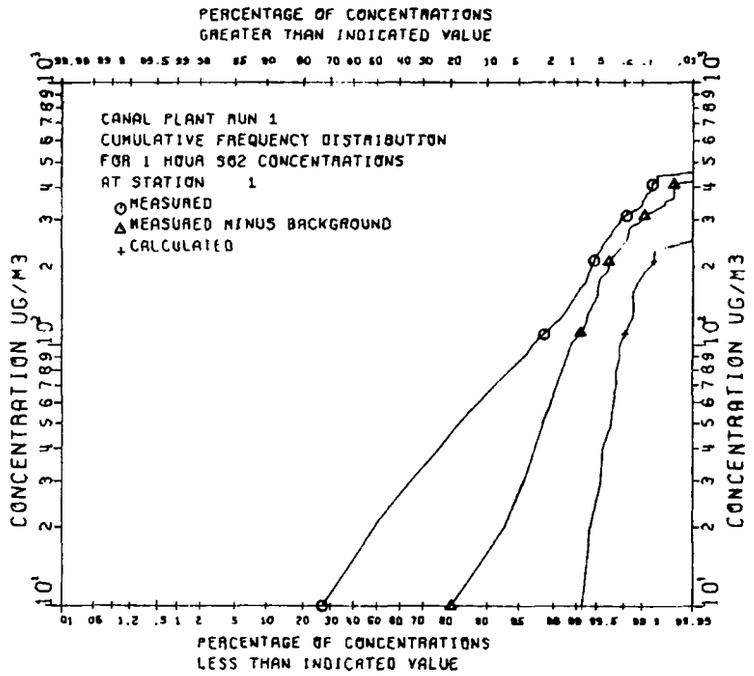

Figure 20a. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

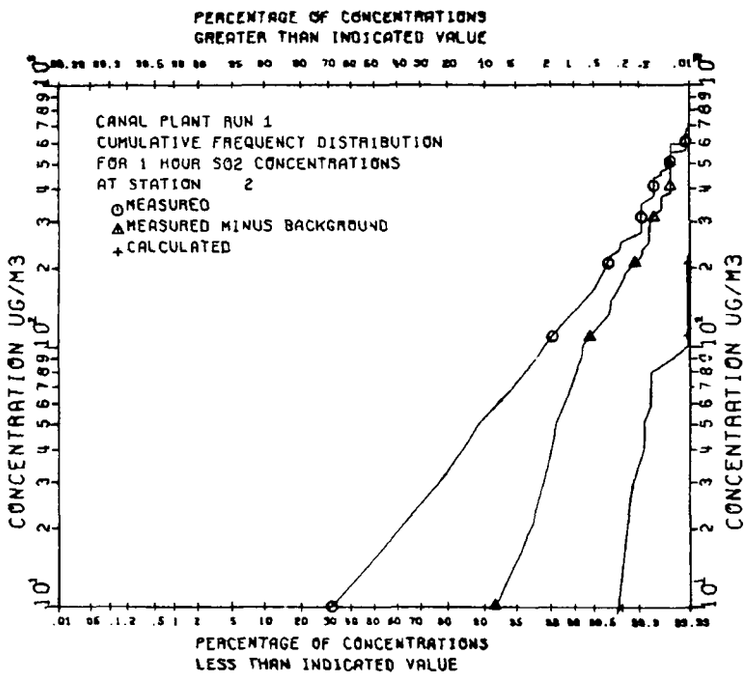

Figure 20b. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of hourly SO_2 concentrations for Canal Plant Station 2

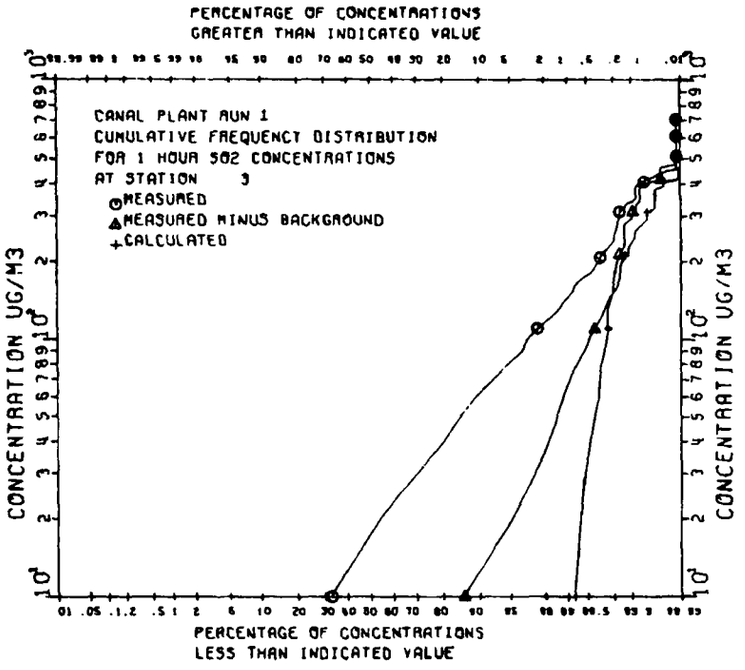

Figure 20c. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

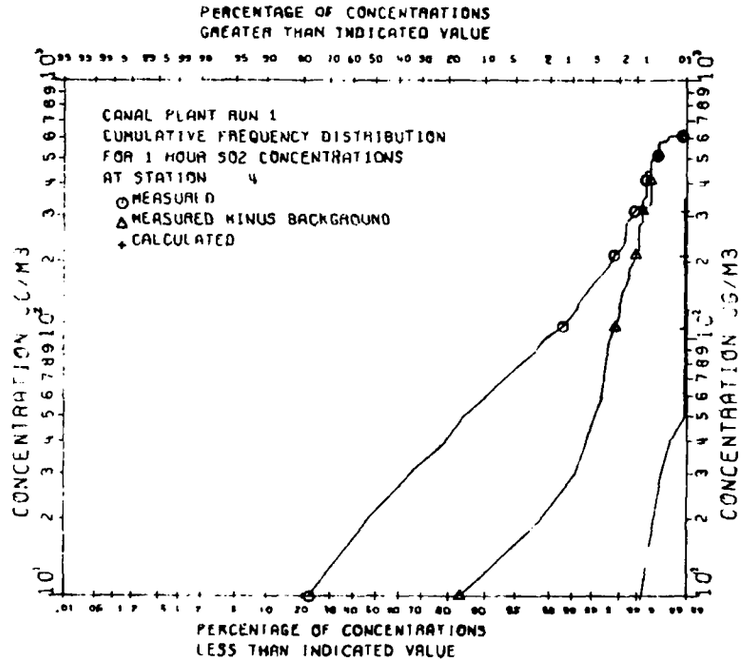

Figure 20d. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

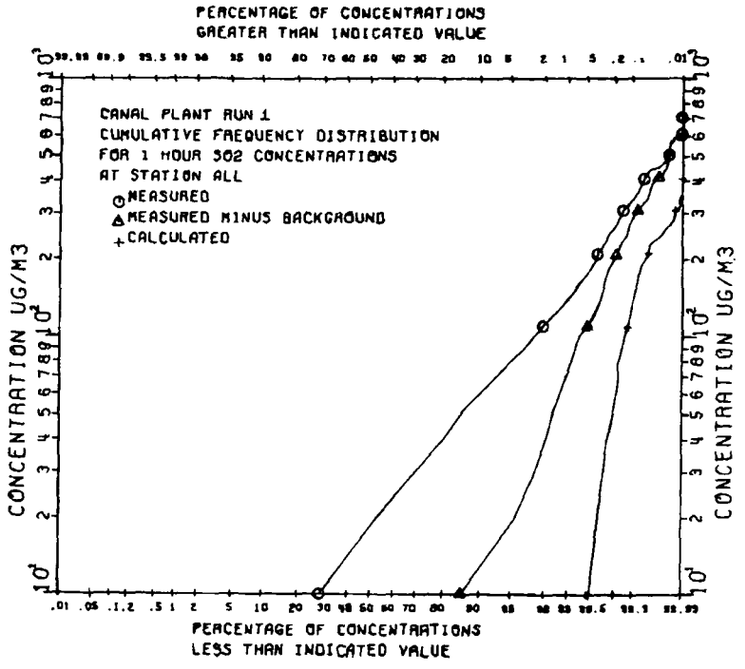

Figure 20e. Model validation Run No. 1. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

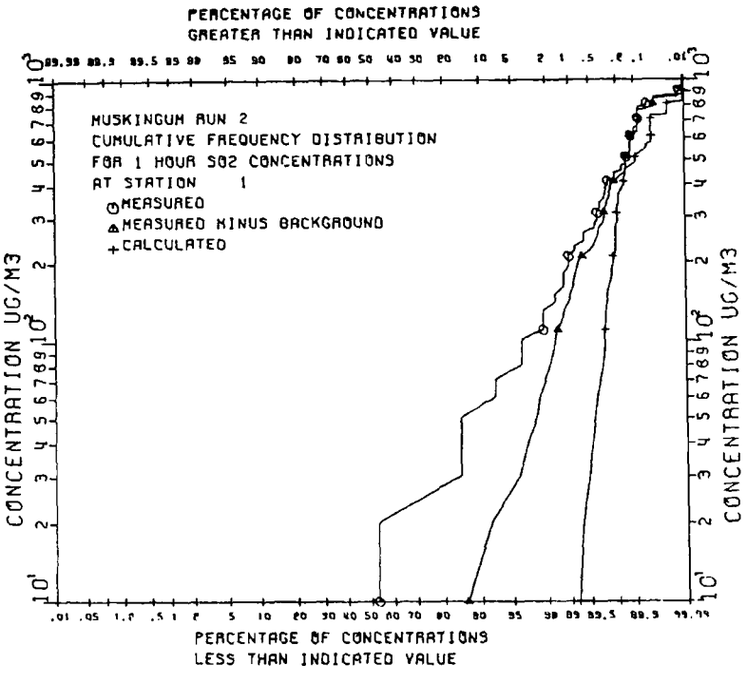

Figure 21a. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

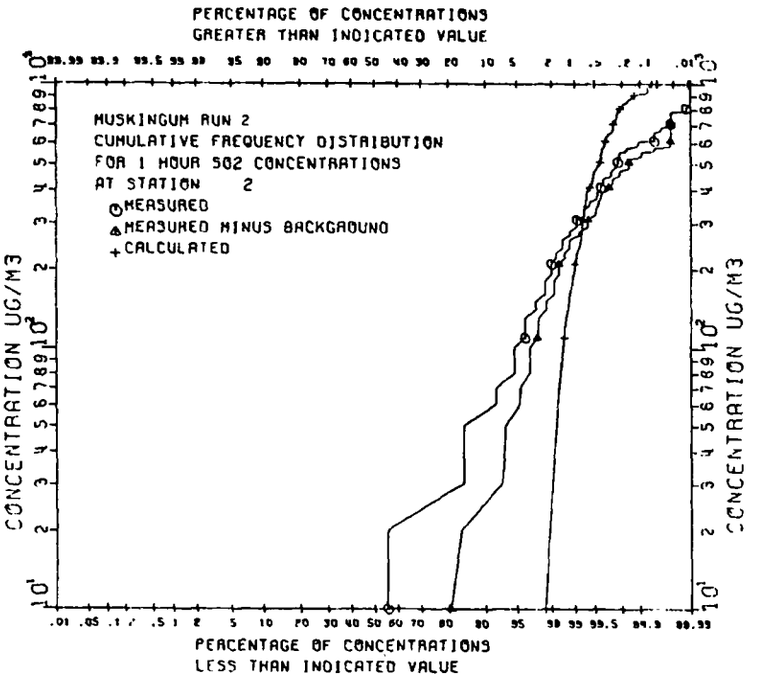

Figure 21b. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

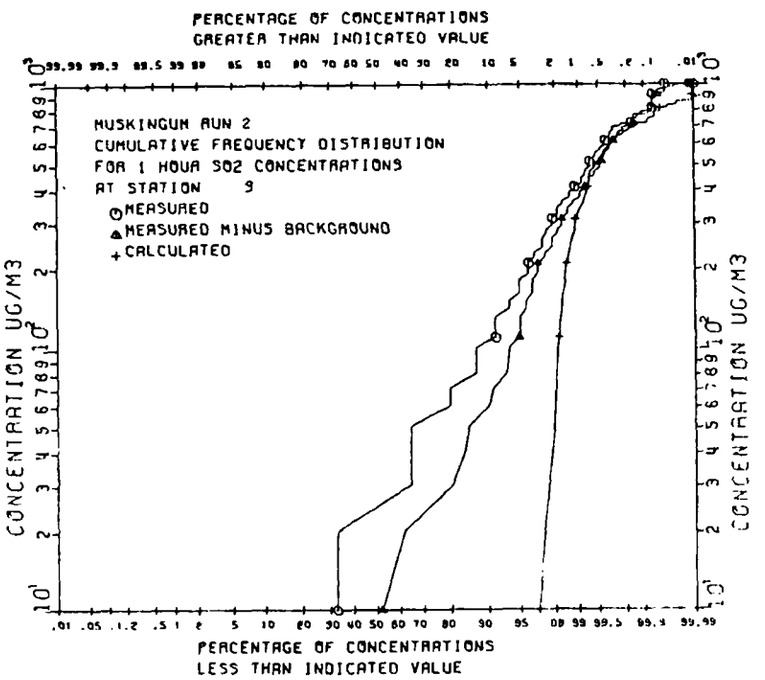

Figure 21c. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

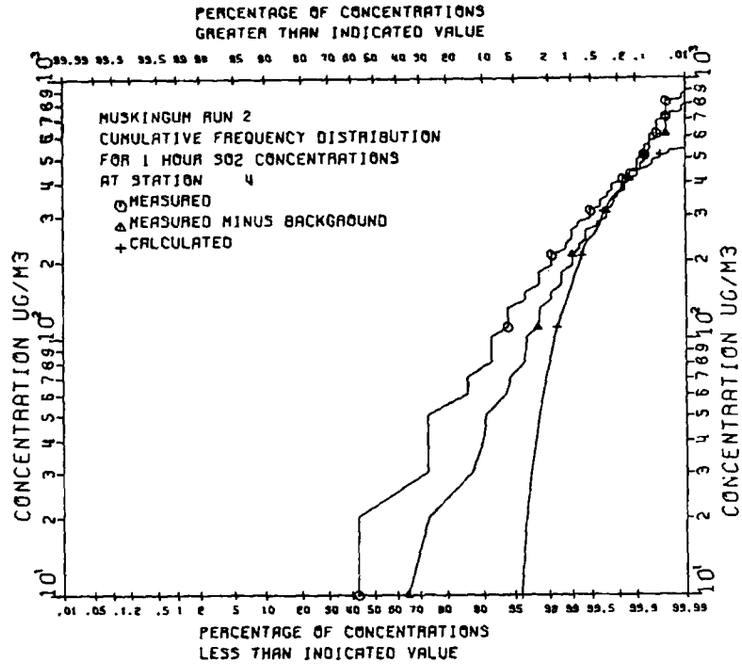

Figure 21d. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

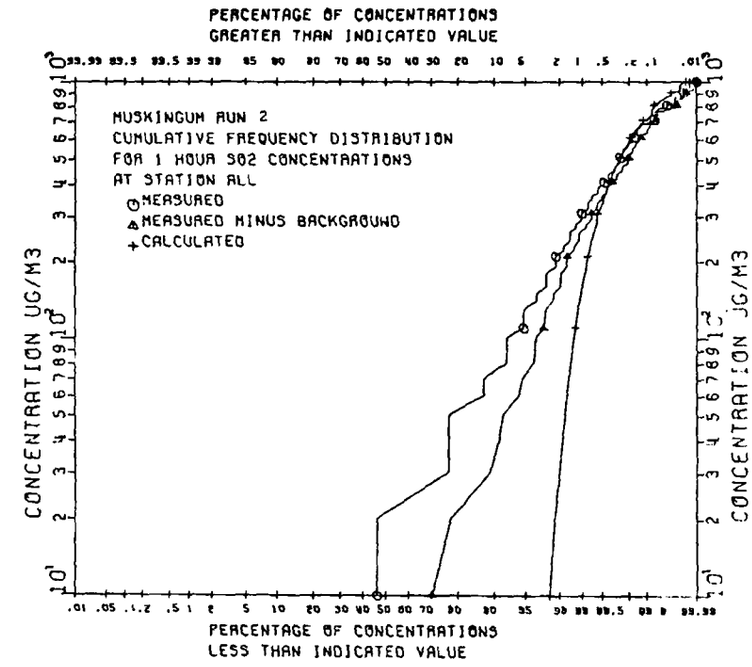

Figure 21e. Model validation Run No. 2. Pasquill-Turner stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

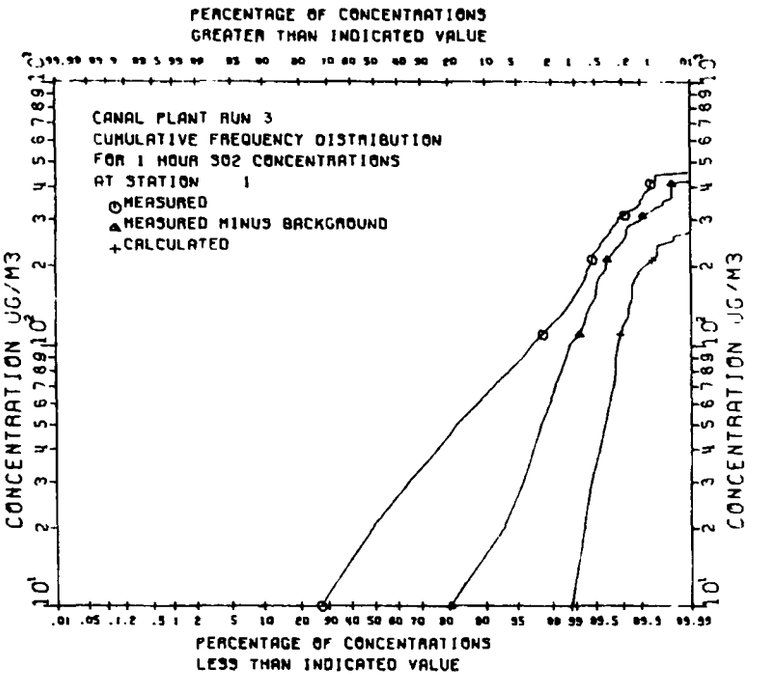

Figure 22a. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

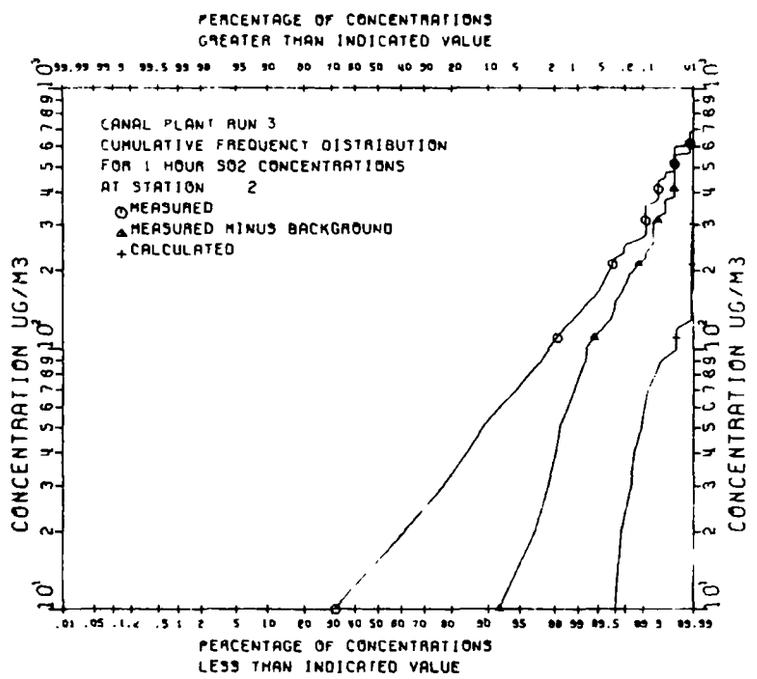

Figure 22b. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

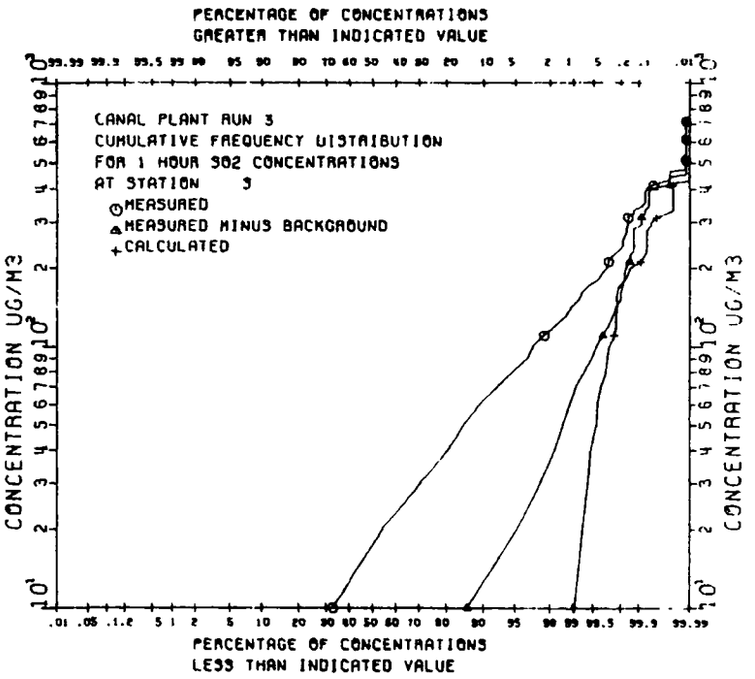

Figure 22c. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

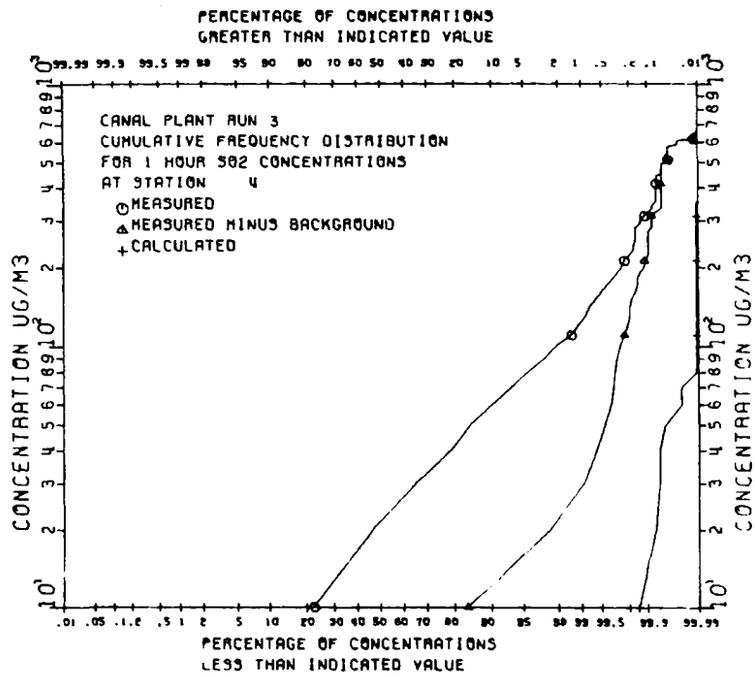

Figure 22d. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

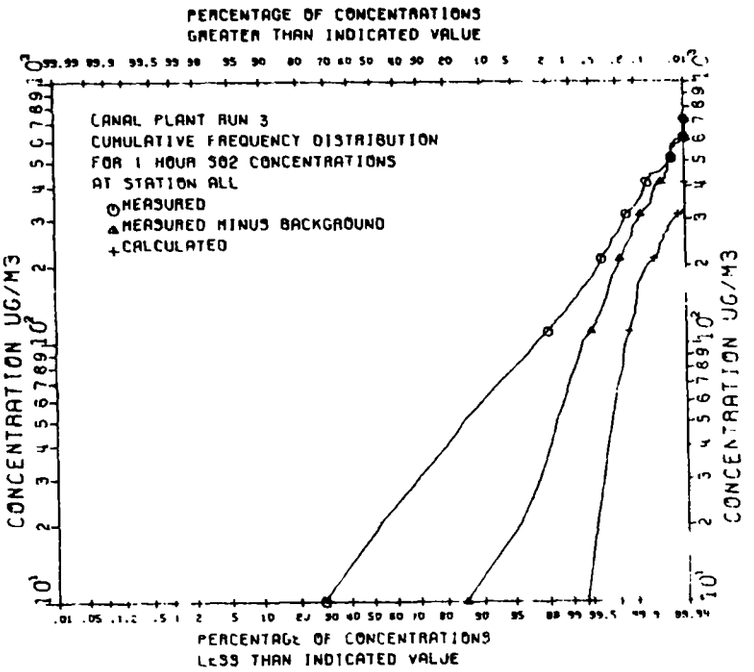

Figure 22e. Model validation Run No. 3. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

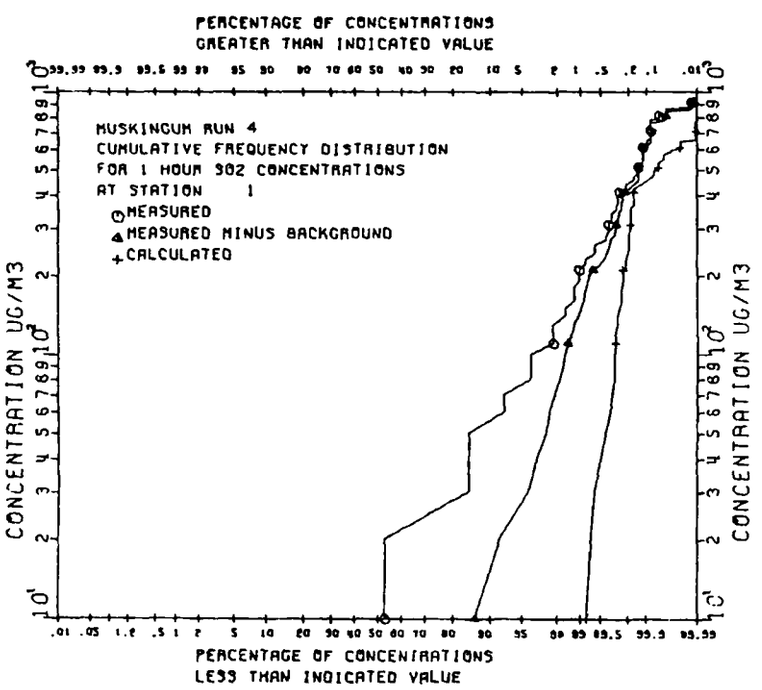

Figure 23a. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

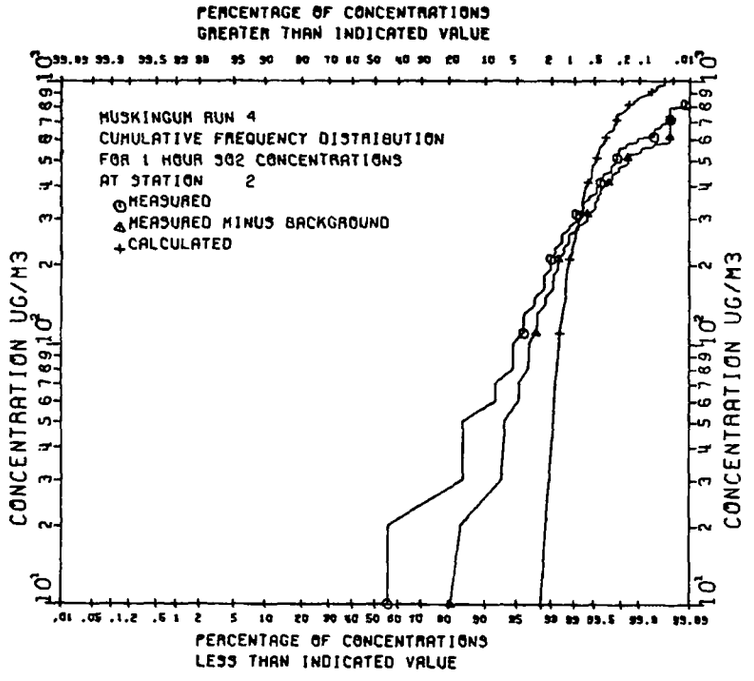

Figure 23b. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

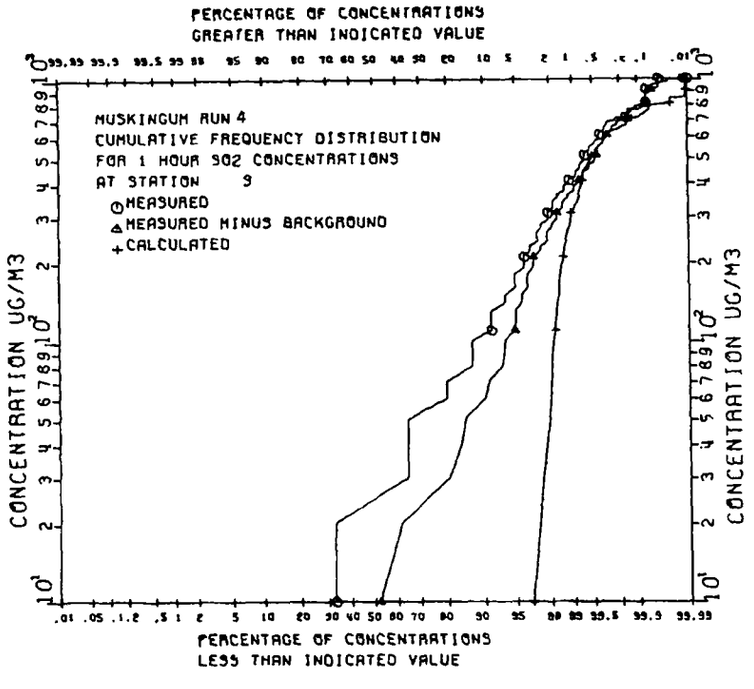

Figure 23c. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

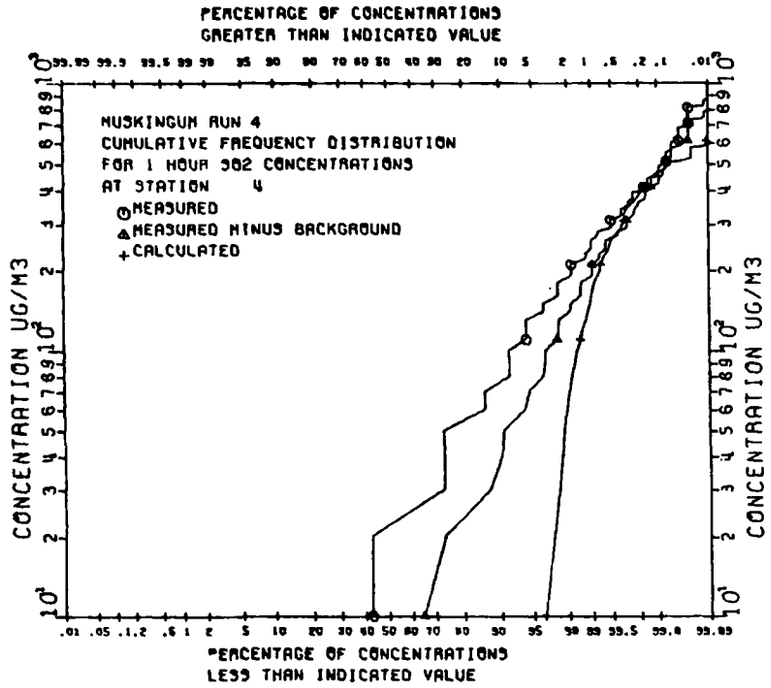

Figure 23d. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

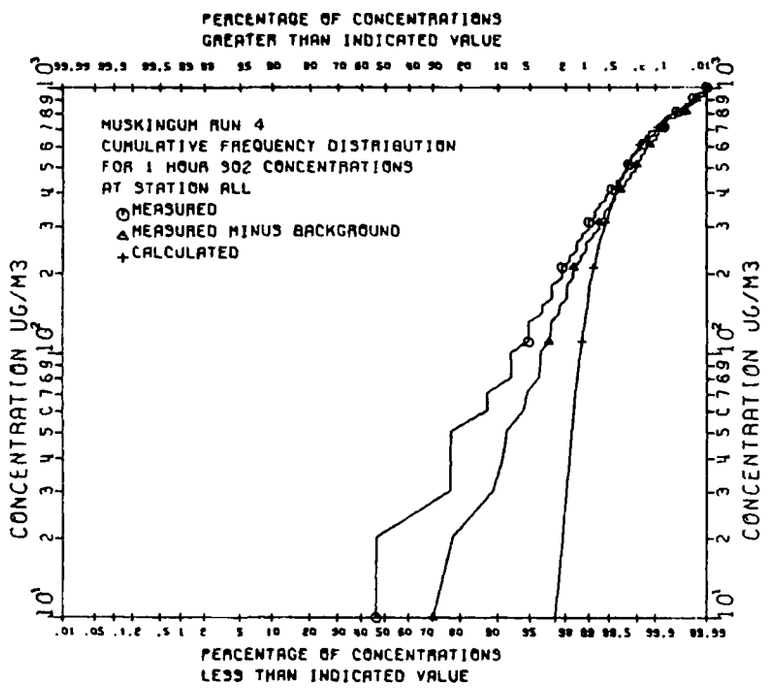

Figure 23e. Model validation Run No. 4. Pasquill-Turner stability assignment method and Gifford-Briggs dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

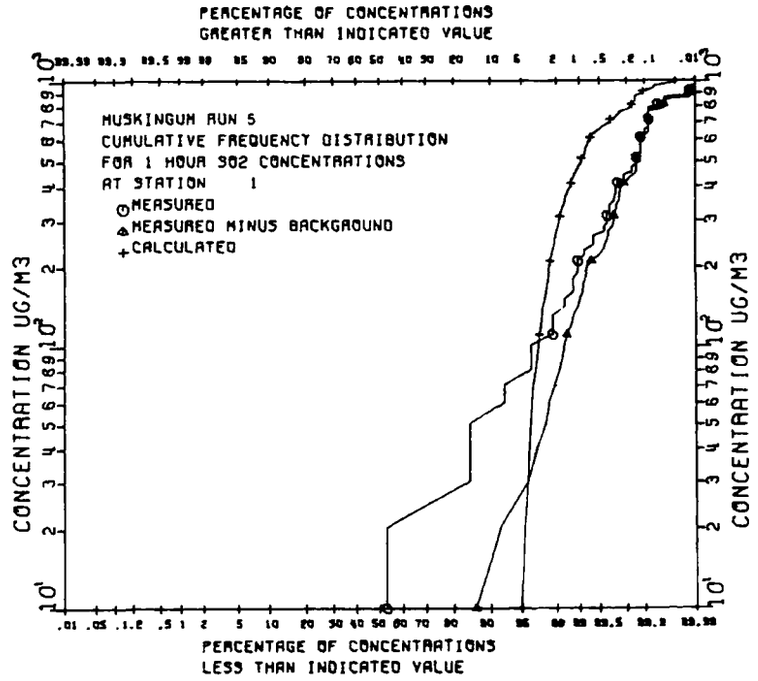

Figure 24a. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

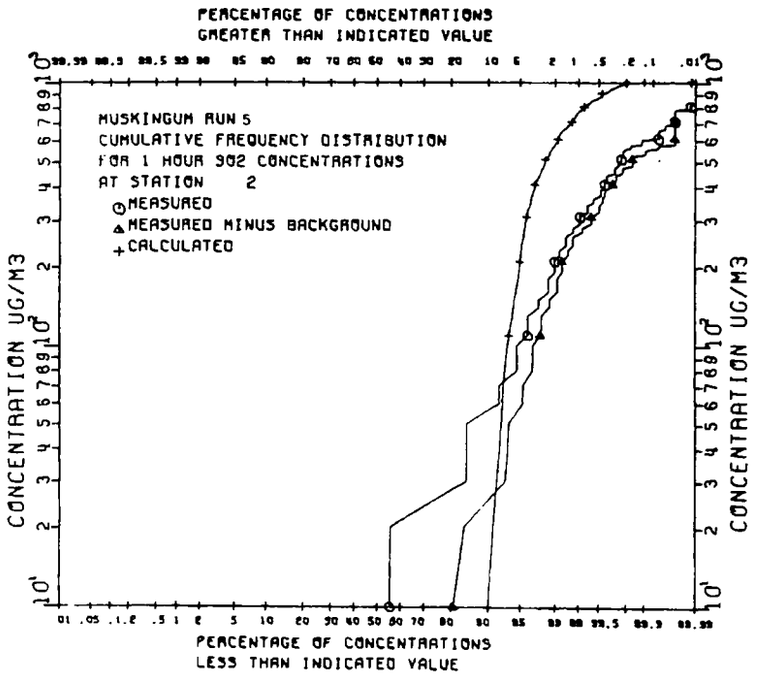

Figure 24b. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

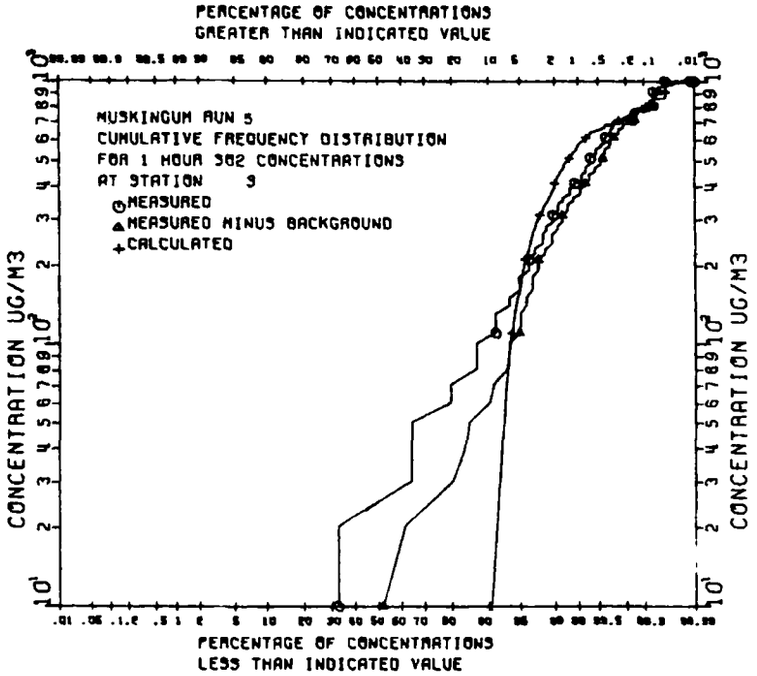

Figure 24c. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. sured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

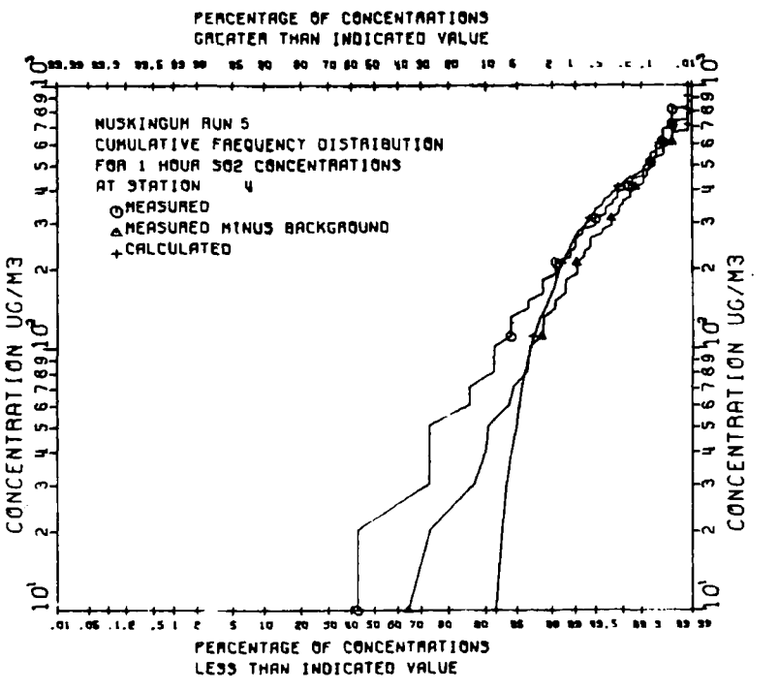

Figure 24d. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

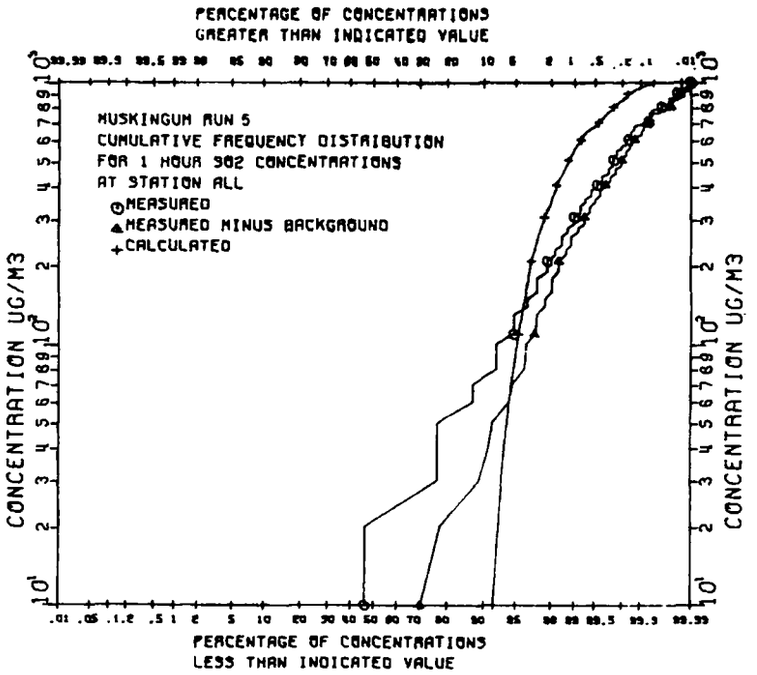

Figure 24e. Model validation Run No. 5. Smith-Singer stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

