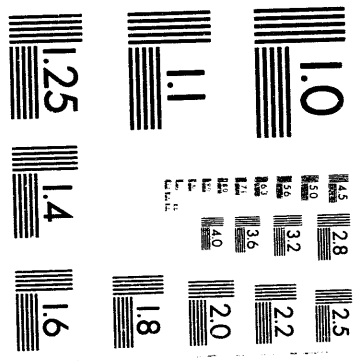
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Waste Management and
Environmental Technology

WSRC-RP-94-96

JUSTIFICATION FOR CHANGE IN AXAIR DISPERSION COEFFICIENTS

A. A. Simpkins

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Technical Reviewer

February 1994

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-88SR18035

DISCLAIMER

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Key Words

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ABSTRACT

The atmospheric dispersion coefficients currently used in AXAIR are analytical expressions developed to fit the curves in the Turner Workbook as referred to in USNRC Regulatory Guide 1.145. This report explores the ramifications and benefits of changing the dispersion coefficients to a combination of Pasquill's lateral dispersion coefficients and Briggs' vertical dispersion coefficients. The differences in the dispersion coefficients have a minor effect on the relative air concentrations for stability classes A-D, but a significant difference is seen for classes E, F, and G.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

JUSTIFICATION FOR CHANGE IN AXAIR DISPERSION COEFFICIENTS

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1.0 INTRODUCTION

AXAIR is the primary dose assessment code used at the Savannah River Site (SRS) to predict doses following hypothetical releases of relatively short durations. The primary purpose of the code is to produce safety-related documentation adhering strictly to the guidance in NRC 1.145 (USNRC, 1982) entitled *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants.* Since AXAIR's creation, dispersion coefficients depicted by the Pasquill-Gifford curves (Turner, 1967) fit by analytical expressions were applied to determine downwind relative air concentrations. This report is prepared to justify changing the dispersion coefficients to the more fundamental Pasquill-Briggs dispersion coefficients.

2.0 DISPERSION COEFFICIENT COMPARISON

This section describes the dispersion coefficients that are currently used within AXAIR (Pasquill-Gifford) and the recommended Pasquill(1976)-Briggs(1973) coefficients. Also, results from the two different models are graphically compared.

2.1 Brief History of Atmospheric Dispersion

A very brief history of issues concerning atmospheric dispersion that are pertinent to this report will be discussed. For a more indepth review see Weber (1976).

In 1958 Pasquill developed the stability categories from meteorological parameters. He set up graphs to display vertical and horizontal dispersion as a function of downwind distance and stability class. In 1961 Gifford used the same data as Pasquill, but changed the plume spreading parameters to values of the standard deviation of the concentration distribution, (σ_y and σ_z). The result led to curves that we refer to as the Pasquill-Gifford curves. These curves, published in an EPA workbook by Turner, (1967) are based on experimental data taken at distances of less than 1 km, then extrapolated out to greater distances. Analytical expressions have been published to fit these curves for computational convenience.

In 1976 the EPA published a study that evaluated the need to update the Turner Workbook values that were used in ever-widening applications. In part II of this work Pasquill recommended analytical expressions for use in determining the lateral dispersion coefficients based on Taylor diffusion theory and several sets of experimental measurements. He recommended more research before new analytical expressions for vertical dispersion coefficients were developed.

Briggs developed formulas for vertical dispersion coefficients based on previous experimental dispersion data. The coefficients were developed based on experimental data from several different experiments (Brookhaven National Lab (Singer, 1966), Tennessee Valley Authority (Carpenter, 1971), St. Louis, (McElroy, 1968), American Meteorological Society, (Pasquill,1975)) Each of these covered a wider range of conditions than the previous experiments.

Pasquill's horizontal dispersion coefficients used in combination with the Briggs vertical dispersion coefficients were used at SRS in the early emergency response models. They provided the most relevant dispersion coefficients formulation that took into account (1) the expected elevated releases at SRS (for which Briggs vertical dispersion coefficients were most relevant) and (2) the direct turbulence intensity measurements provided by SRS bivanes at several towers onsite (which permitted direct evaluation of Pasquill's lateral dispersion coefficient expressions).

2.2 Current Dispersion Coefficients employed in AXAIR

The regulatory guidance in USNRC 1.145 provides graphical representation of the lateral and vertical diffusion coefficients for use in accident analysis. Figures 1 and 2 show the lateral and vertical diffusion coefficients as a function of downwind distance for Pasquill's atmospheric stability categories as taken directly from the Turner Workbook (1967). These curves are often referred to as Pasquill-Gifford curves or the Pasquill-Gifford-Turner formulation. These graphical representations were fitted with Eimutus' and Konicek's (1972) analytical expressions for use in AXAIR. The expression used to determine the lateral diffusion coefficients is :

$$\sigma_y = Ax^{0.9031} \quad (1)$$

where A is represented by the values that are shown in Table 1 as a function of Pasquill's atmospheric stability categories and x is the downwind distance in meters.

Table 1. Values of A for Horizontal Dispersion Coefficients

Pasquill Category	A
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

The equation used to determine the vertical diffusion coefficients taken from Martin and Tikvart (1968) is:

$$\sigma_z = Ax^B + C \quad (2)$$

where the constants A, B, and C are a function of Pasquill atmospheric stability categories and downwind distance from the source. These constants are depicted in Table 2.

Table 2. Constants used for Vertical Dispersion Coefficients

Pasquill Cat.	Valid Range (m)								
	< 100m			100 - 1000 m			> 1000 m		
	A	B	C	A	B	C	A	B	C
A	0.192	0.936	0	0.0015	1.941	9.27	2.4e-4	2.094	-9.6
B	0.156	0.922	0	0.028	1.149	3.3	0.0055	1.098	2.0
C	0.116	0.905	0	0.113	0.911	0.0	0.113	0.911	0.0
D	0.079	0.881	0	0.222	0.725	-1.7	1.26	0.516	-13
E	0.063	0.871	0	0.211	0.678	-1.3	6.73	0.305	-34
F	0.053	0.814	0	0.086	0.74	-.035	18.05	0.18	-48.6

The vertical and horizontal diffusion coefficients for stability class G are determined using the following formula (Hamby, 1990):

$$\sigma_z(G) = 10^{\{2*\log_{10}(\sigma_z(F)) - \log_{10}(\sigma_z(E))\}} \quad (3)$$

2.3 Pasquill-Briggs Dispersion Coefficients

The proposed lateral and vertical dispersion coefficients are those derived by Pasquill (1976) and Briggs (1973), respectively. The equation representing Pasquill's lateral dispersion coefficients is shown below:

$$\sigma_y = \sigma_\theta \times f(x) \tag{4}$$

where

$\sigma_\theta \equiv$ standard deviation of lateral wind direction, (radians)

$x \equiv$ downwind distance (km), and

$f(x) \equiv$ function of distance as discussed below.

Since the value of σ_θ is not readily available from the meteorological database that AXAIR accesses, an assumed average value of σ_θ is chosen for the atmospheric stability class of interest as defined in USNRC Regulatory Guide 1.23 (USNRC, 1972). Values for σ_θ are shown in Table 3.

Table 3. Classification of Atmospheric Stability (USNRC 1.23)

Pasquill Category	σ_θ (degrees)
A	25.0
B	20.0
C	15.0
D	10.0
E	5.0
F	2.5
G	1.7

Pasquill developed formulations for f(x) with a table of values for distances less than 10 km and the following equation for distances greater than 10 km:

$$f(x)=0.33\left(\frac{10}{x}\right)^{0.5} \tag{5}$$

Pasquill developed these formulations using data from experiments at various sites. Pasquill (1976) gives a detailed description on how the coefficients were developed.

Garrett and Murphy (1981) at SRS developed an interpolating formula for values derived by Pasquill for distances of less than 10 km. The equation follows:

$$f(x)=\frac{x^{-0.2}}{1.67+0.3\left\{\frac{|1-x^{-0.2}|}{0.48}\right\}^{0.5}} \quad (6)$$

The vertical diffusion coefficients defined by Briggs (1973) and then refined by Briggs and published in Hanna (1982) for open-country conditions are represented in Table 4 as a function of Pasquill's atmospheric stability classes.

Table 4. Brigg's Vertical Diffusion Coefficient Formulas

Pasquill Type	σ_z
A	$0.20x$
B	$0.12x$
C	$0.08x(1 + 0.0002x)^{-0.5}$
D	$0.06x(1 + 0.0015x)^{-0.5}$
E	$0.03x(1 + 0.0003x)^{-1}$
F	$0.016x(1 + 0.0003x)^{-1}$

As with the coefficients that were previously used within AXAIR, σ_z is limited to a value of 0.8*H, with H being the effective mixing height, which is set to a constant value of 200 m within AXAIR.

Different methods were reviewed for determining the value of σ_z for the extremely stable category G. Stability G is extrapolated from the stability classes E and F in the same manner as shown in equation 3 used in the previous version of AXAIR.

2.4 Comparison of Different Models

Figures 3 through 9 show graphical depiction of differences between the two representations for the lateral diffusion coefficients for stability classes A-G, respectively. Figures 10 through 16 show the differences for the vertical diffusion coefficients. The vertical diffusion coefficients are limited to 160 m ($0.8*H_{inv}$) within AXAIR.

Next, the relative air concentrations were compared. The equation used to determine the two-hour relative air concentrations within AXAIR is:

$$\frac{X}{Q} = \frac{\exp(-H_e^2 / 2\sigma_z^2)}{\pi\sigma_y \sigma_z U_{HS}} \tag{7}$$

where H_e is the effective release height and U_{HS} is the wind speed. The relative air concentrations were calculated using both Pasquill-Gifford and Pasquill-Briggs dispersion coefficients. Figures 17 and 18 show the ratio of relative air concentrations by applying Pasquill-Briggs and Pasquill-Gifford dispersion coefficients for a release height of 10 m. This comparison was done strictly for a non-fumigation case and the vertical dispersion coefficients were limited to 160 m as they are within AXAIR. Different release heights would result in different curves.

Figures 18 is the same as Figure 17 except the downwind distance has been truncated at 10000 m to allow a better view of the differences close in. Looking at Figure 17, the stability classes that will lead to the largest differences are E, F, and G especially for distances greater than 10 km. Input distances within AXAIR are limited to 50 mi or 80 km.

Near the release location on both Figures 17 and 18 the ratio appears to go to zero for Stability classes E, F, and G. This is due to the fact that the ratio of the two are so different that the ratios were less than 0.1 for these cases. As the lateral and vertical dispersion coefficients become smaller the relative air concentrations are more influenced by the difference between the two vertical dispersion coefficients since σ_z is in the denominator of a negative exponent as shown in Equation 7.

For a case where the dose was determined at the site boundary, which is typically around 10 km for a center-of-site release, the user could see an increase in dose of up to a factor of 2.5 depending on the release location and the meteorology that was selected for the 99.5%.

Weber (1993) contains additional information on a comparison study that was done which also considered Draxler's coefficients.

