METHODOLOGY FOR DETERMINING EMISSION THRESHOLDS BASED ON EPA SIGNIFICANCE LEVELS

Appendix to

Air Quality Control, Reporting, and Compliance

Proposed Rule

(30 CFR Part 550: Subparts A, B, C & J)

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Bureau of Ocean Energy Management
DEPARTMENT OF THE INTERIOR
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Methodology for Determining Emission Thresholds Based on EPA Significance Levels

Bureau of Ocean Energy Management (BOEM)

This paper describes the systematic approach to BOEM's analysis of minimal emission rates (E_{min}), as described by BOEM in the proposed rule. The objective of the analysis is to develop a set of formulae similar to those used to calculate the Emission Exemption Thresholds (EETs) existing under BOEM's existing air quality rule at 30 CFR §550.303(d). Under the proposed rule, the existing EETs would represent the higher of a range of emission rates, specific to each submitted plan that BOEM would presume to be exempt from the provisions of the air quality rule. Whereas, E_{min} would represent the lower of the range, and would identify the emissions as having no significant air quality impact and no potential to cause or contribute to a violation of the National Ambient Air Quality Standards (NAAQS). Thus, development of E_{min} formulae, similar to the EET formulae, is based on the concept of *de minimis* effects (i.e., not significant), which applies the U.S. Environmental Protection Agency's (USEPA) Significance Impact Levels (SILs) as the objective in defining a *de minimis* impact (40 CFR § 51.165(b)(2)). The SILS are summarized in ***Table 1***, and reflect the levels that appear in the current table published by the USEPA at 40 CFR § 51.165(b)(2).

***Table 1*. Significance Impact Levels (SILs)**

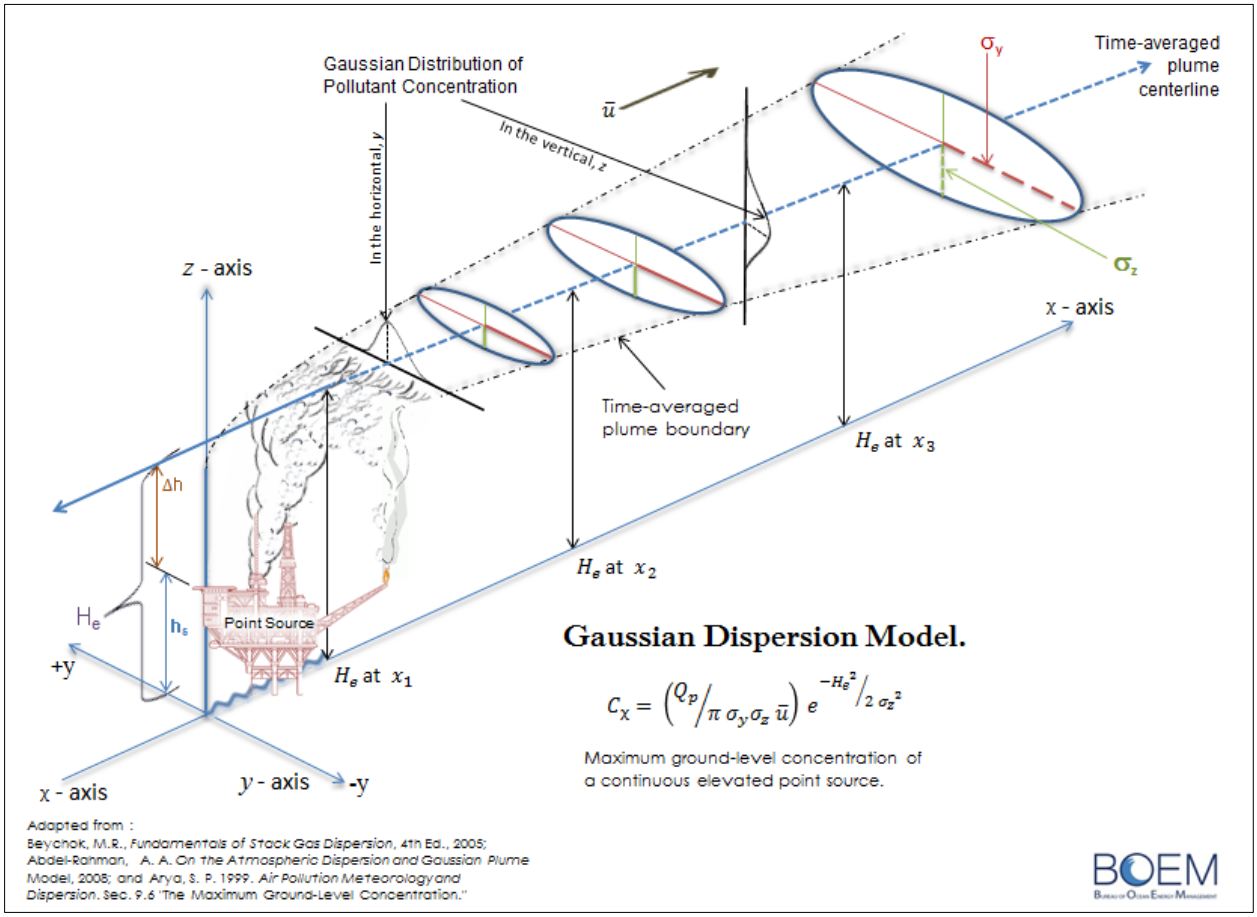
Pollutant	Averaging Periods ($\mu g/m^3$)				
	Annual	**24-hour**	**8-hour**	**3-hour**	**1-hour**
SO_2	1.0	5.0		25.0	
PM_{10}	1.0	5.0			
$PM_{2.5}$	.30	1.20			
NO_2	1.0				
CO			500.0		2,000.0

Source: 40 CFR § 51.165(b)(2), current as of July 1, 2015.