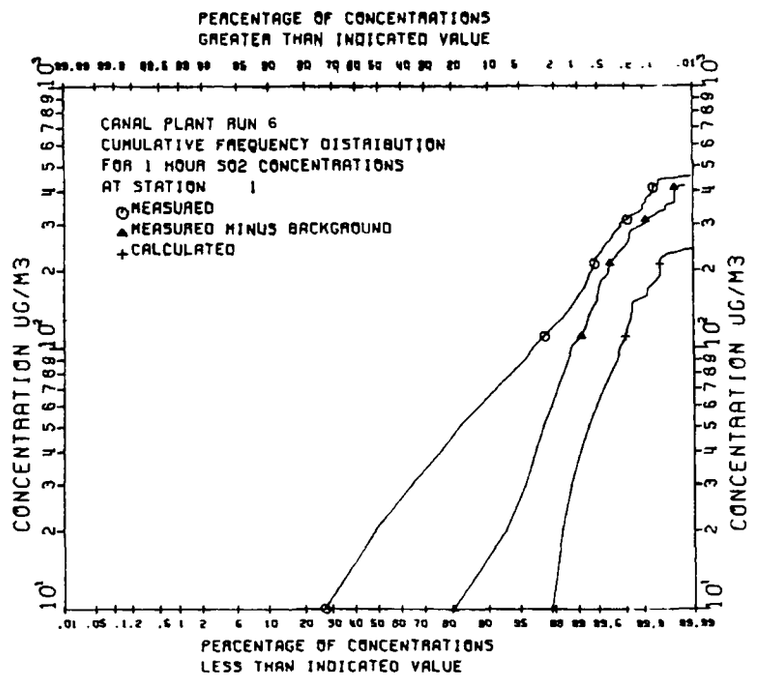

Figure 25a. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

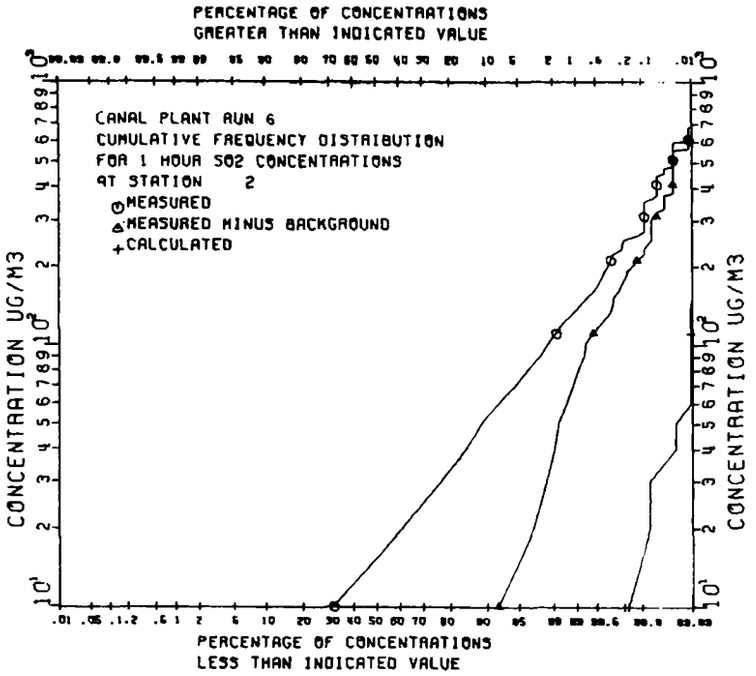

Figure 25b. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

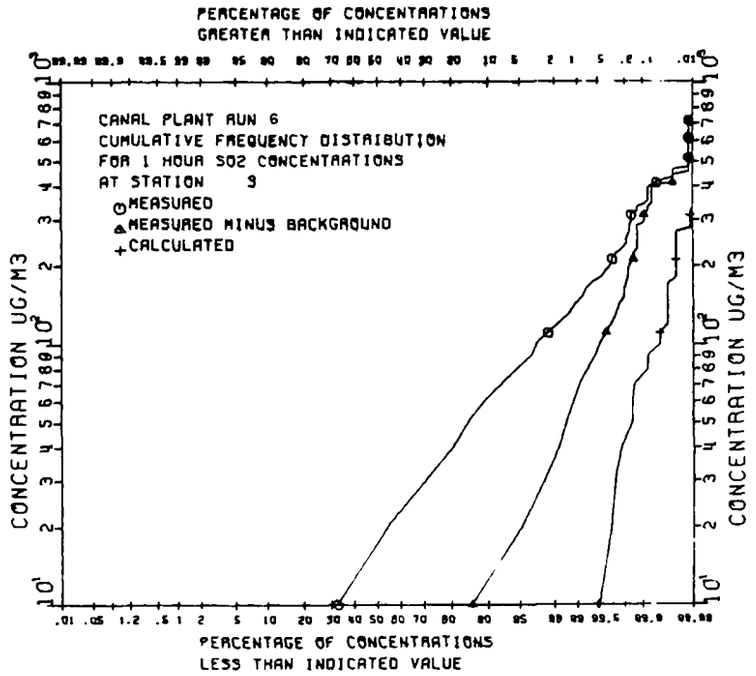

Figure 25c. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

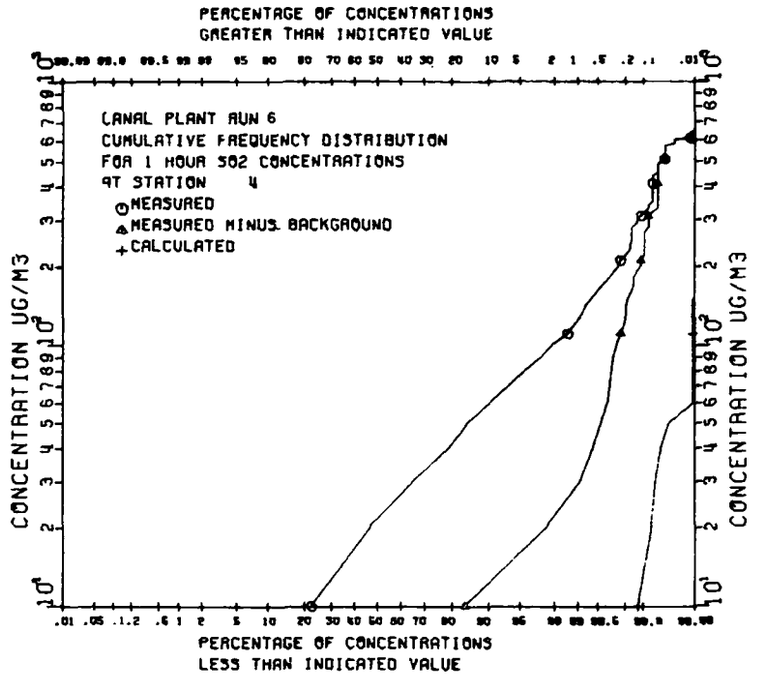

Figure 25d. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

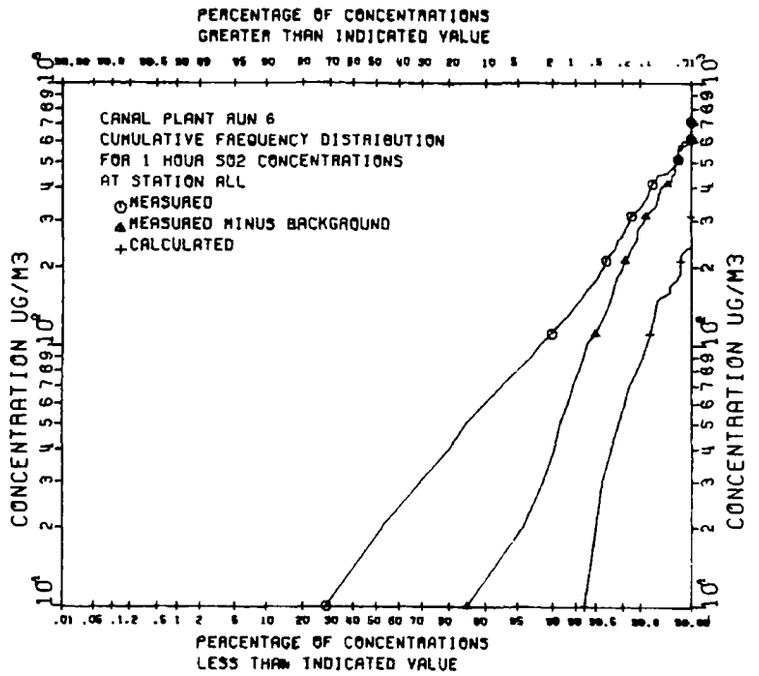

Figure 25e. Model validation Run No. 6. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 10 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

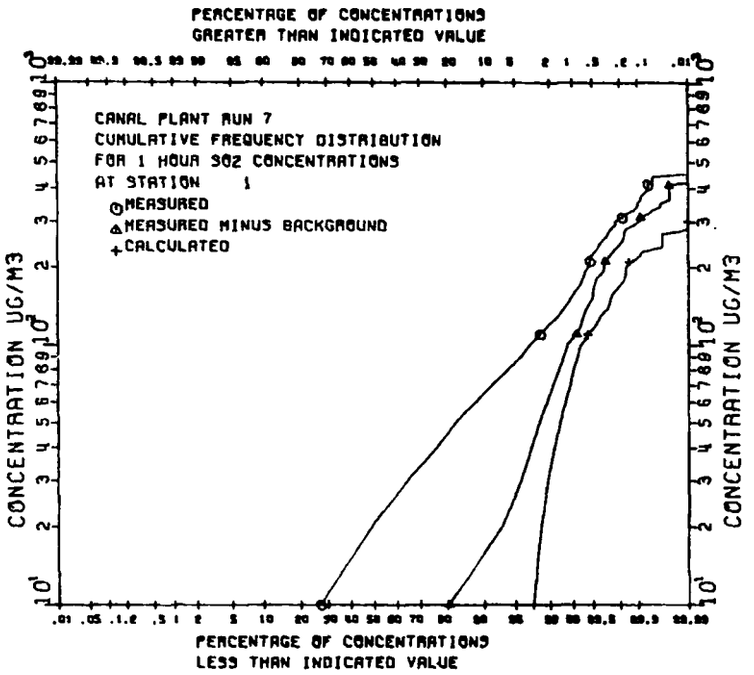

Figure 26a. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

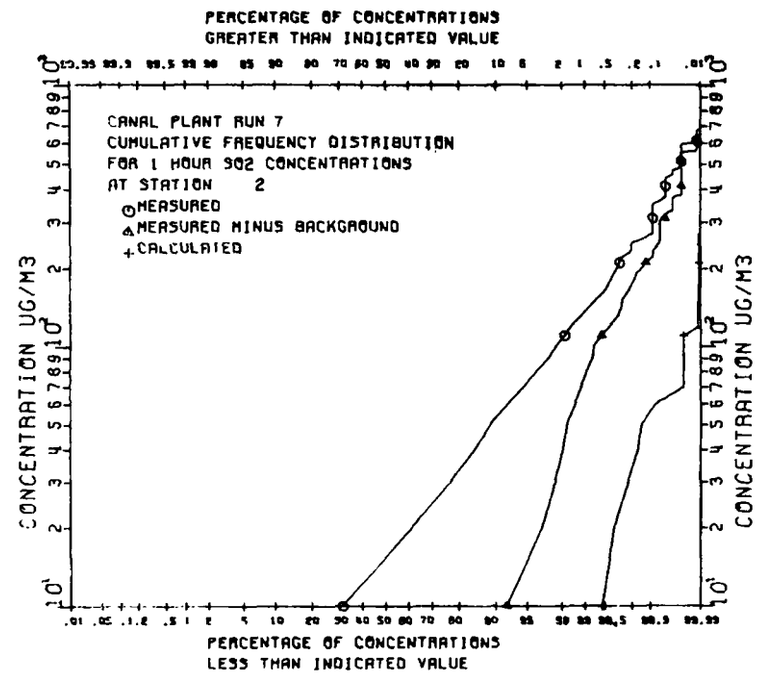

Figure 26b. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

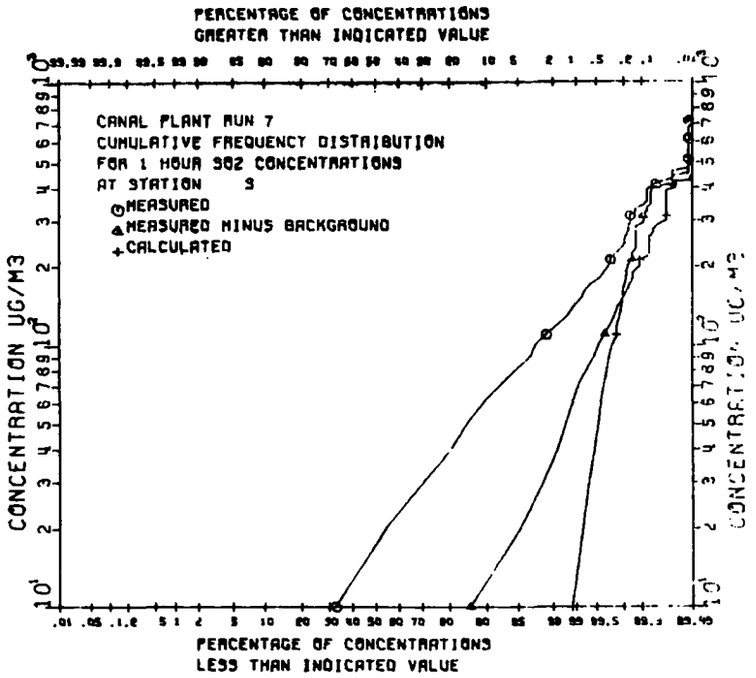

Figure 26c. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

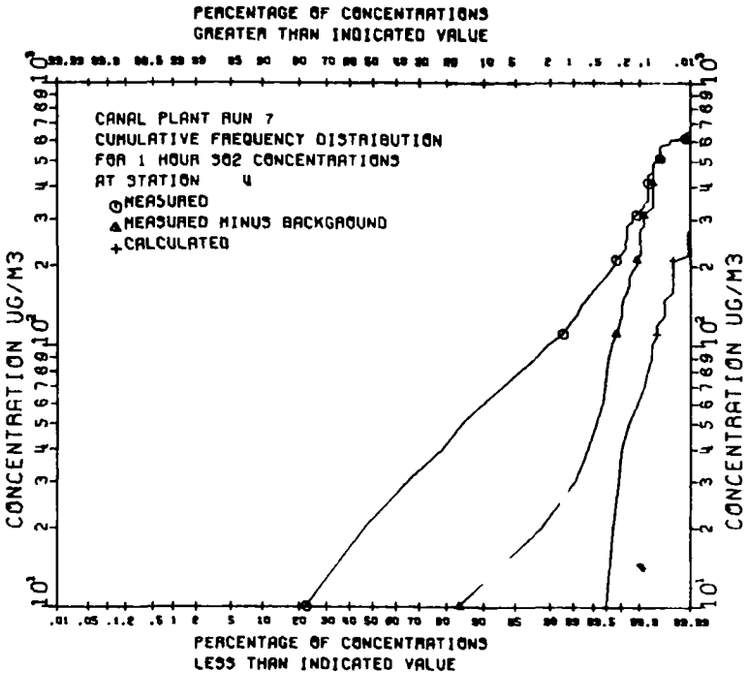

Figure 26d. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

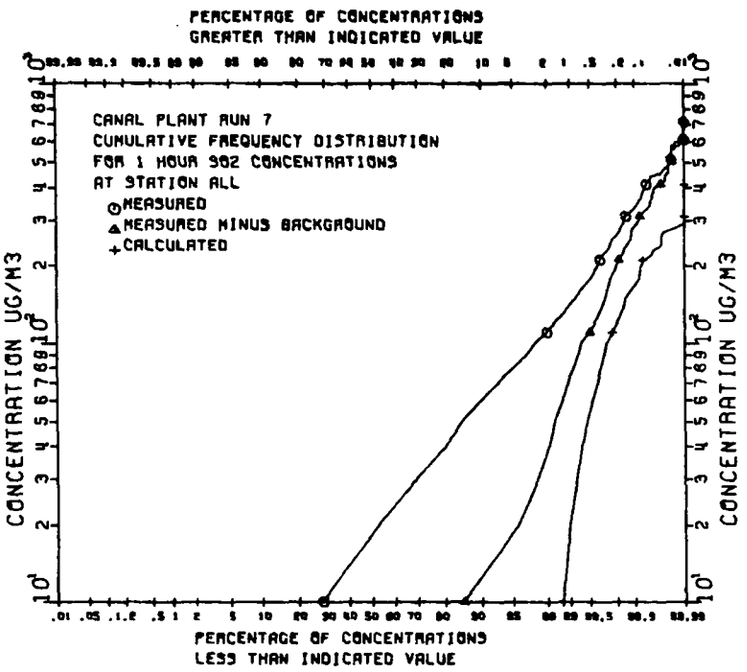

Figure 26e. Model validation Run No. 7. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Surface roughness equal to 100 cm. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

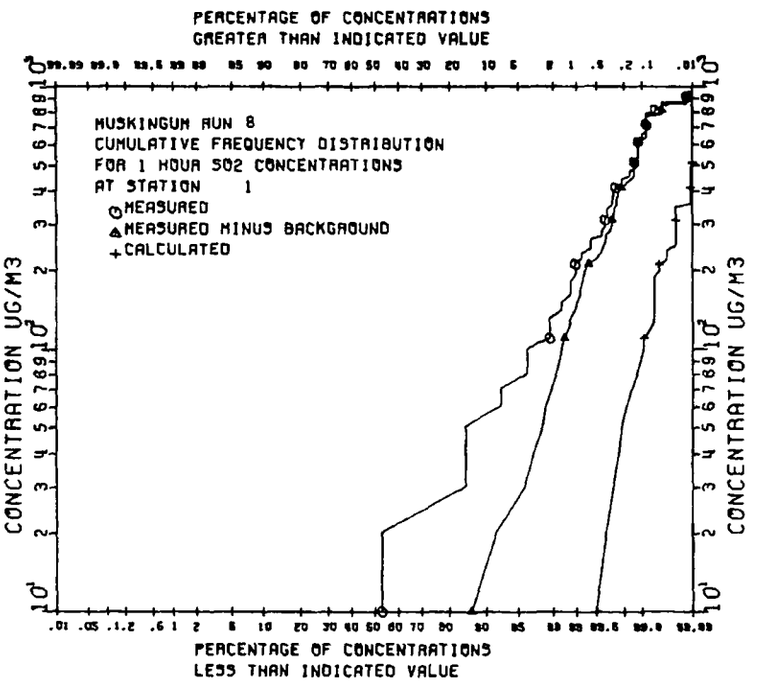

Figure 27a. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

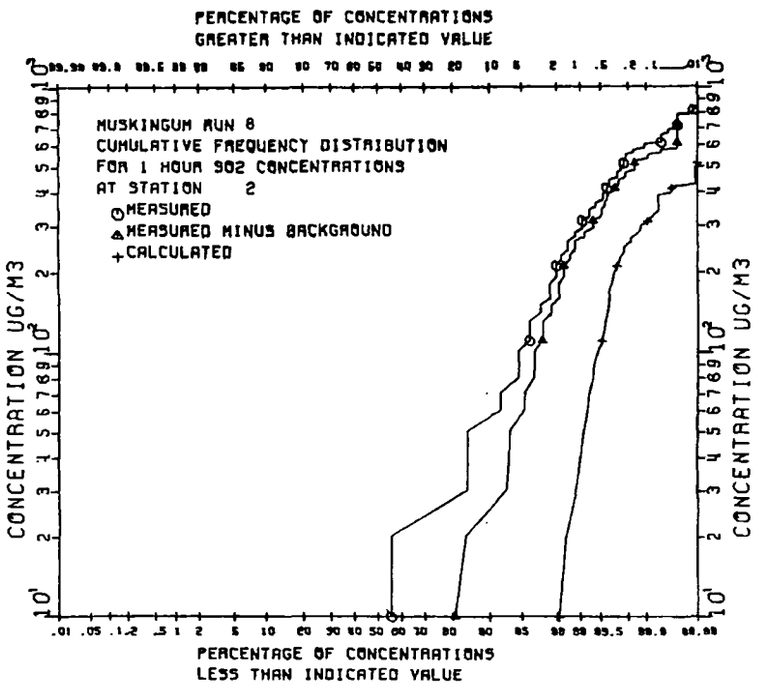

Figure 27b. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

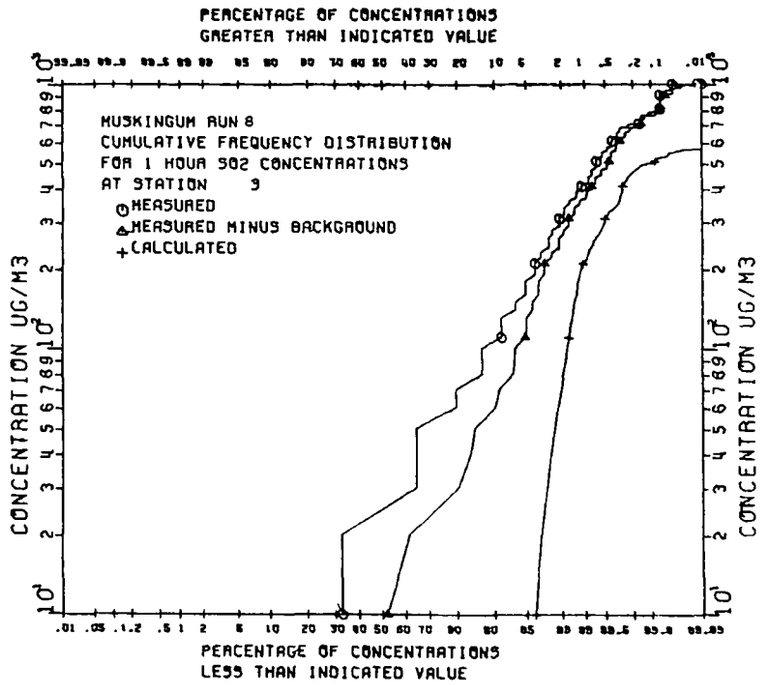

Figure 27c. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

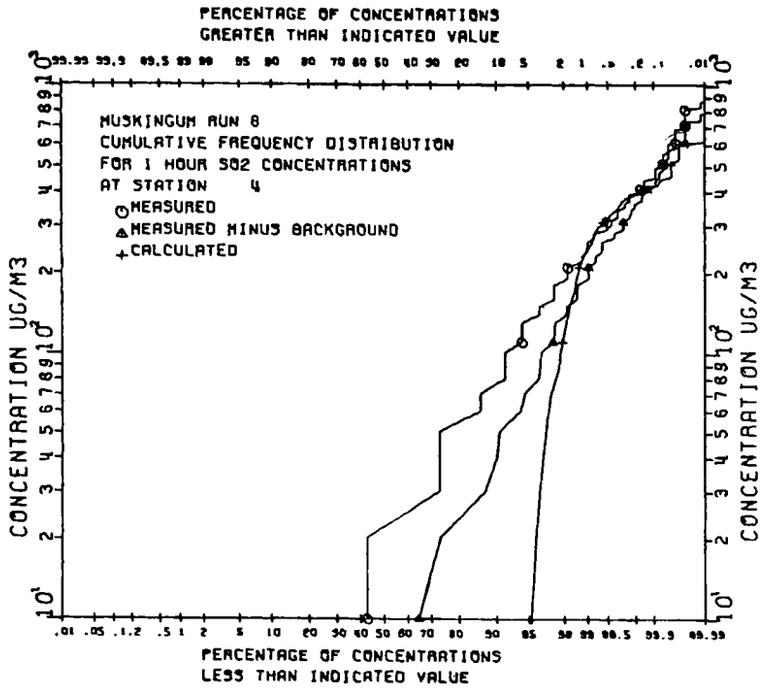

Figure 27d. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

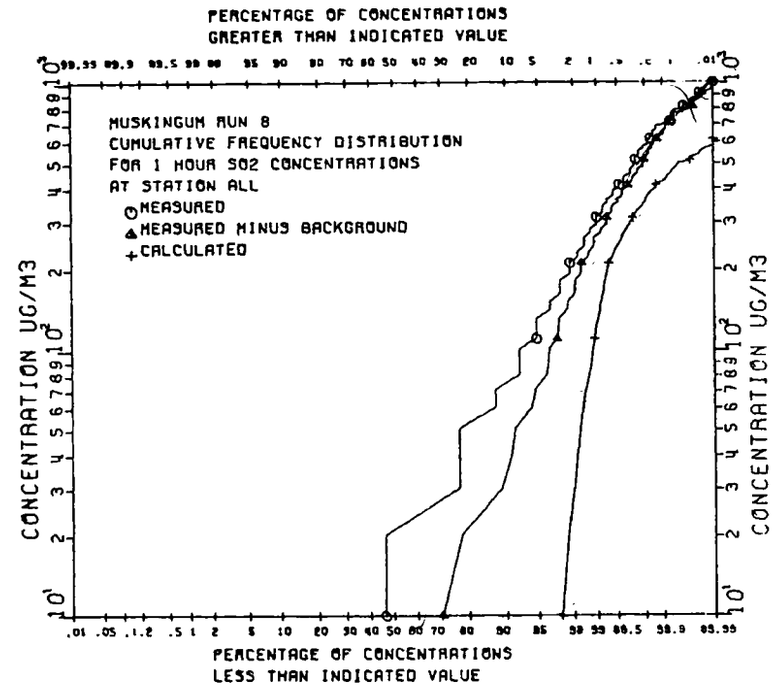

Figure 27e. Model validation Run No. 8. Pasquill-Turner stability assignment method and F.B. Smith dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

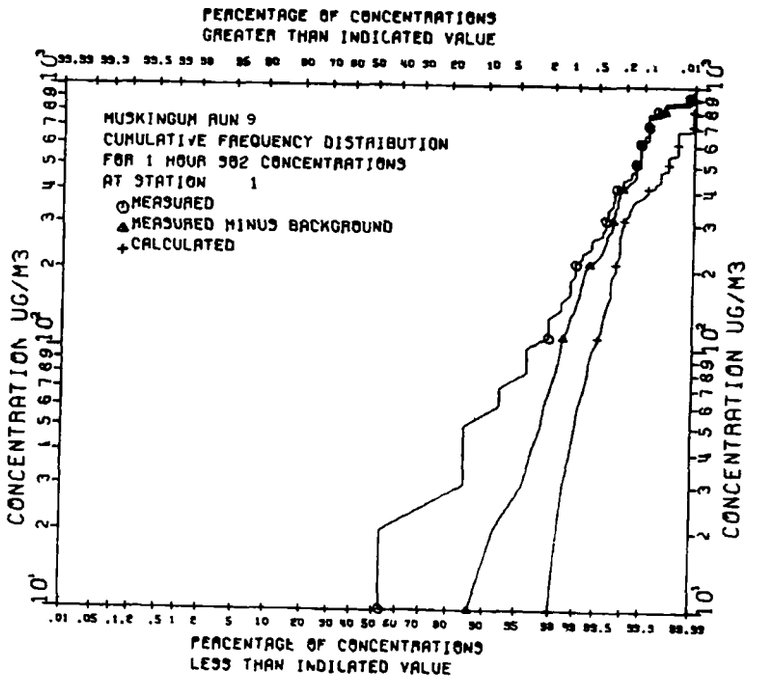

Figure 28a. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

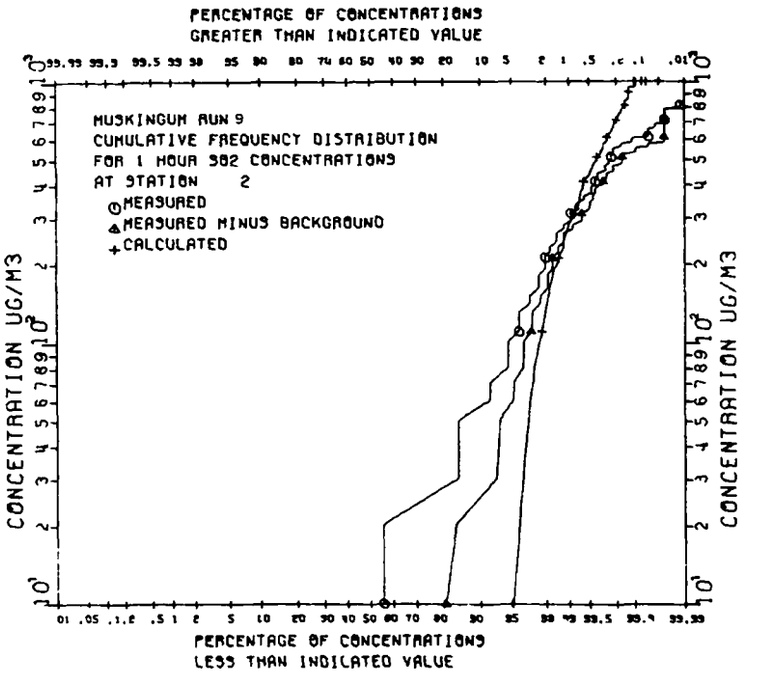

Figure 28b. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

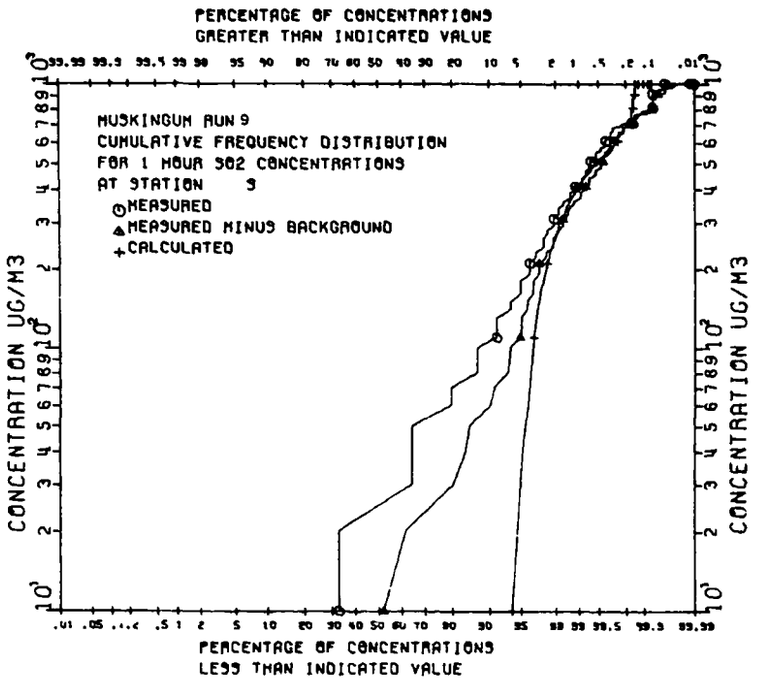

Figure 28c. Model validation Run No. 9. F.B. Smith stabilty assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

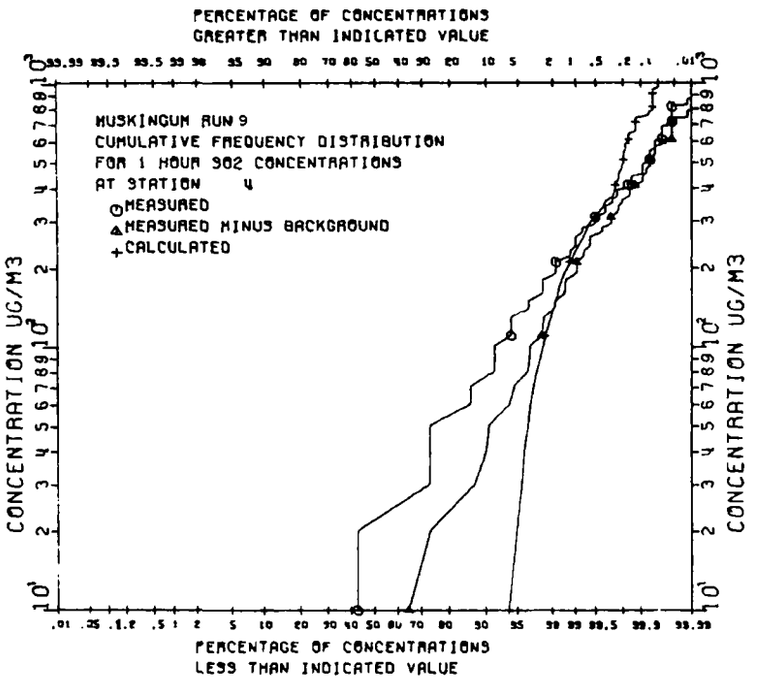

Figure 28d. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

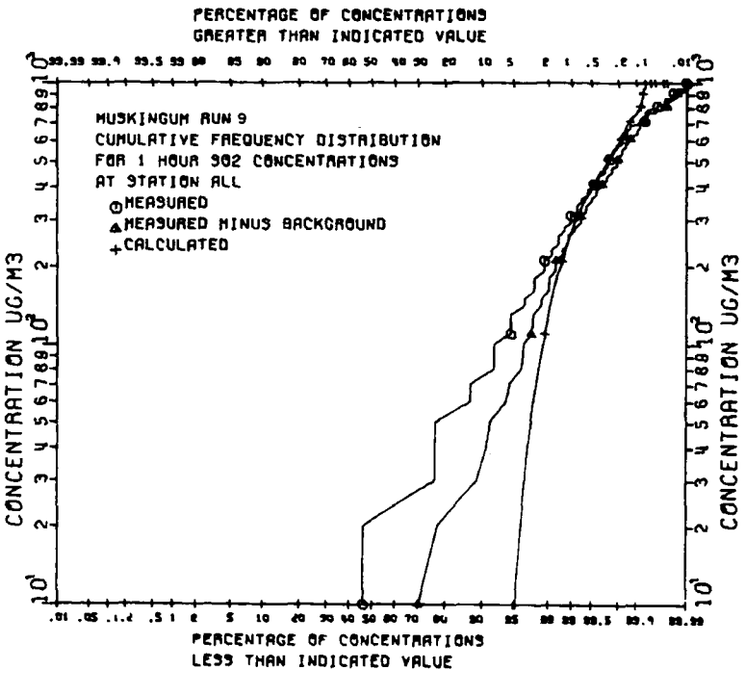

Figure 28e. Model validation Run No. 9. F.B. Smith stability assignment and dispersion calculation method. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

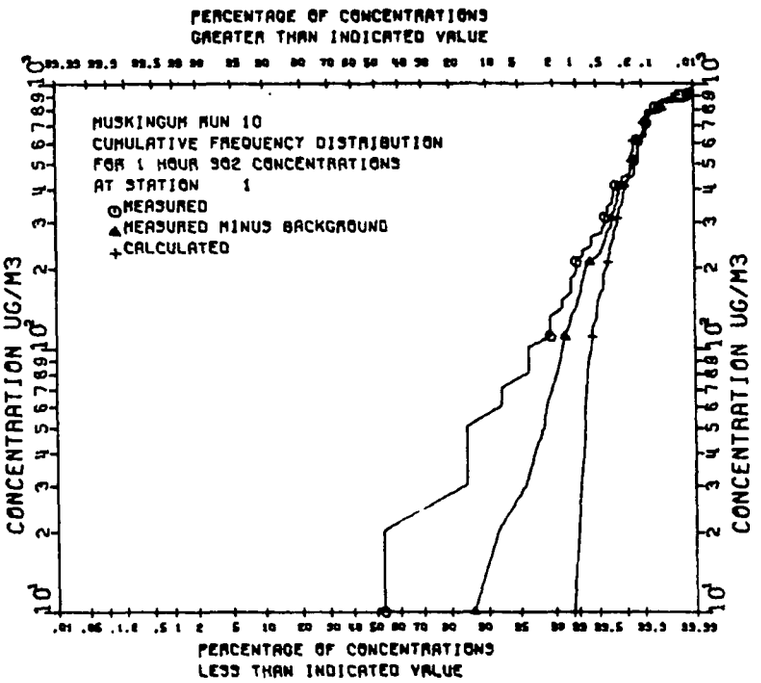

Figure 29a. Model validation Run No. 10. Variable buoyancy flux Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 1

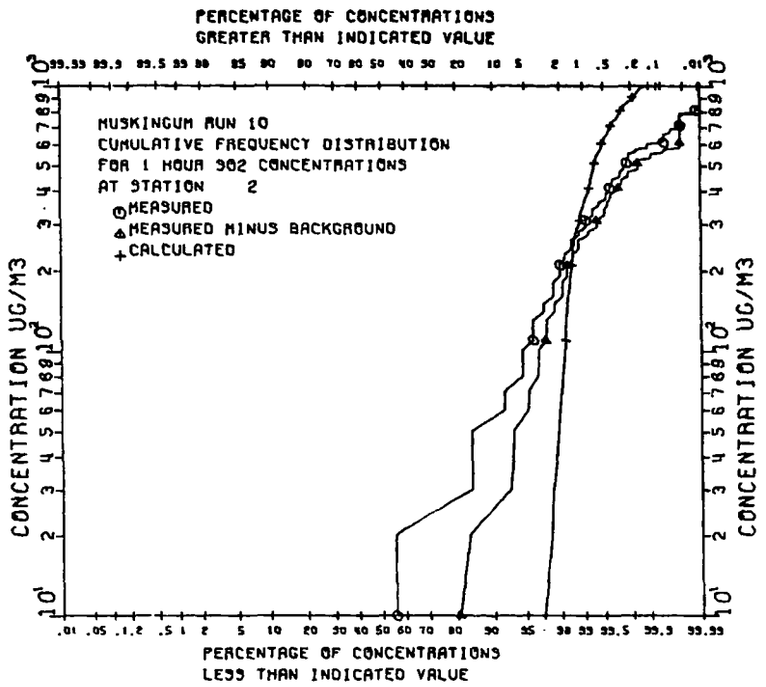

Figure 29b. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 2

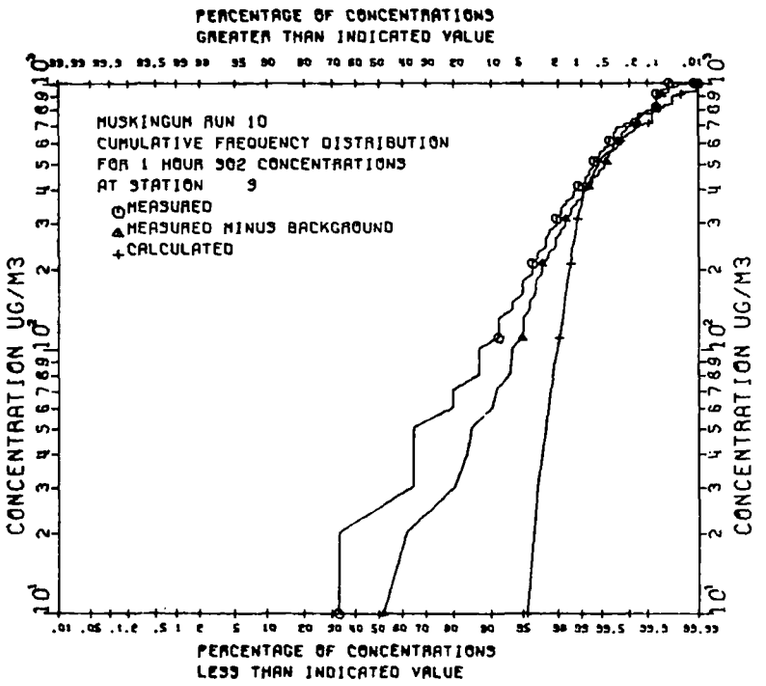

Figure 29c. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 3

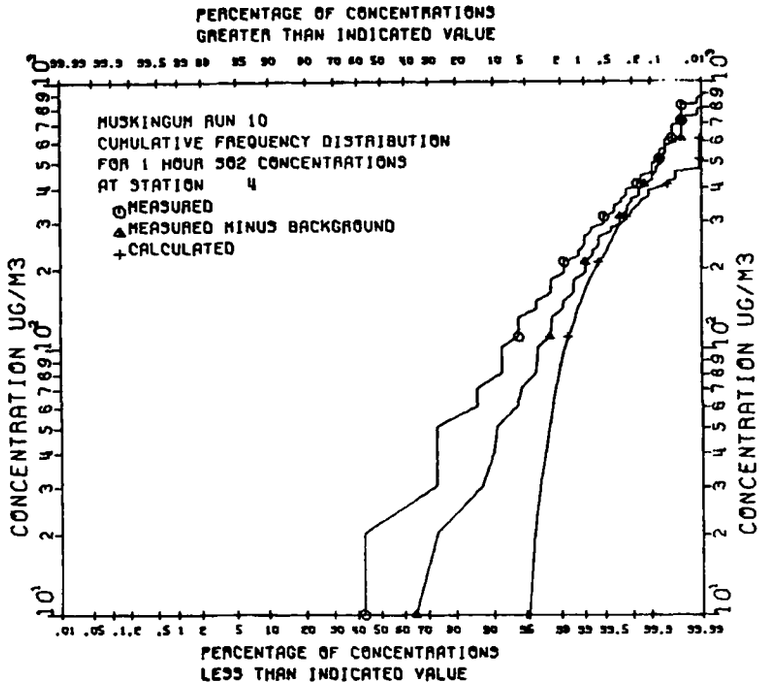

Figure 29d. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant Station 4

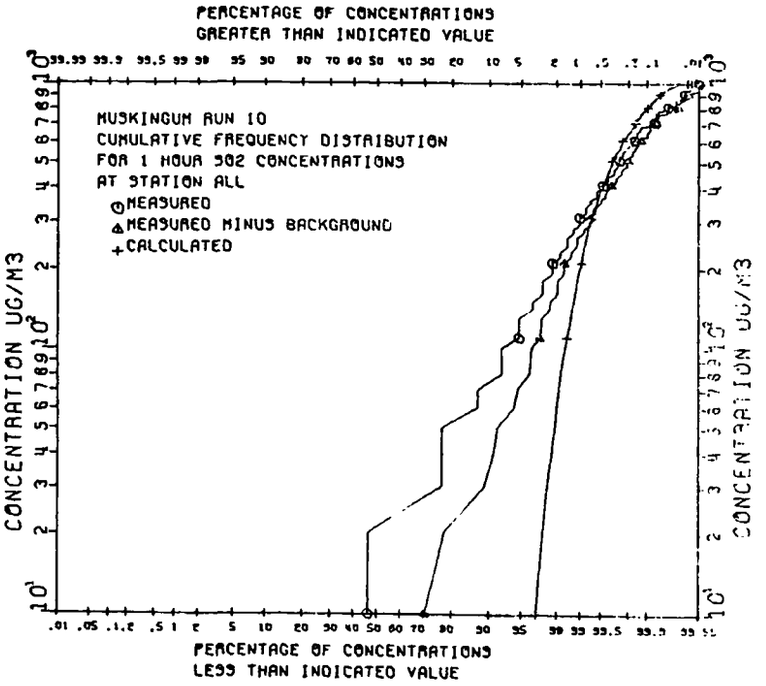

Figure 29e. Model validation Run No. 10. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Muskingum Plant for all stations