3.0 JUSTIFICATION FOR CHANGE

Although the regulatory guidance behind AXAIR recommends the use of the graphical representation as shown in the Turner workbook (1967), Pasquill (1976)-Briggs (Hanna, 1982) dispersion coefficients are more relevant to elevated releases, and hence the code should be changed to use these coefficients. Adoption of Pasquill-Briggs dispersion coefficients also ensures consistency between emergency response calculations and accident analysis calculations.

Although NRC 1.145 graphically depicts the Pasquill-Gifford dispersion coefficients as an example of a usable type, the regulatory position states that the methodologies shown are "acceptable." Also, in the implementation section it states that cases may arise where "an applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations."

The original authors of AXAIR no doubt chose the diffusion coefficients that were the closest to the graphs as recommended in NRC 1.145, however models exist today which are closer to the actual behavior of atmospheric dispersion. Several references have since shown there are better alternatives.

When the technical basis for NRC 1.145 Revision 1 was being discussed during the time frame 1980-1981, many improved ideas in atmospheric dispersion were just beginning to gain acceptance. As a result, the NRC adopted the dispersion coefficients as graphically represented in the Turner Workbook (1967) as representing the most widely accepted at that time. The Turner Workbook graphs are based on the frequently referred to Prairie Grass experiments (Haugen, 1959) that were conducted over a very limited range cf conditions. These experiments considered uniform terrain, ground-level releases, and measurements were taken at distances of less than 1 km.

Further studies have been conducted on the Pasquill-Briggs dispersion coefficients and they have become widely accepted. Briggs developed his formulas by combining the curves of Pasquill-Gifford for near-field, Brookhaven National Laboratory (Singer, 1966) data for intermediate distances, and Tennessee Valley Authority (Carpenter, 1971) data for longer distances. He also produced a different set of formulas for urban settings based on the St. Louis Experiments (McElroy, 1968). These experiments were developed over a wider range of conditions than the Prairie grass experiments of 1959.

Figure 19 shows a comparison between vertical dispersion coefficients as determined by: Briggs, Pasquill-Gifford, and experimental data. For stability class A, switching to Pasquill-Briggs is a major improvement with the coefficients closely following the experimental data. For stability classes D and F Pasquill-Briggs formulations are closer to the experimental data but still on the lower side of the actual data. Underestimating the vertical dispersion coefficients is actually conservative when it comes to predicting the downwind relative air concentration since that the vertical dispersion is inversely proportional to the concentration.

Figure 20 shows a comparison between experimental data and Pasquill's horizontal dispersion coefficients. The vertical axis is actually the ratio of the lateral dispersion coefficient to the standard deviation of wind direction fluctuation (σ_y/σ_θ). Shown in Pasquill (1976) is a plot containing several data points that were taken from the following references: (McElroy, 1968), (Slade, 1968), and (Sagendorf, 1974) . Rather than reproduce all of the original data a range was chosen in which a majority of the data points fell. The data points were concentrated around the center of the bracketed region.

4.0 CODE INCORPORATION

A new version of AXAIR was created containing the Pasquill-Briggs dispersion coefficients. A separate report verifying several other changes to AXAIR will document test calculations to ensure their correctness. Modifications took place within the POLYN subroutine of the AXAMET subroutine. The coefficients were modified to reflect those that are depicted in equation 4 for the horizontal coefficients and Table 4 for the vertical coefficients.

5.0 IMPACT ON PREVIOUS CALCULATIONS

When applying a different type of methodology within a code, a difference is seen in the output. Sample test cases were run for different distances and release heights and the results are discussed below. The version used to perform these calculations is not verified, but several hand calculations were done.

The code was executed for various release areas onsite to compare the differences that were incurred by applying the Pasquill-Briggs dispersion coefficients. These two sample runs are not indicative of the differences are found at all distances and release locations but merely a show of the differences for a specific case. Tables 5 and 6 show the comparisons of sample calculations for H Area for release heights of 10 m and 62 m, respectively. In both of the Tables the biggest difference are seen at a distance of 10.0 km.

Table 5. H Area Sample Calculation
(Release Height = 10 m)

Downwind Distance (km)	AXAIR 1.2 Turner Workbook (rem)	AXAIR 2.0 Pasquill-Briggs (rem)	Ratio of Pasquill-Briggs / Turner Wkbk.
0.5	3.72e-03	4.71e-03	1.27
1.0	1.25e-03	1.72e-03	1.38
2.0	4.51e-04	6.88e-04	1.53
3.0	2.58e-04	4.18e-04	1.62
4.0	1.75e-04	3.01e-04	1.72
5.0	1.31e-04	2.35e-04	1.79
10.0	5.22e-05	1.31e-04	2.50
Bndry	7.59e-05	1.55e-04	2.04

Table 6. H Area Sample Calculation
(Release Height = 62 m)

Downwind Distance (km)	AXAIR 1.2 Turner Workbook (rem)	AXAIR 2.0 Pasquill-Briggs (rem)	Ratio of Pasquill-Briggs / Turner Wkbk.
0.5	2.06e-04	1.31e-04	0.64
1.0	1.50e-04	1.85e-04	1.23
2.0	1.16e-04	1.38e-04	1.19
3.0	8.05e-05	1.07e-04	1.33
4.0	5.87e-05	8.42e-05	1.43
5.0	4.46e-05	9.01e-05	2.02
10.0	2.58e-05	6.72e-05	2.60
Bndry	3.59e-05	7.84e-05	2.18

Tables 7 and 8 show a sample calculation for a release from A Area with release heights of 0 m and 62 m, respectively.

Table 7. A Area Sample Calculation
(Release Height = 0 m)

Downwind Distance (km)	AXAIR 1.2 Turner Workbook (rem)	AXAIR 2.0 Pasquill-Briggs (rem)	Ratio of Pasquill-Briggs / Turner Wkbk.
0.5	1.41e-03	2.16e-03	1.53
1.0	6.12e-04	1.07e-03	1.78
2.0	2.57e-04	5.16e-04	2.01
3.0	1.52e-04	3.44e-04	2.26
4.0	1.19e-04	2.61e-04	2.19
5.0	9.21e-05	2.12e-04	2.30
10.0	4.52e-05	1.27e-04	2.80
Bndry	2.90e-03	3.08e-03	1.06

Table 8. A Area Sample Calculation
(Release Height = 62 m)

Downwind Distance (km)	AXAIR 1.2 Turner Workbook (rem)	AXAIR 2.0 Pasquill-Briggs (rem)	Ratio of Pasquill-Briggs / Turner Wkbk.
0.5	1.87e-04	1.57e-04	0.84
1.0	1.61e-04	1.30e-04	0.81
2.0	1.18e-04	1.30e-04	1.10
3.0	7.36e-05	9.51e-04	1.29
4.0	6.34e-05	8.65e-05	1.36
5.0	4.35e-05	7.28e-04	1.67
10.0	2.10e-05	4.56e-05	2.17
Bndry	2.27e-04	1.79e-04	0.80

6.0 CONCLUSIONS

Analytical expressions of dispersion coefficients developed by Pasquill and Briggs are a better alternative for the dispersion model with AXAIR. Although the previous curves were following regulatory suggestions, these coefficients better represent the atmospheric stability as shown by the comparisons with experimental data. From this point forward a recommendation is made that all dose calculations done involving AXAIR apply Pasquill-Briggs dispersion coefficients.