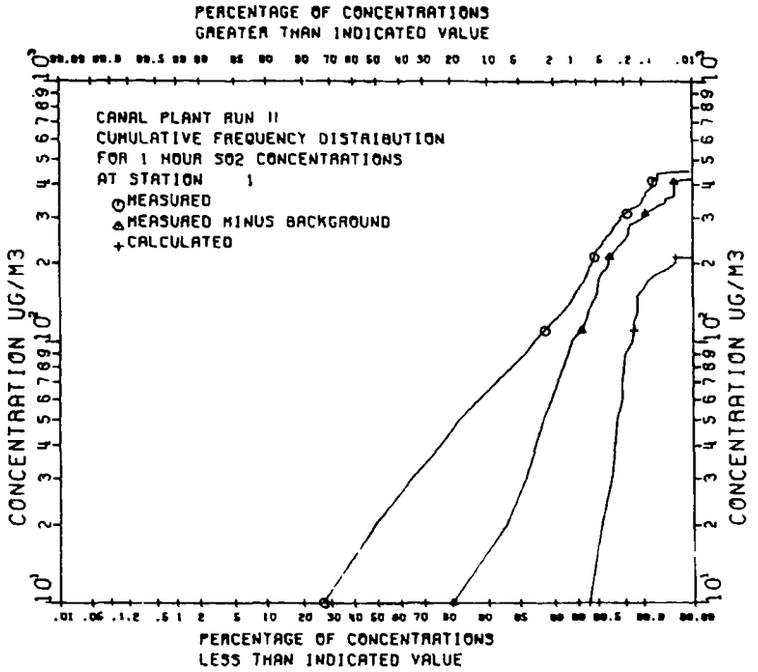

Figure 30a. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 1

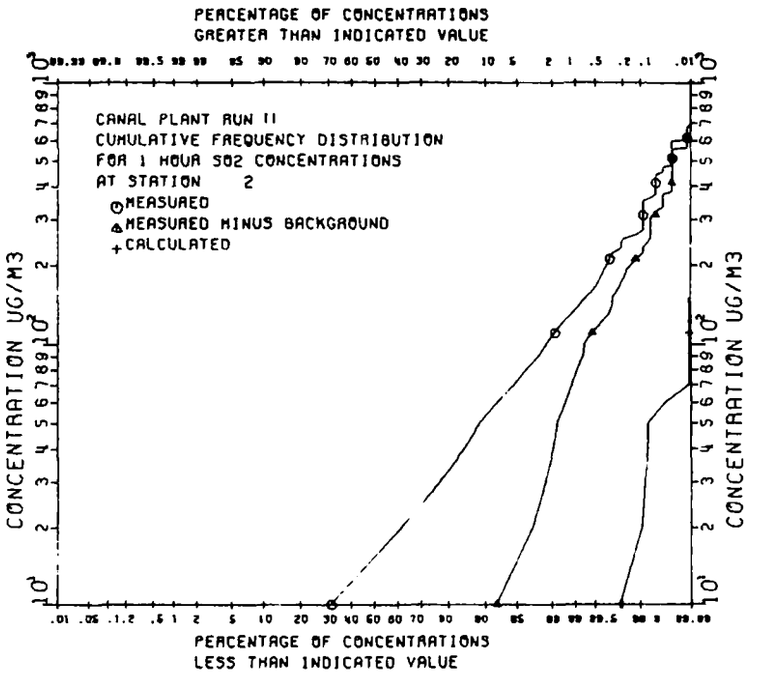

Figure 30b. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 2

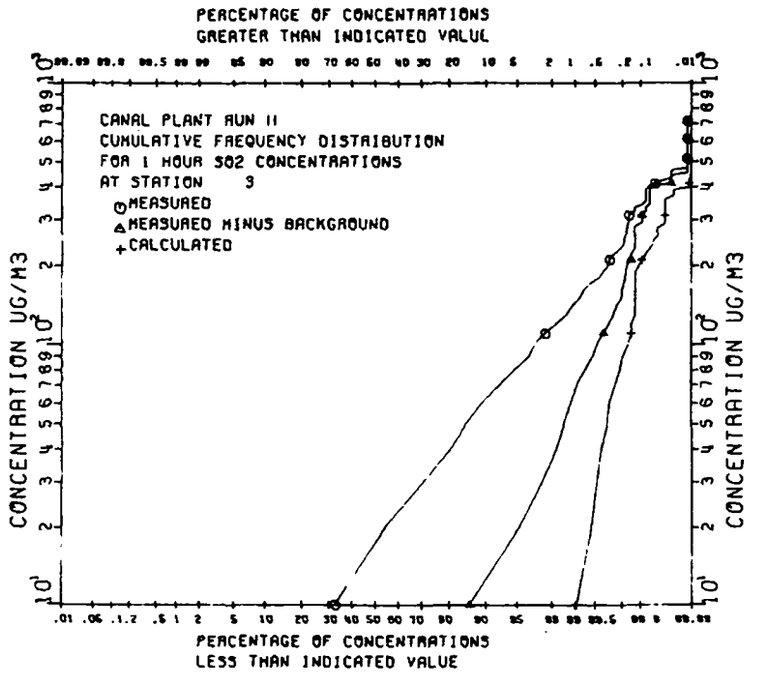

Figure 30c. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 3

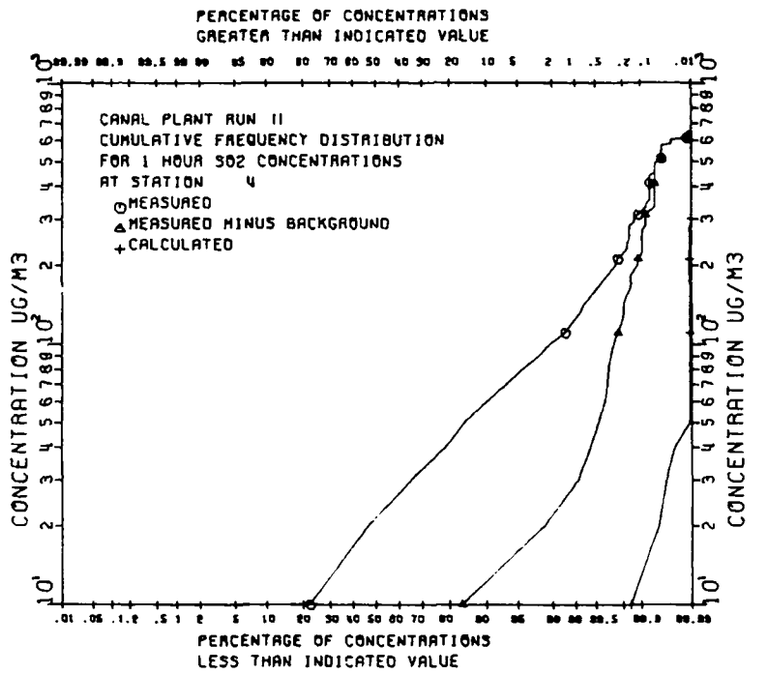

Figure 30d. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant Station 4

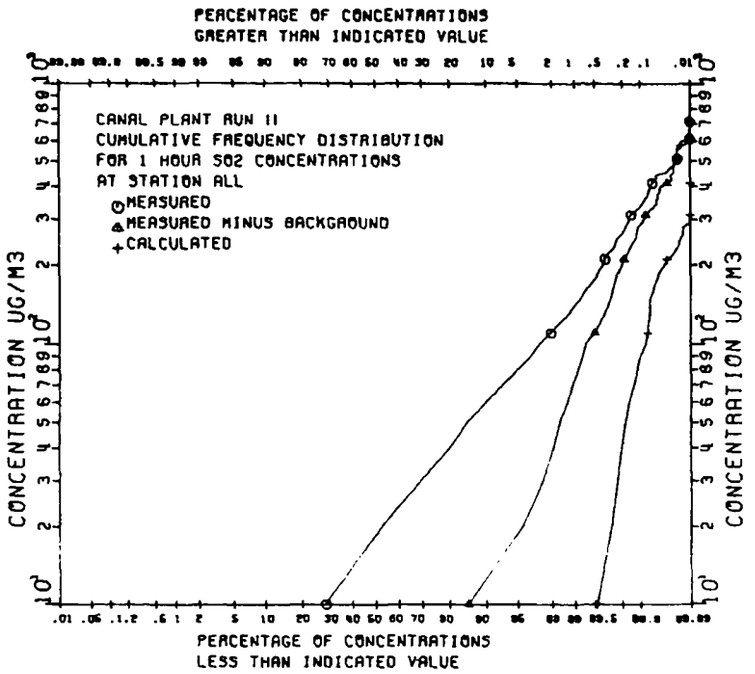

Figure 30e. Model validation Run No. 11. Variable buoyancy flux. Measured and predicted cumulative frequency distributions of 1-hour SO_2 concentrations for Canal Plant for all stations

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of this study we would recommend that the methods currently used for the calculation of dispersion coefficients and the selection of stability classes not be replaced by alternate techniques, at least until further model validation studies are conducted. Since data from only two power plants were used in this study the results could hardly be called definitive. Nevertheless, even from these limited results, we may draw a number of conclusions:

1. The similarity between the Pasquill-Turner and Gifford-Briggs dispersion coefficients (except for stability A) will require that a large number of model validation exercises be carried to determine which method is more accurate.

2. The use of the Smith-Singer stability assignment and dispersion calculation methods in the Single Source Model may yield unrealistic frequency distributions of 1-hour concentrations. This observation must be qualified, however, by the fact that the validation was carried out only for the Muskingum Plant. Since the rather subjective stability assignment scheme may have been carried out differently at the Muskingum Plant, the Smith-Singer version of the Single Source Model may give better agreement with measured concentrations if applied elsewhere.

3. Due to the strong variation of calculated concentrations as a function of stability, the use of fractional stability assignments should, in principle, lead to more accurate model predictions. The F.B. Smith stability classification method did not, however, provide better agreement between measured and calculated concentration frequency distributions, primarily because of its tendency to underestimate the stability class.

4. The use of a variable buoyancy flux in the Single Source Model did little to improve the agreement between measured and calculated concentration frequency distributions. This conclusion is similar to others reached when more detailed or applicable emissions or meteorological data has been used in model validation exercises. The success or failure of the model in any given application is much more a function of the assumptions regarding plume rise, dispersion, and terrain effects that form the theoretical basis for the model.

SECTION VI

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APPENDIX A

TURNER SCHEME FOR STABILITY CLASSIFICATION

The following scheme for stability classification was described by D. Bruce Turner in the February 1964 edition of the Journal of Applied Meteorology:

This system of classifying stability on an hourly basis for research in air pollution is based upon work accomplished by Dr. F. Pasquill of the British Meteorological Office. Stability near the ground is dependent primarily upon net radiation and wind speed. Without the influence of clouds, insolation (incoming radiation) during the day is dependent upon solar altitude, which is a function of time of day and time of year. When clouds exist their cover and thickness decrease incoming and outgoing radiation. In this system insolation is estimated by solar altitude and modified for existing conditions of total cloud cover and cloud ceiling height. At night estimates of outgoing radiation are made by considering cloud cover. This stability classification system has been made completely objective so that an electronic computer can be used to compute stability classes. The stability classes are as follows: (1) Extremely unstable; (2) unstable; (3) slightly unstable; (4) neutral; (5) slightly stable; (6) stable; (7) extremely stable. Table A-1 gives the stability class as a function of wind speed and net radiation. The net radiation index ranges from 4, highest positive net radiation (directed toward the ground), to -2, highest negative net radiation (directed away from the earth). Instability occurs with high positive net radiation and low wind speed, stability with high negative net radiation and light winds, and neutral conditions with cloudy skies or high wind speeds.

Table A-1. STABILITY CLASS AS A FUNCTION OF NET RADIATION AND WIND SPEED

Wind speed, knots	Net radiation index						
	4	3	2	1	0	-1	-2
0,1	1	1	2	3	4	6	7
2,3	1	2	2	3	4	6	7
4,5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8,9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
$\geq$12	3	4	4	4	4	4	4

The net radiation index used with wind speed to obtain stability class is determined by the following procedure:

1. If the total cloud cover is 10/10 and the ceiling is less than 7000 feet, use net radiation index equal to 0 (whether day or night).

2. For night-time (between sunset and sunrise):

   a. If total cloud cover $\leq$4/10, use net radiation index equal to -2.

   b. If total cloud cover >4/10, use net radiation index equal to -1.

3. For daytime:

   a. Determine the insolation class number as a function of solar altitude from Table A-2.

   b. If total cloud cover $\leq$5/10, use the net radiation index in Table A-1 corresponding to the insolation class number.

   c. If cloud cover >5/10, modify the insolation class number by following these six steps.

      (1) Ceiling <7,000 ft, subtract 2.

Table A-2. INSOLATION AS A FUNCTION OF SOLAR ALTITUDE

Solar altitude (a)	Insolation	Insolation class number
$60^{o} < a$	Strong	4
$35^{o} < a \leq 60^{o}$	Moderate	3
$15^{o} < a \leq 35^{o}$	Slight	2
$a \leq 15^{o}$	Weak	1

(2) Ceiling $\geq$ 7000 ft but < 16,000 ft, subtract 1.

(3) Total cloud cover equal 10/10, subtract 1. (This will only apply to ceilings $\geq$ 7000 ft since cases with 10/10 coverage below 7000 ft are considered in item 1 above.)

(4) If insolation class number has not been modified by steps (1), (2), or (3) above, assume modified class number equal to insolation class number.

(5) If modified insolation class number is less than 1, let it equal 1.

(6) Use the net radiation index in Table A-1 corresponding to the modified insolation class number.

The Pasquill-Turner technique for stability class assignment is the one currently employed in the Single Source Model Preprocessor program except that Table A-1 has been expanded to provide a greater resolution according to wind speed (see Table A-3).

Table A-3. ADAPTATION OF TABLE A-1 FOR USE IN THE SINGLE SOURCE MODEL PREPROCESSOR PROGRAM

Wind speed, knots	Net radiation index						
	4	3	2	1	0	-1	-2
1	1	1	2	3	4	7	7
2	1	2	2	3	4	7	7
3	1	2	2	3	4	6	7
4	1	2	3	4	4	5	7
5	1	2	3	4	4	5	6
6	2	2	3	4	4	5	6
7	2	2	3	4	4	4	5
8	2	3	3	4	4	4	5
9	2	3	3	4	4	4	5
10	3	3	4	4	4	4	5
11	3	3	4	4	4	4	4
$\geq$12	3	4	4	4	4	4	4

APPENDIX B

LISTINGS OF THE FRACTIONAL STABILITY PREPROCESSOR PROGRAM AND CORRESPONDING VERSION OF THE SINGLE SOURCE MODEL

```
PREP:   PROCEDURE OPTIONS(MAIN);

 STMT LEVEL NEST
    1             PREP:   PROCEDURE OPTIONS(MAIN);
                  /* OCTOBER 1972 VERSION */
    2     1       DECLARE ASHV FILE RECORD;
    3     1       DECLARE MET FILE RECORD OUTPUT;
    4     1       DECLARE IDC FIXED DECIMAL(5,0),
                        (YRC,LWD,XHR) FIXED DECIMAL(2,0),
                        (IND,ISKY,IROOF,IRADX,IREC INITIAL(1),I,J,IDY,IHR,KHR,IY,
                        IX INITIAL(65549) ,IMO INITIAL(1),
                        ICN,KSTSP,ZONE,KST(24) INITIAL((24) 0)) FIXED BIN(31),
                        (IDFAC(12) INITIAL(0,31,59,90,120,151,181,212,243,273,304,334),
                        ANGL(3) INITIAL(60., 35., 15.) ,FV,XDIR) FIXED DECIMAL(3,0),
                        IFVR FIXED DECIMAL(1,0),
                        (YFL,DAYNO,TDAYNO,SIND,COSD,SINTD,COSTD,SIGMA,DSIN,DCOS,
                        SINLAT,COSLAT,ALAT,ALONG,HCOS,H2,H1,CONST INITIAL(57.29578),
                        ALF,ALFSN,AMM,TSR,TSS) FLOAT DECIMAL,
                              (S,XAF,XAFP1,XAFM1,XMN,XMNP1,XMNM1) FIXED DECIMAL(8,3);
    5     1       DECLARE HSKIP INITIAL(0) FIXED BIN(31);
    6     1       DECLARE       (COEF(4,14) INITIAL(.3696429E+01,.3877143E+01,
                  .4148571E+01,.4479286E+01,.462E+01,.4755E+01,.4932857E+01,
                  .3649495E+01,.3913232E+01,.4554444E+01,.5839798E+01,
                  .7017677E+01,.9922898E+01,.1471869E+02,
                  -.9542929E-02,-.3097042E-01,-.6534488E-01,-.103329,-.1196898,
                  -.135526,-.1548445,-.8374218E-02,-.5276575E-01,-.1726251,
                  -.4260185,-.7639839,-.2155727E+01,-.4151976E+01,
                  -.1655844E-04,.2341991E-03,.7816017E-03,.1350649E-02,
                  .1526299E-02,.1738961E-02,.1946537E-02,.1219336E-02,
                  .3607504E-02,.1104257E-01,.245202E-01,.5354618E-01,
                  .2839127,.5724983,
                  .2020202E-06,-.1161616E-05,-.4343434E-05,
                  -.7121212E-05,-.7853535E-05,-.8939394E-05,
                  -.9520202E-05,-.1178451E-03,-.2356902E-03,
                  -.5387205E-03,-.7744108E-03,-.1380471E-02,
                  -.1416177E-01,-.284291E-01),
                  CLOUD(9) INITIAL(8.,7.,6.,5.,4.,3.,2.,1.,0.), CMULT(9) INITIAL
                  (.23,.45,.59,.67,.72,.76,.81,.89,1.07),WIND(7) INITIAL
                  (8.,6.,5.,4.,3.,2.,0.),XMULT,WATTS,WATTS1,FKST(24) INITIAL(
                  (24) 0.),P1,P2,CLD,Z,ZALF,A0) FLOAT DECIMAL;
    7     1       DECLARE 1 INDATA,
                        2 ID PICTURE '99999',
                        2 IYEAR PICTURE '99',
                        2 IMONTH PICTURE '99',
                        2 IDAY PICTURE '99',
                        2 IHOUR PICTURE '99',
                        2 ICEIL CHAR(3),
                        2 IDUM1 CHAR(22),
                        2 IDIR PICTURE '99',
                        2 ISPEED PICTURE '99',
                        2 IDUM2 CHAR(4),
                        2 ITEMP PICTURE '999',
                        2 IDUM3 CHAR(29),
                        2 ICOVER CHAR(1),
                        2 IDUM4 CHAR(1),
                  1 OUTDATA,
                        2 YR PICTURE '99',
                        2 MONTH PICTURE '99',
                        2 DAY1 PICTURE '999',
```

```
PREP:  PROCEDURE OPTIONS(MAIN);

STMT LEVEL NEST
                                    2 KKST(0:23) PICTURE '99',
                                    2 SPEED(0:23) PICTURE '999V99',
                                    2 TEMP(0:23) PICTURE '999V9',
                                    2 AFV(0:23) PICTURE '999',
                                    2 FVR(0:23) PICTURE '999',
                                    2 HLH(2,0:23) PICTURE '99999V999';
   8     1          DECLARE TITLEA CHAR(8);
   9     1          DECLARE TITLEB CHAR(8);
  10     1          F1:     FORMAT(COL(14),F(4,0),COL(25),F(4,0));
  11     1                  ON ENDFILE(SYSIN)GO TO FINISH;
                    /* READ CARD TO INITIALIZE MET TAPE ID,YEAR & LAST WIND DIRECTION*/
  13     1          AGAIN:  GET FILE(SYSIN) DATA (IDC,YRC,LWD,ALAT,ALONG,ZONE,TITLEA,
                             TITLEB);
  14     1                  IREC=1; IMO=1; IX=65549;
  17     1                  OPEN FILE(ASHV) RECORD TITLE(TITLEA);
  18     1                  OPEN FILE(MET) RECORD OUTPUT TITLE(TITLEB);
  19     1                  ON ERROR PUT FILE(SYSPRINT) EDIT
                             ('RECORD # AT TIME OF ERROR CONDITION=',IREC) (A(36),F(4,0));
  21     1                  ON ENDFILE(ASHV) GO TO LAST;
                    /* READ A CARD WITH FIRST HOUR'S DATA */
  23     1                  READ FILE(ASHV) INTO(INDATA);
                    /* READ PRIOR DAY'S MIXING HEIGHT VALUES */
  24     1                  GET FILE(SYSIN) EDIT    (XMNM1,XAFM1) (R(F1));
                    /* READ PRESENT DAY'S MIXING HEIGHT VALUES */
  25     1                  GET FILE(SYSIN) EDIT    (XMN,XAF) (R(F1));
                    /* ENTER DAY LOOP TO READ NEXT DAY'S MIXING HEIGHT VALUES */
  26     1                  DO IDY=1 TO 365;
  27     1     1            GET FILE(SYSIN) EDIT    (XMNP1,XAFP1) (R(F1));
                    /* CALCULATE THE DAYNO AND THE TIME OF SUNRISE AND SUNSET */
  28     1     1              DAY1=IDAY+1DFAC*IMONTH);
                    /* CONSTANT 20926.82528=365.242*57.29578  */
  29     1     1              DAYNO=((DAY1-1.0)*360.)/20926.82528 ;
  30     1     1              TDAYNO=2.*DAYNO  ;
  31     1     1              SIND=SIN(DAYNO)   ;
  32     1     1              COSD=COS(DAYNO)   ;
  33     1     1              SINTD=SIN(TDAYNO)  ;
  34     1     1              COSTD=COS(TDAYNO)  ;
  35     1     1              SIGMA=279.9348+(DAYNO*CONST)+1.914827*SIND-0.079525*COSD+
                             0.019938*SINTD-0.00162*COSTD ;
                    /* CONSTANT .4091720193=23.44383/57.29578  */
  36     1     1              DSIN=SIN(.4091720193)*SIN(SIGMA/CONST);
  37     1     1              DCOS=SQRT(1.0-DSIN*DSIN) ;
  38     1     1              AMM=12.0+0.12357*SIND-0.004289*COSD+0.153809*SINTD+0.060783*COSTD;
  39     1     1              SINLAT=SIN(ALAT/CONST)  ;
  40     1     1              COSLAT=COS(ALAT/CONST)   ;
  41     1     1              HCOS=(-SINLAT*DSIN)/(COSLAT*DCOS) ;
  42     1     1                 H2=ATAND(SQRT(1.-HCOS*HCOS),HCOS)/15.0;
  43     1     1              TSR=(ALONG/15.0+AMM-H2)-ZONE ;
  44     1     1              TSS=(ALONG/15.0+AMM+H2)-ZONE ;
  45     1     1                 DO KHR=0 TO 23;
                    /*CHECK DATA FOR CORRECTNESS & CONTINUITY */
  46     1     2    CHECK:  IF ID¬=IDC THEN DO;
  48     1     3                 PUT SKIP FILE(SYSPRINT) EDIT
                                 ('ID DOES NOT MATCH IN RECORD # ',IREC,'   ID IS ',ID)
                                 (A(30),F(4,0),A(9),F(5,0));
```

```
PREP:   PROCEDURE OPTIONS(MAIN);

STMT LEVEL NEST
  49     1    3                 GO TO NEWREC;
  50     1    3                 END;
  51     1    2               IF IYEAR ¬=YRC THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                                 ('YEAR IS ',IYEAR,' INSTEAD OF ',YRC,' IREC=',IREC)
                                 (A(8),F(2,0),A(12),F(2,0),A(6),F(4,0));
  54     1    3                 GO TO NEWREC; END;
  56     1    2               OUTDATA.YR=IYEAR;
  57     1    2               IF IMONTH¬=IMO THEN      IF IMONTH¬=IMO+1  THEN DO;
  60     1    3                 PUT SKIP FILE(SYSPRINT) EDIT
                                 ('MONTH ',IMONTH,' DOES NOT AGREE WITH LOOP ',IMO,' IREC=',
                                 IREC) (A(6),F(2,0),A(26),F(2,0),A(6),F(4,0));
  61     1    3                 GO TO FINISH; END;
  63     1    2               ELSE IMO=IMONTH;
  64     1    2               OUTDATA.MONTH=IMONTH;
  65     1    2               IF DAY1¬=IDY THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                                 ('DAY ',DAY1,' DOES NOT AGREE WITH LOOP ',IDY,' IREC=',IREC)
                                 (A(4),F(2,0),A(26),F(2,0),A(6),F(4,0));
  68     1    3                 GO TO DLOOP;  END;
  70     1    2               IF IHOUR¬=KHR THEN DO; PUT SKIP FILE(SYSPRINT) EDIT
                                 ('HOUR ',IHOUR,' DOES NOT AGREE WITH LOOP ',KHR,' IREC=',
                                 IREC) (A(5),F(2,0),A(26),F(2,0),A(6),F 4,0));
  73     1    3               HSKIP=1;
  74     1    3               END;
                          /* CONVERSION OF ISKY & IROOF  */
  75     1    2               IF ICEIL='---' THEN IROOF=998;
  77     1    2                 ELSE IROOF=ICEIL;
  78     1    2               IF ICOVER='-' THEN ISKY=10;
  80     1    2                 ELSE ISKY=ICOVER;
                          /* CONVERT TEMPERATURE FROM FAHRENHEIT TO KELVIN  */
  81     1    2               OUTDATA.TEMP(KHR)=0.5556*(ITEMP-32.)+273.15 ;
                          /* CONVERT WIND SPEED FROM KNOTS TO METERS/SECOND  */
  82     1    2               S=ISPEED*0.51444 ;
  83     1    2               IF S<1.0 THEN S=1.0 ;
  85     1    2               OUTDATA.SPEED(KHR)=S ;
  86     1    2               CLD=ISKY*.8;
                          /* CHECK FOR CALMS */
  87     1    2               IF IDIR=0. THEN IDIR=LWD;
  89     1    2               ELSE LWD=IDIR;
  90     1    2               XDIR=IDIR*10.;
                          /* CALCULATE FLOW VECTOR AND RANDOM FLOW VECTOR  */
  91     1    2               IF XDIR>180. THEN FV=XDIR-180.;
  93     1    2                 ELSE FV=XDIR+180.;
  94     1    2               OUTDATA.AFV(KHR)=FV;
  95     1    2               (NOFIXEDOVERFLOW):B1:BEGIN;
  96     2    2               IY=IX*65539 ;
  97     2    2               IF IY<0 THEN IY=IY+2147433647+1 ;
  99     2    2               YFL=IY ;
 100     2    2               YFL=YFL*.4656613E-09 ;
 101     2    2               IX=IY ;
 102     2    2               END;
 103     1    2               IFVR=YFL*10000;
 104     1    2               OUTDATA.FVR(KHR)=FV+IFVR-4.0 ;
 105     1    2               IF OUTDATA.FVR(KHR)>360. THEN
 106     1    2                 OUTDATA.FVR(KHR)=OUTDATA.FVR(KHR)-360.;
                          /* DETERMINE STABILITY */
```

```
PREP:  PROCEDURE OPTIONS(MAIN);

STMT LEVEL NEST
107     1    2          IF S>8. THEN GO TO BB;
109     1    2          IF IHOUR<TSR THEN GO TO C;
111     1    2          IF IHOUR>TSS THEN GO TO C;
                    /* DETERMINE THE ANGLE OF ELEVATION  */
113     1    2     DAYTIME: H1=(15.0*((KHR+ZONE)-AMM)-ALONG)/CONST;
114     1    2          ALFSN=SINLAT*DSIN+DCOS*COSLAT*COS(H1) ;
115     1    2          ALF=ATAND(ALFSN,SQRT(1.-ALFSN*ALFSN));
116     1    2          ZALF=90.-ALF;
117     1    2          AO=.57+.0045*ZALF;
118     1    2          ZALF=ZALF/CONST;
119     1    2          WATTS1=135.3*AO**(1./COS(ZALF))*COS(ZALF);
                    /* INTERPOLATE INCOMING SOLAR RADIATION FACTOR */
120     1    2          DO I=2 TO 9;
121     1    3          IF CLD>=CLOUD(I) & CLD<=CLOUD(I-1) THEN GO TO A;
123     1    3          END;
124     1    2     A:   K=I-1;
125     1    2          XMULT=CMULT(K)-((CLOUD(K)-CLD)*(CMULT(K)-CMULT(I))/(CLOUD(K)-
                        CLOUD(I)));
126     1    2          WATTS=WATTS1*XMULT;
127     1    2          IF WATTS<10. THEN GO TO C;
                    /* FIND STABILITY USING RADIATION, WIND, AND CLOUD COVER */
129     1    2          DO J=2 TO 7;
130     1    3          IF S>=WIND(J) & S<=WIND(J-1) THEN GO TO B;
132     1    3          END;
133     1    2     B:   M=J-1;
134     1    2          P1=COEF(1,M) +COEF(2,M)*WATTS+COEF(3,M)*WATTS**2+COEF(4,M)
                        *WATTS**3;
135     1    2          P2=COEF(1,J)+COEF(2,J)*WATTS+COEF(3,J)*WATTS**2+COEF(4,J)
                        *WATTS**3;
136     1    2          FKST(KHR)=P1-((WIND(M)- S  )*(P1-P2)/(WIND(M)-WIND(J)));
137     1    2          GO TO D;
138     1    2     BB:  FKST=3.6;
139     1    2          GO TO D;
                    /* CALCULATE STABILITY USING CLOUD COVER AND WINDSPEED */
140     1    2     C:   DO J=2 TO 7;
141     1    3          IF S>=WIND(J) & S<=WIND(J-1) THEN GO TO CC;
143     1    3          END;
144     1    2     CC:  M=J+6;
145     1    2          MM=J+7;
146     1    2          K=J-1;
147     1    2          P1=COEF(1,M)+COEF(2,M)*CLD+COEF(3,M)*CLD**2+COEF(4,M)*CLD**3;
148     1    2          P2=COEF(1,MM)+COEF(2,MM)*CLD+COEF(3,MM)*CLD**2+COEF(4,MM)*
                        CLD**3;
149     1    2          FKST(KHR)=P1-((WIND(K)- S  )*(P1-P2)/(WIND(K)-WIND(J)));
150     1    2     D:   KST(KHR)=FKST(KHR)+0.9;
151     1    2          ITEST=10.*(FKST(KHR)+0.4);
152     1    2          OUTDATA.KKST(KHR)=ITEST
153     1    2          IF ITEST>70 THEN OUTDATA.KKST(KHR)=70;
                    /* CALCULATE MIXING HEIGHT */
155     1    2          IHR=KHR+1;
156     1    2          XHR=IHR;
157     1    2          IF IHR>14 THEN IF XHR<=TSS THEN DO;
160     1    3            HLH(1,KHR)=XAF;
161     1    3            HLH(2,KHR)=XAF;
162     1    3            GO TO NEWREC;  END;
```

```
PREP:   PROCEDURE OPTIONS(MAIN);

STMT LEVEL NEST
 164     1    2              IND=2;
 165     1    2              IF XHR>TSS THEN DO;
 167     1    3                IF KST(KHR)¬=4 THEN DO;
 169     1    4                  HLH(2,KHR)=XAF+(XMNP1-XAF)*((XHR-TSS)/(24.-TSS));
 170     1    4                  IND=1;  END;
 172     1    3                HLH(IND,KHR)=XAF+(XAFP1-XAF)*((XHR-TSS)/(38.-TSS));
 173     1    3                IF IND=2 THEN HLH(1,KHR)=HLH(2,KHR);
 175     1    3              GO TO NEWREC;   END;
 177     1    2              IF XHR<=TSR THEN DO;
 179     1    3                KSTSP=KST(KHR);
 180     1    3                IF KST(KHR)¬=4 THEN DO;
 182     1    4                  HLH(2,KHR)=XMN;
 183     1    4                  IND=1;   END;
 185     1    3                HLH(IND,KHR)=XAFM1+(XAF-XAFM1)*((24.-TSS+XHR)/(24.-TSS+14.));
 186     1    3                IF IND=2 THEN HLH(1,KHR)=HLH(2,KHR);
 188     1    3              GO TO NEWREC;   END;
 190     1    2              IF KSTSP¬=4 THEN DO;
 192     1    3                HLH(2,KHR)=XMN+(XAF-XMN)*((XHR-TSR)/(14.-TSR));
 193     1    3                HLH(1,KHR)=XAF*(XHR-TSR)/(14.-TSR);
 194     1    3                END;
 195     1    2              ELSE DO;
 196     1    3                HLH(1,KHR)=XAFM1+(XAF-XAFM1)*((24.-TSS+XHR)/(24.-TSS+14.));
 197     1    3              HLH(2,KHR)=HLH(1,KHR);
 198     1    3                END;
                       /* READ NEXT HOUR'S MET DATA */
 199     1    2        NEWREC: IF HSKIP=0 THEN DO;
 201     1    3                READ FILE(ASHV) INTO(INDATA);
 202     1    3                IREC=IREC+1;
 203     1    3                END;
 204     1    2              ELSE HSKIP=0;
 205     1    2        HLOOP:  END;
                       /* UPDATE MIXING HEIGHTS */
 206     1    1              XMNM1=XMN;
 207     1    1              XAFM1=XAF;
 208     1    1              XMN=XMNP1;
 209     1    1              XAF=XAFP1;
                       /* WRITE A DAY'S CALCULATIONS ON TO TAPE */
 210     1    1              WRITE FILE(MET) FROM(OUTDATA);
 211     1    1        DLOOP:  END;
 212     1         1    LAST:   WRITE FILE(MET) FROM(OUTDATA);
 213     1                    CLOSE FILE(ASHV),FILE(MET);
 214     1                    PUT SKIP FILE(SYSPRINT) EDIT
                              (' ALL RECORDS HAVE BEEN PROCESSED ') (A(33));
 215     1                    GO TO AGAIN;
 216     1              FINISH: END PREP;
```

```
FORTRAN IV G1  RELEASE 2.0            MAIN              DATE   76153        15/29/09

                C***  PROGRAM JMHCRS1 (KLUG VALIDATION)                                  00001800
                C***     THIS PROGRAM CALCULATES HOURLY AND 24-HOURLY CONCENTRATIONS FOR  00001900
                C***       A YEAR ABOUT A SINGLE SOURCE.                                00002000
                C*** OCTOBER 1972 VERSION ***                                           00002100
                C***DESCRIPTION OF ARRAYS***                                            00002200
                C***   DHRS(L)=RECEPTOR ELEVATION MINUS SOURCE ELEVATION(METERS)        00002300
                C***   QHOUR(IHOUR)=HOURLY SOURCE STRENGTH OF SO2(GM/SEC)               00002400
                C***   HMAX(RECEPTOR,3) 1=HOURLY CONCENTRATION, 2=DAY, 3=HOUR           00002500
                C***   DMAX(RECEPTOR,2) 1=24-HOUR CONCENTRATION, 2=DAY                  00002600
                C***   HMAXYR(5) 1=MAX HOUR CONCENTRATION, 2=DIRECTION, 3=DISTANCE,     00002700
                C***      4=DAY, 5=HOUR                                                 00002800
                C***   DMAXYR(4) 1=MAX 24-HOUR CONCENTRATION, 2=DIRECTION, 3=DISTANCE, 4=00002900
                C***   CHI(RECEPTOR,26) 1-24=HOURLY CONCENTRATIONS, 25=24-HOUR CONCENTRAT00003000
                C***      26=ANNUAL CONCENTRATION                                       00003100
                C*** IUR IS INDICATOR FOR 1=RURAL, 2=URBAN MIXING HEIGHTS             00003200
                C***                                                                    00003300
                C***   NSTA=NUMBER OF STATIONS UP TO 7                                  00003400
                C***   NMOD=NUMBER OF MODEL STATIONS    =NSTA*36                        00003500
0001                   DIMENSION RNG(7),DTH(11),IHC(4),SYD(7,60),SZD(7,60),P(6),WS(20),
                      *HE(20),HMAX(252,3),CHI(252,26),DMAX(252,2),LOOP(6,2),           00003700
                      *HMAXYR(5),DMAXYR(4),Q(20),HP(20),TS(20),VF(20),ISTAB(24),AWS(24), 00003800
                      *TEMP(24),AFV(24),AFVR(24),HLH(2,24),TITLE(20),SOURCE(20),        00003900
                      *IDENT(5),ISTABP(24)
0002                   DIMENSION DHRS(7),QHOUR(20,24),IDSOR(3)                          00004100
0003                   DATA IHC/6,13,18,24/, P/0.1,0.15,0.2,0.25,0.3,0.3/,              00004200
                      * DTH/-50., -40., -30., -20., -10., 0., 10., 20., 30., 40., 50./  00004300
0004                   DATA HMAXYR/5*0.0/, DMAXYR/4*0.0/                                00004400
0005                   DATA LOOP/1, 1, 2, 3, 4, 4, 11, 11, 10, 9, 8, 8/                 00004500
0006                   IE=4                                                             00004600
0007                   IN=5                                                             00004700
0008                   IO=6                                                             00004800
0009                   IP=7                                                             00004900
0010                   READ(IN,5501) TITLE                                              00005000
0011            5501   FORMAT(20A4)                                                     00005100
0012                   WRITE(IO,5500) TITLE                                             00005200
0013            5500   FORMAT('1',20A4//1X)                                             00005300
                C***READ CARD TO INITIALIZE STABILITY AND TO DETERMINE RURAL OR URBAN   00005400
                C***MIXING HEIGHTS                                                      00005500
0014                   READ(IN,5502) KSTL,IUR,IDENT,NSTA                                00005600
0015                   KSTLP=10*KSTL
0016            5502   FORMAT(T11,I1,T17,I1,T20,5A4,T45,I1)                             00005700
0017                   IF(NSTA.LT.1.OR.NSTA.GT.7) NSTA=7                                00005800
0018                   READ(IN,603) (DHRS(L),L=1,NSTA)                                  00005900
0019             603   FORMAT(7F10.2)                                                   00006000
0020                   WRITE(IO,604) (DHRS(L),L=1,NSTA)                                 00006100
0021             604   FORMAT(/,1X,'ELEVATION DIFFERENCES BETWEEN RECEPTOR AND SOURCE LOC00006200
                      &ATIONS=',7E10.2,/)                                               00006300
0022                   WRITE(IO,5504) IUR                                               00006400
```

```
0023          5504 FORMAT(1X,'IUR=',I2,/)                                    00006500
              C***INITIALIZATIONS                                            00006600
0024               NMOD=NSTA*36                                              00006700
0025               JDAY=0                                                    00006800
0026               NS=0                                                      00006900
0027               DO 4 I=1,NMOD                                             00007000
0028               CHI(I,26)=0.0                                             00007100
0029               DO 3 J=1,3                                                00007200
0030          3    HMAX(I,J)=0.0                                             00007300
0031               DO 6 J=1,2                                                00007400
0032          6    DMAX(I,J)=0.0                                             00007500
0033          4    CONTINUE                                                  00007600
              C***                                                           00007700
              C***INPUT RECEPTOR RANGES                                      00007800
0034               READ(IN,605) RNG                                          00007900
0035            605 FORMAT(7F10.3)                                           00008000
              C***CALCULATE AND STORE SIGMAS FOR 6 STAB. & NSTA DIST.        00008100
              C***DISTANCE IS ASSUMED TO BE IN KILOMETERS***                 00008200
              C***                                                           00008300
0036               DO 7 J=1,NSTA                                             00008400
0037               X=RNG(J)                                                  00008500
0038               DO 7 KSTP=10,60
0039               CALL SIGMA(X,X,KSTP,SY,SZ)
0040               SYD(J,KSTP)=SY
0041               SZD(J,KSTP)=SZ
0042          7    CONTINUE                                                  00009000
              C***                                                           00009100
              C***INPUT SOURCES TO BE CONSIDERED                             00009200
0043          2    NS=NS+1                                                   00009300
0044               READ(IN,5501) SOURCE                                      00009400
0045               READ(IN,200) HP(NS),TS(NS),VS,D                           00009500
0046           200 FORMAT(10X,F6.2,8X,3F8.2)                                 00009600
0047               VF(NS) = 0.785398*VS*D*D                                  00009700
0048               IF(HP(NS).LE.0.001) GO TO 5                               00009800
0049               WRITE(IO,5555) SOURCE                                     00009900
0050          5555 FORMAT(1X,20A4)                                           00010000
0051               WRITE(IO,201) NS,HP(NS),TS(NS),VS,D,VF(NS)                00010100
0052           201 FORMAT(1X,'NS=',I2,' HP=',F7.2,' TS=',F5.0,' VS=',        00010200
             *F7.2,' D=',F6.2,' VF=',F8.2//1X)                               00010300
0053               GO TO 2                                                   00010400
0054          5    NS=NS-1                                                   00010500
0055               WRITE(IO,203) (RNG(J),J=1,NSTA)                           00010600
0056            203 FORMAT('           RANGE(KM)=',7F7.2,/)                  00010700
              C***                                                           00010800
              C***                                                           00010900
              C***BEGIN LOOP ON DAYS***                                      00011000
0057               DO 90 IDY=1,365                                           00011100
              C***RE-INITIALIZE DAILY AVERAGE AT BEGINNING OF EACH DAY***    00011200
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0058                  VPS=0.0                                                    00011400
0059                  UPS=0.0                                                    00011500
0060                  WSS=0.0                                                    00011600
0061                  DO 33 IR=1,NMOD                                            00011700
0062                  DO 33 IHR=1,25                                             00011800
0063            33    CHI(IR,IHR)=1.0E-50                                        00011900
0064                  HMAXT=0.0                                                  00012000
0065                  MIH=0                                                      00012100
0066                  MJH=0                                                      00012200
                C***                                                             00012300
                C***INPUT INFORMATION FROM MET FILE***                           00012400
                C***                                                             00012500
0067                  JODAY=JDAY                                                 00012600
0068                  READ(9,400) JYR,IMO,JDAY,ISTABP,AWS,TEMP,AFV,AFVR,
                     *((HLH(I,J),J=1,24),I=1,2)                                  00012800
0069             400  FORMAT(2I2,I3,24I2,24F5.2,24F4.1,24F3.0,24F3.0,48F8.3)     00012900
0070                  DO 399 LL=1,24
0071                  IF(ISTABP(LL).LT.10) ISTABP(LL)=10
0072                  IF(ISTABP(LL).GT.70) ISTABP(LL)=70
0073                  ISTAB(LL)=FLOAT(ISTABP(LL))/10.+0.5
0074             399  CONTINUE
                C* CHANGE                                                         00013000
                C     IF(IDY.GT.10.AND.(JDAY.EQ.(JODAY+1).OR.JDAY.EQ.1)) GO TO 6404 00013100
0075                  IF(JDAY.NE.(JODAY+1).AND.JDAY.NE.1)  WRITE(IE,6403)        00013200
0076             6403 FORMAT(' MET DATA INPUT ERROR')                            00013300
0077                  WRITE(IO,6400) JYR,IMO,JDAY                                00013400
0078             6400 FORMAT(' JYR=',I2,' IMO=',I2,' JDAY=',I3)                  00013500
0079                  WRITE(IO,6401) ISTABP
0080             6401 FORMAT(' ISTAB= ',24(I2,3X))
0081                  WRITE(IO,6402) AWS,TEMP,AFV,AFVR,((HLH(I,J),J=1,24),I=1,2) 00013800
0082             6402 FORMAT(' AWS=  ',24(F4.1,1X)/' TEMP=',24(F4.0,1X)/' AFV= ', 00013900
                     *24(F4.0,1X /' AFVR=',24(F4.0,1X)/' HLH1=',12(F5.0,1X)/6X,  00014000
                     *12(F5.0,1X)/' HLH2=',12(F5.0,1X)/6X,12(F5.0,1X))           00014100
                C* CHANGES                                                       00014200
0083             6404 CONTINUE                                                   00014300
0084                  IDSOR=IDSOR(3)                                             00014400
0085                  DO 610 IH=1,NS                                             00014500
0086                  DO 610 LOOP3=1,3                                           00014600
0087                  ITHIRD=(LOOP3-1)*8                                         00014700
0088                  READ(10,606) (IDSOR,((QHOUR(IH,IHOUR+ITHIRD)),IHOUR=1,8))  00014800
0089             606  FORMAT(A4,2I2,8E9.3)                                       00014900
0090                  IF(LOOP3.EQ.1) IOID=IDSOR(1)                               00015000
0091                  IF((LOOP3.GT.1.AND.IOID.NE.IDSOR(1)).OR.(IDSOR(3).NE.(IOSOR+1)
                     &.AND.IDSOR(3).NE.1)) WRITE(IE,607) IDSOR                  00015200
0092             607  FORMAT(' ERROR IN SO2 INPUT ',A4,2(2X,I2))                 00015300
                C     IF(IDY.LT.10) WRITE(6,608)IDSOR,(QHOUR(IH,IHOUR+ITHIRD),IHOUR=1,8)00015400
0093                  WRITE(6,608)IDSOR,(QHOUR(IH,IHOUR+ITHIRD),IHOUR=1,8)       00015500
0094             608  FORMAT(1X,A4,2(1X,I2),8(2X,E10.3))                         00015600
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0095          610 CONTINUE                                                    00015700
              C***LOOP ON HOURS                                               00015800
0096                DO 80 IHR=1,24                                            00015900
0097                XWS=AWS(IHR)                                              00016000
0098                FV=AFV(IHR)                                               00016100
0099                FVR=AFVR(IHR)                                             00016200
0100                XMH=HLH(IUR,IHR)                                          00016300
0101                T=TEMP(IHR)                                               00016400
              C***SUM WIND PERSISTANCE  DATA                                  00016500
0102                FVRAD=FV/57.29578                                         00016600
0103                UP=XWS*SIN(FVRAD)                                         00016700
0104                VP=XWS*COS(FVRAD)                                         00016800
0105                UPS=UPS+UP                                                00016900
0106                VPS=VPS+VP                                                00017000
0107                WSS=WSS+XWS                                               00017100
              C***                                                            00017200
              C***DO NOT ALLOW STABILITY TO VARY RAPIDLY                      00017300
              C***                                                            00017400
0108                IF((ISTAB(IHR)-KSTL).GT.1) GO TO 12                       00017500
0109                GO TO 13                                                  00017600
0110          12    ISTAB(IHR)=KSTL+1                                         00017700
0111                ISTABP(IHR)=KSTLP+10
0112                GO TO 10                                                  00017800
0113          13    IF((KSTL-ISTAB(IHR)).GT.1)  ISTAB(IHR)=KSTL-1            00017900
0114                IF((KSTL-ISTAB(IHR)).GT.1) ISTABP(IHR)=KSTKP-10
0115          10    IF(IUR.NE.2) GO TO 11                                     00018000
0116                IF(ISTAB(IHR).GT.4) ISTAB(IHR)=4                          00018100
0117                IF(ISTAB(IHR).GT.4) ISTABP(IHR)=40
0118          11    KST=ISTAB(IHR)                                            00018200
0119                KSTP=ISTABP(IHR)
0120                KSTL=KST                                                  00018300
0121                KSTLP=KSTP
              C*** IF STABILITY=7 THE PLUME DOES NOT GET TO THE GROUND***     00018400
0122                IF(ISTABP(IHR).GE.60) GO TO 80
0123                ILOW=LOOP(KST,1)                                          00018600
0124                ITOP=LOOP(KST,2)                                          00018700
              C***                                                            00018800
              C***DETERMINE WIND SPEED AT TOP OF STACK AND PLUME RISE FOR EACH SOURCE 00018900
              C***                                                            00019000
0125                DO 79 IS=1,NS                                             00019100
0126                WS(IS)=XWS*((HP(IS)/7.)**P(KST))                          00019200
0127                F = 3.12139*VF(IS)*(TS(IS)-T)/TS(IS)                      00019300
0128                GO TO(71,71,71,71,75,76),KST                              00019400
0129          71    IF(F-55.) 72,73,73                                        00019500
0130          72    XST=14.*F**.625                                           00019600
0131                GO TO 74                                                  00019700
0132          73    XST=34.*F**.4                                             00019800
0133          74    DISTF=3.5*XST                                             00019900
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0134                  DHA=1.6*F**0.333333*DISTF**0.666667/WS(IS)                    00020000
0135                  GO TO 78                                                      00020100
0136            75    DTHDZ = 0.02                                                  00020200
0137                  GO TO 77                                                      00020300
0138            76    DTHDZ = 0.035                                                 00020400
0139            77    S = 9.80616*DTHDZ/T                                           00020500
0140                  DHA = 2.9*(F/(WS(IS)*S))**0.333333                            00020600
0141              78  HE(IS)=HP(IS)+DHA                                             00020700
0142            79    CONTINUE                                                      00020800
                C***                                                              00020900
                C***LOOP ON DIRECTIONS***                                         00021000
                C***                                                              00021100
0143                  DO 25 IDT=ILOW,ITOP                                           00021200
0144                  DIR=FV+DTH(IDT)                                               00021300
0145                  IDIR=DIR/10.                                                  00021400
0146                  IF(IDIR.LE.0)  GO TO 18                                       00021500
0147                  IF(IDIR.LE.36)  GO TO 19                                      00021600
0148                  IDIR=IDIR-36                                                  00021700
0149                  GO TO 19                                                      00021800
0150            18    IDIR=IDIR+36                                                  00021900
0151            19    ANG=(FVR-DIR)/57.29578                                        00022000
                C***                                                              00022100
                C***CALCULATE YD AND CONCENTRATIONS FOR EACH DISTANCE***          00022200
                C***YD IS IN METERS                                               00022300
                C***                                                              00022400
0152                  DO 25 J=1,NSTA                                                00022500
0153                  IR=IDIR+36*(J-1)                                              00022600
0154                  YD=RNG(J)*ANG*1000.                                           00022700
0155                  SY=SYD(J,KSTP)
0156                  SZ=SZD(J,KSTP)
                C***LOOP ON SOURCES***                                            00023000
0157                  DO 310 IH=1,NS                                                00023100
0158                  U=WS(IH)                                                      00023200
0159                  H=HE(IH)-DHRS(J)                                              00023300
0160                  AN=0.                                                         00023400
                C***IF THE SOURCE IS ABOVE THE LID, NO CONCENTRATION IS ADDED     00023500
0161                  IF(H-XMH)40,40,310                                            00023600
0162            40    C1=0.5*(YD/SY)*(YD/SY)                                        00023700
0163                  IF(C1-50.)50,310,310                                          00023800
0164            50    CHEK=SZ/XMH                                                   00023900
0165                  IF(CHEK.GE.1.6) GO TO 251                                     00024000
0166                  A1=1./(6.28318*U*SY*SZ*EXP(C1))                               00024100
0167                  IF(A1.LT.1.0E-30) GO TO 310                                   00024200
0168                  C2=2.*SZ*SZ                                                   00024300
0169                  C3=H*H/C2                                                     00024400
0170                  IF(C3-50.)60,70,70                                            00024500
0171            60    A2=2./EXP(C3)                                                 00024600
0172                  GO TO 110                                                     00024700
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0173          70   A2=0.                                                    00024800
0174         110   SUM=0.                                                   00024900
0175               THL=2.*XMH                                               00025000
0176         120   AN=AN+1.                                                 00025100
0177               C5=AN*THL                                                00025200
0178               CC=H-C5                                                  00025300
0179               CE=H+C5                                                  00025400
0180               C6=CC*CC/C2                                              00025500
0181               C8=CE*CE/C2                                              00025600
0182               IF(C6-50.) 130,140,140                                   00025700
0183         130   A4=2./EXP(C6)                                            00025800
0184               GO TO 180                                                00025900
0185         140   A4=0.                                                    00026000
0186         180   IF(C8-50.) 190,194,194                                   00026100
0187         190   A6=2./EXP(C8)                                            00026200
0188               GO TO 240                                                00026300
0189         194   A6=0.                                                    00026400
0190         240   TOT=A4+A6                                                00026500
0191               SUM=SUM+TOT                                              00026600
0192               IF(TOT-0.01) 250,260,260                                 00026700
0193         260   IF(AN-45.) 120,270,270                                   00026800
0194         270   WRITE(IO,9)   RNG(J),YD,H,TOT,SUM                        00026900
0195          9    FORMAT(1X,'N GREATER THAN 45',/,6X,'X= ',F7.0,5X,'YD= ',F7.0,5X,  00027000
                  *'H = ',F5.1,5X,'TOT = ',F7.3,5X,'SUM = ',F7.3)           00027100
0196         250   RC=A1*(A2+SUM)                                           00027200
0197               GO TO 252                                                00027300
0198         251   RC=1./(2.5066*SY*XMH*U*EXP(C1))                          00027400
0199               IHOUR=IDY*24+IHR-IDY                                     00027500
0200         252   CHI(IR,IHR)=CHI(IR,IHR)+QHOUR(IH,IHR)*RC                00027600
0201         310   CONTINUE                                                 00027700
                 C***SAVE MAX 1-HOUR CONC FOR THIS 24-HOUR PERIOD          00027800
                 C***SPECIFY RECEPTOR WHERE MAX OCCURRED                   00027900
0202               IF(CHI(IR,IHR).LE.HMAXT)  GO TO 31                       00028000
0203               HMAXT=CHI(IR,IHR)                                        00028100
0204               MIH=IDIR                                                 00028200
0205               MJH=J                                                    00028300
0206               MHH=IHR                                                  00028400
                 C***ACCUMULATE 24-HOUR CONCENTRATIONS FOR EACH RECEPTOR   00028500
0207          31   CHI(IR,25)=CHI(IR,25)+CHI(IR,IHR)                        00028600
                 C***                                                      00028700
                 C***CHECK THIS DAY'S MAX 1 HOUR CONC AGAINST MAX FROM PREVIOUS DAYS  00028800
                 C*** AT THE SAME RECEPTOR.                                00028900
                 C***FINAL VALUE IS MAX 1-HOUR CONC FOR EACH RECEPTOR      00029000
0208               IF(CHI(IR,IHR).LE.HMAX(IR,1)) GO TO 25                   00029100
0209               HMAX(IR,1)=CHI(IR,IHR)                                   00029200
0210               HMAX(IR,2)=IDY+.05                                       00029300
0211               HMAX(IR,3)=IHR+.05                                       00029400
                 C***END OF RANGES AND AZIMUTHS                            00029500
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0212          25   CONTINUE                                                  00029600
              C***END OF 24 HOUR PERIOD                                      00029700
0213          80   CONTINUE                                                  00029800
              C***                                                           00029900
              C***OUTPUT HOURLY CONCENTRATIONS FOR THIS DAY                  00030000
              C***24 RECORDS OF NMOD HOURLY CONCENTRATIONS***                00030100
              C***                                                           00030200
0214                DO 36 J=1,24                                           00030300
0215                WRITE(8)  (CHI(IR,J),IR=1,NMOD)                        00030400
0216          36   CONTINUE                                                  00030500
              C***                                                           00030600
              C***CALCULATE 24-HOUR AVERAGES FOR EACH RECPTOR                00030700
0217                DMAXT=0.0                                              00030800
0218                DO 35 I=1,36                                           00030900
0219                DO 35 J=1,NSTA                                         00031000
0220                IR=I+36*(J-1)                                          00031100
0221                CHI(IR,25)=CHI(IR,25)/24.                              00031200
0222                IF(CHI(IR,25).LE.DMAXT) GO TO 34                       00031300
0223                DMAXT=CHI(IR,25)                                       00031400
0224                MID=I                                                  00031500
0225                MJD=J                                                  00031600
              C***                                                           00031700
              C***SAVE DAILY AVERAGES***                                     00031800
              C***                                                           00031900
              C***CHECK THIS DAY'S MAX CONC AGAINST PREVIOUS 24-HOUR MAX.    00032000
              C***FINAL VALUE IS MAX 24 HOUR CONC FOR EACH RECEPTOR          00032100
              C***                                                           00032200
0226          34   IF(CHI(IR,25).LE.DMAX(IR,1)) GO TO 35                     00032300
0227                DMAX(IR,1)=CHI(IR,25)                                  00032400
0228                DMAX(IR,2)=IDY+.05                                     00032500
              C***                                                           00032600
              C***SUM DAILY AVERAGES FOR CALCULATION OF ANNUAL MEAN          00032700
              C***                                                           00032800
0229          35   CHI(IR,26)=CHI(IR,26)+CHI(IR,25)                          00032900
              C***COMPUTE WIND PERSISTANCE                                   00033000
0230                RSP=SQRT(UPS*UPS+VPS*VPS)/24.                          00033100
0231                PERST=RSP/(WSS/24.)                                    00033200
0232                RATIO=HMAXT/DMAXT                                      00033300
              C***                                                           00033400
              C***OUTPUT DAILY CONCENTRATIONS                                00033500
              C***1 RECORD OF NMOD 24-HOUR CONCENTRATIONS***                 00033600
              C***                                                           00033700
0233                WRITE(8) (CHI(IR,25),IR=1,NMOD)                        00033800
              C***                                                           00033900
              C***OUTPUT MAX 1-HOUR CONC AND HIGHEST 24-HOUR CONC AT ANY RECEPTOR 00034000
              C     WRITE(IP,601) IDY,DMAXT,MID,RNG(MJD),HHH,HMAXT,MIH,RNG(MJH), 00034100
              C    *RATIO,PERST,IDENT                                        00034200
0234           601  FORMAT(I3,1PE11.4,I3,0PF5.1,I3,1PE11.4,I3,0PF5.1,0P2F7.3,T61,5A4) 00034300
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0235                    WRITE(IO,600) IDY,HMAXT,MIH,RNG(MJH),MHH,DMAXT,MID,RNG(MJD)      00034400
0236               600  FORMAT(' DAY= ',I3,'  MAX HOURLY CONC=',1PE13.6,'  DIRECTION=',  00034500
                       *I2,'  DISTANCE=',0PF7.1,' KM  HOUR=',I2/1X,T11,                  00034600
                       *'MAX 24-HOUR CONC=',1PE13.6,'  DIRECTION=',I2,'  DISTANCE='.     00034700
                       *0PF7.1,' KM')                                                    00034800
0237                    WRITE(IO,7000) RATIO,PERST                                       00034900
0238               7000 FORMAT(' RATIO=',F9.3,' PERSIST=',F9.3//1X)                      00035000
0239                    IF(HMAXT.LE.HMAXYR(1)) GO TO 85                                  00035100
0240                    HMAXYR(1)=HMAXT                                                  00035200
0241                    HMAXYR(2)=MIH                                                    00035300
0242                    HMAXYR(3)=RNG(MJH)                                               00035400
0243                    HMAXYR(4)=IDY                                                    00035500
0244                    HMAXYR(5)=MHH                                                    00035600
0245               85   IF(DMAXT.LE.DMAXYR(1)) GO TO 90                                  00035700
0246                    DMAXYR(1)=DMAXT                                                  00035800
0247                    DMAXYR(2)=MID                                                    00035900
0248                    DMAXYR(3)=RNG(MJD)                                               00036000
0249                    DMAXYR(4)=IDY                                                    00036100
                  C***END DAILY LOOP***                                                  00036200
0250               90   CONTINUE                                                         00036300
                  C***                                                                   00036400
                  C***CALCULATE ANNUAL MEANS AND DETERMINE THE MAXIMUM                   00036500
                  C***                                                                   00036600
0251                    AMMAX=0.0                                                        00036700
0252                    MAXI=0                                                           00036800
0253                    MAXJ=0                                                           00036900
0254                    DO 91 I=1,36                                                     00037000
0255                    DO 91 J=1,NSTA                                                   00037100
0256                    IR=I+36*(J-1)                                                    00037200
0257                    CHI(IR,26)=CHI(IR,26)/365.                                       00037300
0258                    IF(CHI(IR,26).LE.AMMAX) GO TO 91                                 00037400
0259                    AMMAX=CHI(IR,26)                                                 00037500
0260                    MAXI=I                                                           00037600
0261                    MAXJ=J                                                           00037700
0262               91   CONTINUE                                                         00037800
                  C***                                                                   00037900
                  C***OUTPUT ANNUAL MEAN AT EACH RECEPTOR AND PRINT RECEPTOR WITH HIGHEST 00038000
                  C***   ANNUAL MEAN CONCENTRATION                                       00038100
                  C***1 RECORD OF NMOD MEAN ANNUAL CONCENTRATIONS***                     00038200
                  C***                                                                   00038300
0263                    WRITE(8) (CHI(IR,26),IR=1,NMOD)                                  00038400
                  C***PUNCH HMAXYR,DMAXYR & AMMAX, HOURLY,DAILY & YEARLY MAXIMA FOR THE YE00038500
                  C       WRITE(IP,710) HMAXYR,IDENT                                     00038600
0264               710  FORMAT(' MAX HOURLY ',1PE11.4,0PF4.0,0PF5.1,0PF5.0,0PF4.0,T61,5A4)00038700
                  C       WRITE(IP,720) DMAXYR,IDENT                                     00038800
0265               720  FORMAT(' MAX DAILY  ',1PE11.4,0PF4.0,0PF5.1,0PF5.0,T61,5A4)    00038900
                  C       WRITE(IP,730) AMMAX,MAXI,RNG(MAXJ),IDENT                       00039000
0266               730  FORMAT(' MAX ANNUAL ',1PE11.4,I3,0PF6.1,T61,5A4)                00039100
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                C       DO 740 I=1,36                                                   00039200
                C       WRITE(IP,703) I,(CHI(((I+36*(J-1)),26),J=1,5),IDENT             00039300
0267             703    FORMAT(I3,1P5E11.4,T61,5A4)                                     00039400
                C       IF(NSTA.GT.5) WRITE(IP,704) (CHI(((I+36*(J-1)),26),J=6,7)       00039500
0268               704  FORMAT(3X,1P2E11.4)                                             00039600
0269             740    CONTINUE                                                        00039700
                C***WRITE MAX ANNUAL MEAN***                                            00039800
0270                    WRITE(IO,5500) TITLE                                            00039900
0271                    WRITE(IO,700) AMMAX,MAXI,RNG(MAXJ)                              00040000
0272             700    FORMAT(1X,T4,'     MAXIMUM MEAN CONC=',1PE12.4,'  DIRECTION=',  00040100
                       *I3,'  DISTANCE=',0PF5.1,' KM'//1X)                             00040200
                C***                                                                    00040300
                C*** PRINT ANNUAL MEANS***                                              00040400
                C***                                                                    00040500
0273                    WRITE(IO,900) (RNG(IDUM),IDUM=1,NSTA)                           00040600
0274             900    FORMAT(1X,        /1X,T21,'ANNUAL MEAN CONCENTRATION AT EACH RECEPT00040700
                       *OR'/1X,T7,'RANGE',2X,7(F5.1,' KM',7X)/1X,T2,'DIR')              00040800
0275                    DO 420 I=1,36                                                   00040900
0276                    WRITE(IO, 800) I,(CHI(((I+36*(J-1)),26),J=1,NSTA)               00041000
0277             800    FORMAT(1X,T3,I2,T10,1P7E15.5)                                   00041100
0278             420    CONTINUE                                                        00041200
                C***                                                                    00041300
                C*** PRINT HIGHEST 24-HOUR CONCENTRATION FOR THE YEAR AT EACH RECEPTOR  00041400
0279                    WRITE(IO,5500) TITLE                                            00041500
0280                    WRITE(IO,705) DMAXYR                                            00041600
0281             705    FORMAT(1X,'YEARLY MAXIMUM 24-HOUR CONC=',1PE12.4 '  DIRECTION=', 00041700
                       *0PF4.0,'  DISTANCE=',0PF5.1,' KM',',  DAY=',0PF5.0//1X)         00041800
0282                    WRITE(IO,910) (RNG(IDUM),IDUM=1,NSTA)                           00041900
0283             910    FORMAT(1X,        /1X,T17,'HIGHEST 24-HOUR CONCENTRATION AT EACH RE00042000
                       *CEPTOR'/1X,T4,'RANGE   ',7(F5.1,' KM',7X)/1X,T2,'DIR')          00042100
0284                    DO 421 I=1,36                                                   00042200
0285                    WRITE(IO,801) I,(DMAX(((I+36*(J-1)),1),J=1,NSTA)                00042300
0286             801    FORMAT(1X,T3,I2,T6,7(1PE15.5))                                  00042400
0287                    WRITE(IO,803) I,(DMAX(((I+36*(J-1)),2),J=1,NSTA)                00042500
0288              803   FORMAT(1X,'(',I2,')',7(9X,'(',0PF4.0,')'))                      00042600
0289             421    CONTINUE                                                        00042700
                C***                                                                    00042800
                C*** PRINT HIGHEST 1-HOUR CONCENTRATIONS FOR THE YEAR AT EACH RECEPTOR  00042900
0290                    WRITE(IO,5500) TITLE                                            00043000
0291                    WRITE(IO,701) HMAXYR                                            00043100
0292             701    FORMAT(1X,'YEARLY MAXIMUM 1-HOUR CONC=',1PE12.4,'  DIRECTION=', 00043200
                       *0PF4.0,'  DISTANCE=',0PF5.1,' KM',',  DAY=',0PF5.0,'  HOUR=',   00043300
                       *0PF4.0//1X)                                                    00043400
0293                    WRITE(IO,920) (RNG(IDUM),IDUM=1,NSTA)                           00043500
0294             920    FORMAT(1X,        /1X,T17,'HIGHEST 1-HOUR CONCENTRATION AT EACH REC00043600
                       *EPTOR'/1X,T4,'RANGE   ',7(F5.1,' KM',7X)/1X,T2,'DIR')          00043700
0295                    DO 422 I=1,36                                                   00043800
0296                    WRITE(IO,802) I,(HMAX(((I+36*(J-1)),1),J=1,NSTA)                00043900
```

```
FORTRAN IV 31  RELEASE 2.0            MAIN                DATE = 75153      15/29/09

 0297          602  FORMAT(1X,T3,I2,T6,7(1PE15.5))                                  00044000
 0298               WRITE(IO,804) I,((HMAX((I+36*(J-1)),L),L=2,3),J=1,NSTA)         00044100
 0299           804 FORMAT(1X,'(',I2,')',7(5X,'(',0P2F4.0,')'))                      00044200
 0300           422 CONTINUE                                                        00044300
 0301               CALL EXIT                                                       00044400
 0302               END                                                             00044500
```

```
FORTRAN IV G1  RELEASE 2.0          SIGMA1          DATE   76153          15/29/09

0001                  SUBROUTINE SIGMA1 (X,XY,KST,SY,SZ)
                    C SUBROUTINE TO CALCULATE SIGMA Y AND SIGM Z USING F.B.SMITH'S METHOD
                    C (SMITH-SIGMA Z,PASQUILL-SIGMA Y)
0002                  GO TO (10,20,30,40,50,60),KST
                    C  STABILITY A(10)
0003                  10 TH = (24.167 - 2.5334*ALOG(XY))/57.2958
0004                  SZ=.112*(X*1000.)**1.06/(1.+.000538*(X*1000.)**.815)
0005                  GO TO 71
                    C  STABILITY B(20)
0006                  20 TH   (18.333 - 1.8096*ALOG(XY))/57.2958
0007                  SZ=.130*(X*1000.)**.950/(1.+.000652*(X*1000.)**.750)
0008                  GO TO 71
                    C  STABILITY C(30)
0009                  30 TH = (12.5 - 1.0857*ALOG(XY))/57.2958
0010                  SZ=.112*(X*1000.)**.920/(1.+.000903*(X*1000.)**.718)
0011                  GO TO 71
                    C  STABILITY D(40)
0012                  40 TH = (8.3333-0.72382*ALOG(XY))/57.2958
0013                  SZ=.098*(X*1000.)**.889/(1.+.00135*(X*1000.)**.688)
0014                  GO TO 71
                    C  STABILITY E(50)
0015                  50 TH = (6.25 - 0.54287*ALOG(XY))/57.2958
0016                  SZ=.0609*(X*1000.)**.895/(1.+.00196*(X*1000.)**.684)
0017                  GO TO 71
                    C  STABILITY F(60)
0018                  60 TH = (4.1667 - 0.36191*ALOG(XY))/57.2958
0019                  SZ=.0638*(X*1000.)**.783/(1.+.00136*(X*1000.)**.672)
0020                  71 SY = 1000. * XY * SIN(TH)/(2.15 * COS(TH))
0021                  RETURN
0022                  END
```

```
FORTRAN IV G1  RELEASE 2.0            SIGMA              DATE = 76156          12/34/10

0001                  SUBROUTINE SIGMA(X,XY,KST,SY,SZ)
0002                  FKST=FLOAT(KST)/10.
0003                  KST1=FKST
0004                  KST2=KST1+1
0005                  IF(KST1.LT.1) KST1=1
0006                  IF(KST2.GT.6) KST2=6
0007                  CALL SIGMA1(X,XY,KST1,SY1,SZ1)
0008                  CALL SIGMA1(X,XY,KST2,SY2,SZ2)
0009                  DY=SY2-SY1
0010                  DZ=SZ2-SZ1
0011                  DK=FKST-KST1
0012                  SY=SY1+DK*DY
0013                  SZ=SZ1+DK*DZ
0014                  RETURN
0015                  END
```

ELEVATION DIFFERENCES BETWEEN RECEPTOR AND SOURCE LOCATIONS= 0.64E+02 0.82E+02 0.10E+03 0.13E+03
IUR= 1

MUSKINGUM RIVER POWER PLANT STACK 1 BOILERS 1-4 00062500
NS= 1 HP= 251.00 TS= 430. VS= 28.50 D= 7.60 VF= 1292.89

MUSKINGUM RIVER POWER PLANT STACK 2 BOILER 5 00062700
NS= 2 HP= 251.00 TS= 425. VS= 24.80 D= 6.70 VF= 874.36

RANGE(KM)= 5.27 4.28 8.26 19.63

JYR=73 IMO= 1 JDAY= 1

ISTAB=	70	70	70	70	60	70	70	45	70	36	35	29	34	32	34	34	34	47	67	63	59	63	70	70
AWS=	2.6	2.6	2.1	3.1	4.1	2.1	2.6	5.6	3.1	5.1	6.2	5.1	7.2	6.2	6.7	6.2	4.6	5.1	3.1	3.6	3.6	3.1	2.6	3.1
TEMP=	277.	277.	276.	275.	275.	275.	274.	274.	274.	274.	275.	277.	278.	279.	280.	280.	281.	279.	278.	276.	276.	275.	274.	274.
AFV=	20.	20.	20.	20.	20.	20.	20.	50.	20.	60.	60.	80.	60.	50.	60.	50.	50.	70.	80.	80.	90.	110.	120.	110.
AFVR=	20.	22.	21.	19.	16.	22.	18.	50.	18.	60.	64.	83.	65.	57.	62.	50.	46.	70.	85.	79.	94.	112.	118.	115.
HLH1=	1002.	1002.	1002.	1002.	1002.	1002.	1002.	21.	195.	348.	512.	675.												
	839.	1002.	1002.	1002.	1002.	996.	988.	980.	972.	965.	957.	949.												
HLH2=	958.	958.	958.	958.	958.	958.	958.	959.	966.	973.	980.	988.												
	995.	1002.	1002.	1002.	1002.	984.	959.	935.	911.	887.	863.	839.												

MUS4 1 1	0.426E+04	0.426E+04	0.423E+04	0.424E+04	0.424E+04	0.424E+04	0.435E+04	0.432E+04
MUS4 1 1	0.426E+04	0.439E+04	0.439E+04	0.444E+04	0.440E+04	0.434E+04	0.426E+04	0.426E+04
MUS4 1 1	0.442E+04	0.441E+04	0.463E+04	0.517E+04	0.512E+04	0.461E+04	0.442E+04	0.437E+04
MUS5 1 1	0.147E+04	0.147E+04	0.142E+04	0.143E+04	0.143E+04	0.142E+04	0.143E+04	0.142E+04
MUS5 1 1	0.142E+04	0.144E+04	0.142E+04	0.143E+04	0.145E+04	0.144E+04	0.134E+04	0.139E+04
MUS5 1 1	0.152E+04	0.147E+04	0.141E+04	0.186E+04	0.167E+04	0.142E+04	0.142E+04	0.146E+04

DAY= 1 MAX HOURLY CONC= 6.336607E-04 DIRECTION= 6 DISTANCE= 8.3 KM HOUR=10
MAX 24-HOUR CONC= 6.656564E-05 DIRECTION= 6 DISTANCE= 8.3 KM
RATIO= 9.519 PERSIST= 0.898

JYR=73 IMO= 1 JDAY= 2

ISTAB=	70	70	70	70	57	54	53	56	48	38	27	25	22	21	21	25	35	65	46	46	48	48	46	45
AWS=	3.1	3.1	2.1	2.6	2.6	2.1	2.6	1.5	1.0	1.0	1.0	3.1	2.6	2.1	2.1	2.1	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.5
TEMP=	273.	273.	272.	271.	271.	271.	271.	270.	270.	270.	271.	272.	273.	274.	275.	276.	276.	275.	274.	274.	273.	271.	271.	271.
AFV=	110.	100.	40.	40.	60.	120.	160.	130.	130.	130.	130.	50.	80.	360.	170.	20.	200.	200.	200.	200.	200.	200.	200.	280.
AFVR=	113.	101.	41.	39.	64.	117.	158.	129.	126.	129.	130.	53.	81.	2.	172.	23.	205.	202.	198.	204.	199.	205.	201.	279.
HLH1=	941.	933.	925.	918.	910.	902.	894.	18.	155.	292.	428.	565.												
	702.	839.	839.	839.	839.	817.	788.	760.	731.	702.	673.	644.												
HLH2=	839.	839.	839.	839.	839.	939.	839.	839.	839.	839.	839.	939.												
	839.	839.	839.	839.	839.	772.	683.	595.	506.	418.	329.	241.												

MUS4 1 2	0.460E+04	0.464E+04	0.460E+04	0.469E+04	0.471E+04	0.511E+04	0.584E+04	0.621E+04
MUS4 1 2	0.758E+04	0.838E+04	0.843E+04	0.840E+04	0.842E+04	0.848E+04	0.852E+04	0.869E+04
MUS4 1 2	0.840E+04	0.829E+04	0.841E+04	0.830E+04	0.840E+04	0.850E+04	0.734E+04	0.599E+04
MUS5 1 2	0.169E+04	0.174E+04	0.174E+04	0.174E+04	0.175E+04	0.175E+04	0.174E+04	0.177E+04
MUS5 1 2	0.227E+04	0.235E+04	0.211E+04	0.227E+04	0.225E+04	0.225E+04	0.228E+04	0.229E+04
MUS5 1 2	0.199E+04	0.202E+04	0.225E+04	0.223E+04	0.224E+04	0.224E+04	0.191E+04	0.154E+04

DAY= 2 MAX HOURLY CONC= 1.101867E-03 DIRECTION=20 DISTANCE= 19.6 KM HOUR=23
MAX 24-HOUR CONC= 1.917259E-04 DIRECTION=20 DISTANCE= 19.6 KM
RATIO= 5.747 PERSIST= 0.459

JYR=73 IMO= 1 JDAY= 3

ISTAB=	42	52	43	41	41	41	41	41	41	41	39	36	34	34	35	38	40	40	40	40	40	40	41	41
AWS=	3.6	3.1	2.1	3.6	2.6	3.1	1.5	3.6	3.6	3.1	2.6	2.1	2.6	2.1	2.1	2.1	4.1	4.6	5.1	5.2	5.6	5.6	3.6	3.6
TEMP=	271.	272.	272.	272.	272.	273.	273.	273.	273.	274.	274.	275.	275.	275.	275.	275.	277.	279.	280.	281.	283.	283.	283.	283.
AFV=	240.	200.	240.	250.	240.	220.	200.	270.	240.	240.	300.	280.	300.	280.	240.	260.	290.	300.	310.	320.	320.	360.	340.	10.

APPENDIX C

CONCENTRATION PROFILES FOR THE CANAL AND MUSKINGUM PLANTS FOR DIFFERENT SETS OF DISPERSION CURVES

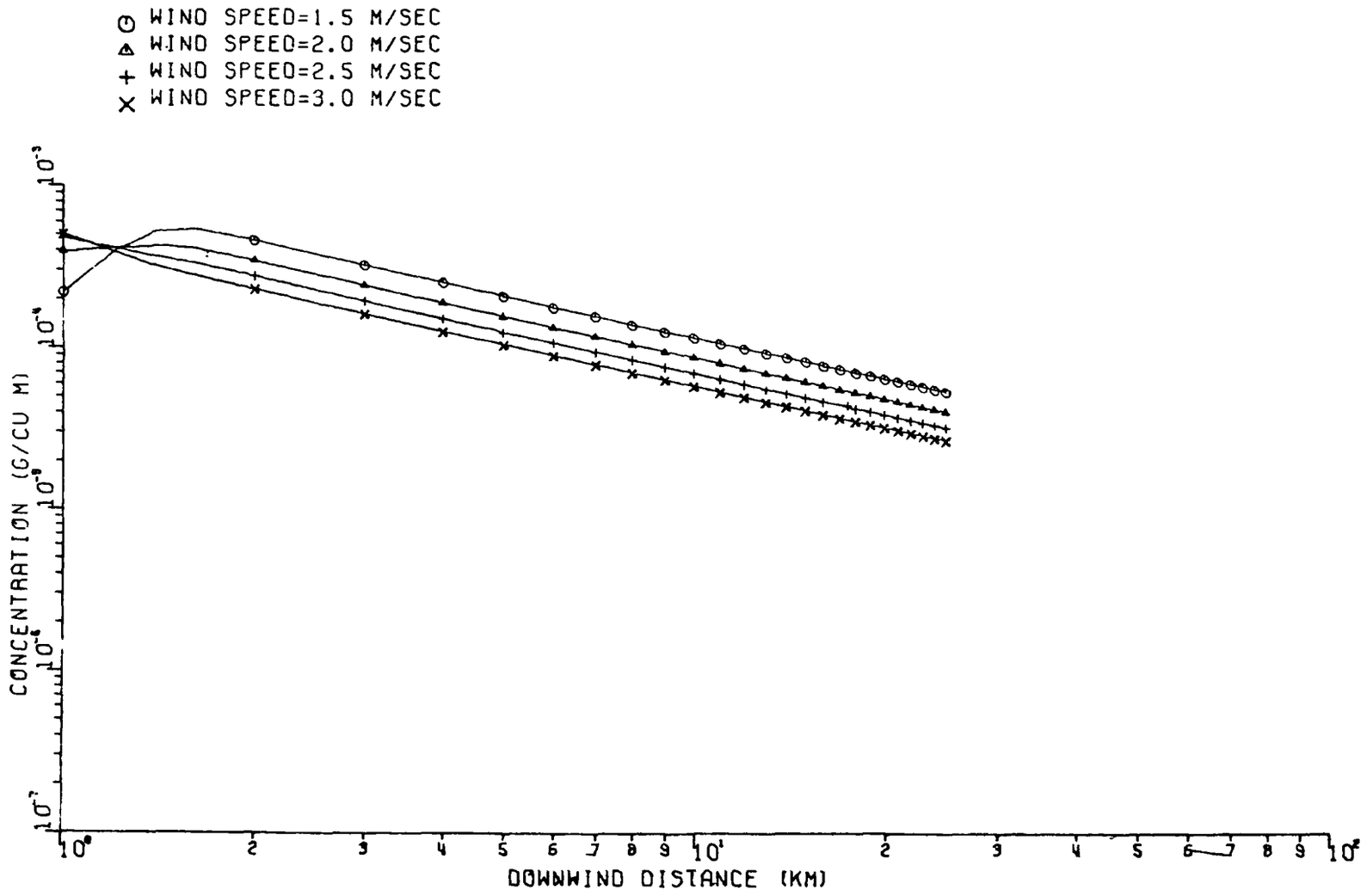

Figure C-1a. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

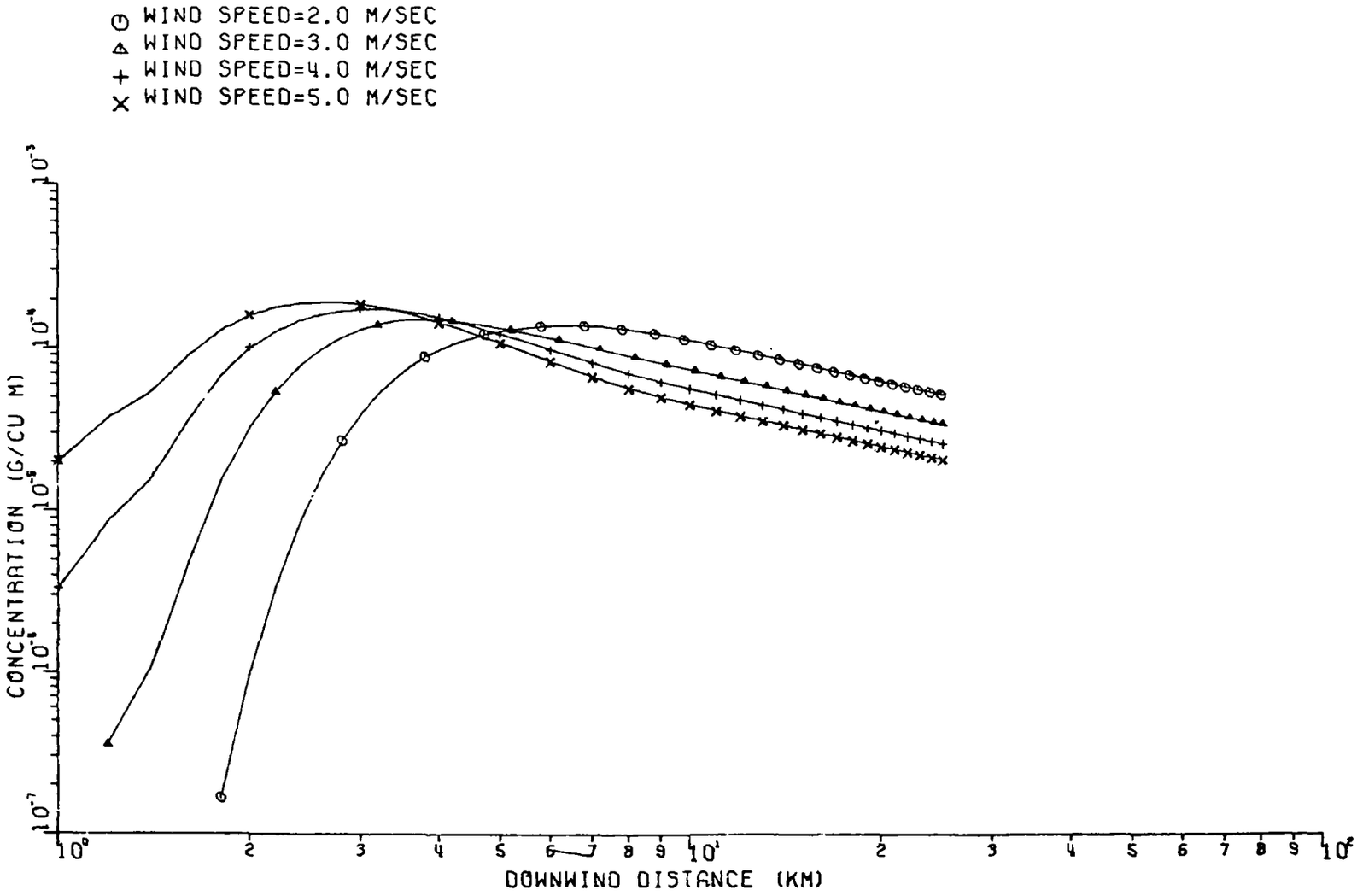

Figure C-1b. Plume centerline concentration versus downwind distance for stability Class B at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