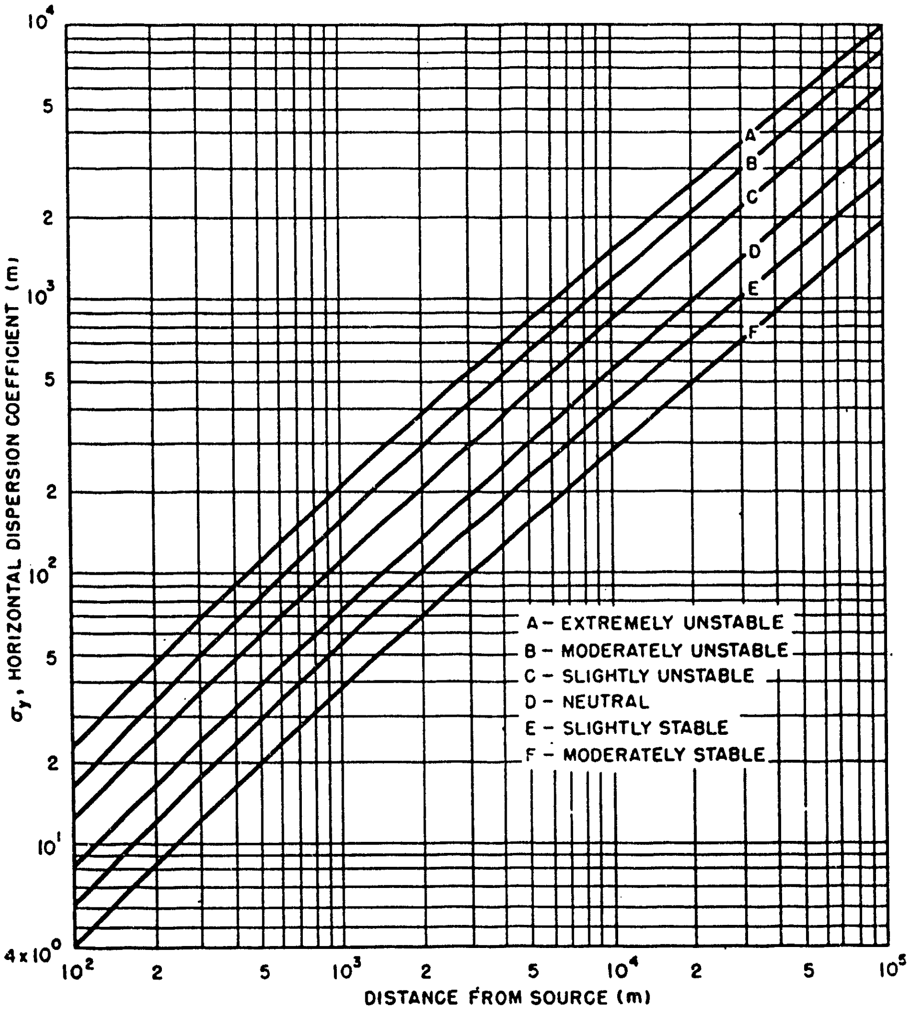

Figure 1. Lateral Diffusion Coefficients from NRC 1.145

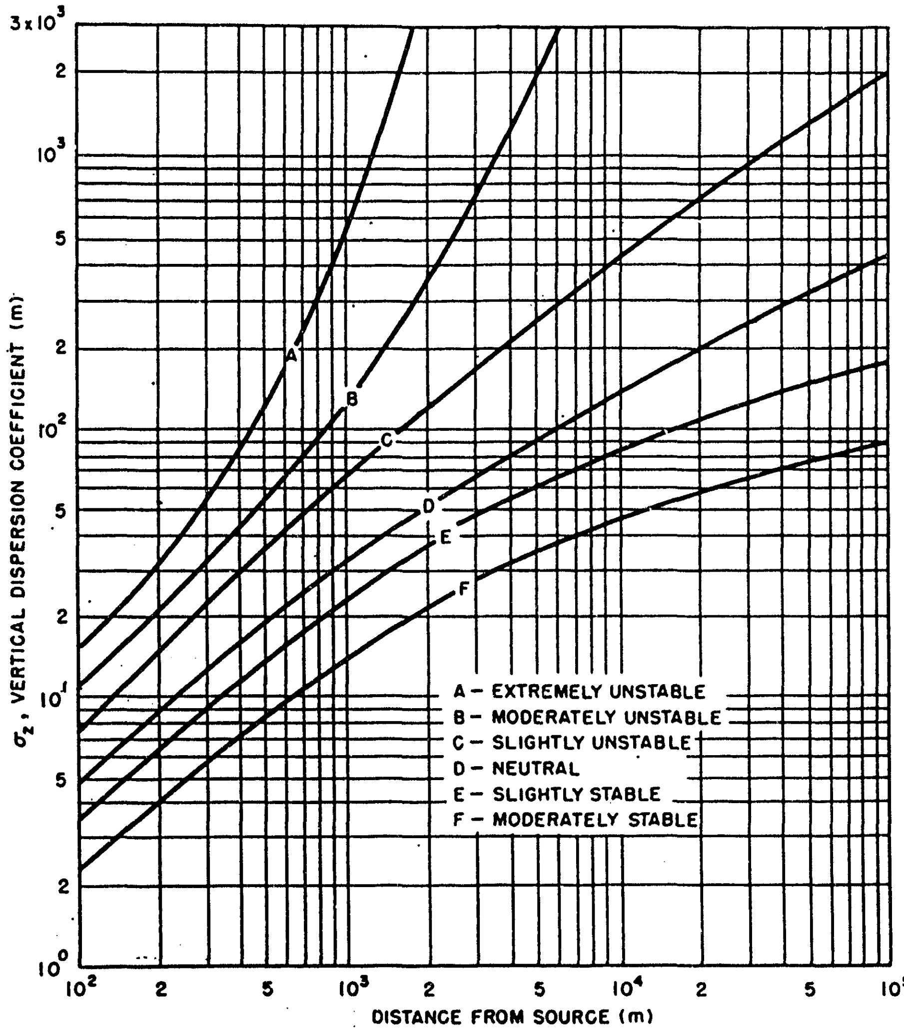

Figure 2. Vertical Diffusion Coefficients from NRC 1.145

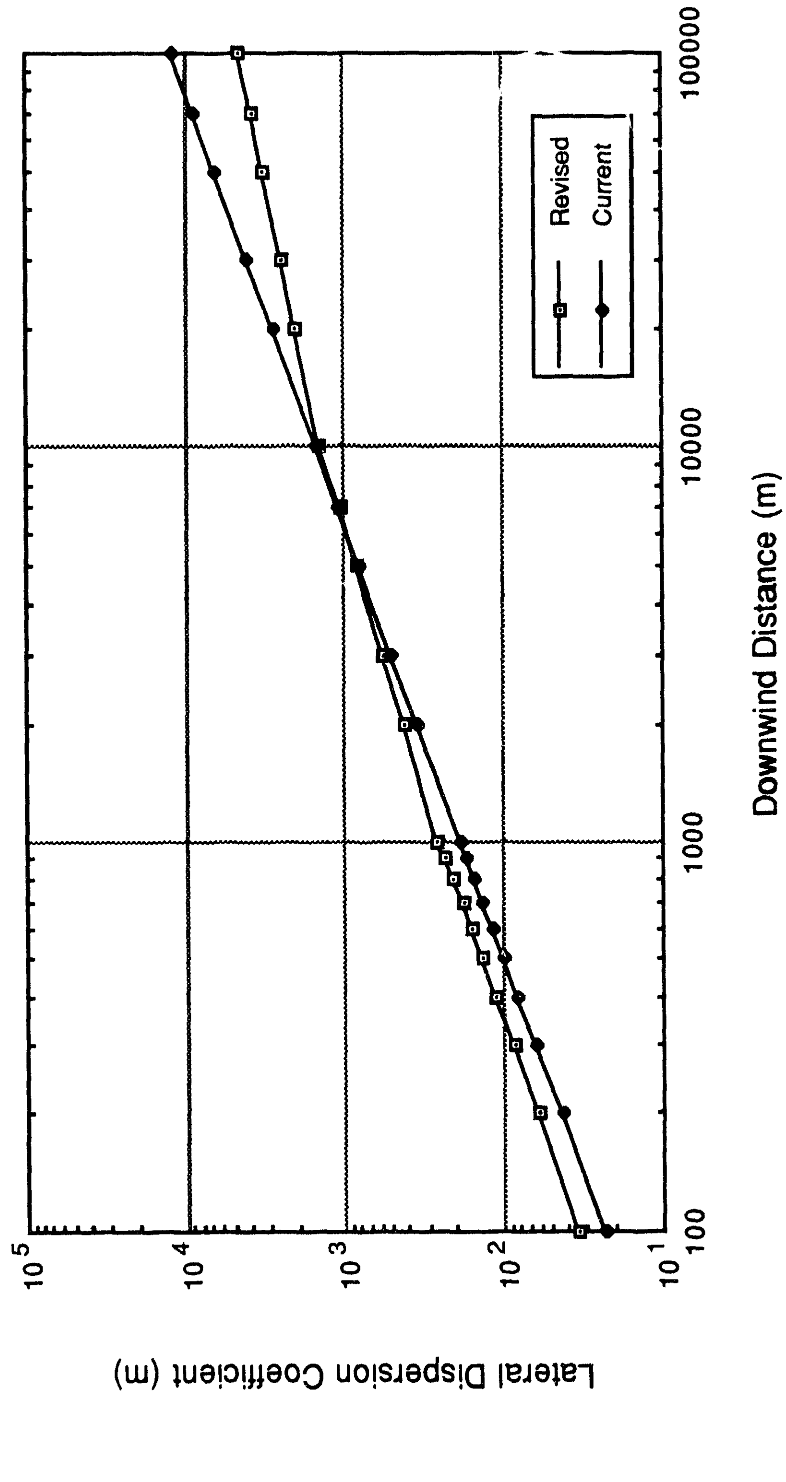

Figure 3. Lateral Dispersion Coefficient Comparison for Stability Class A.