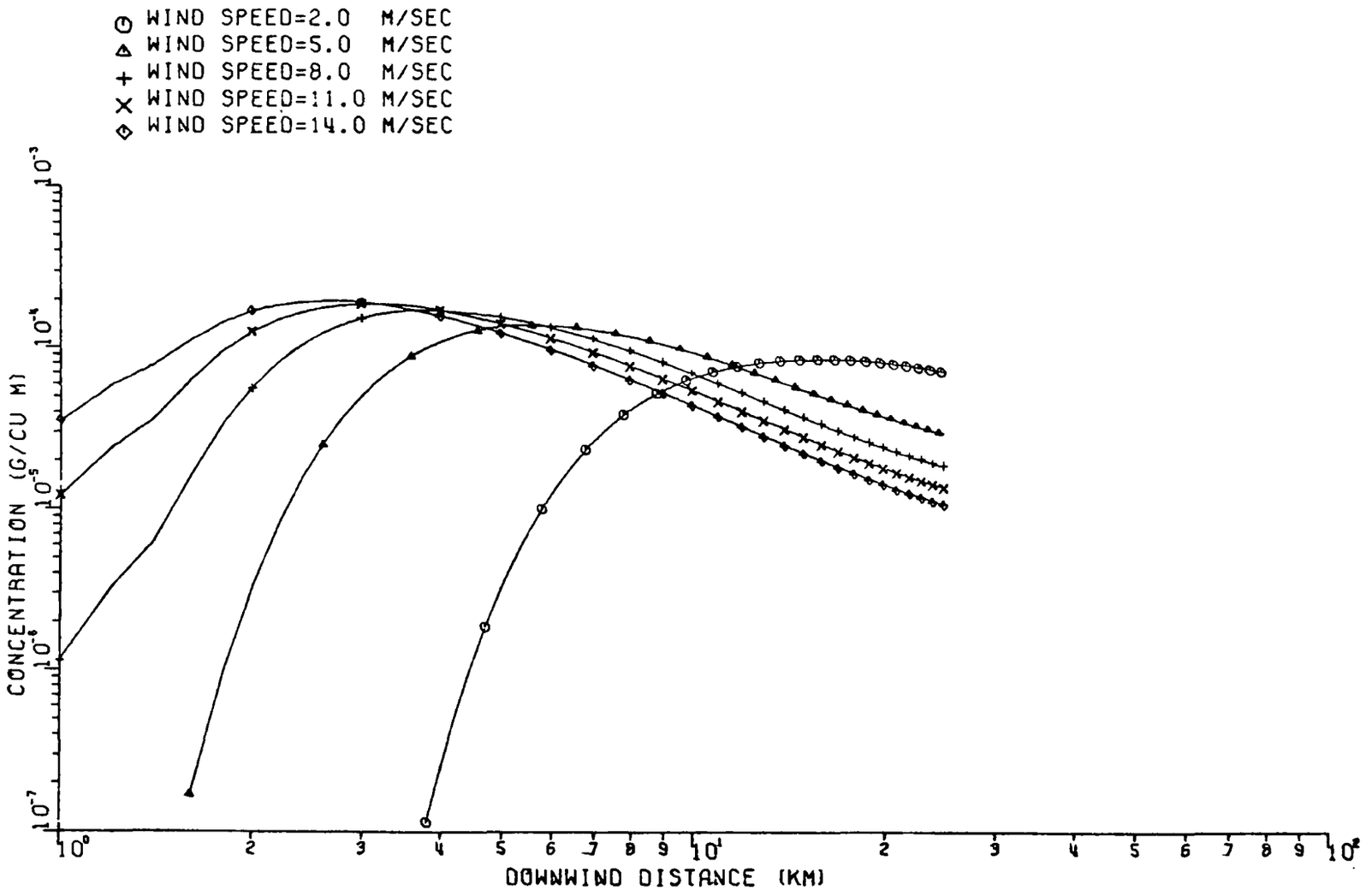

Figure C-1c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

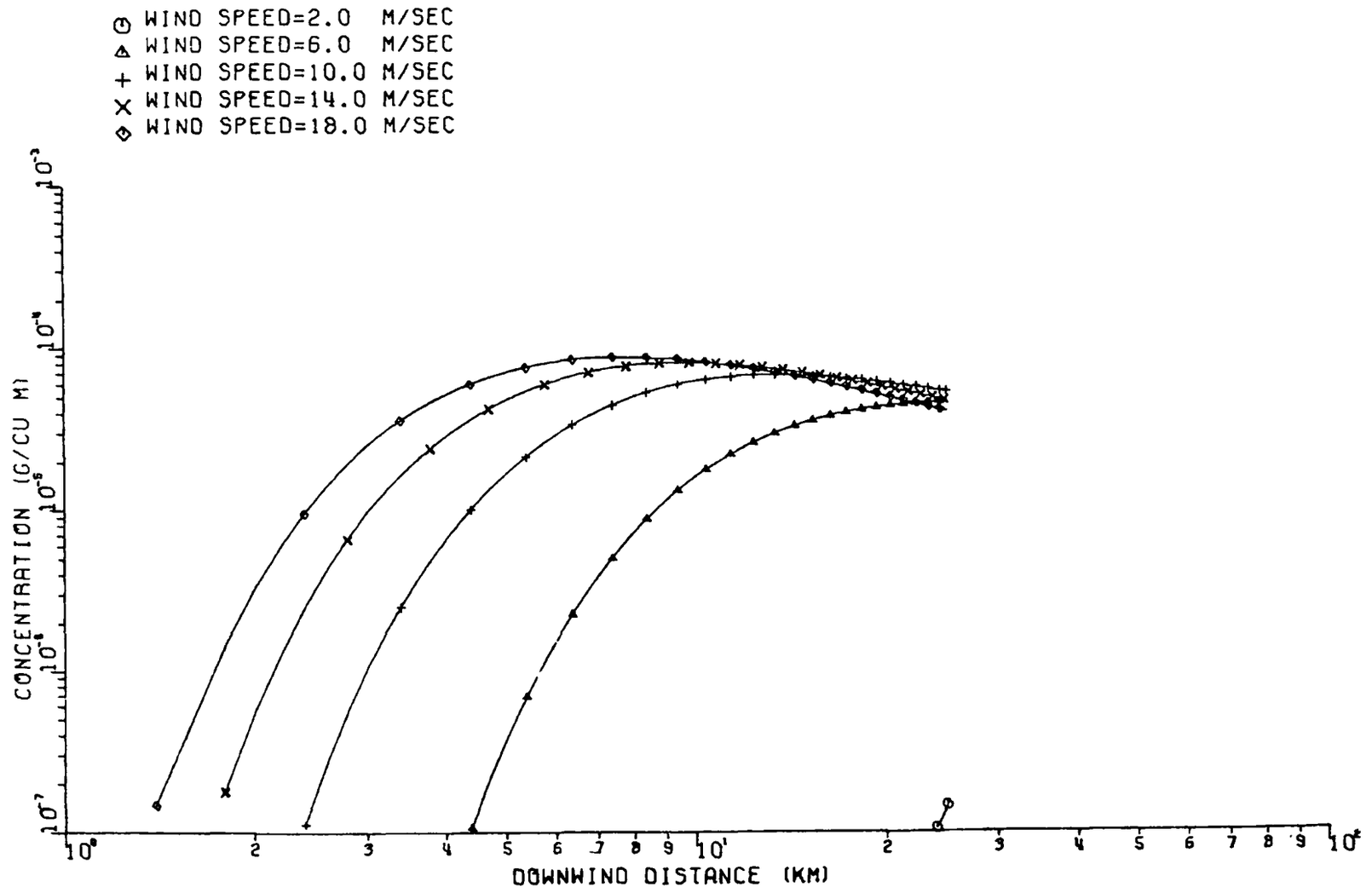

Figure C-1d. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

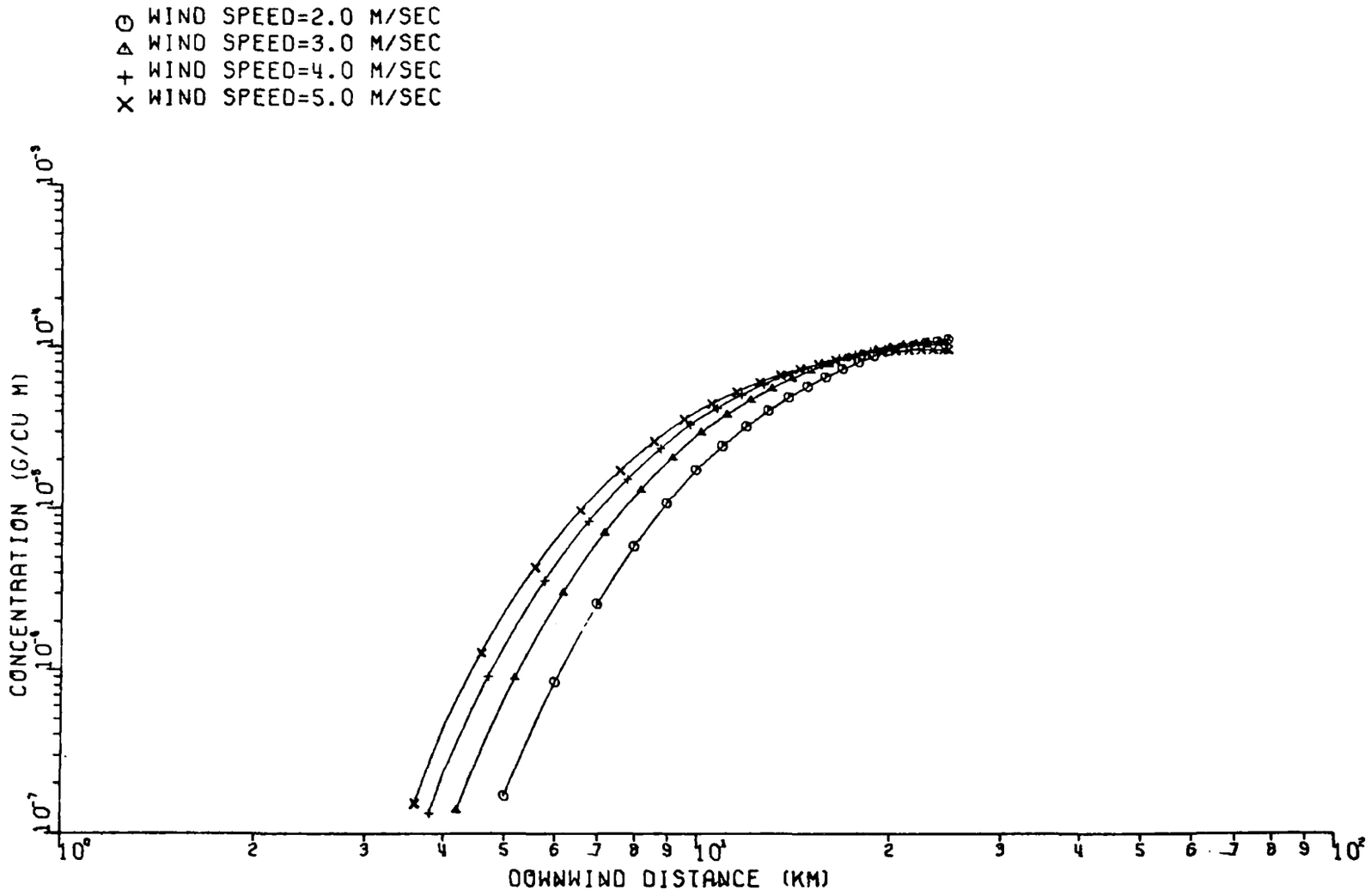

Figure C-1e. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

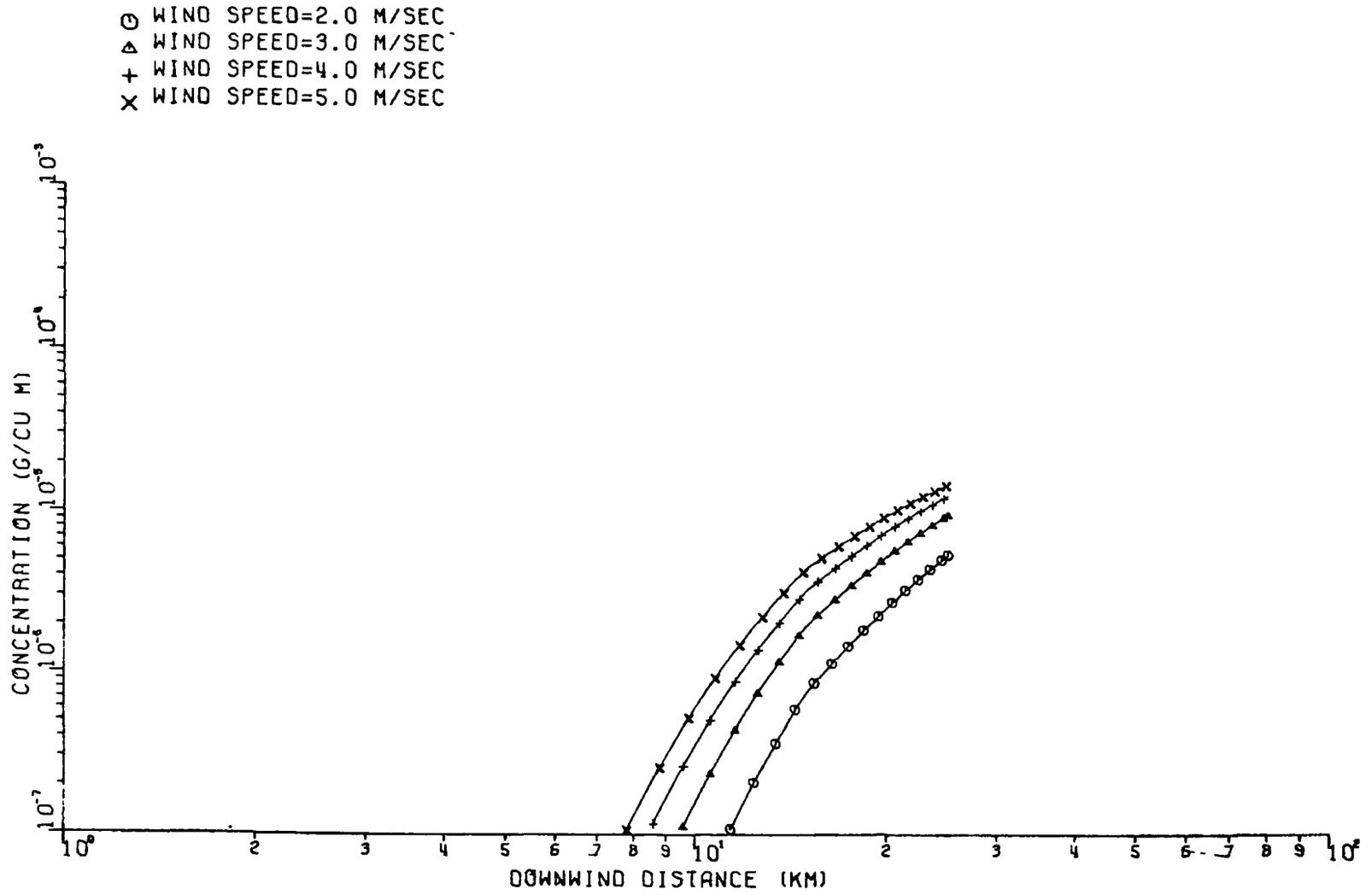

Figure C-1f. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

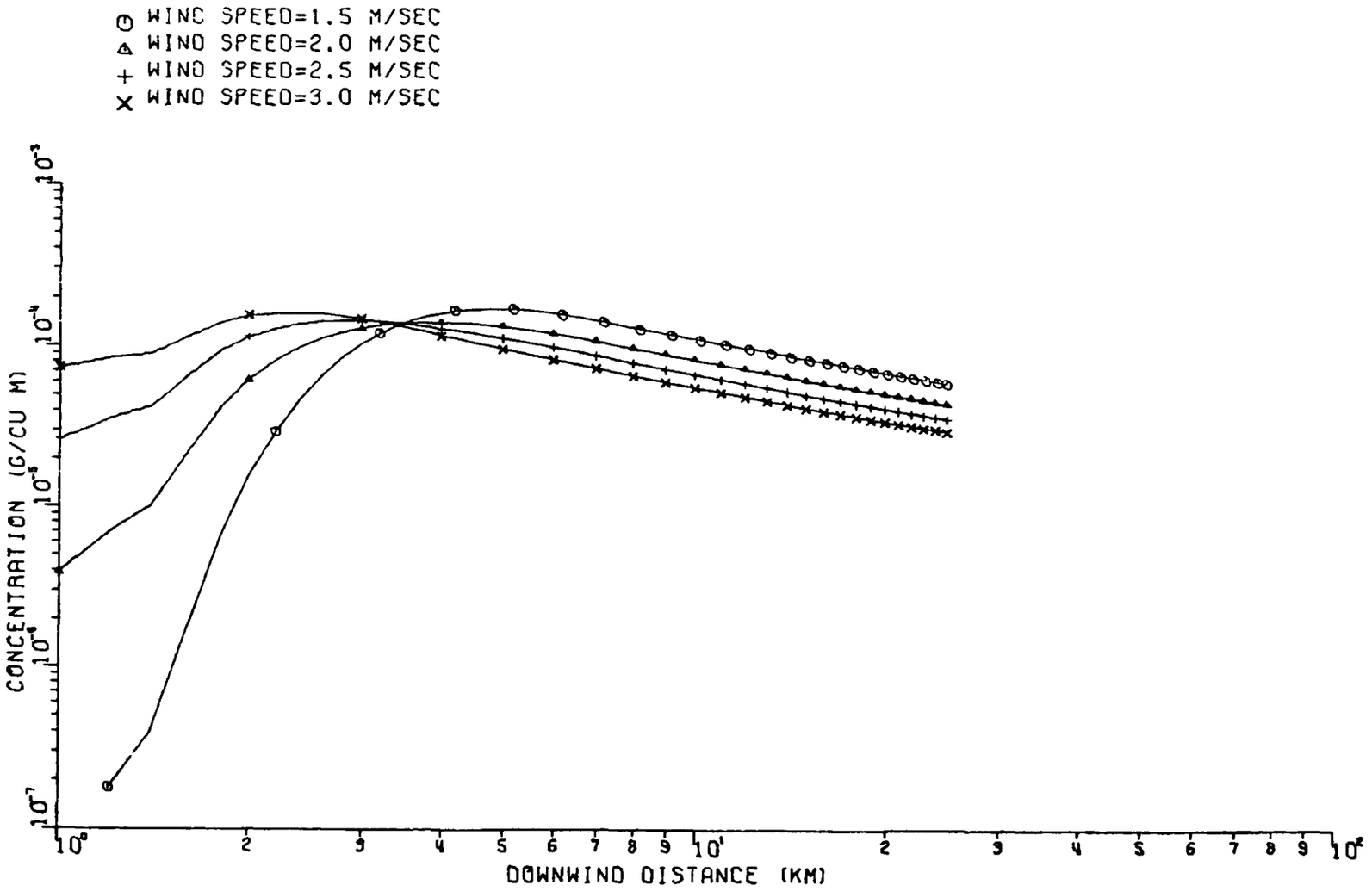

Figure C-2a. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

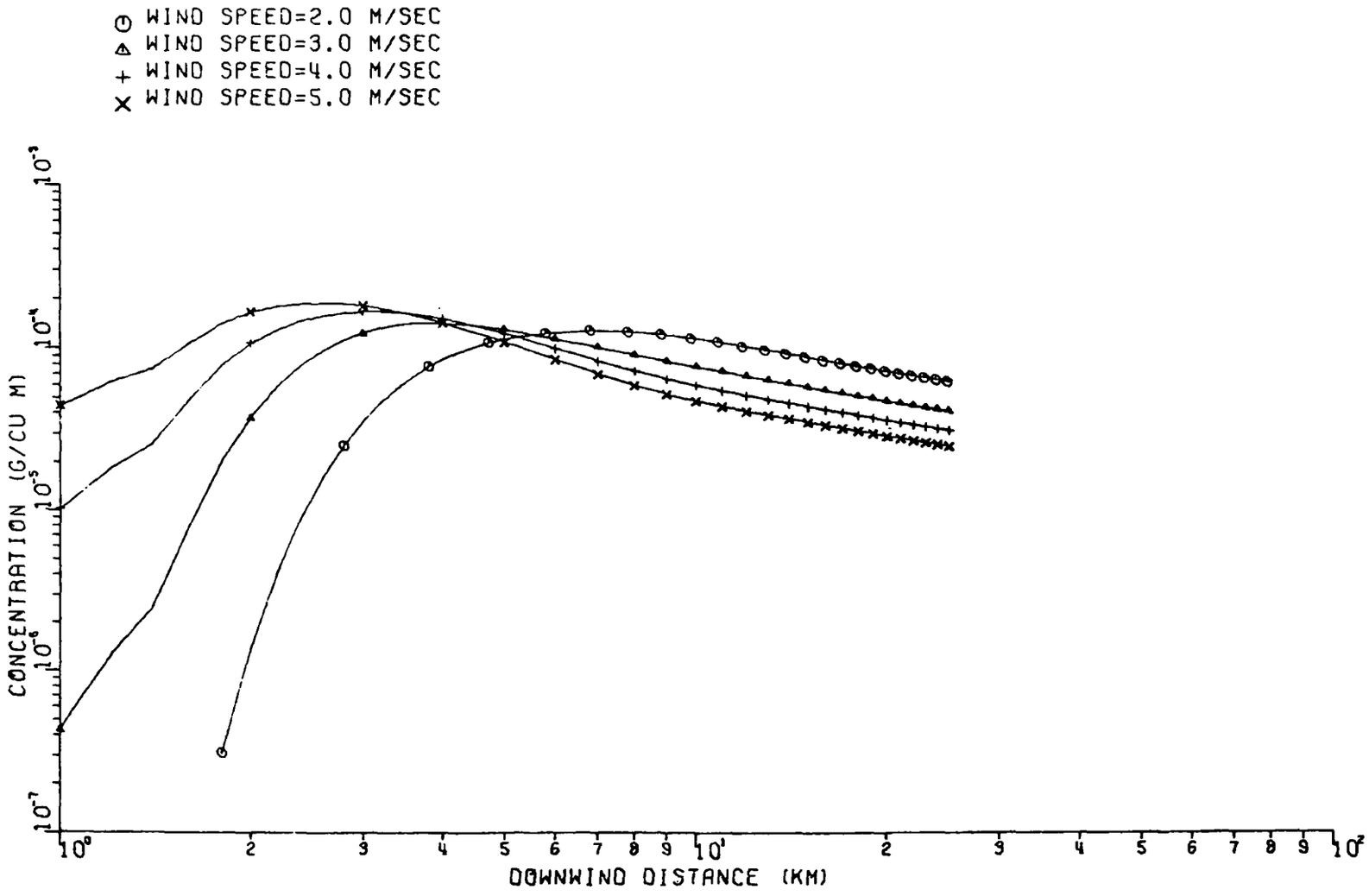

Figure C-2b. Plume centerline concentration versus downwind distance for stability Class B at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

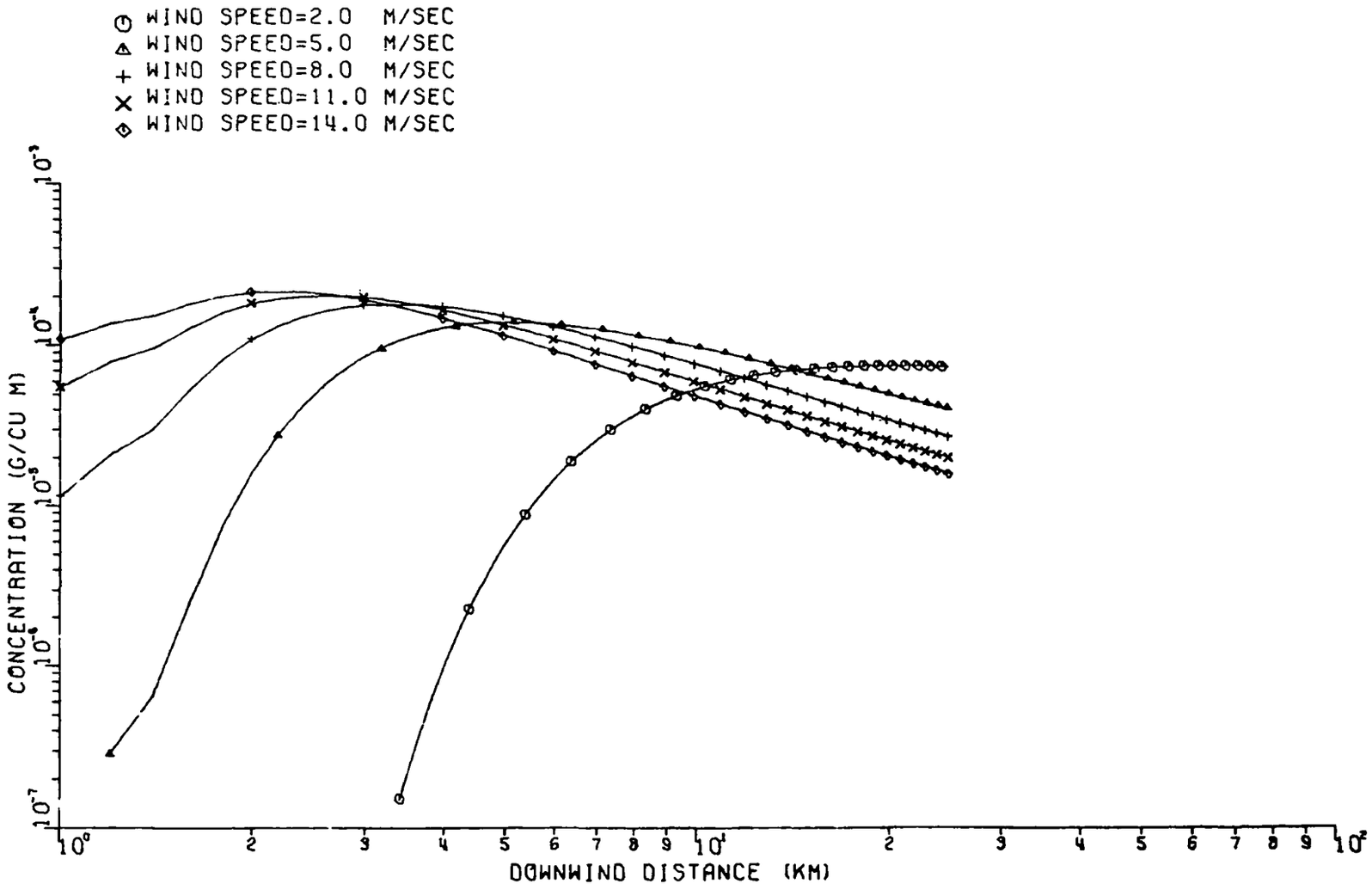

Figure C-2c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

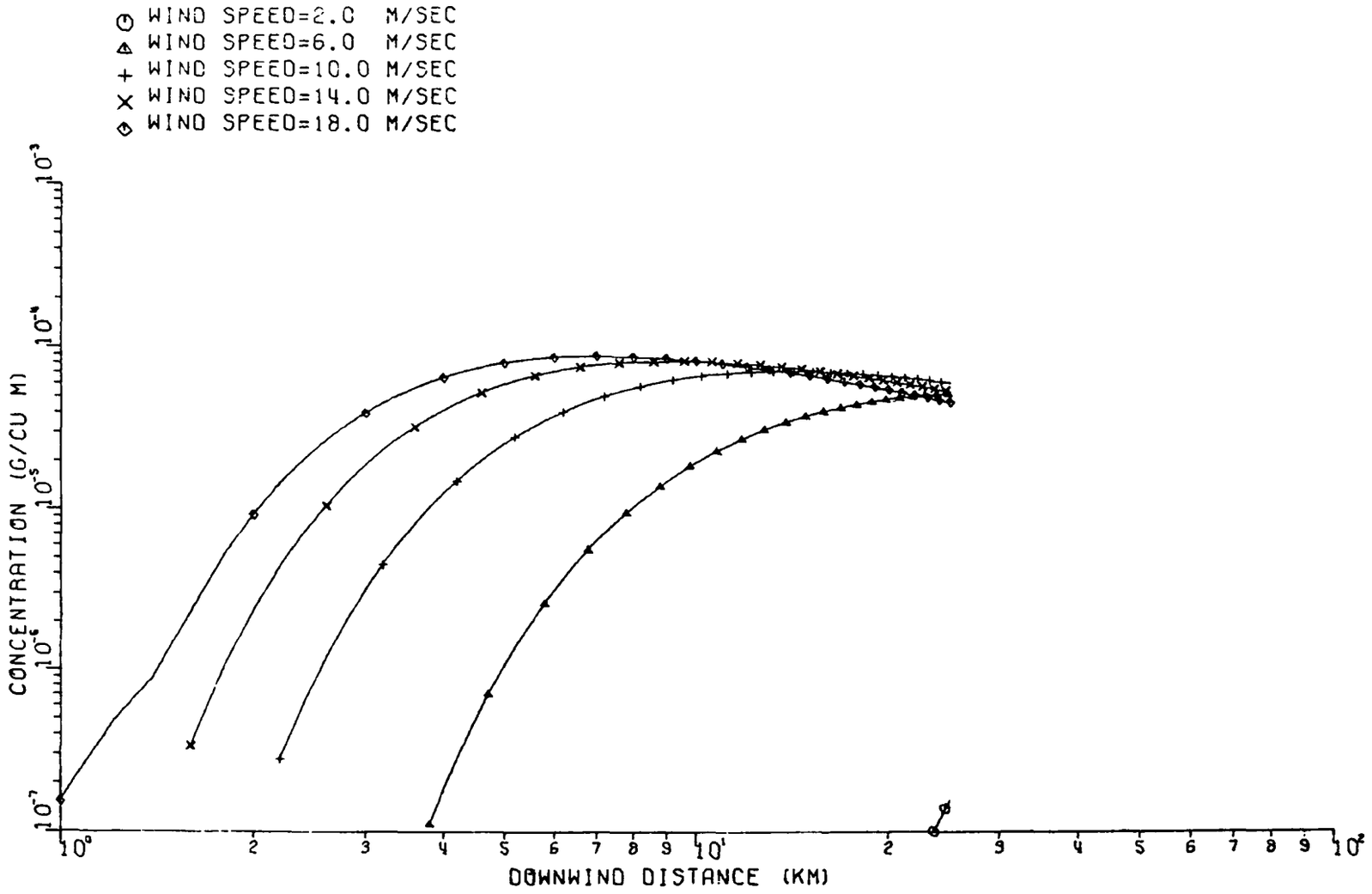

Figure C-2d. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

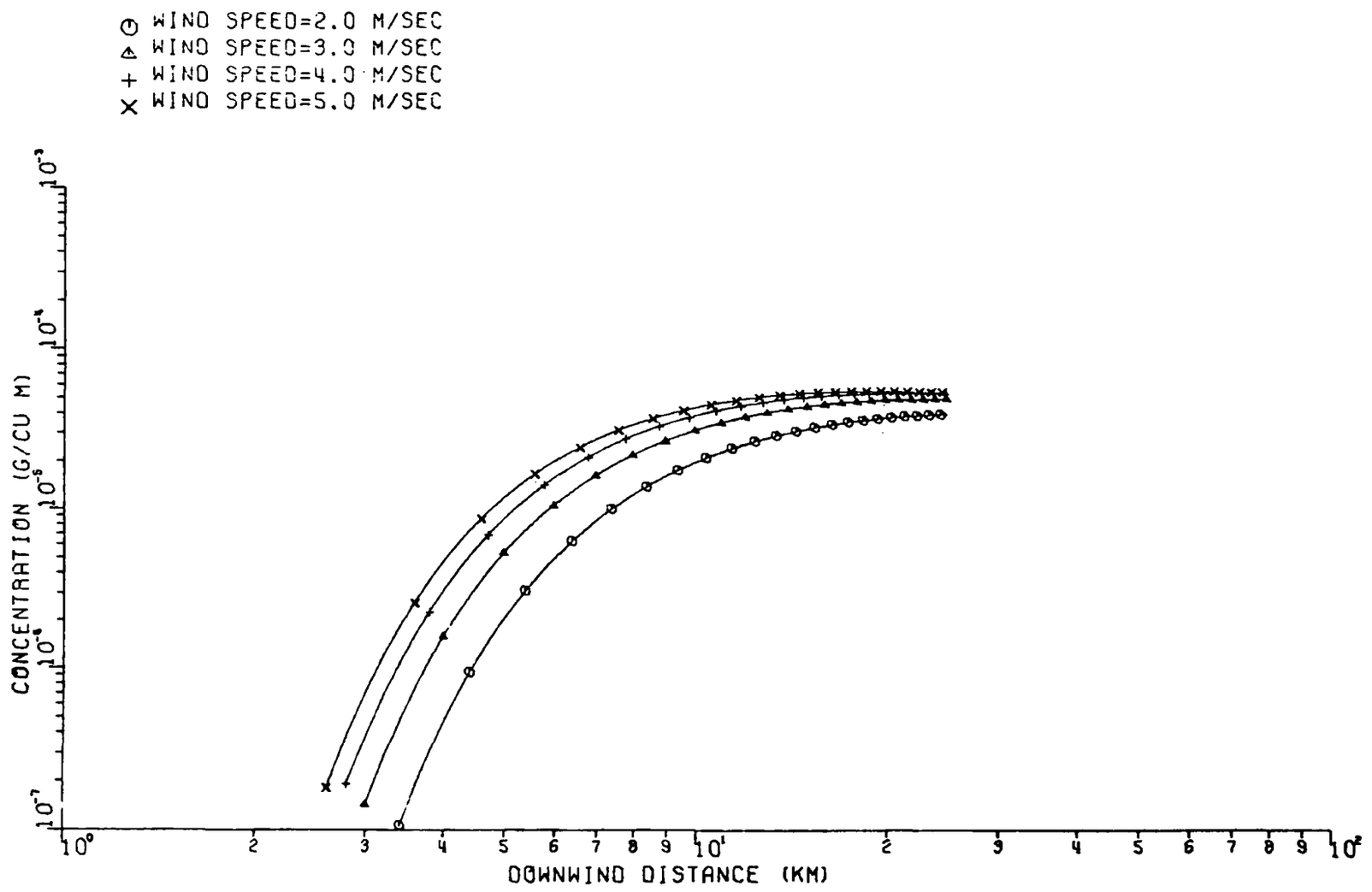

Figure C-2e. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

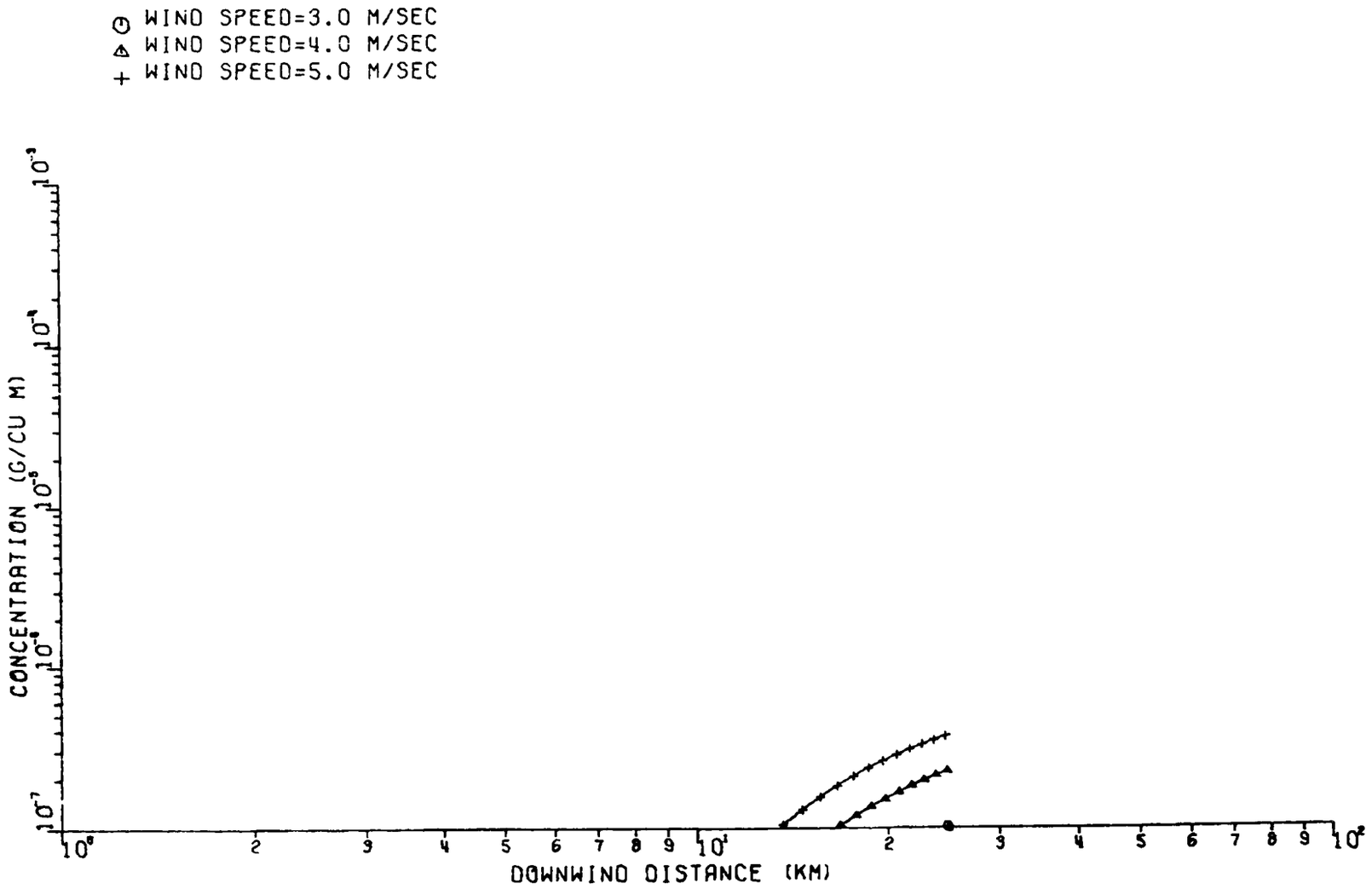

Figure C-2f. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

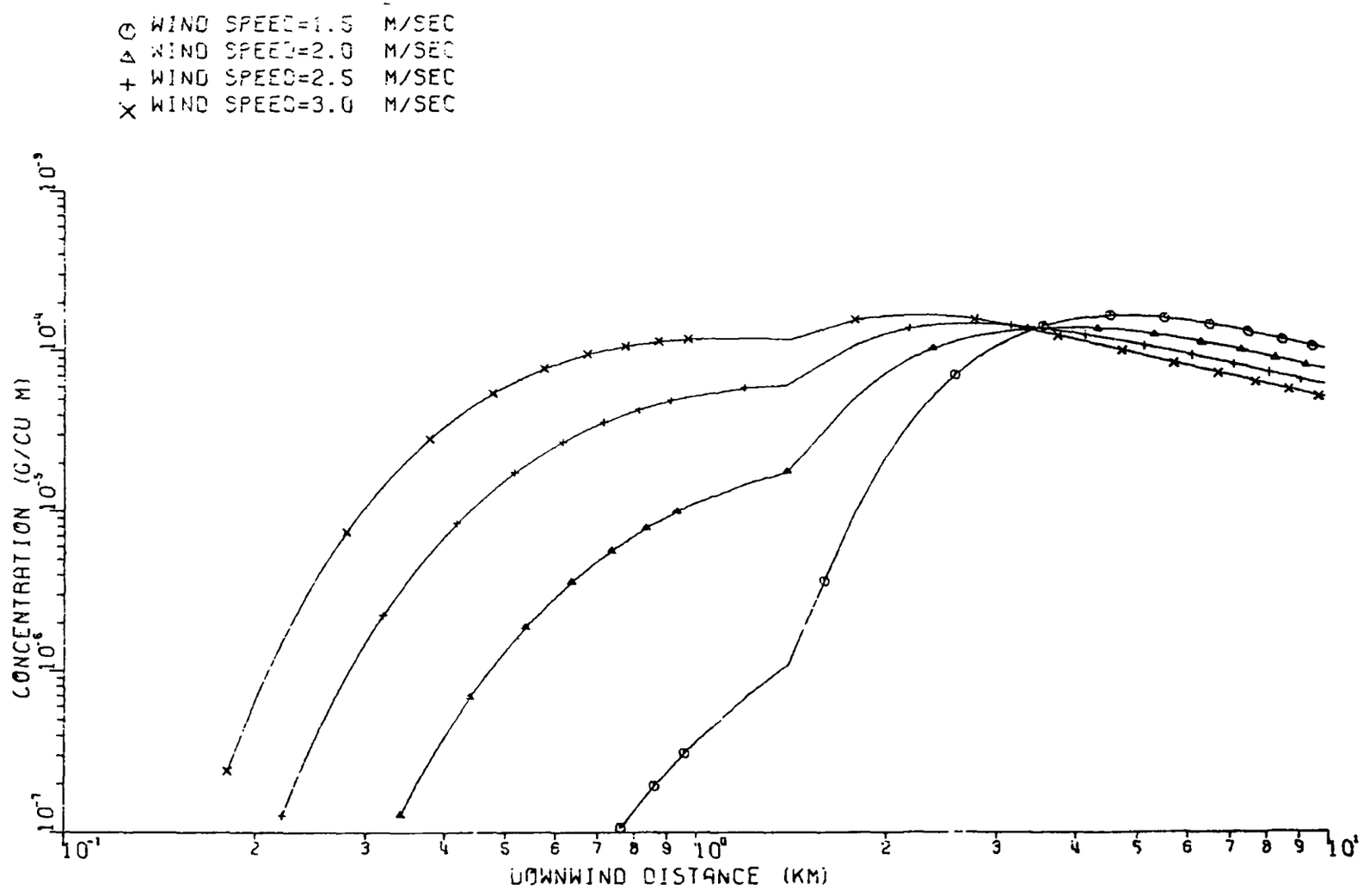

Figure C-3a. Plume centerline concentration versus downwind distance for stability Class B2 at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

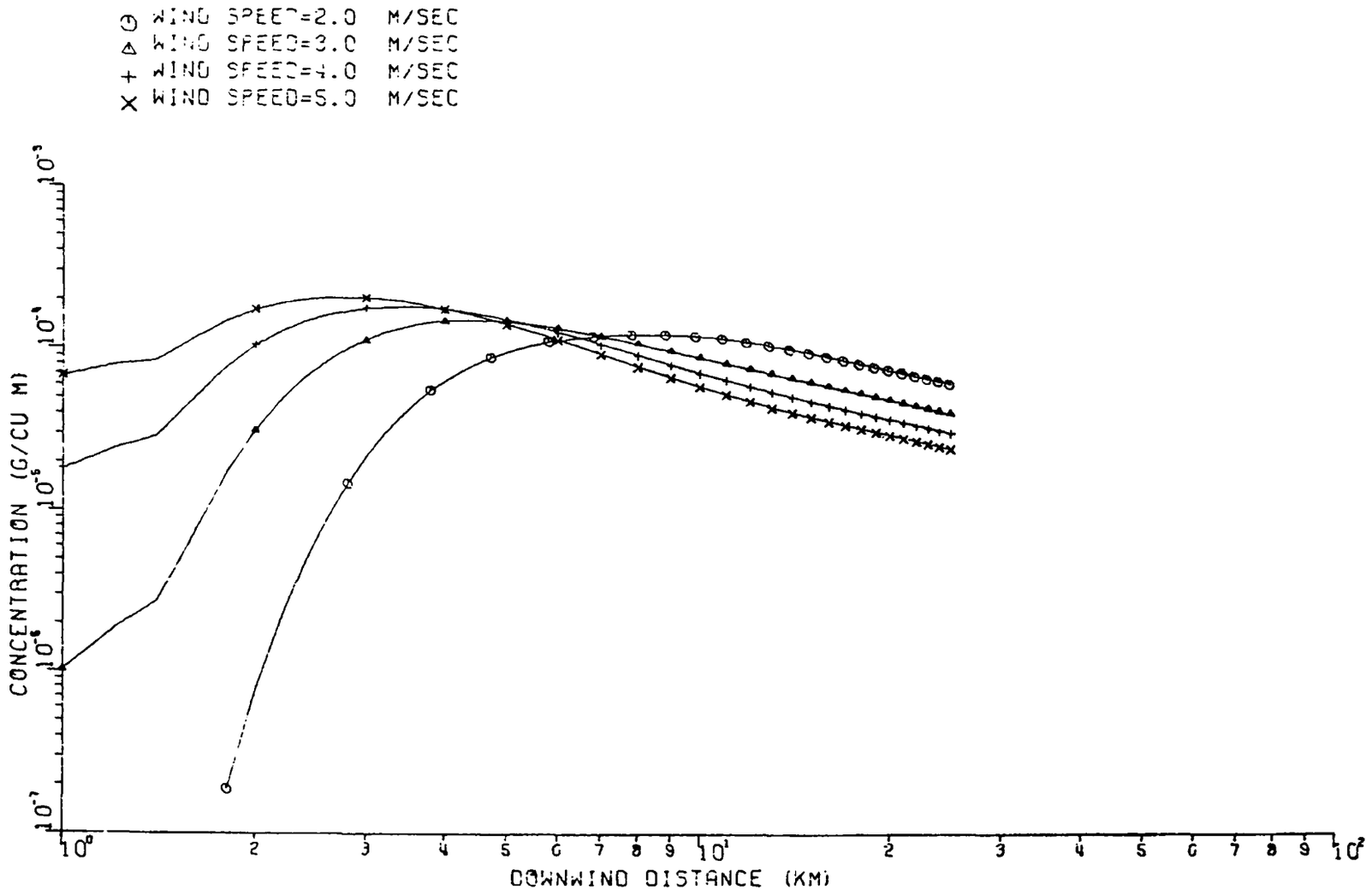

Figure C-3b. Plume centerline concentration versus downwind distance for stability Class B1 at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

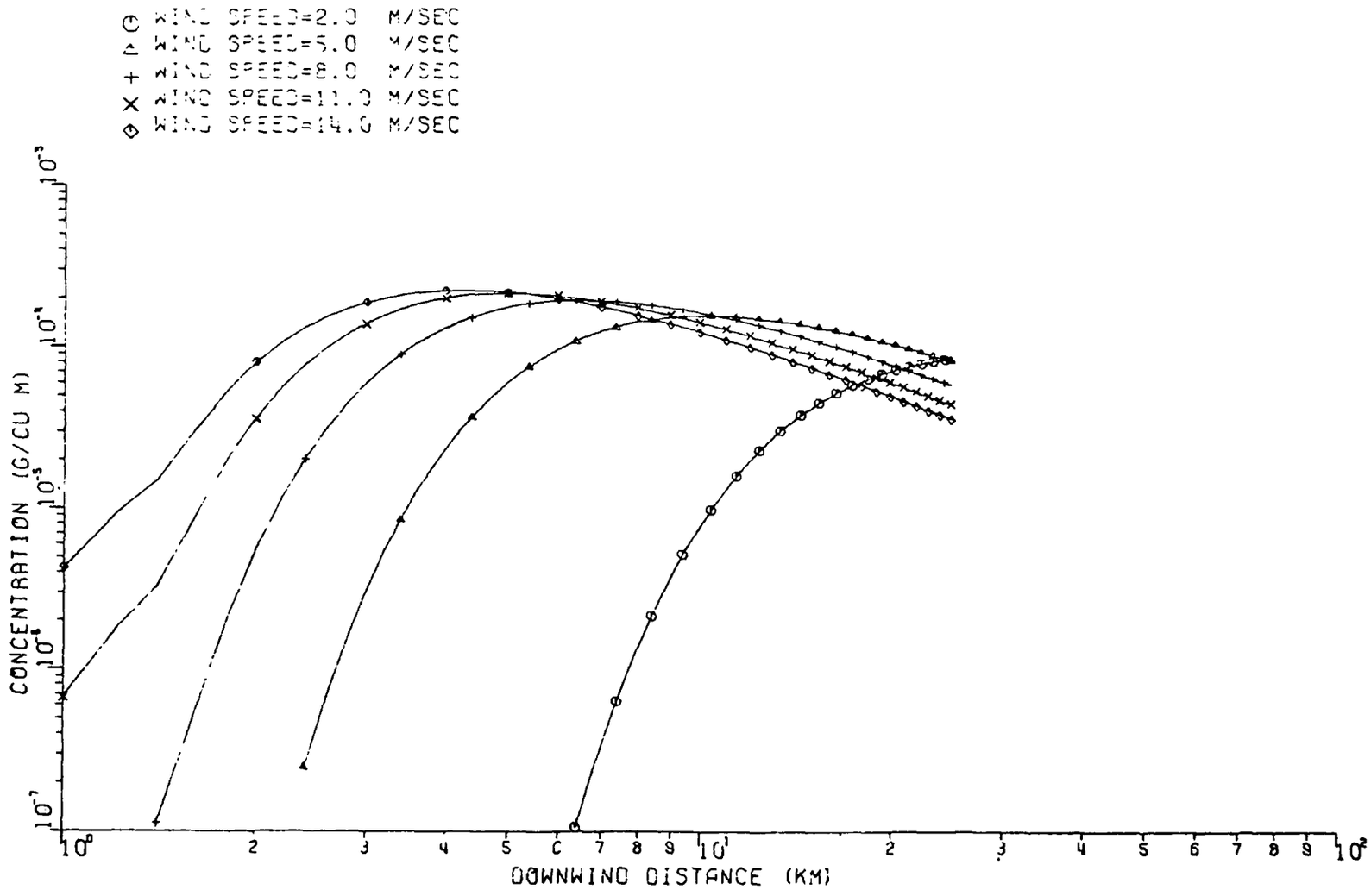

Figure C-3c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

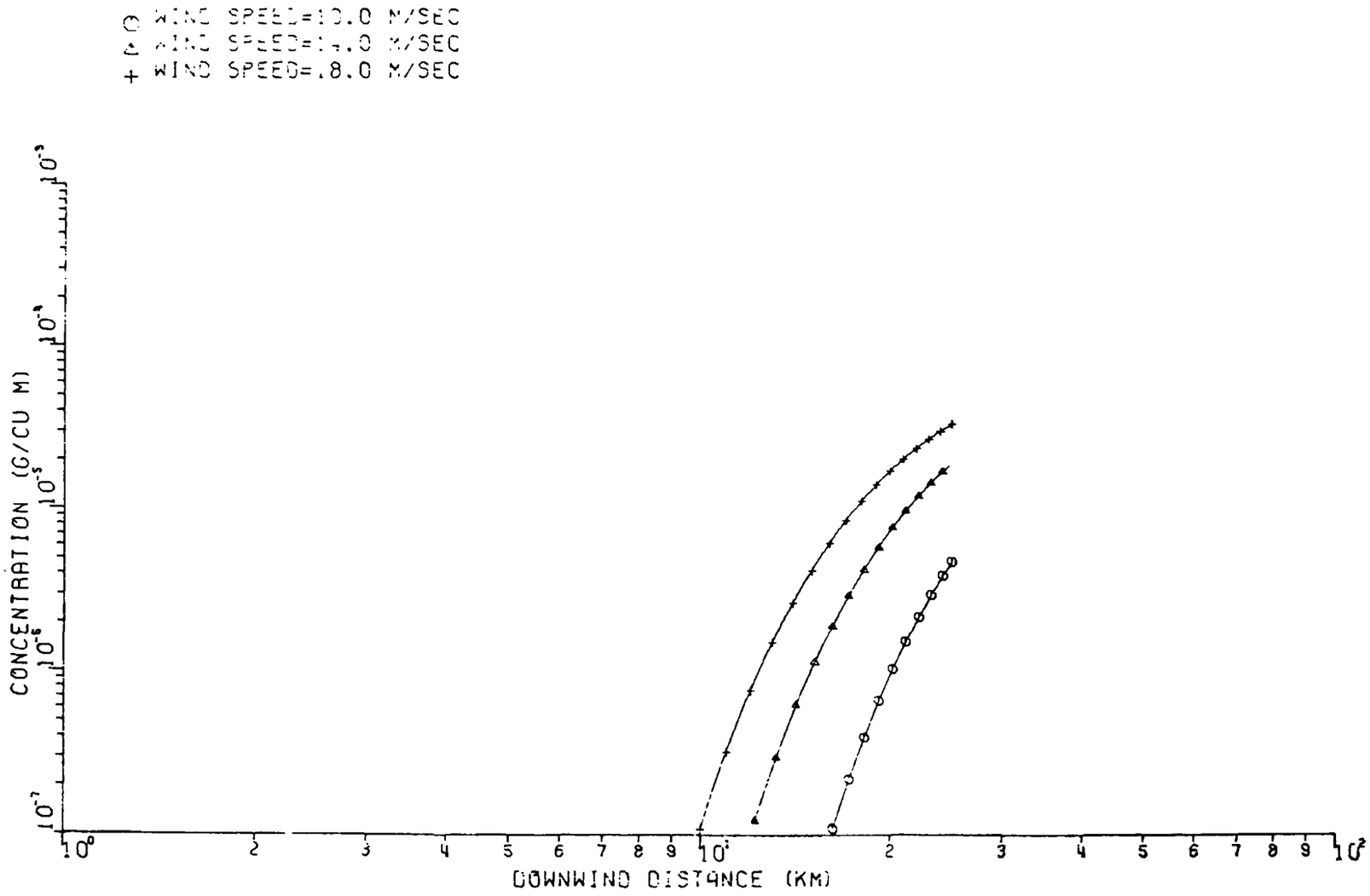

Figure C-3d. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

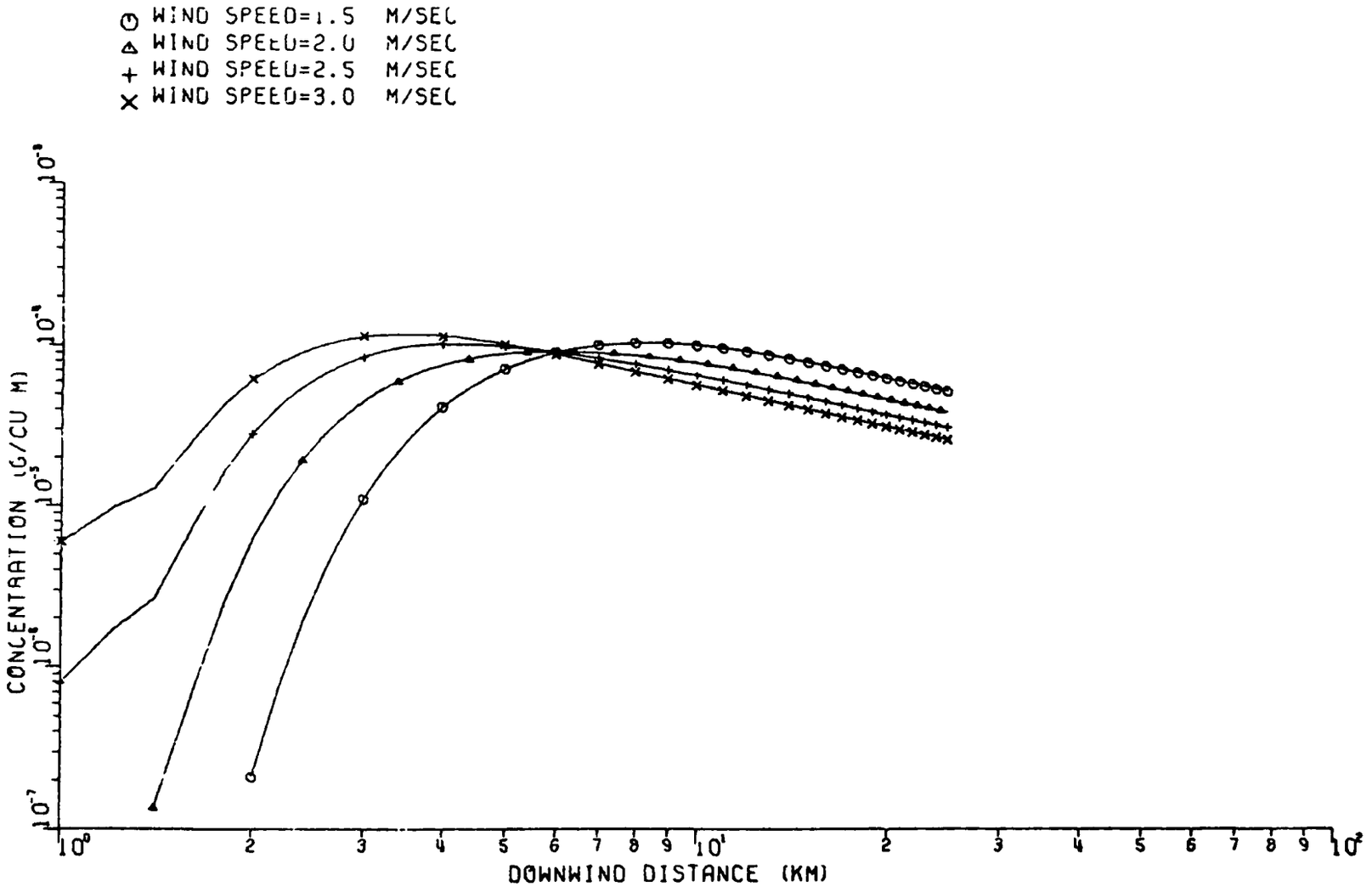

Figure C-4a. Plume centerline concentration versus downwind distance for stability Class A at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

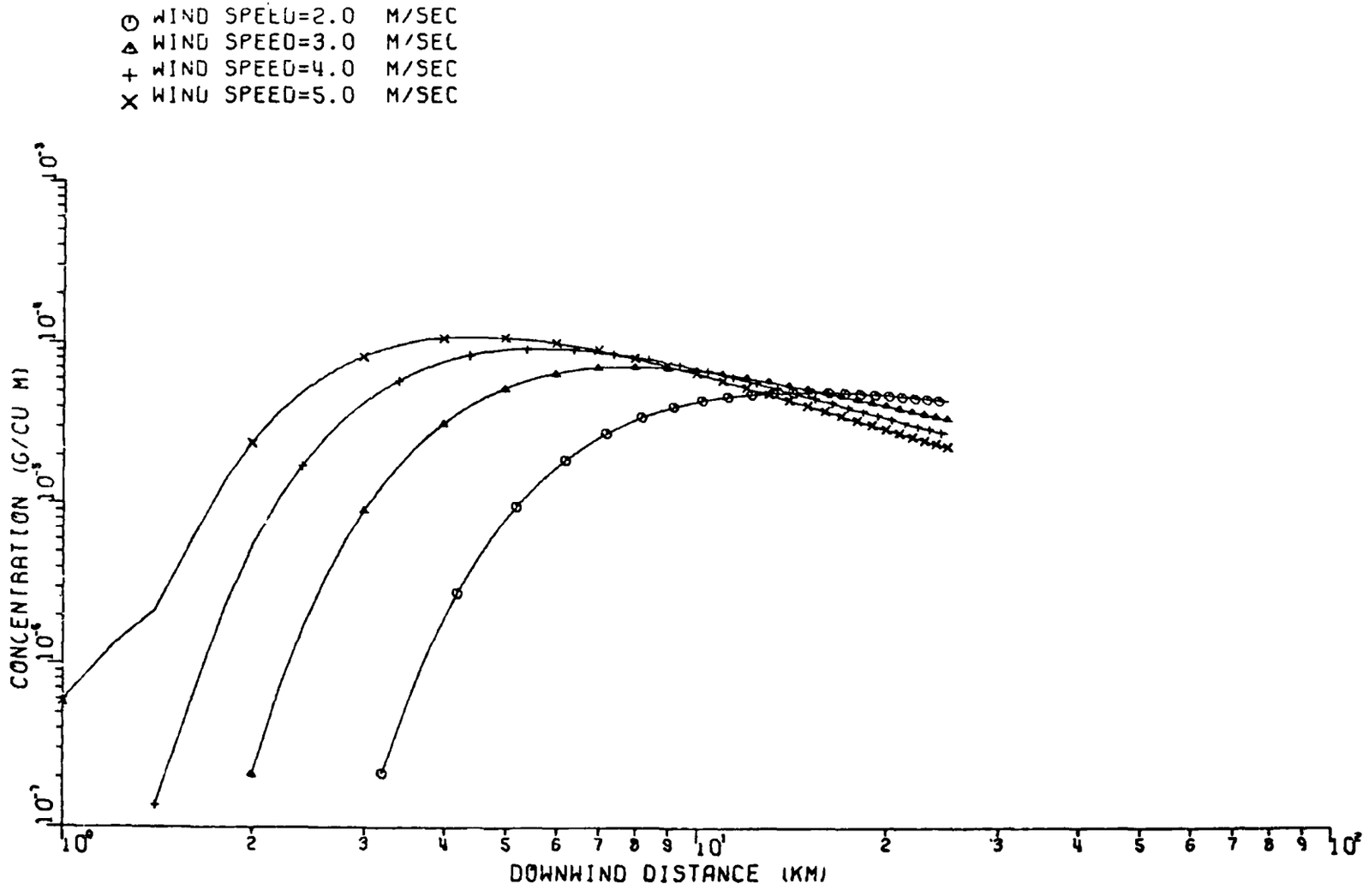

Figure C-4b. Plume centerline concentration versus downwind distance for stability Class B at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

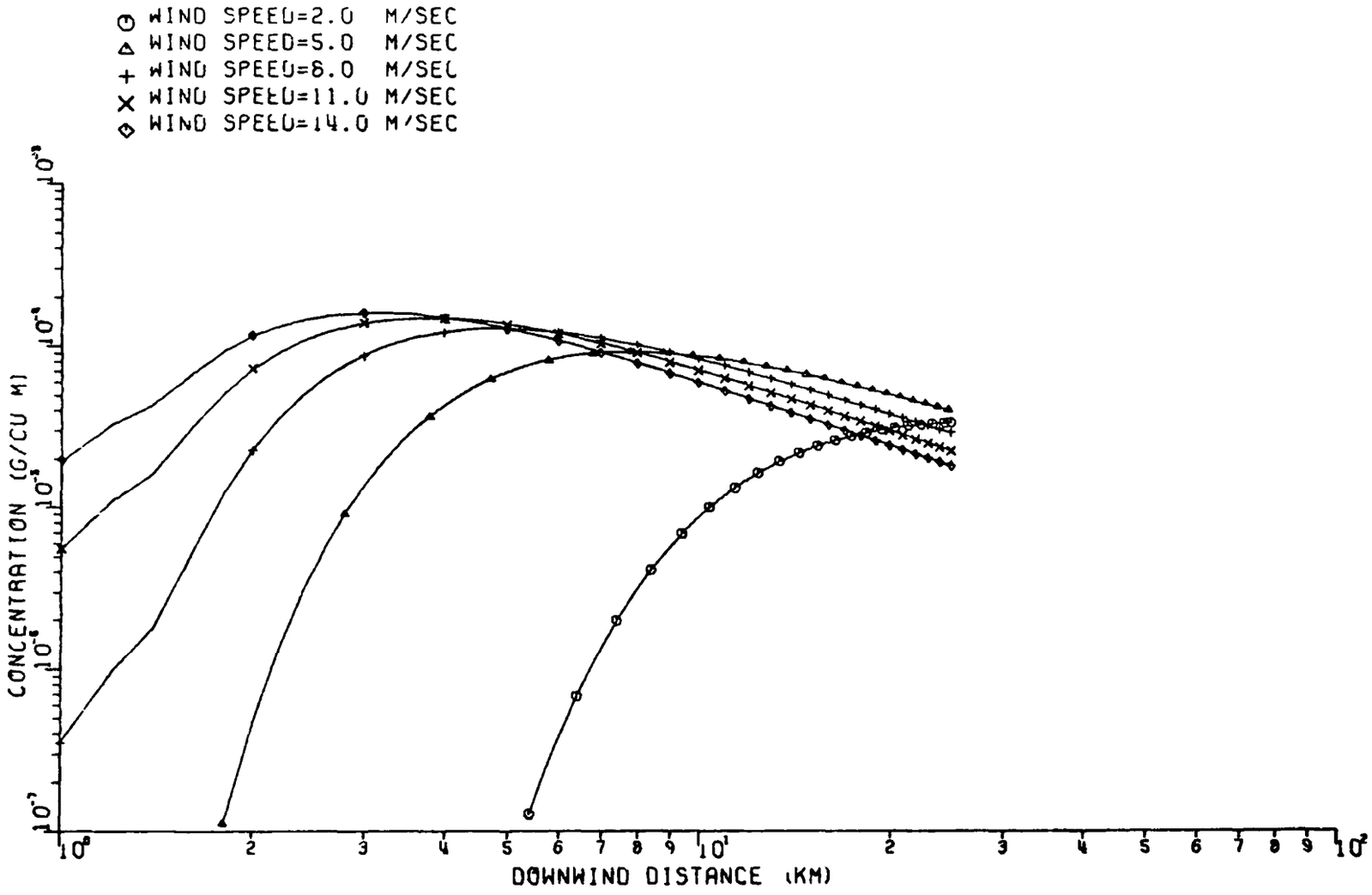

Figure C-4c. Plume centerline concentration versus downwind distance for stability Class C at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

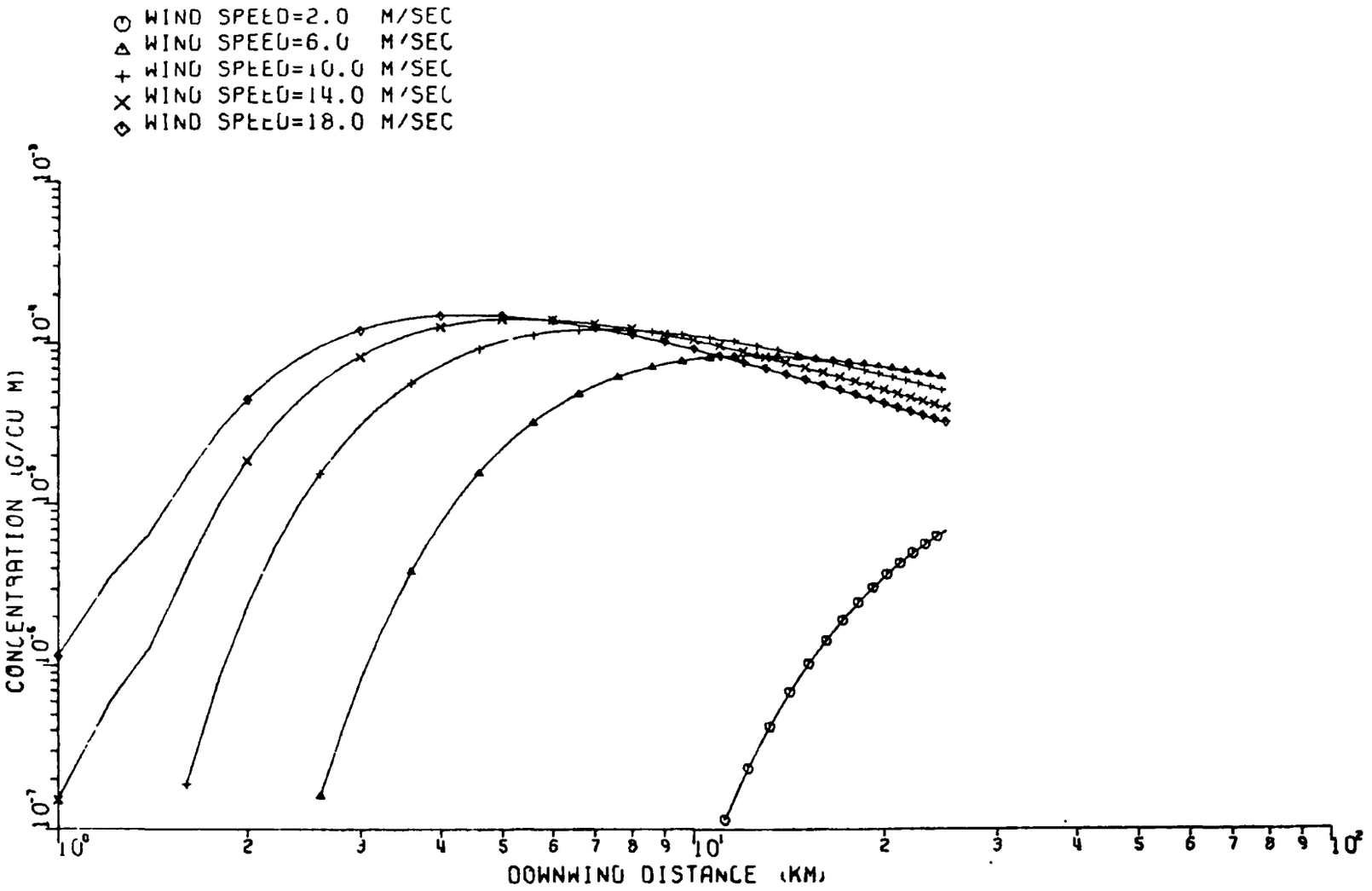

Figure C-4d. Plume centerline concentration versus downwind distance for stability Class D at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrian assumed. Wind speeds are at stack top

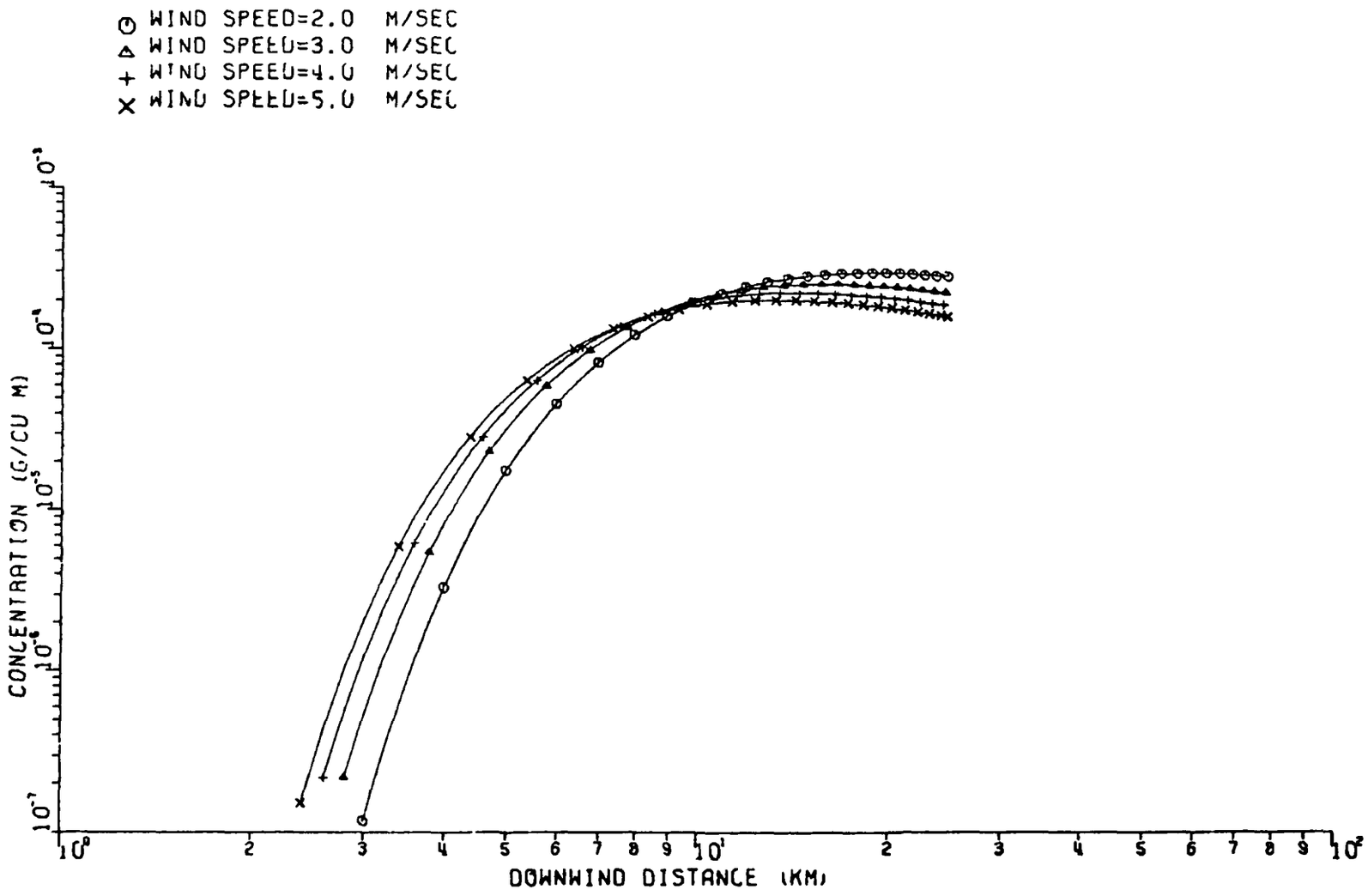

Figure C-4e. Plume centerline concentration versus downwind distance for stability Class E at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrian assumed. Wind speeds are at stack top

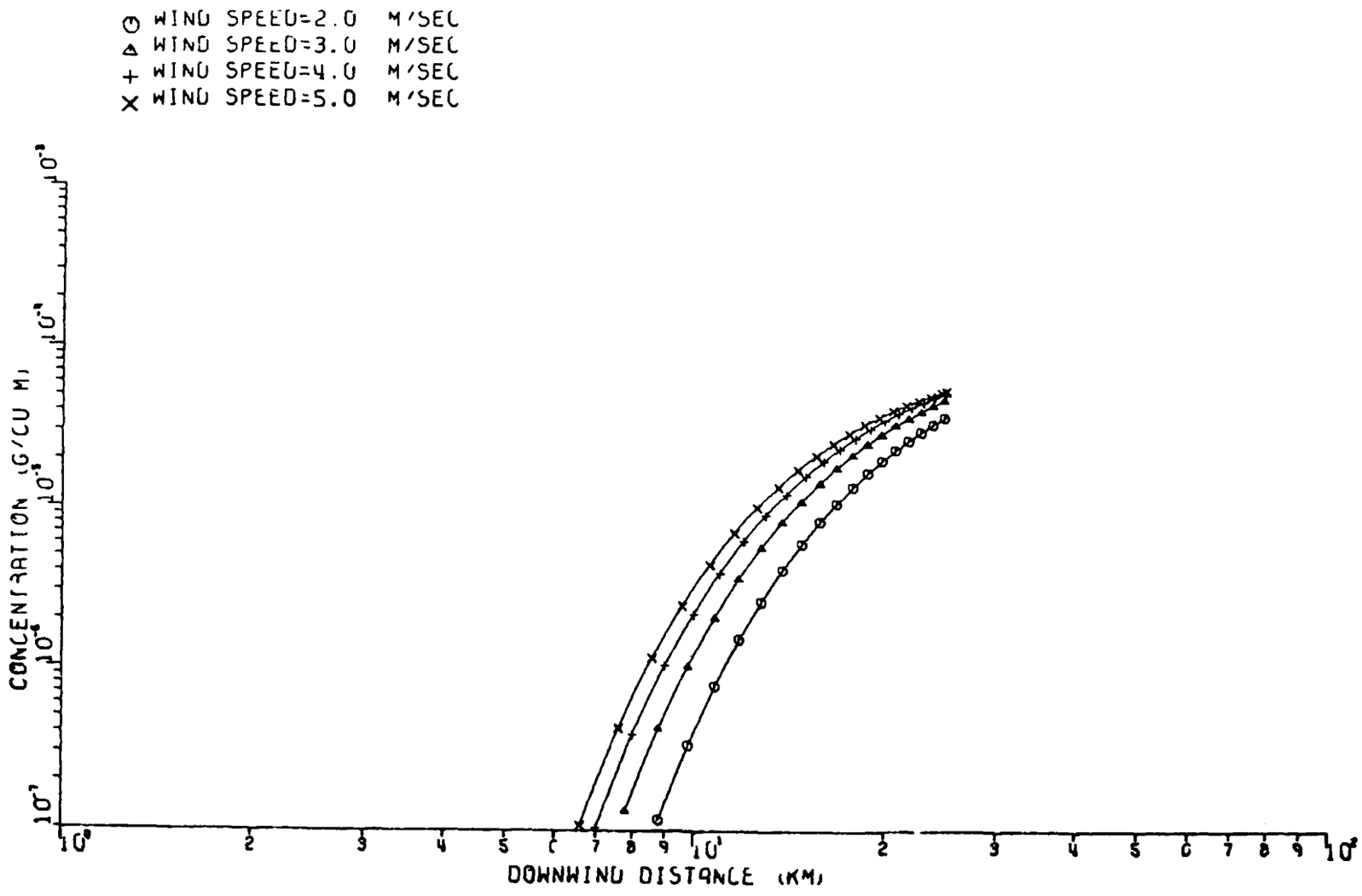

Figure C-4f. Plume centerline concentration versus downwind distance for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrian assumed. Wind speeds are at stack top

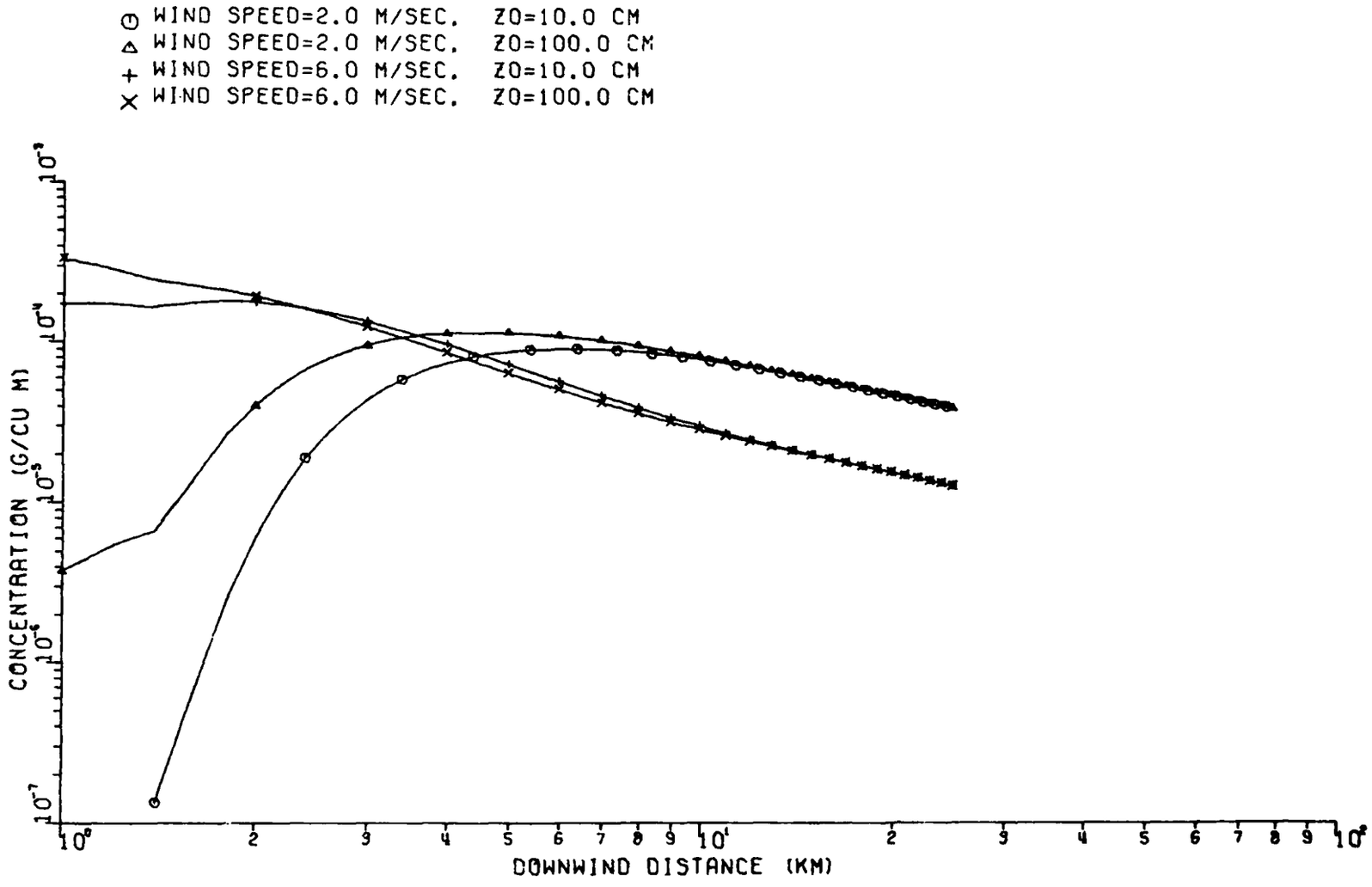

Figure C-5a. Effect of surface roughness upon ground level air concentrations for stability Class A at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