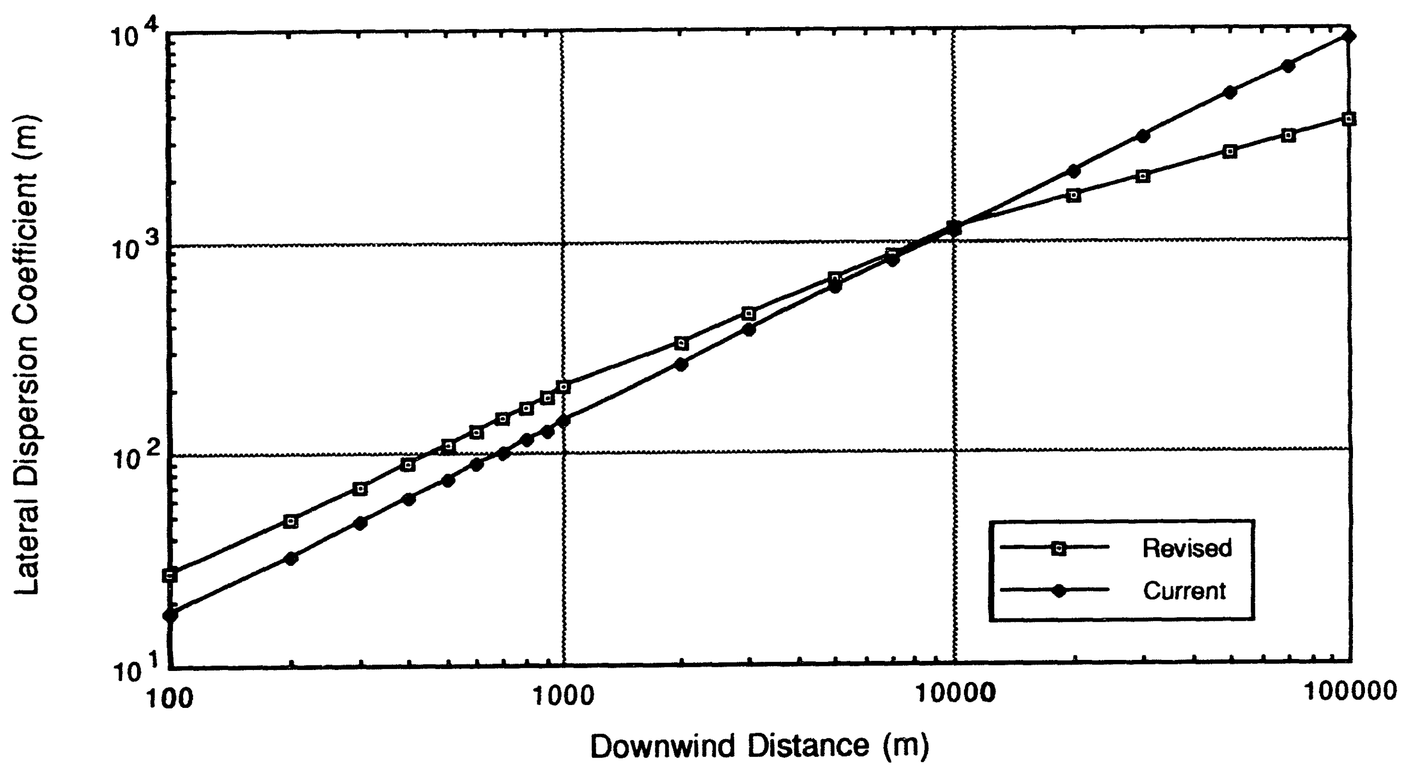

Figure 4. Lateral Dispersion Coefficient Comparison for Stability Class B

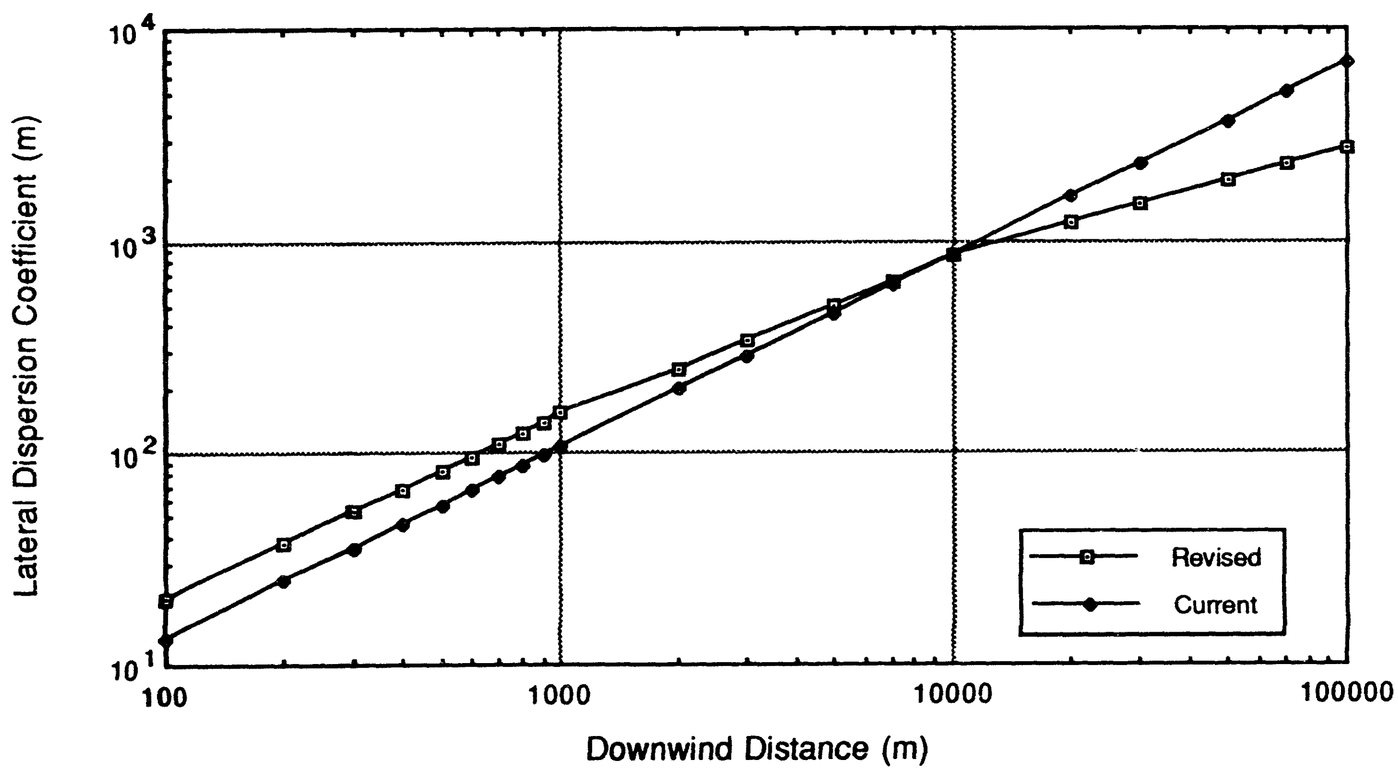

Figure 5. Lateral Dispersion Coefficient Comparison for Stability Class C

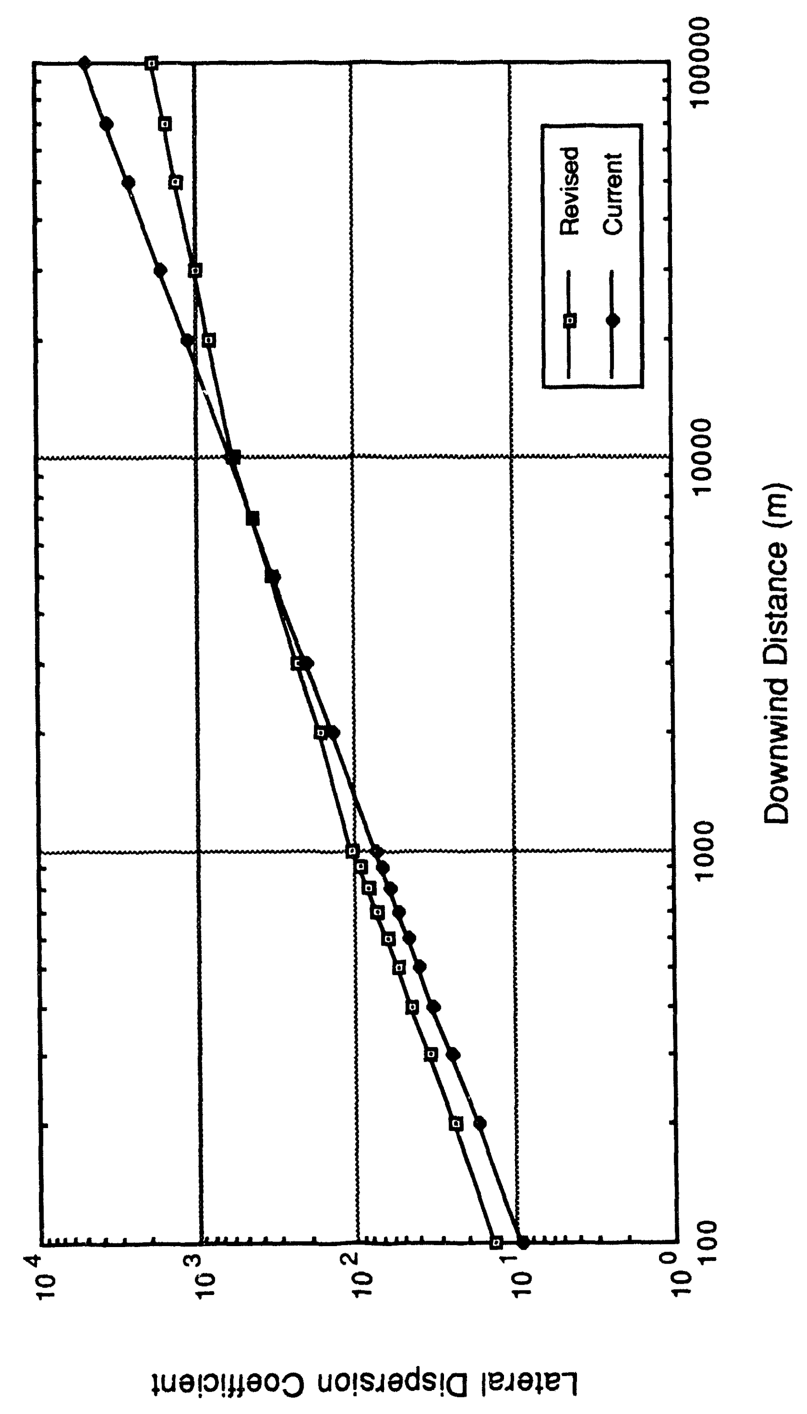

Figure 6. Lateral Dispersion Coefficient Comparison for Stability D

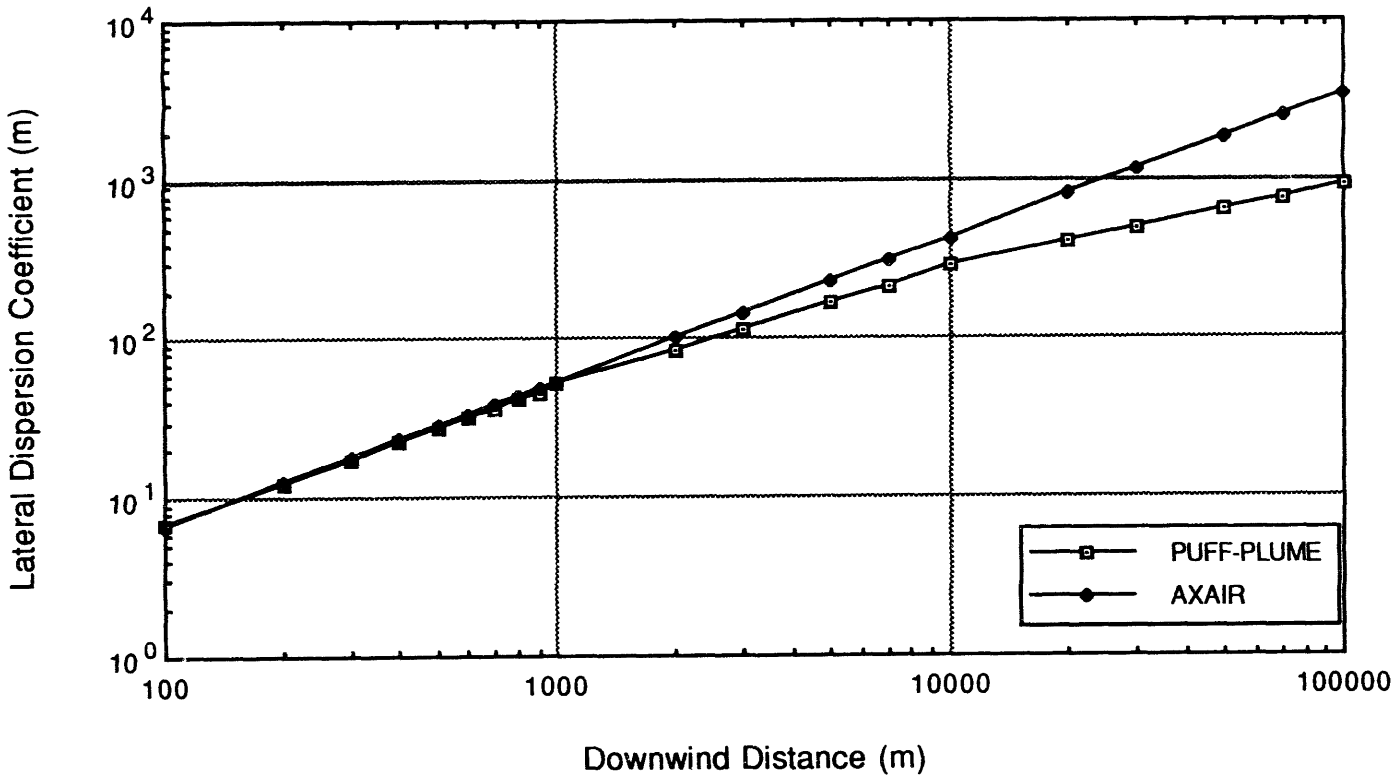