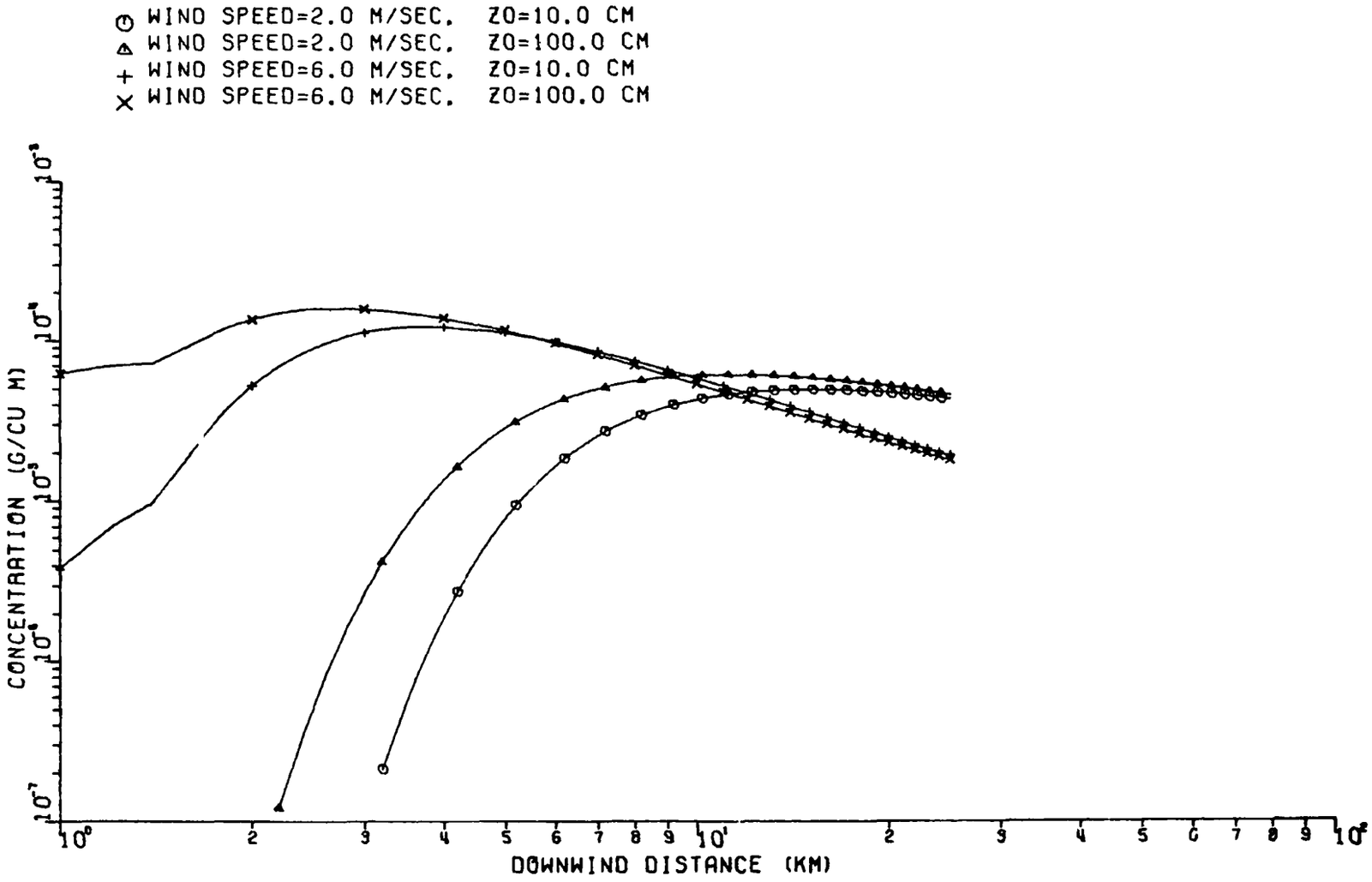

Figure C-5b. Effect of surface roughness upon ground level air concentrations for stability Class B at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

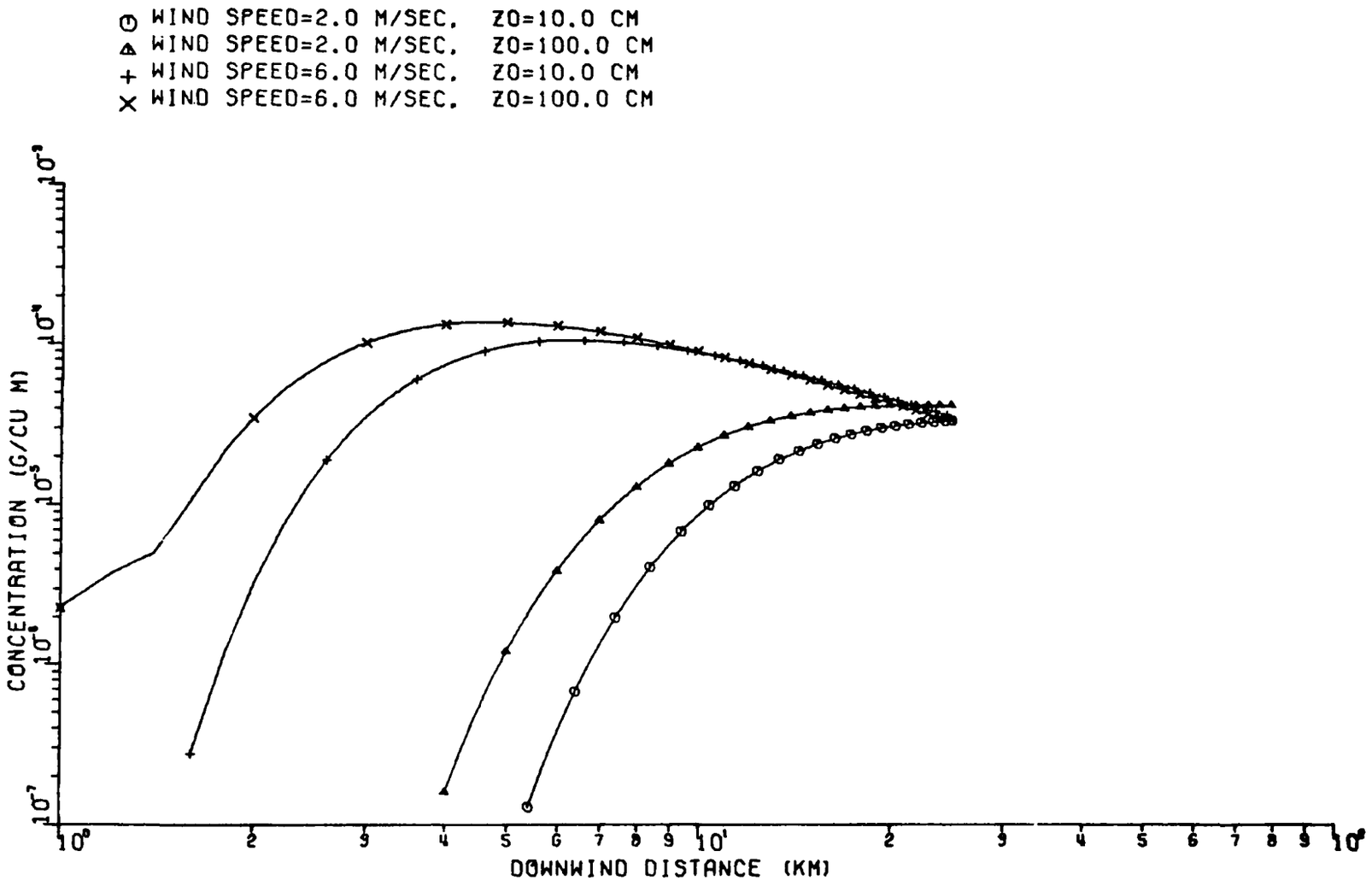

Figure C-5c. Effect of surface roughness upon ground level air concentrations for stability Class C at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

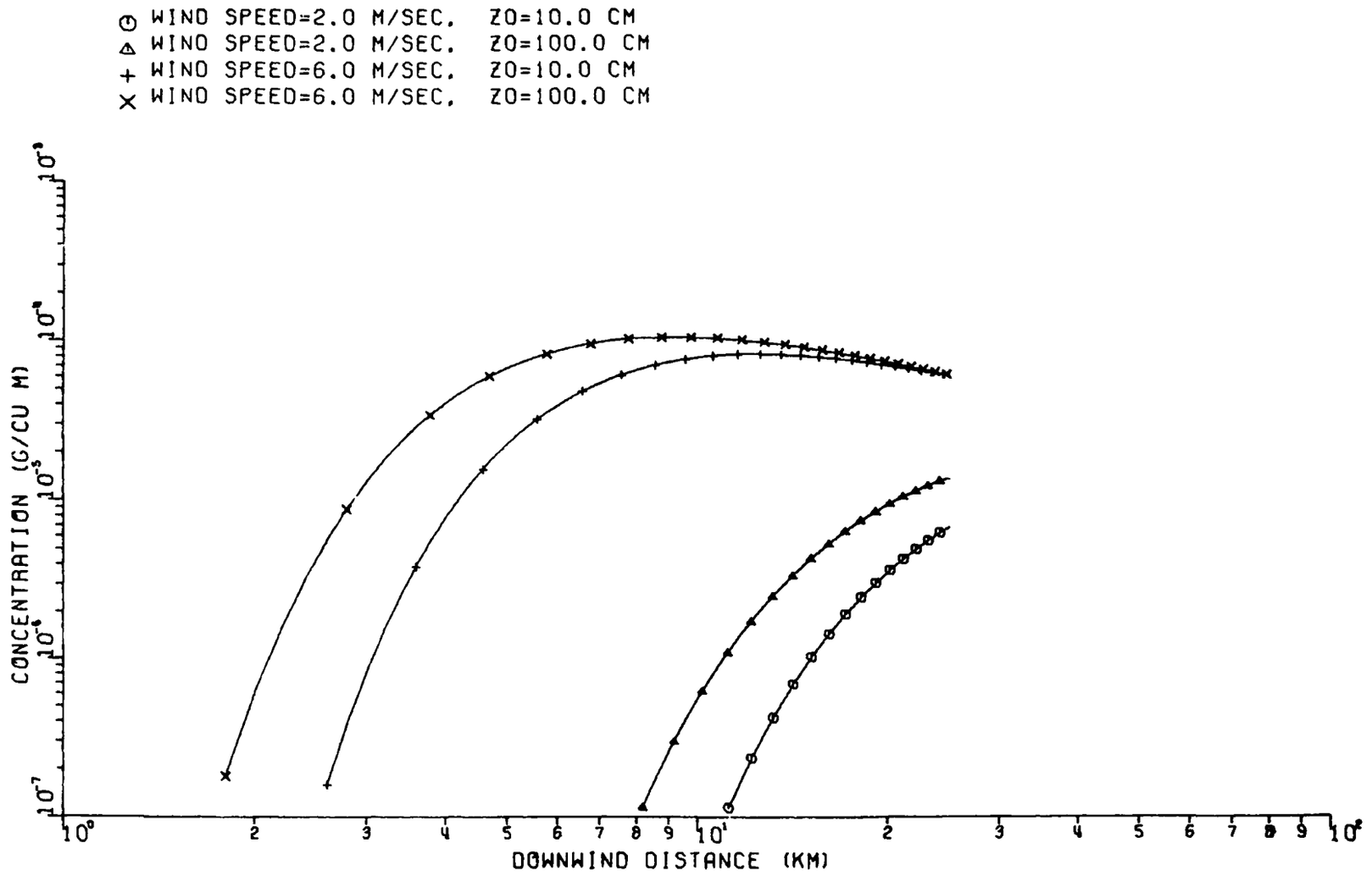

Figure C-5d. Effect of surface roughness upon ground level air concentrations for stability Class D at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

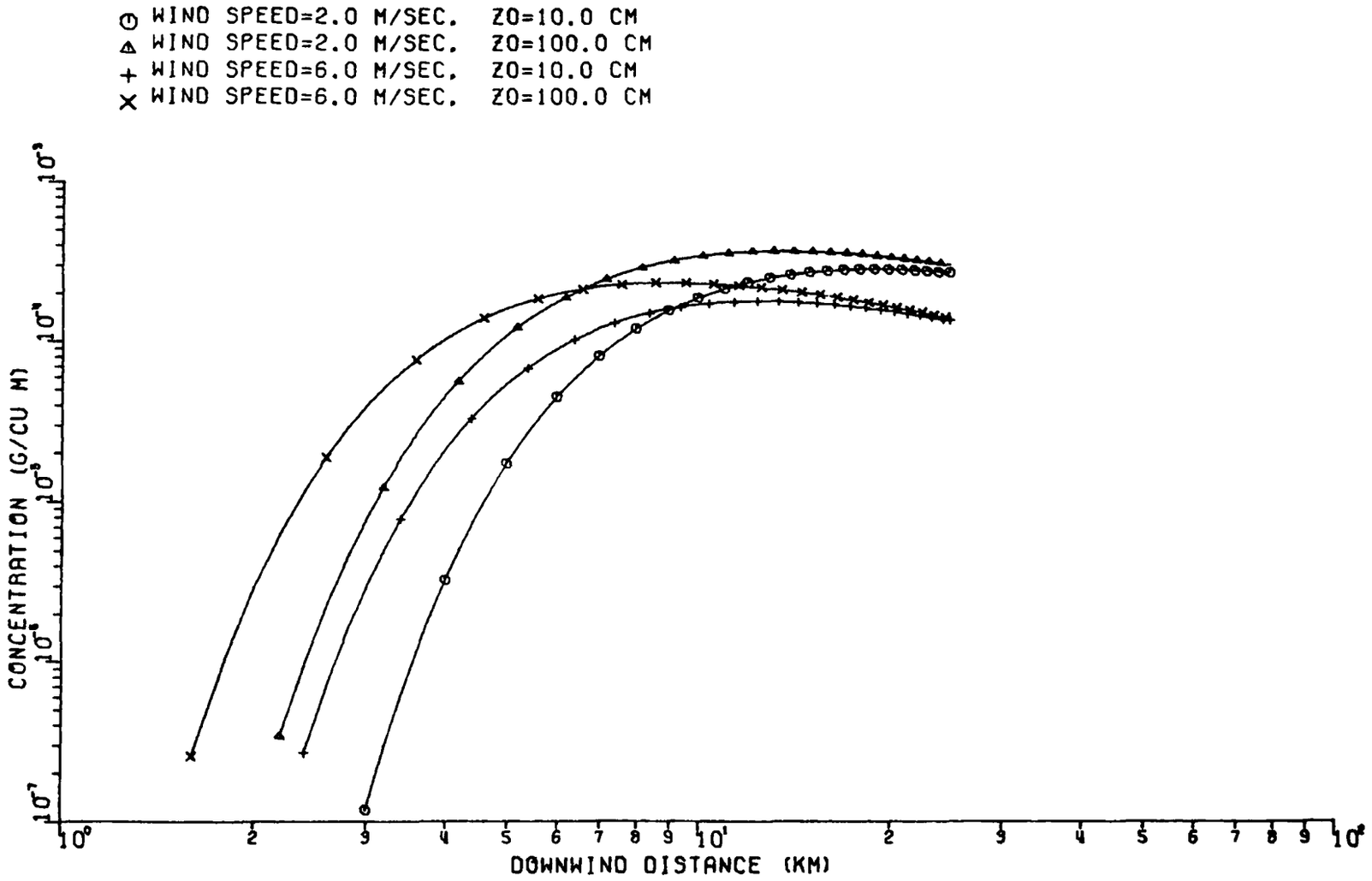

Figure C-5e. Effect of surface roughness upon ground level air concentrations for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_y curves used. Flat terrain assumed

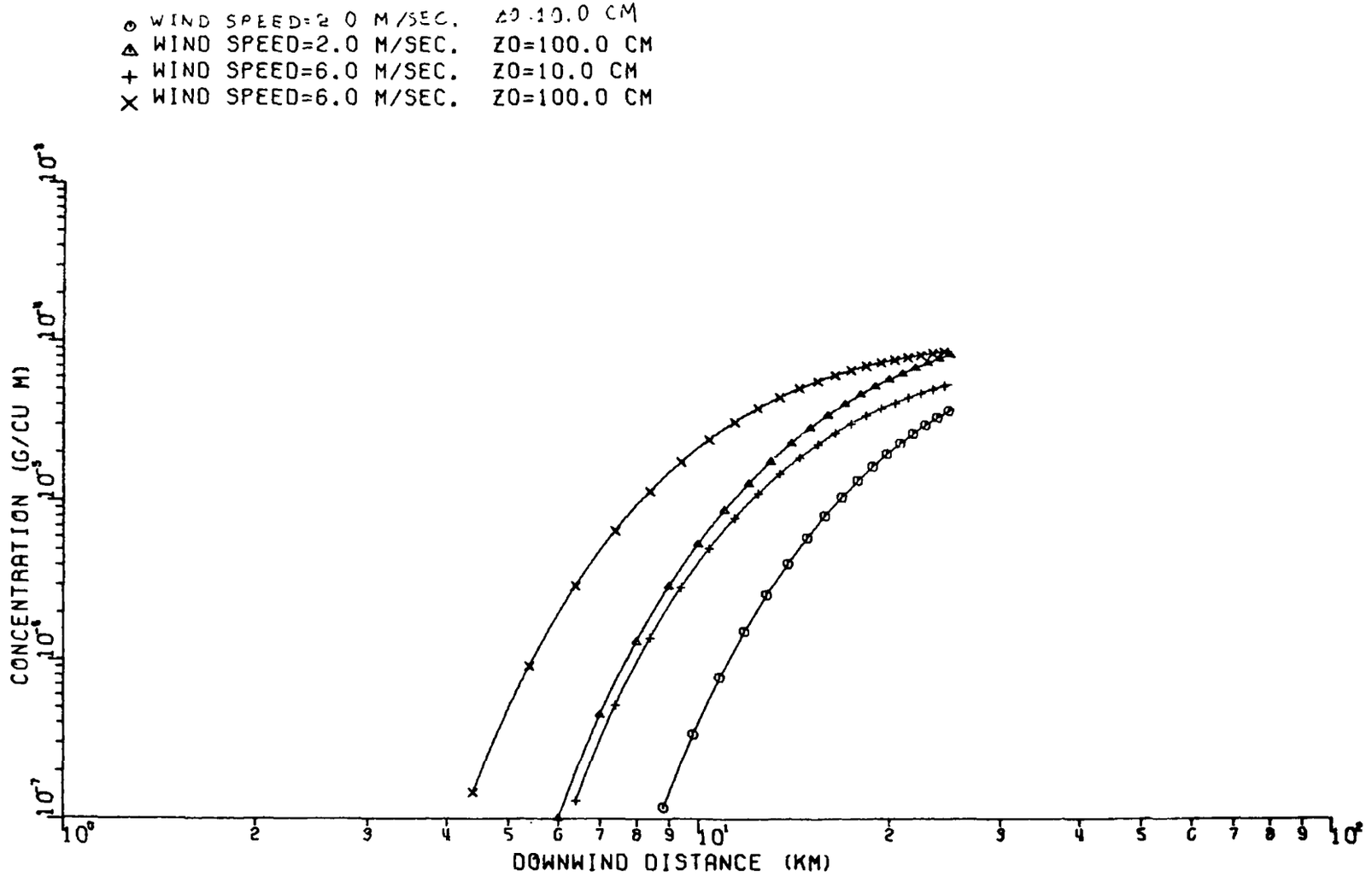

Figure C-5f. Effect of surface roughness upon ground level air concentrations for stability Class F at the Canal Plant. F. B. Smith σ_z and Pasquill-Turner σ_z curves used. Flat terrain assumed

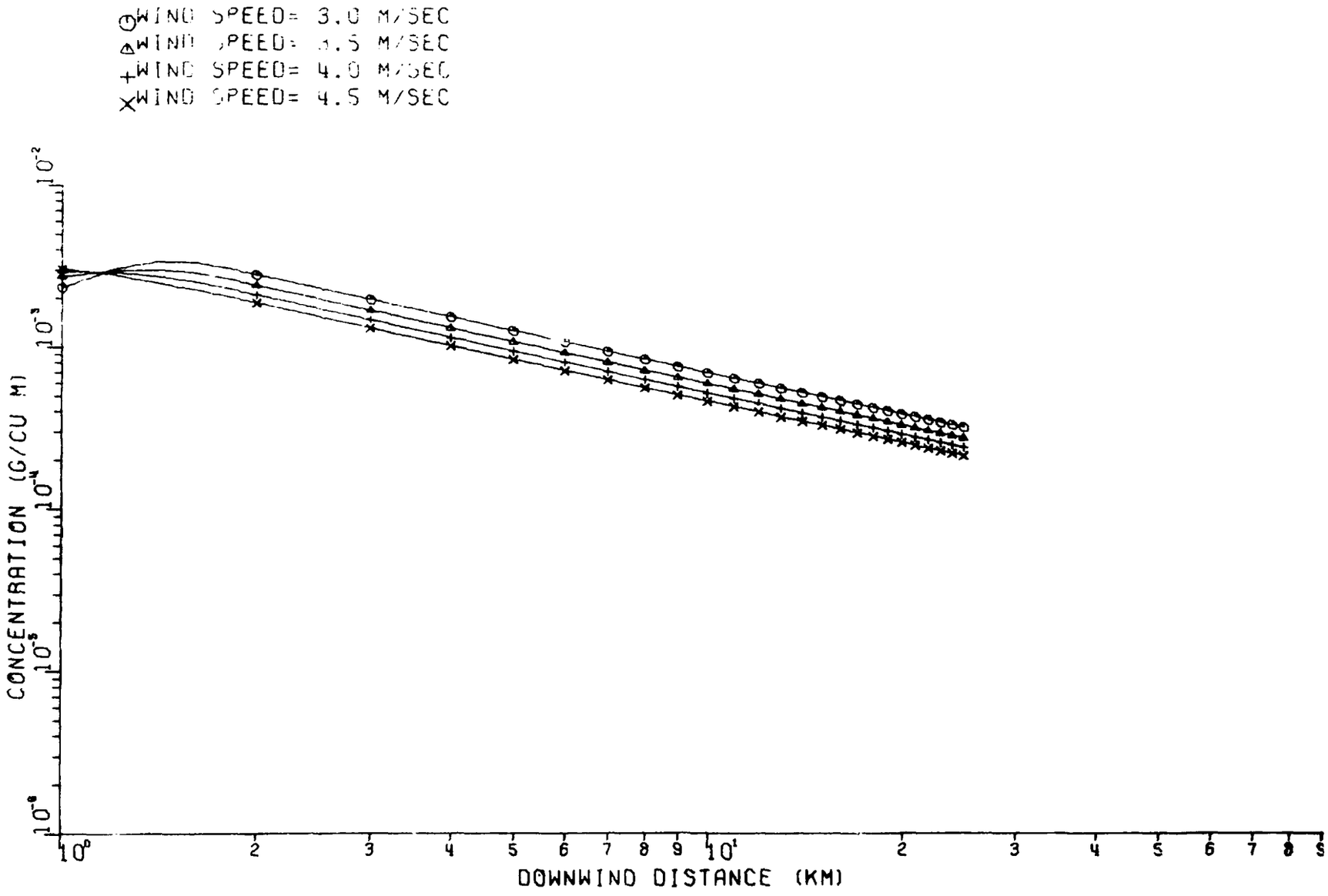

Figure C-6a. Plume centerline concentration versus downwind distance for stability Class A at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

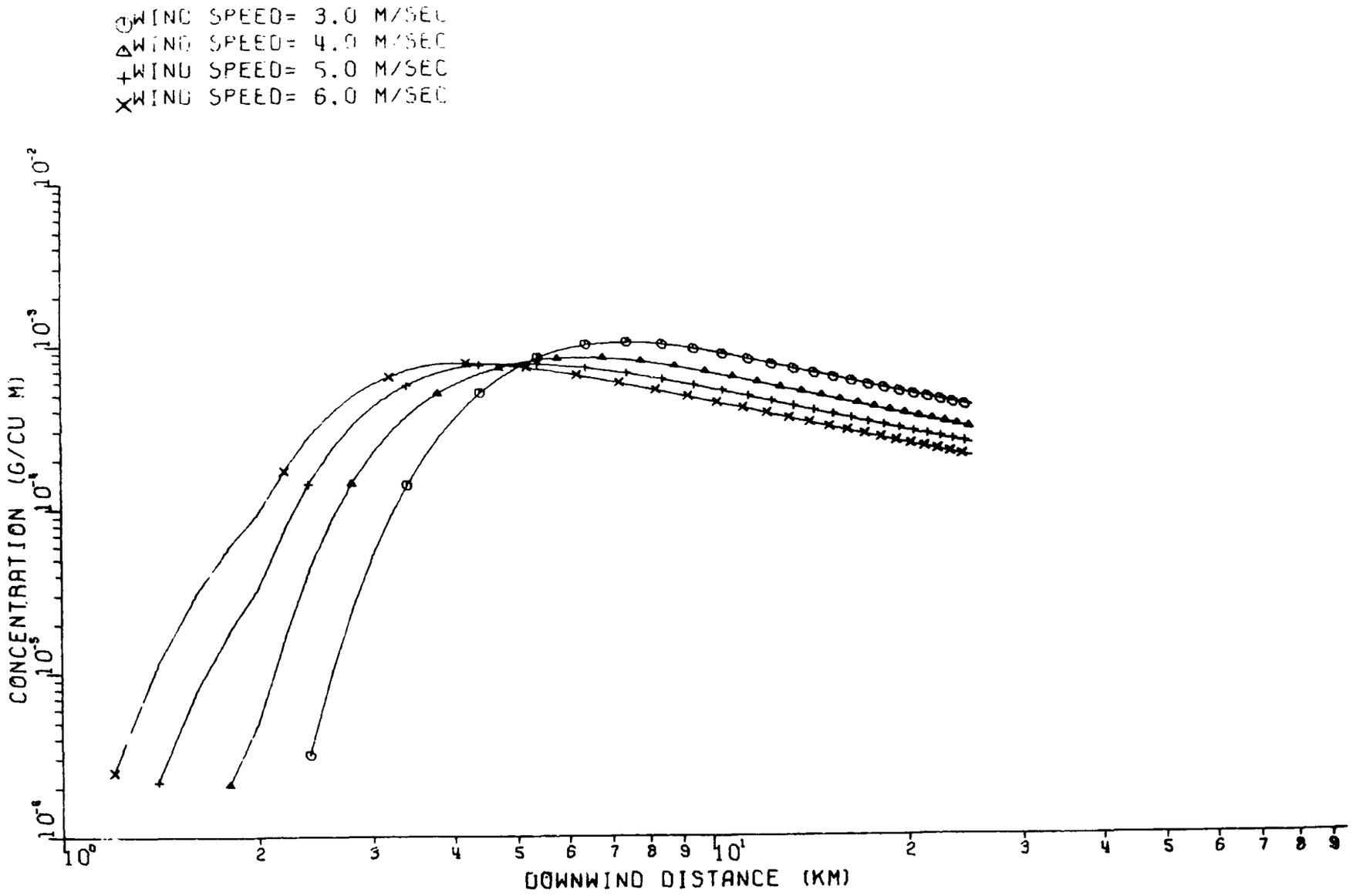

Figure C-6b. Plume centerline concentration versus downwind distance for stability Class B at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

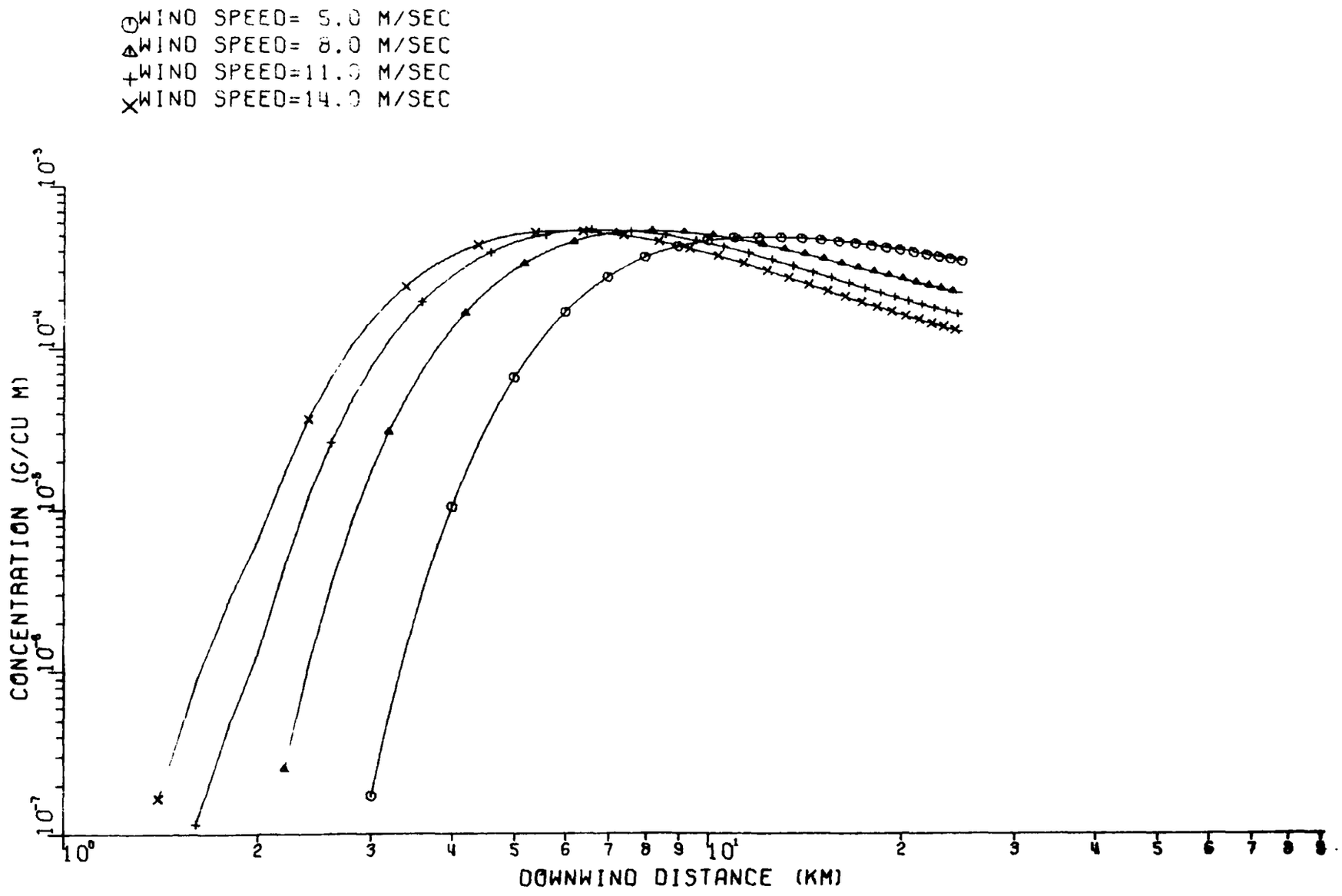

Figure C-6c. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

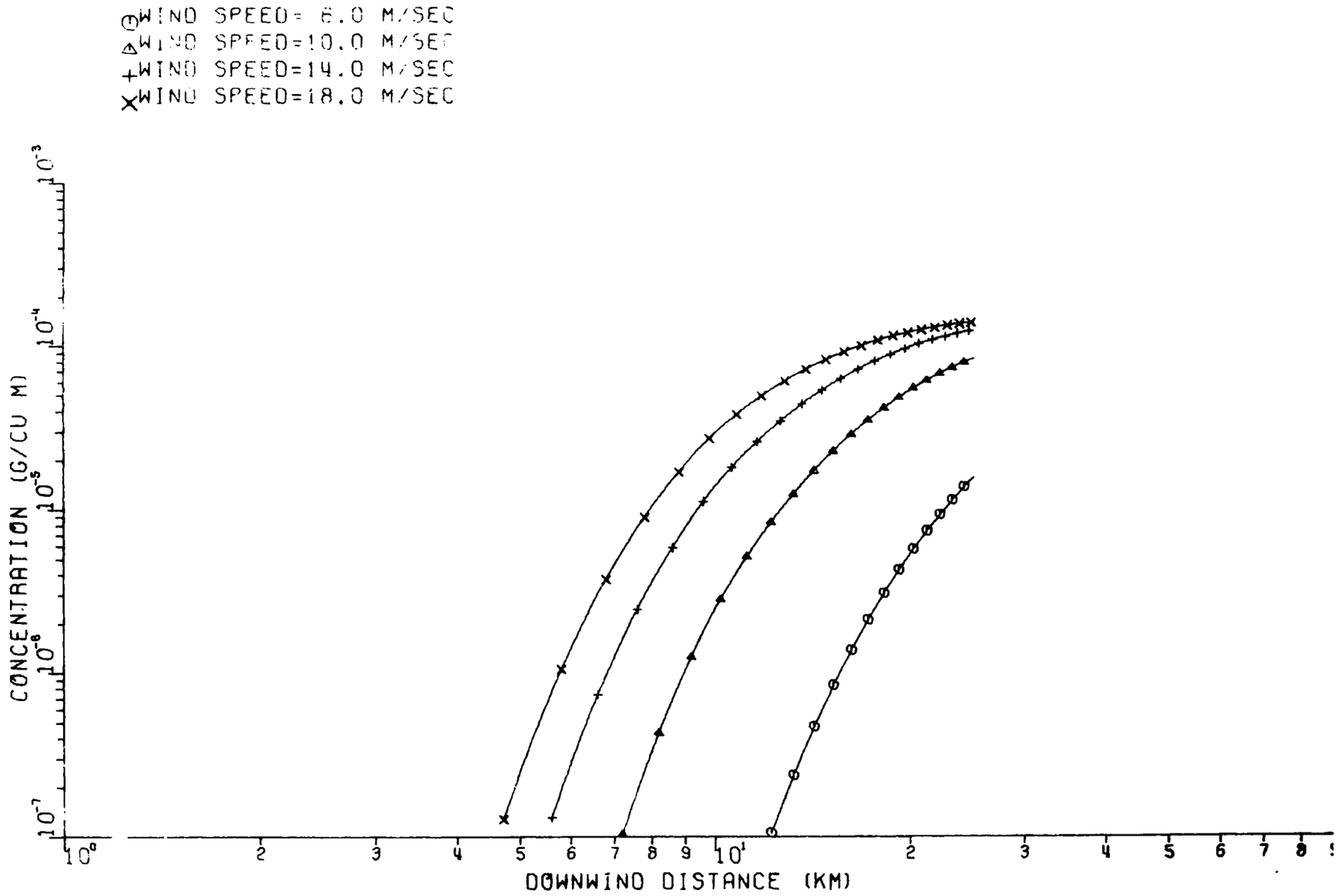

Figure C-6d. Plume centerline concentration versus downwind distance for stability Class D at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

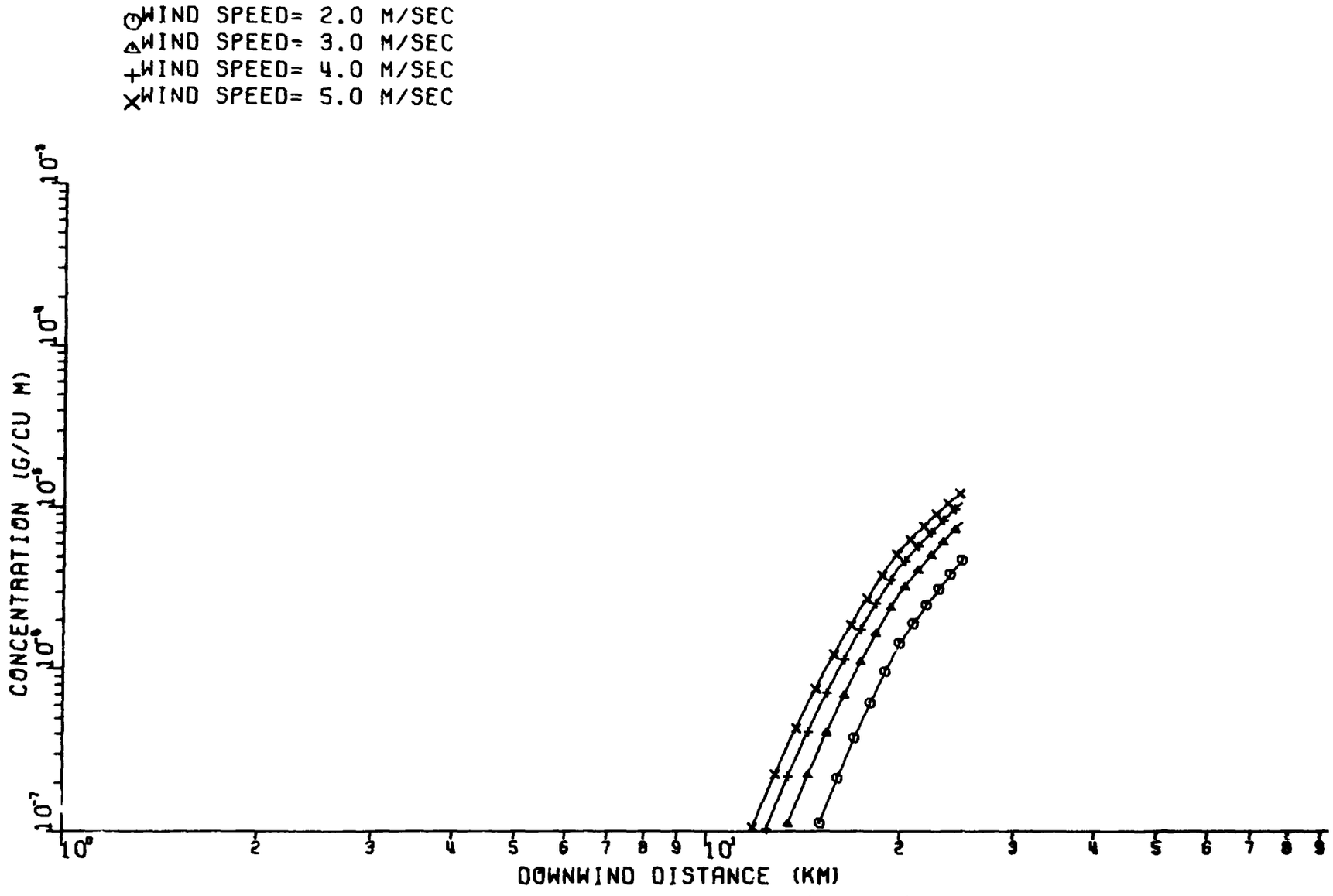

Figure C-6e. Plume centerline concentration versus downwind distance for stability Class E at the Muskingum Plant. Pasquill-Turner dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

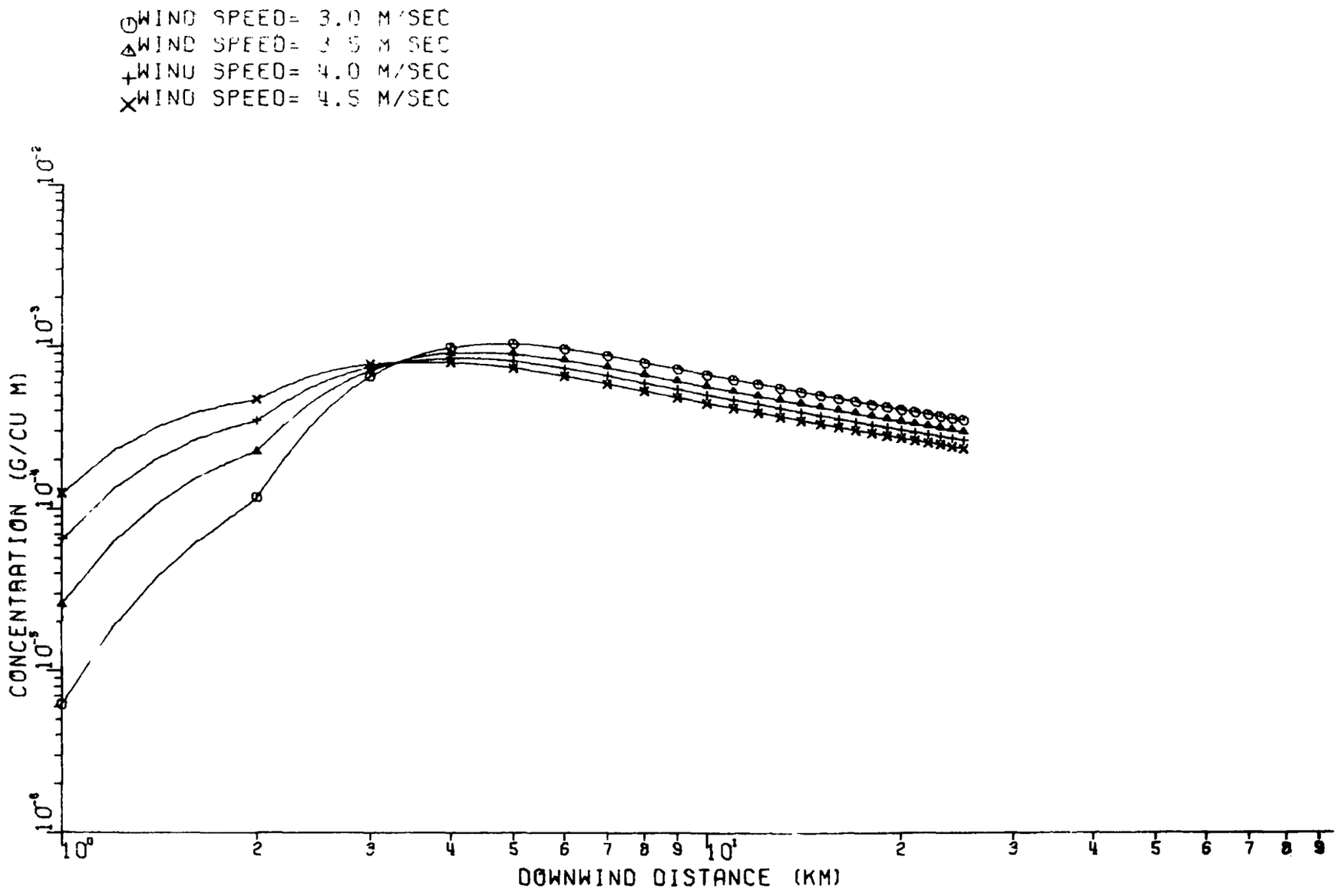

Figure C-7a. Plume centerline concentration versus downwind distance for stability Class A at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