Figure 7. Lateral Dispersion Coefficient Comparison for Stability E

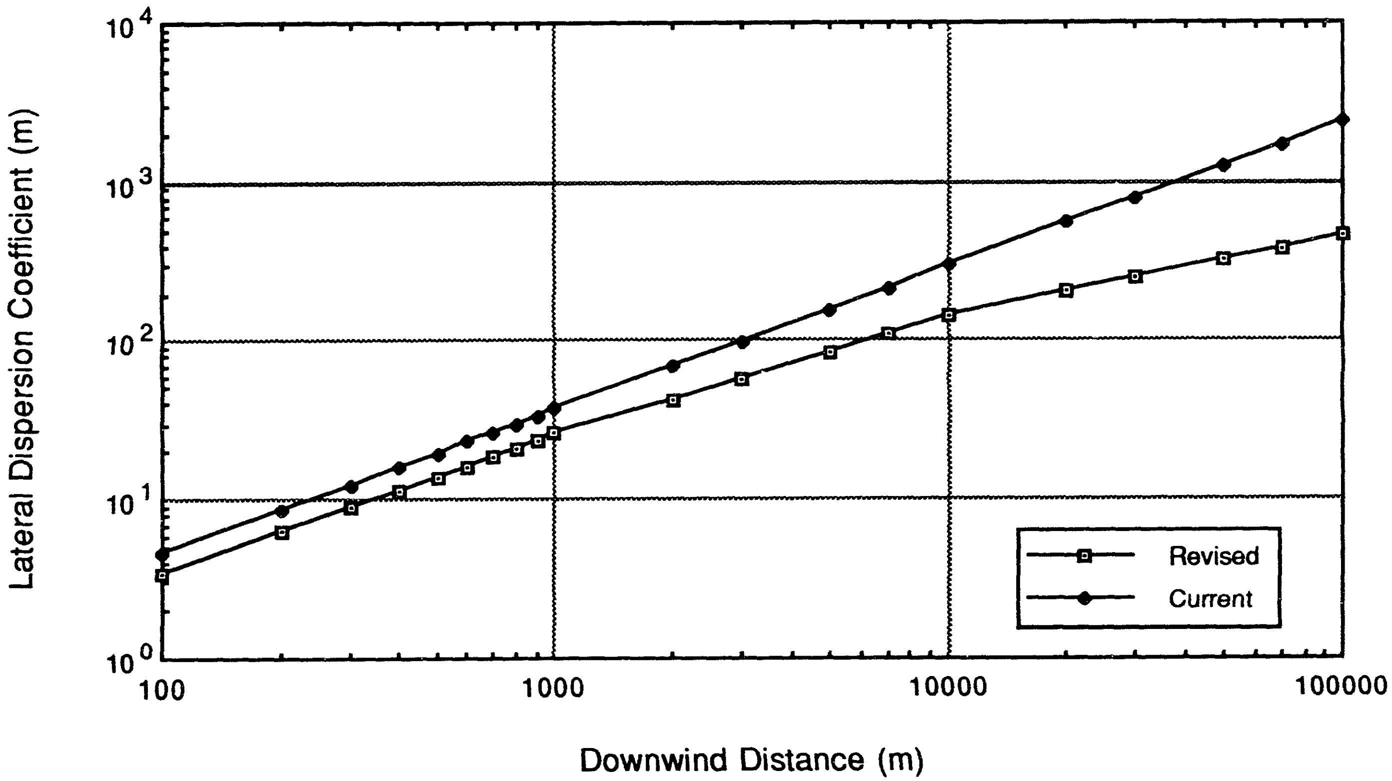

Figure 8. Lateral Dispersion Coefficient Comparison for Stability F

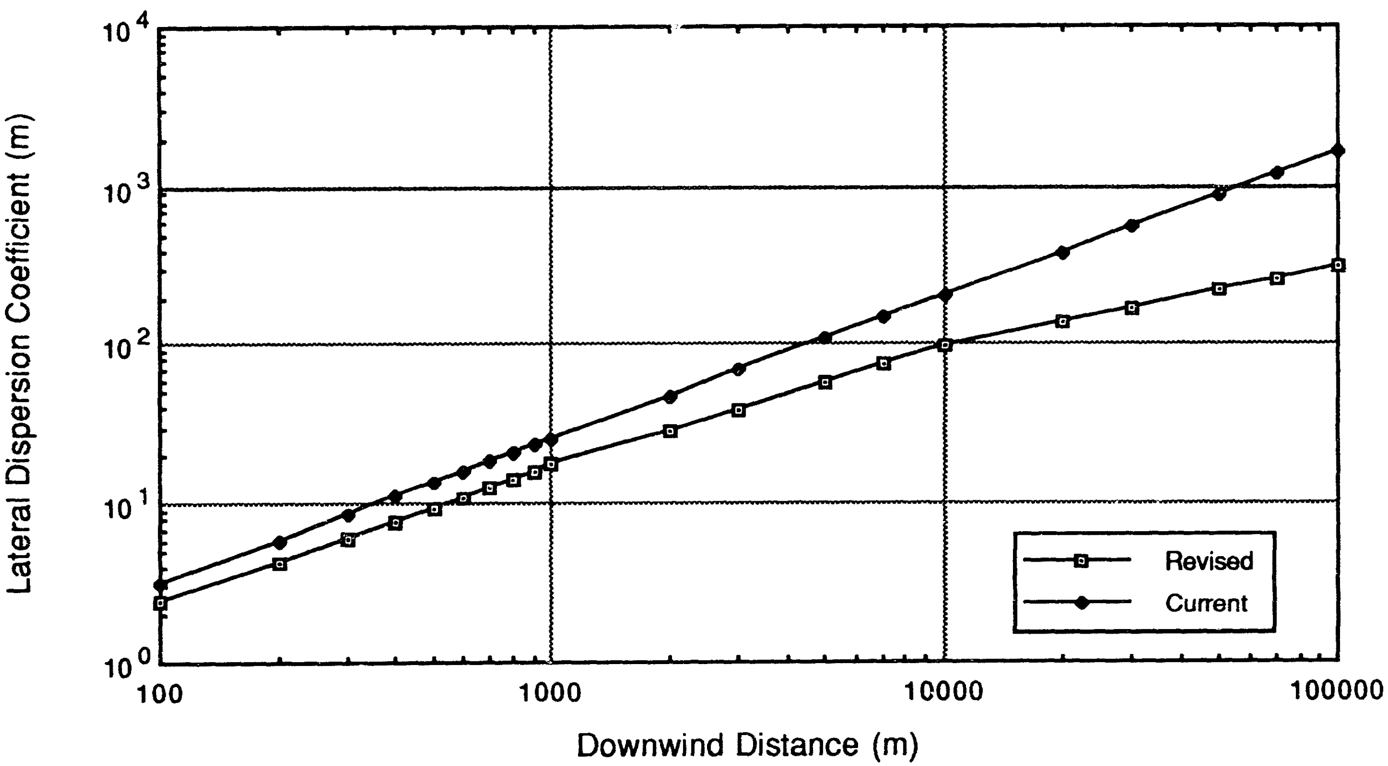

Figure 9. Lateral Dispersion Coefficient Comparison for Stability G

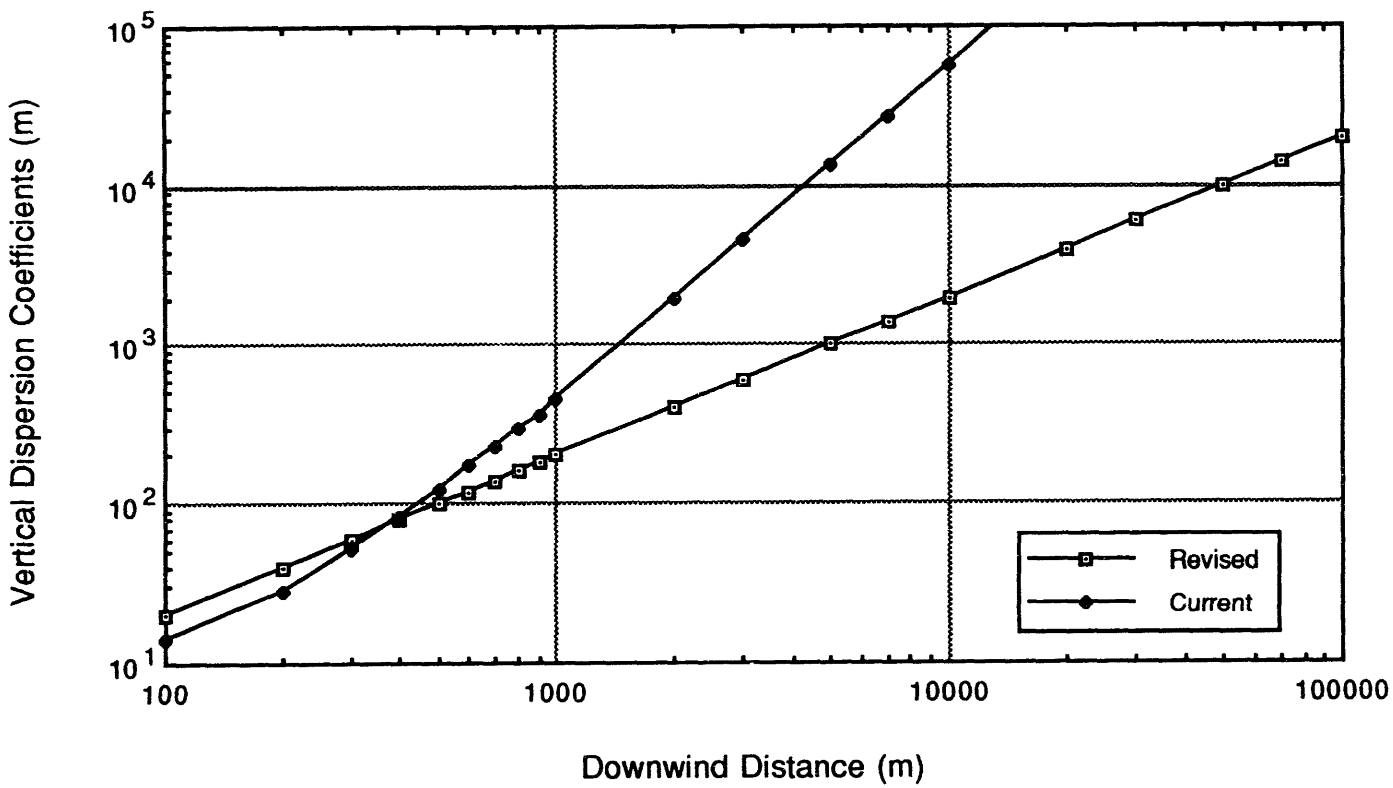

Figure 10. Vertical Dispersion Coefficient Comparison for Stability A

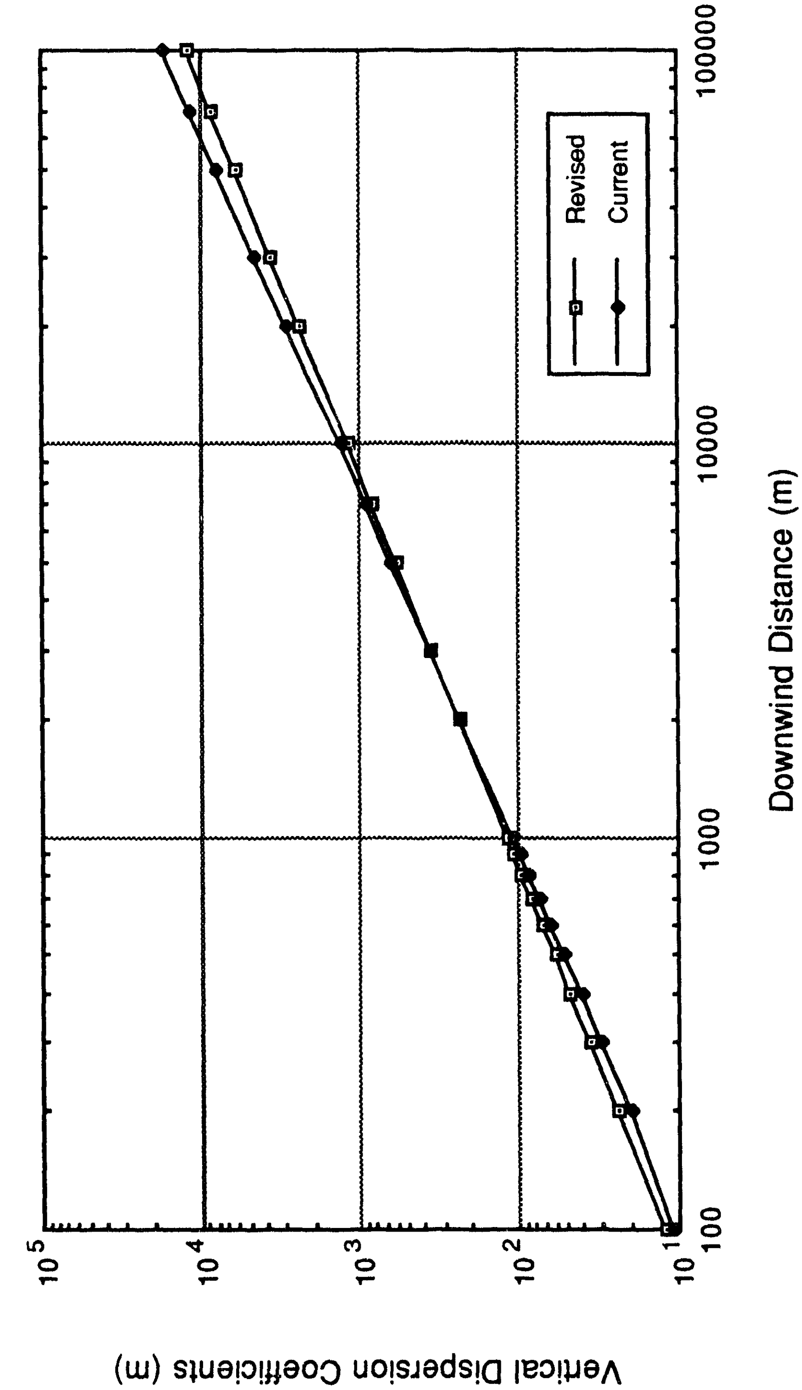

Figure 11. Vertical Dispersion Coefficient Comparison for Stability B

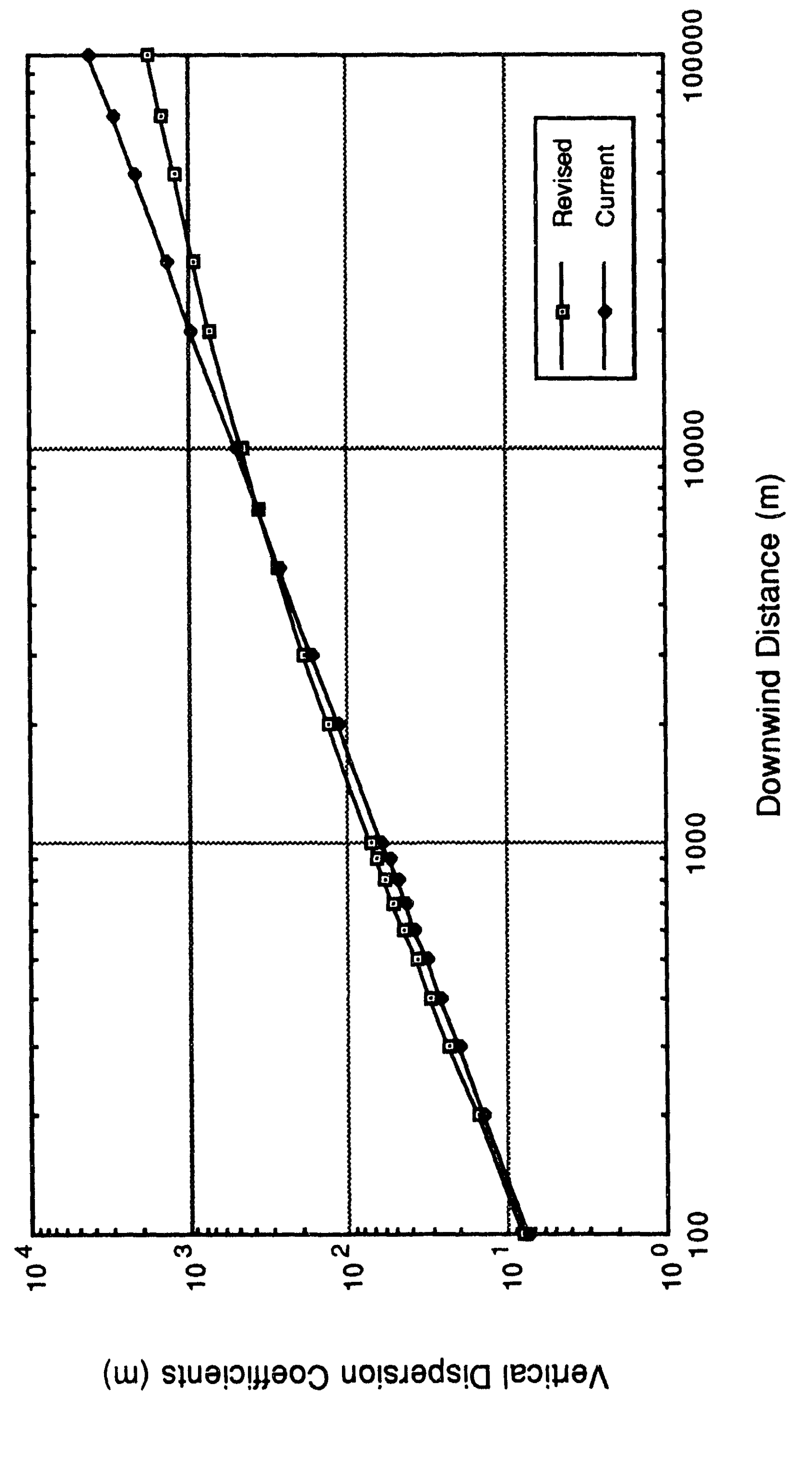

Figure 12. Vertical Dispersion Coefficient Comparison for Stability C

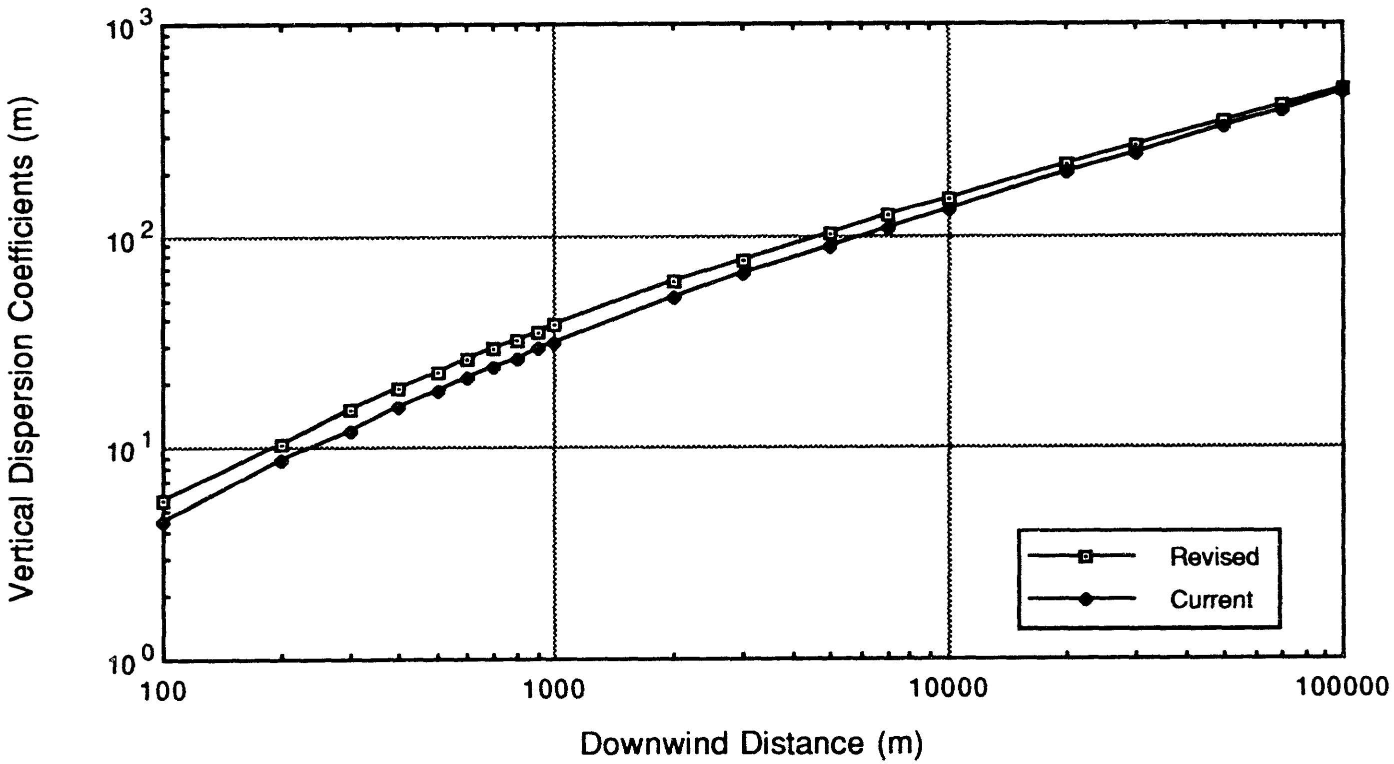

Figure 13. Vertical Dispersion Coefficient Comparison for Stability D

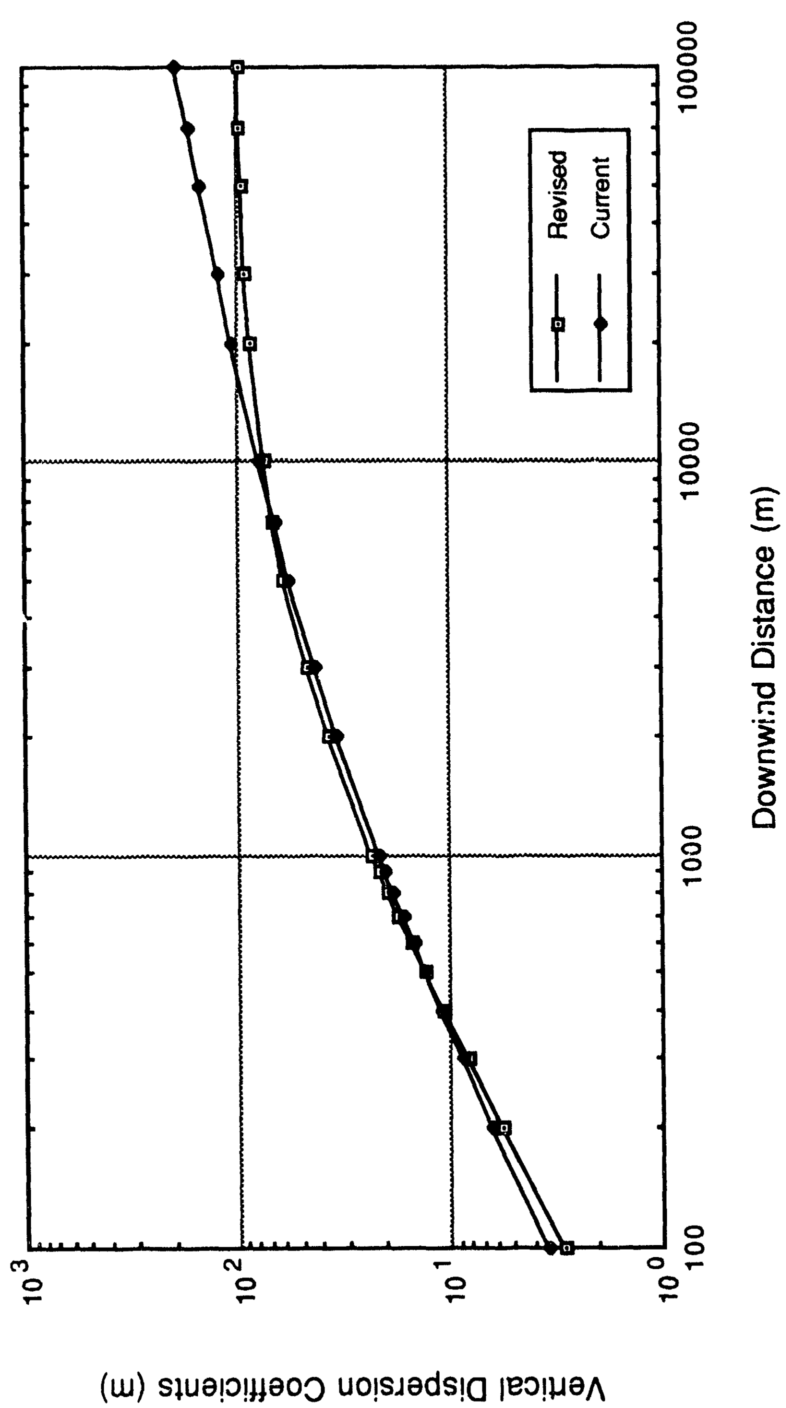