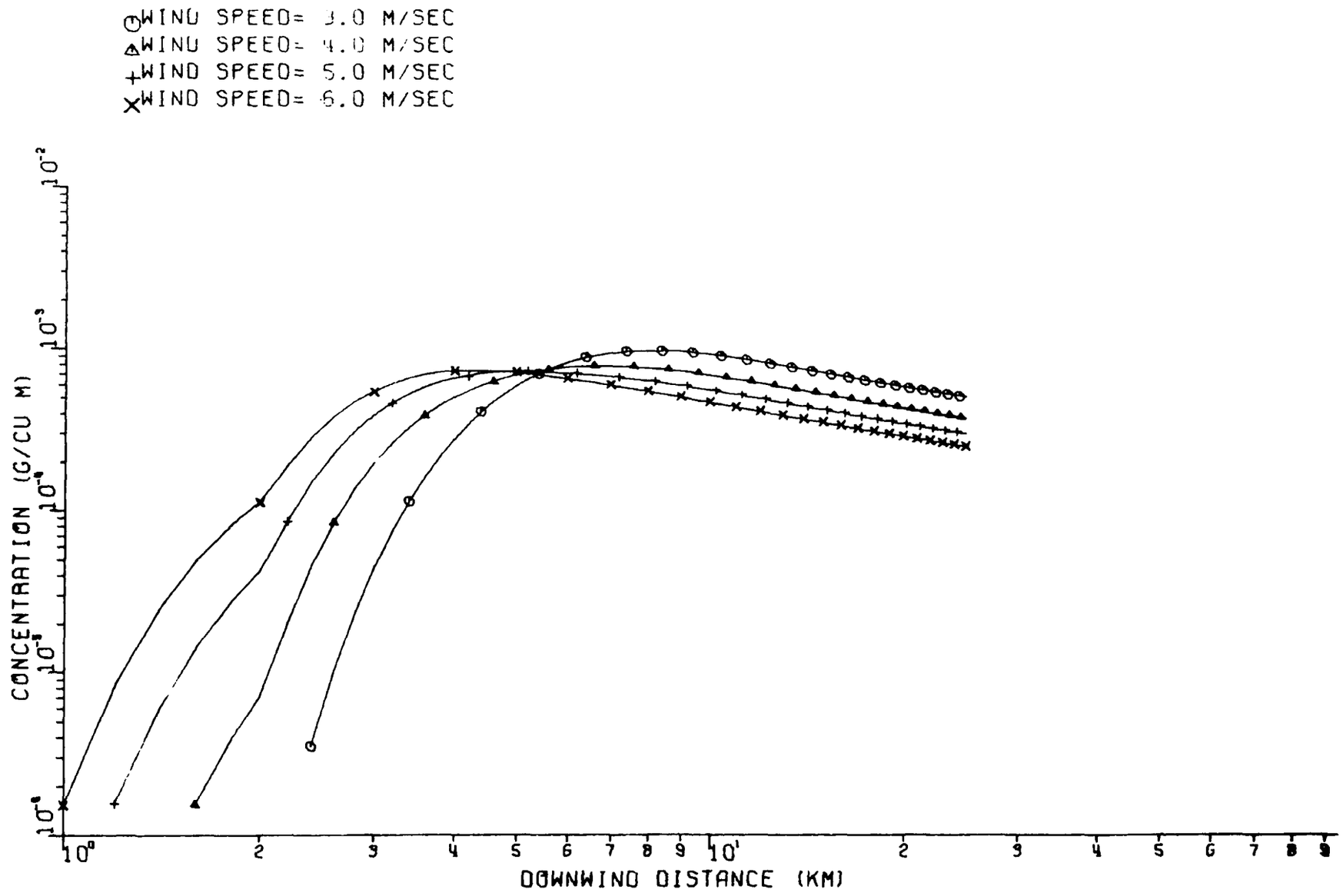

Figure C-7b. Plume centerline concentration versus downwind distance for stability Class B at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

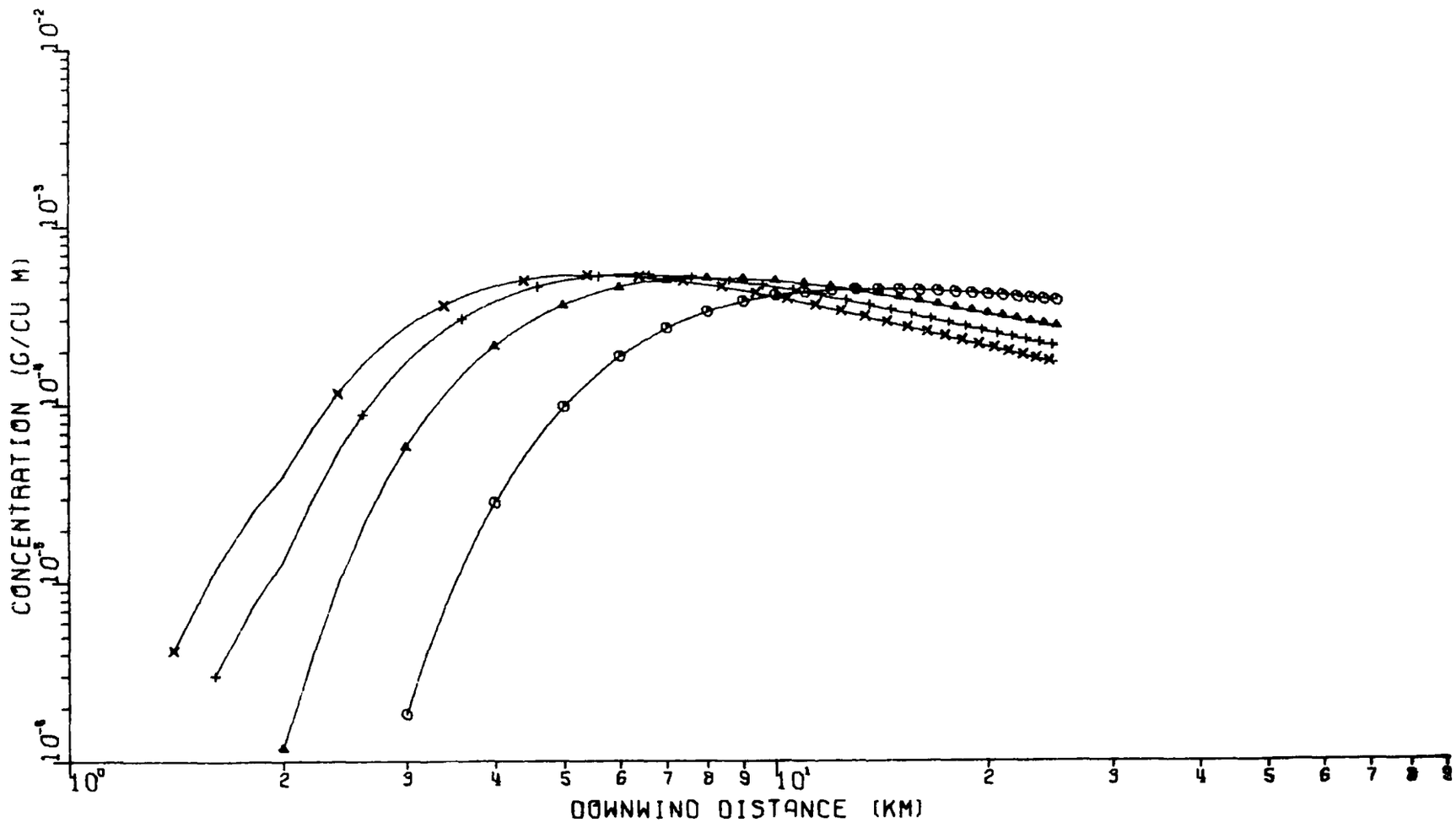

Figure C-7c. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

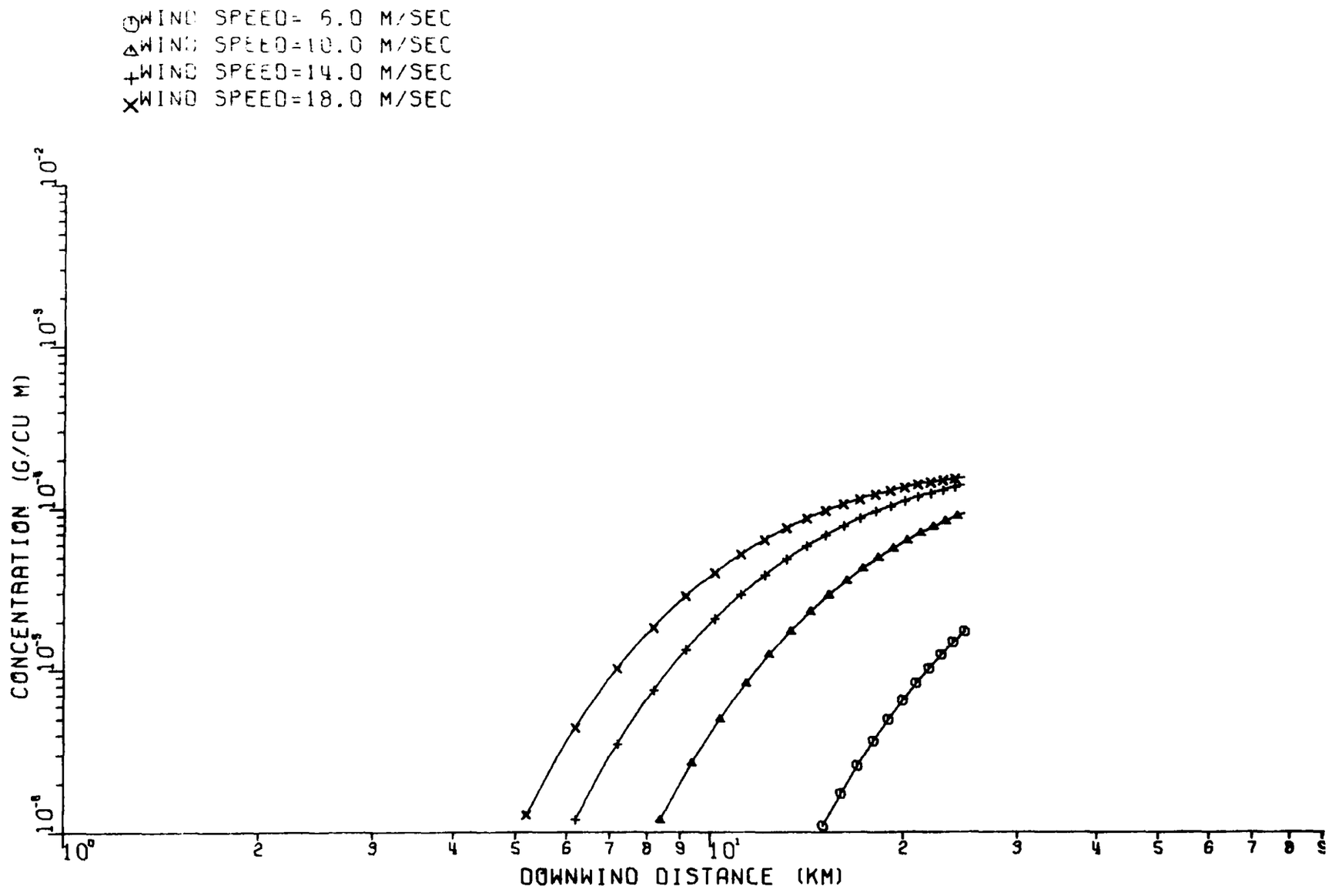

Figure C-7d. Plume centerline concentration versus downwind distance for stability Class D at the Muskingum Plant. Gifford-Briggs dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

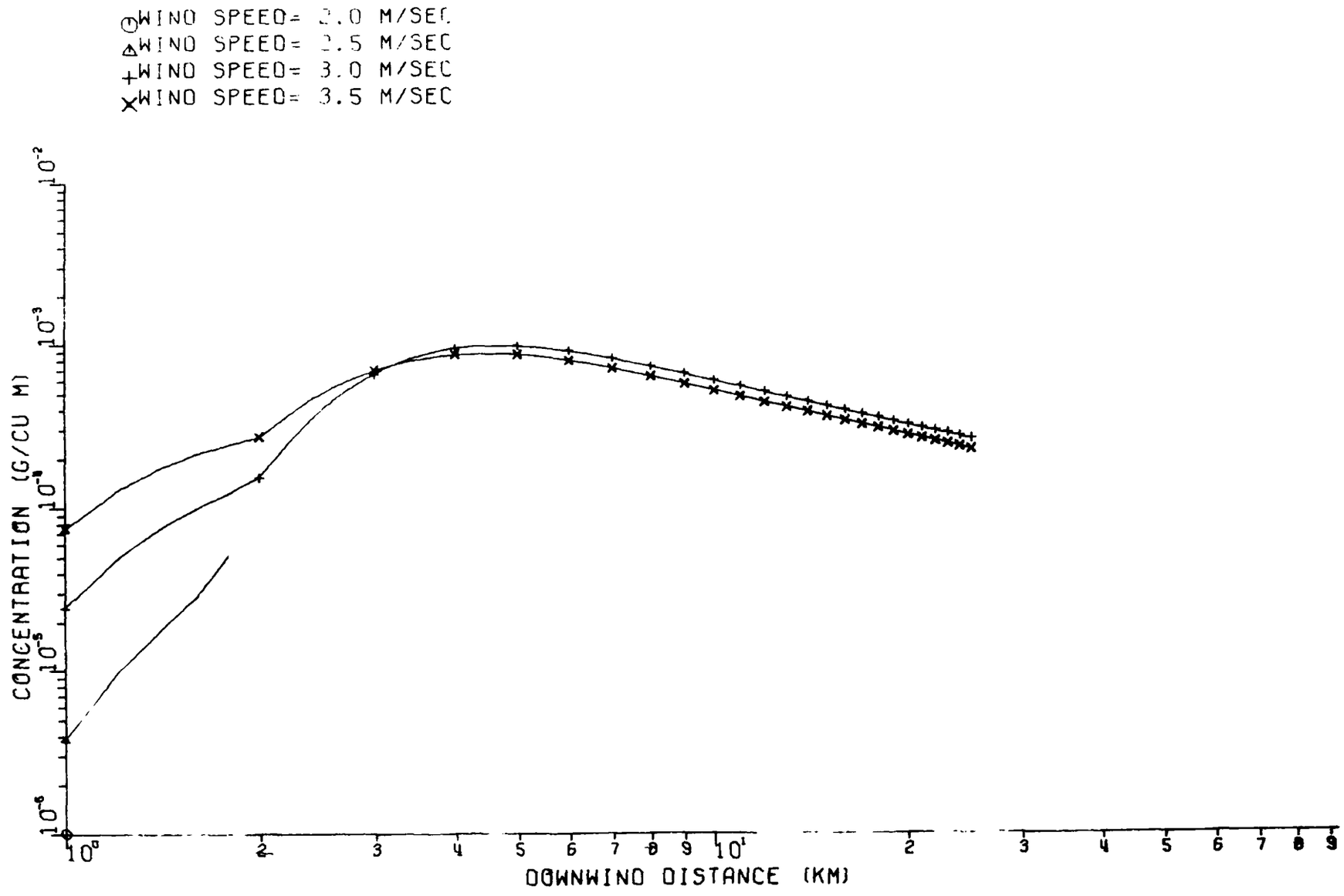

Figure C-8a. Plume centerline concentration versus downwind distance for stability Class B2 at the Muskingum Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

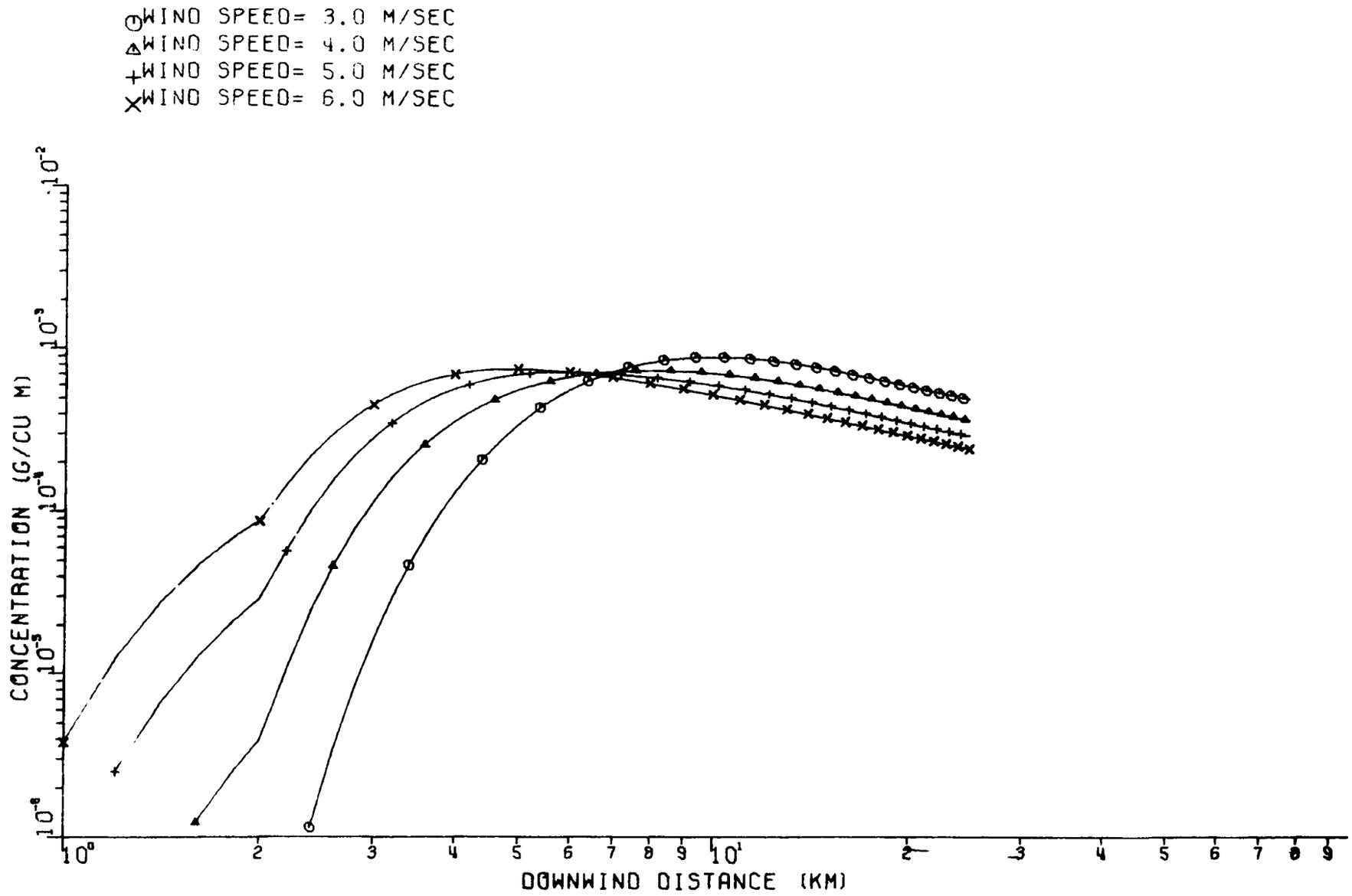

Figure C-8b. Plume centerline concentration versus downwind distance for stability Class B1 at the Muskingum Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

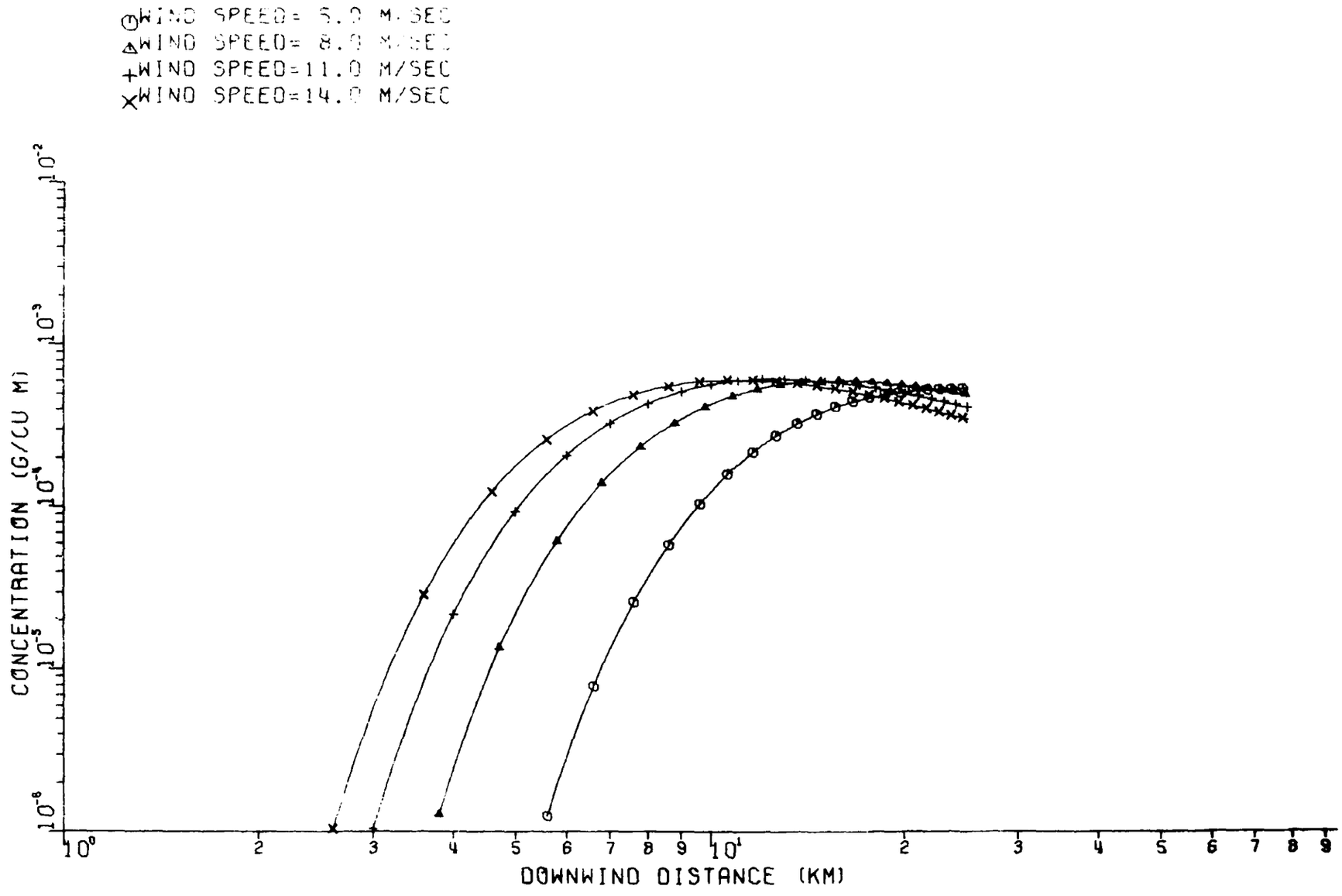

Figure C-8c. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. Smith-Singer dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

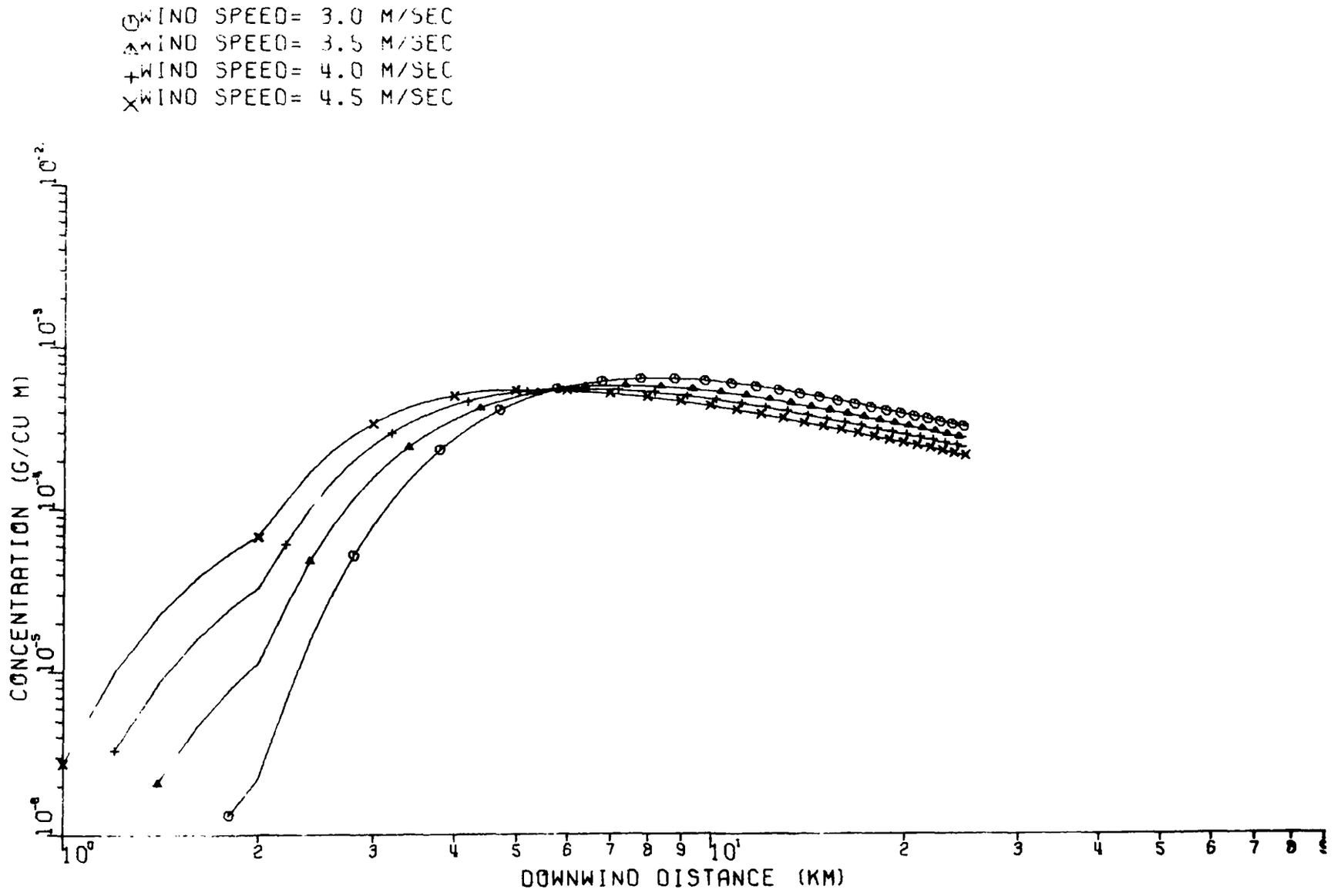

Figure C-9a. Plume centerline concentration versus downwind distance for stability Class A at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

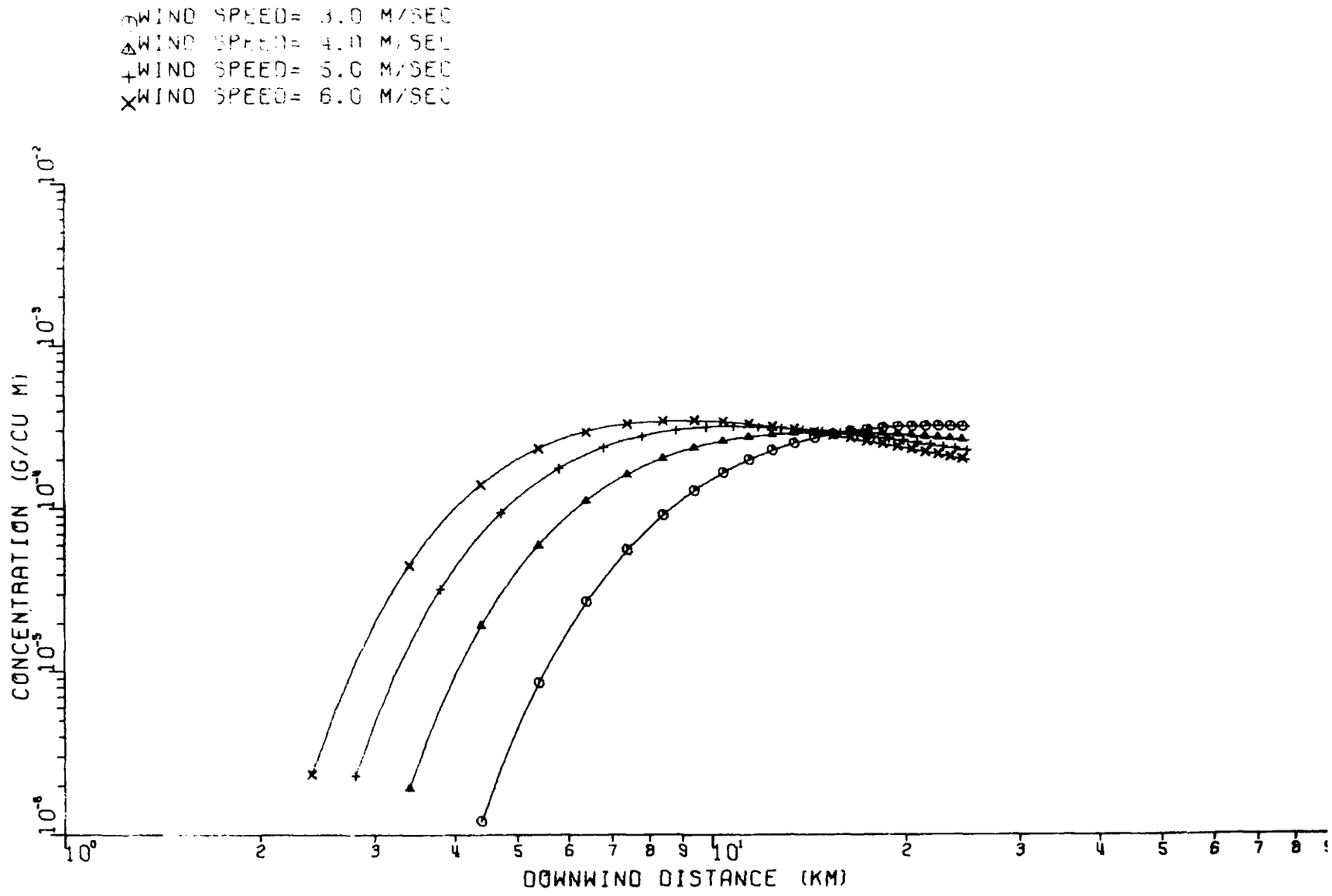

Figure C-9b. Plume centerline concentration versus downwind distance for stability Class B at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

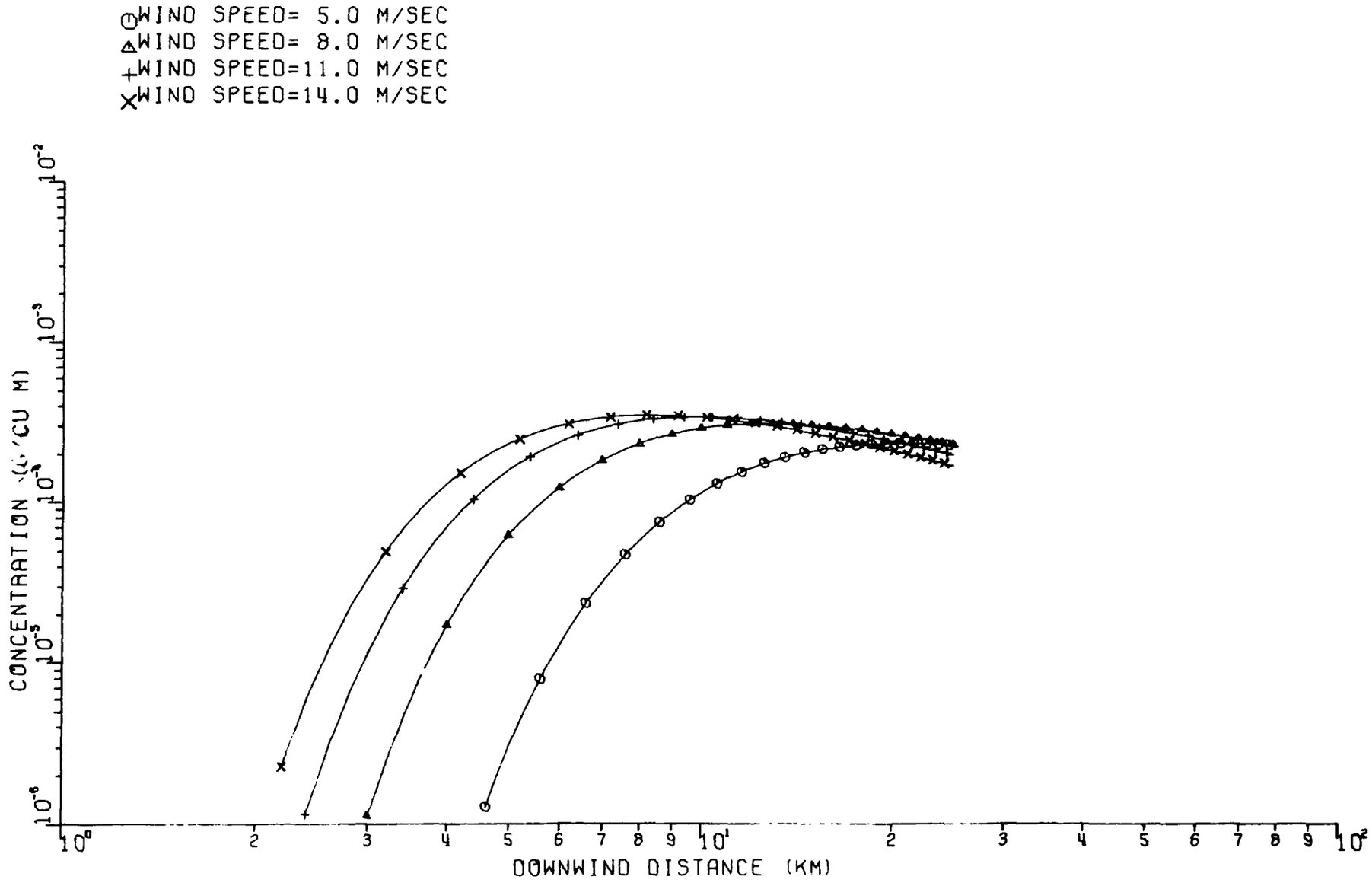

Figure C-9c. Plume centerline concentration versus downwind distance for stability Class C at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

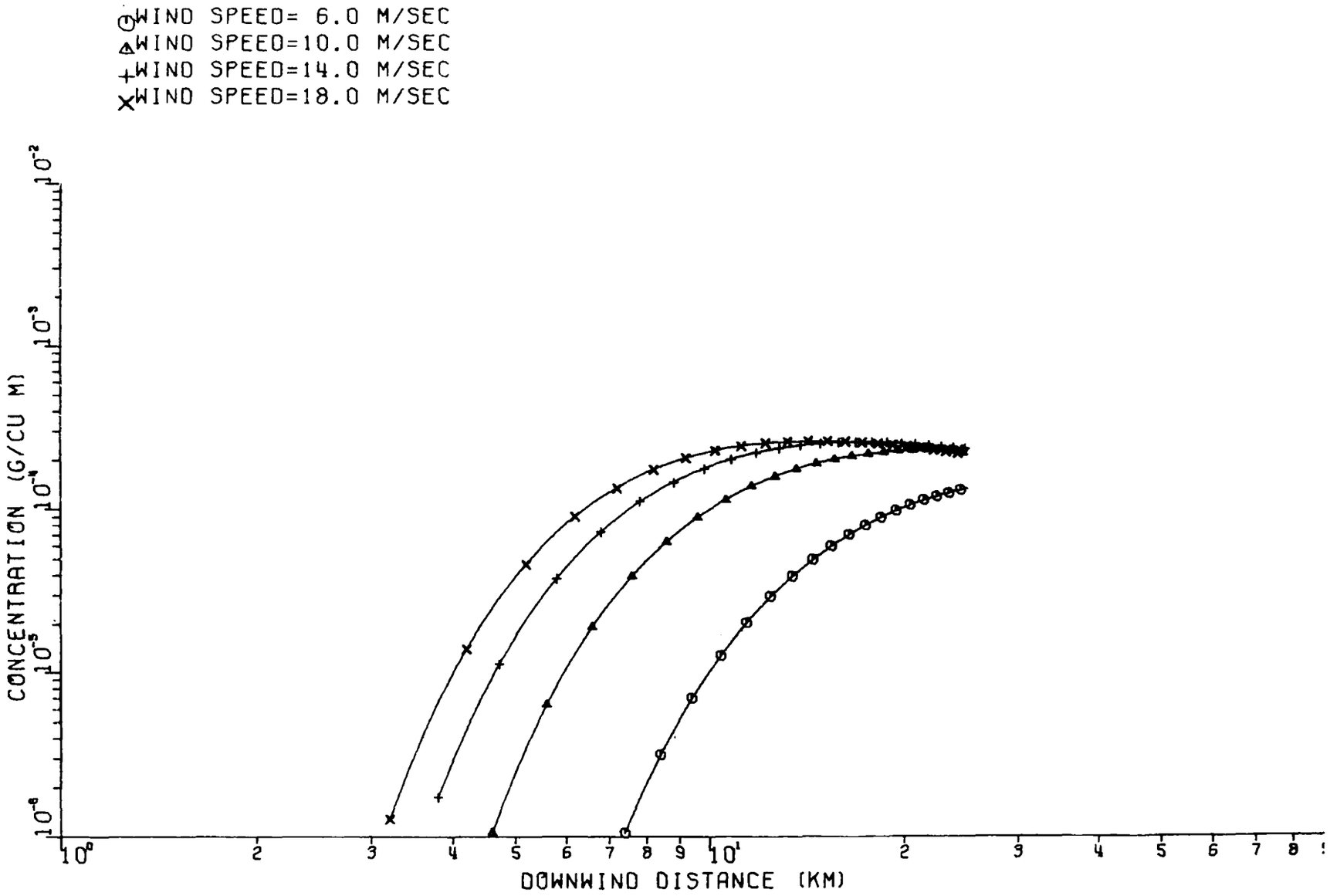

Figure C-9d. Plume centerline concentration versus downwind distance for stability Class D at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

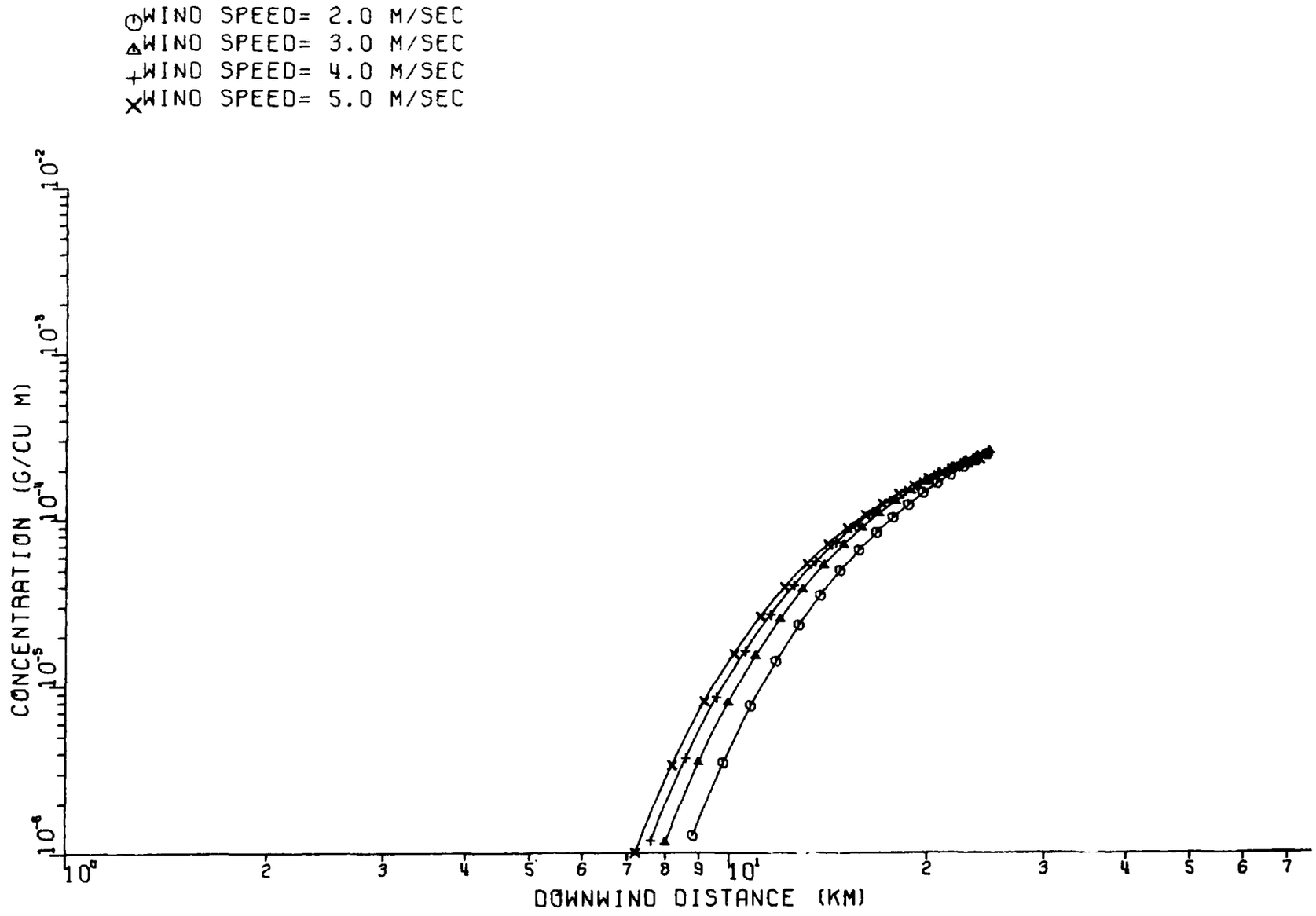

Figure C-9e. Plume centerline concentration versus downwind distance for stability Class E at the Muskingum Plant. F. B. Smith σ_z and Pasquill-Turner σ_y dispersion curves used. Flat terrain assumed. Wind speeds are at stack top

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The main purpose of this study was to determine whether alternate methods for stability index assignment and dispersion calculation would yield better agreement between measured and calculated cumulation frequency distributions of 1-hour SO_2 concentrations when used in the EPA Single Source Model. The following dispersion curves were tested: Pasquill-Turner, Gifford-Briggs, Smith-Singer and F. B. Smith. A fractional stability assignment technique based upon the work of F. B. Smith was also investigated. Based upon model validation results for the Canal Power Plant in Massachusetts and the Muskingum Power Plant in Ohio, the Pasquill-Turner dispersion curves and stability index assignment algorithm currently used in the model were found to give the best agreement with measured concentration distributions. During the course of the study the incorporation of a variable stack gas exit velocity was evaluated and found not to appreciably affect the model predictions.

17. KEY WORDS AND DOCUMENT ANALYSIS

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