Figure 14. Vertical Dispersion Coefficient Comparison for Stability E

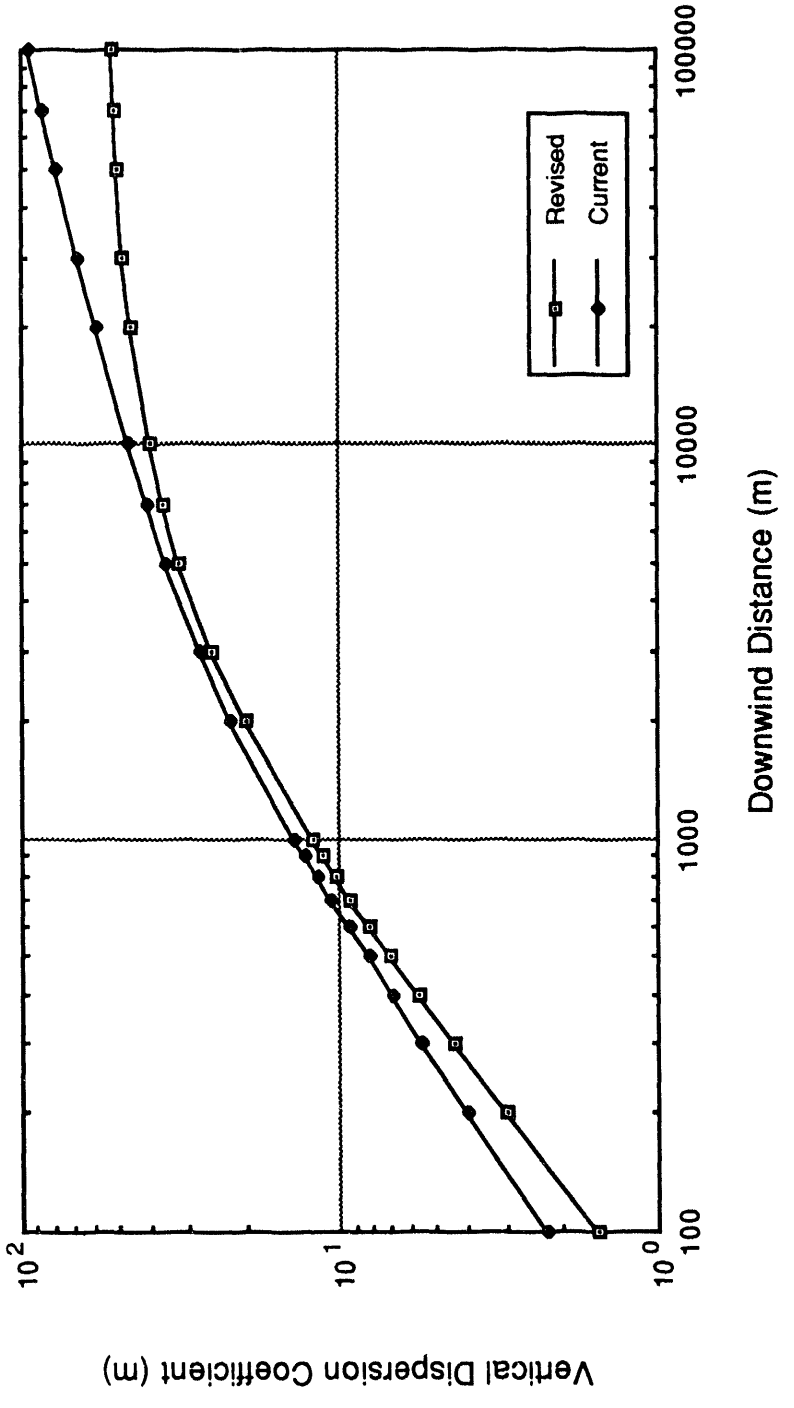

Figure 15. Vertical Dispersion Coefficient Comparison for Stability F

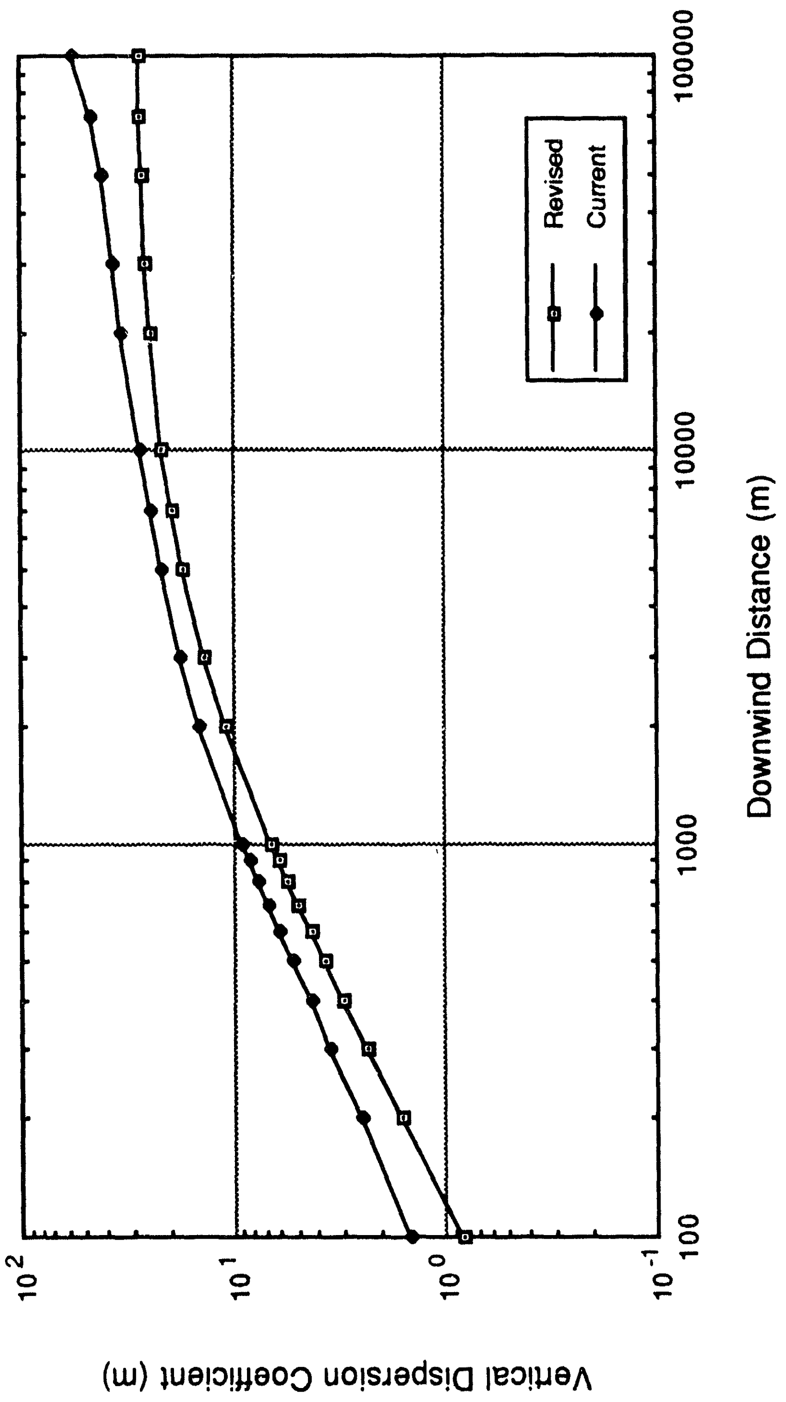

Figure 16. Vertical Dispersion Coefficient Comparison for Stability G

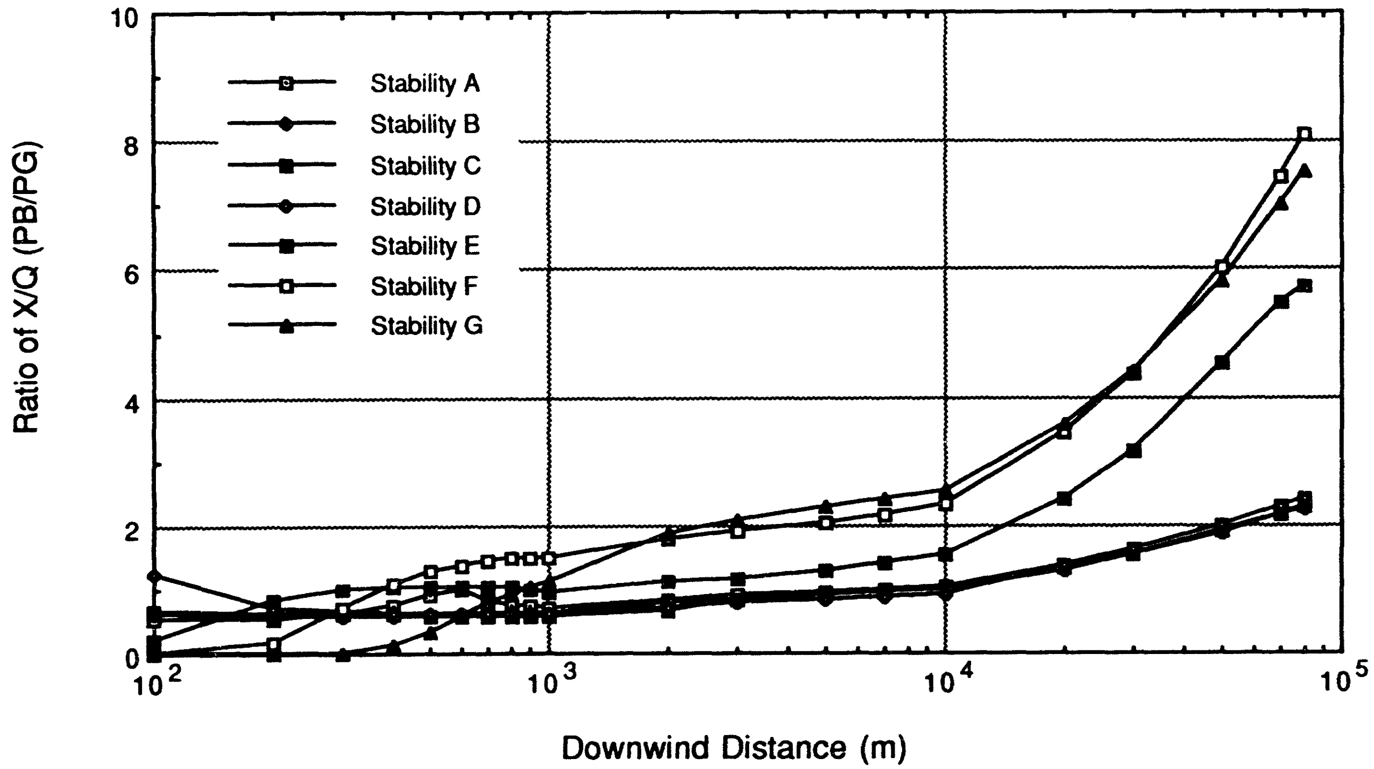

Figure 17. Ratio of Relative Air Concentrations (Pasquill-Briggs/Pasquill-Gifford) (Far)

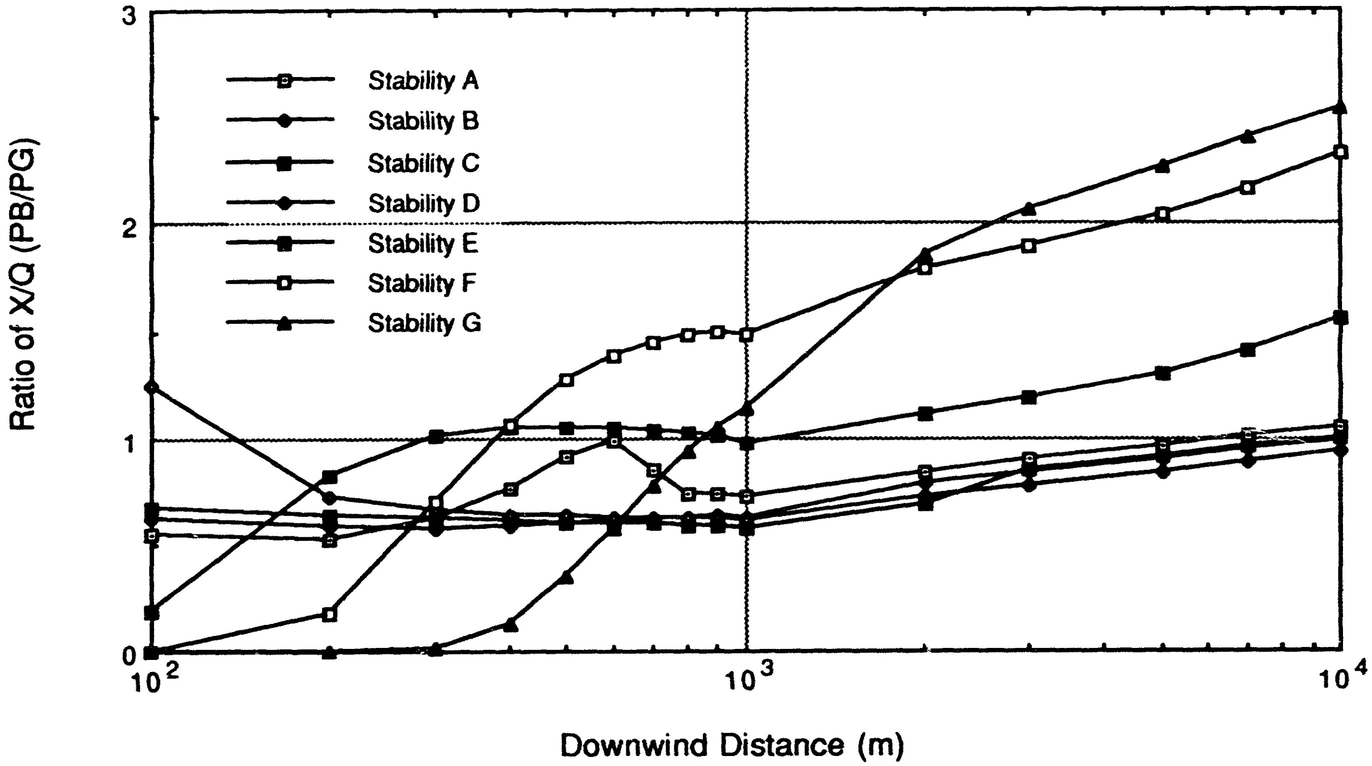

Figure 18. Ratio of Relative Air Concentrations (Pasquill-Briggs)/(Pasquill-Gifford) (Near)

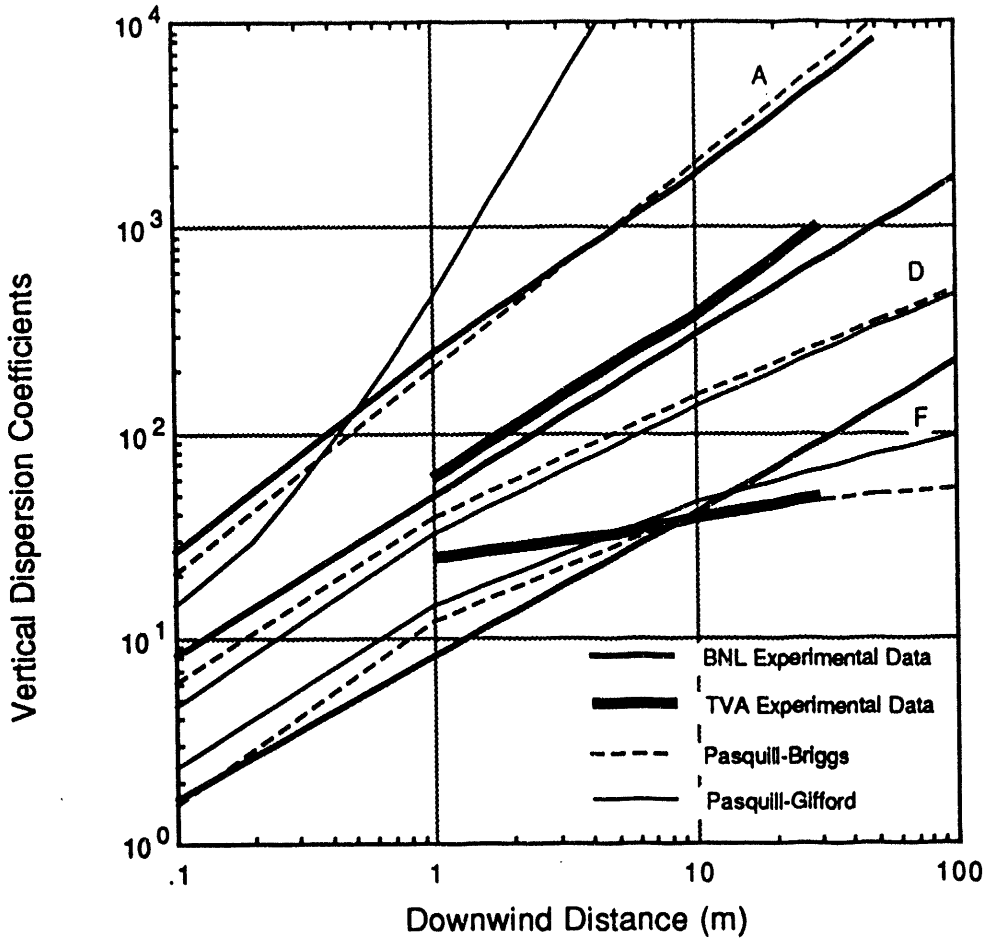

Figure 19. Vertical Dispersion Coefficient Comparison with Experimental Data

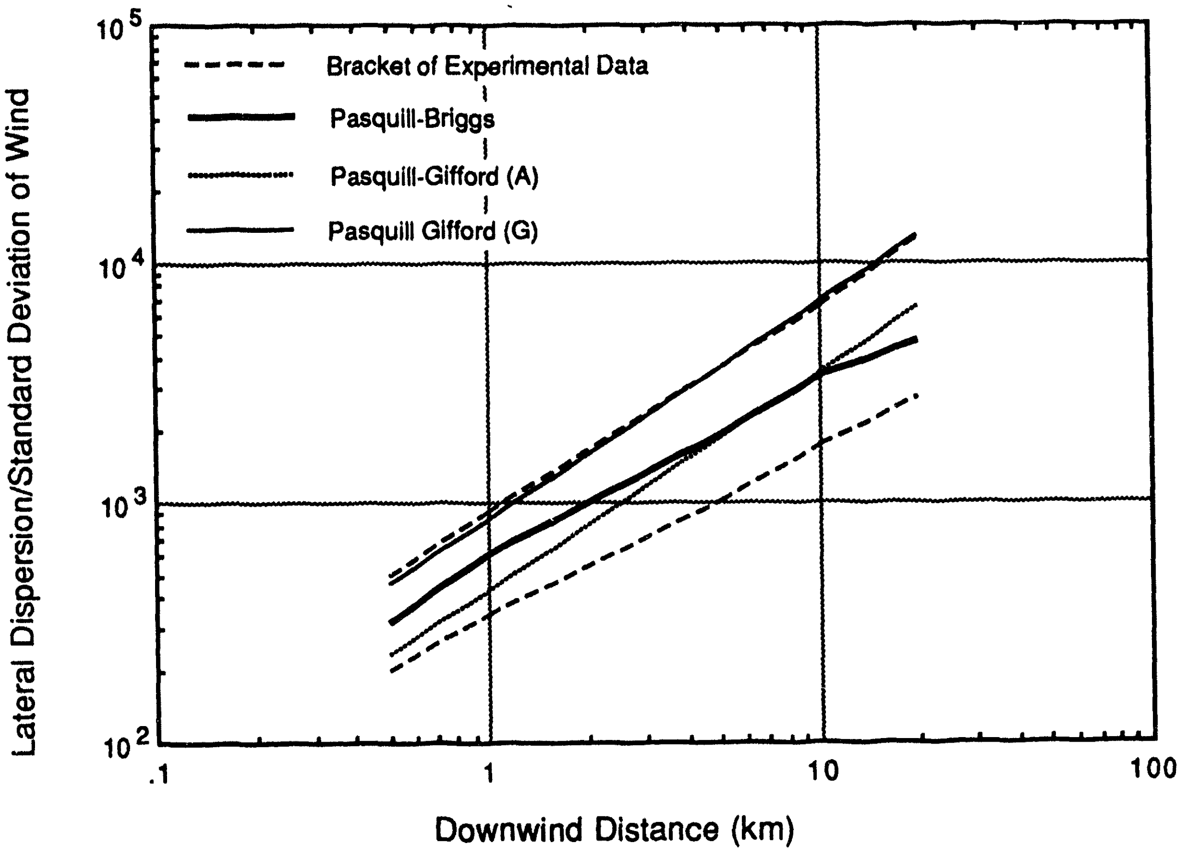

Figure 20. Horizontal Dispersion Coefficient Comparison w/ Experimental Data

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