The USEPA states in its guidance for applying SILs that, "a modeled air quality impact [not exceeding a SIL] is *de minimis*, and thereby would not be considered to cause or contribute to a modeled violation of the NAAQS," and states further that, "[t]he concept of a SIL is grounded on the *de minimis* principles described by the court in *Alabama Power Co.* v. *Castle*, 636 F.2d 323,360 (D.C. Cir. 1980); *See* also *Sur Contra La Contaminacion* v. *EPA*, 202 F.3d 443,448-49 (1 st Cir. 2000) (upholding EPA's use of SIL to allow permit applicant to avoid full impact analysis); *In re: Prairie State Gen. Co.*, PSD Appeal No. 05-05, Slip. Op. at 139 (EAB 2006)" (USEPA, 2010).

GAUSSIAN PLUME DISPERSION MODEL

BOEM's approach is based on the classical Gaussian plume model by Sutton (as cited in Abdel-Rahman, 2008), which is applied in the USEPA-preferred American Meteorological Society/USEPA Regulatory Model (AERMOD) model for dispersion, and is widely used in other air pollution dispersion models. The analysis applies the Gaussian Dispersion Equation (hereinafter referred to by the acronym, GDE) to predict the maximum ground-level centerline concentration at a receptor from a continuous point-source plume at a given distance, χ, downwind.[1] The GDE provides an analytical solution to the dispersion of pollutants under idealized conditions (Abdel-Rahman, 2008). The application of the GDE is depicted graphically in ***Figure 1*** and is followed by a legend to explain the variables.



[1] Much of this material is a summary of the physics of atmospheric pollutant dispersion contained in the publication by Milton Beychok, "Fundamentals of Stack Gas Dispersion," 4th ed. 2005, and Turner's 1961, "Workbook of Atmospheric Dispersion Estimates," revised 1970. All sources are noted in the paper's bibliography.

Legend

C_χ	Maximum pollutant concentration in micrograms per cubic meter, (g/m^3), at a point, χ
Q_p	Emission rate of a polluant, p, in grams per second (g/s)
π	Pi, a value of approximately 3.14, where Pi has no units
e	Natural exponential function, no units, where $e^1 = 2.718$, $e^0 = 1$, and $\ln x = 1/e^x$
H	Actual stack height, expressed in meters (m)
Δh	Extent of plume rise above the stack at release due to heat bouyancy, where without bouyancy, $\Delta h = 0\ m$
H_e	Effective stack height at a point, χ, expressed in m, where, $h_s + \Delta h = H_e$ at $\chi=0$, and where $(H_e \text{ at } \chi_1) > (H_e \text{ at } \chi_2) > (H_e \text{ at } \chi_3)$
$\bar{u}$	Mean surface wind speed in the direction of the χ-axis, averaged over a 10-minute period, recorded at a height $10\ m$ above the observation surface in miles per hour (mph), and converted to meters per second (m/s)
σ_z	Vertical dispersion coefficient, distance of plume's vertical expansion below the centerline expressed in m
σ_y	Horizontal dispersion coefficient, distance of plume's horizontal expansion outward from the centerline, expressed in m

Figure 1. Diagram and Legend to the Gaussian Plume Dispersion Model and Equation. Source: BOEM, Alaska OCS Region, 2015.

The Gaussian Plume Dispersion Model predicts the concentration of emissions downwind from a source, where the plume is free to expand outward from the centerline in both the horizontal (y) and vertical (z) planes. The extent of the plane-expansion is given by the "sigma" terms, σ_y and σ_z, expressed in meters (m), and are dependent on the stability of idealized atmospheric conditions and the arbitrary distance, χ, from the source to the receptor (i.e., target).

Model Constraints for Idealized Conditions

The idealized GDE conditions used by BOEM are subject to the following constraining assumptions:

1. Point source rate of emissions, Q_p (in grams/second, *g/s*), is a continuous mass-flow rate;
2. Pasquill (1961) stability category "E" is applied, which characterizes a stable atmosphere;
3. Horizontal wind velocity is constant at 2 meters per second (*m/s*) and is assumed in the direction of the receptor;
4. Vertical and crosswind dispersion terms, σ_y and σ_z (each in m) occur according to the Gaussian (normal) distribution and are constants to a given downwind distance, χ (in m), where the dispersion of the emissions assumes an expanding cone-shaped plume implicitly requiring homogeneous turbulence throughout the x, y, and z-planes of the plume;
5. Solutions to the GDE, C_χ, are the 1-hour average concentrations in *g/s*. Where necessary, this value is converted to other averaging times based on the USEPA AERMOD Screening Model (AERSCREEN) assumptions (USEPA, 2011); and
6. There is no deposition, washout, chemical conversion, or absorption of pollutants by the ground or other physical bodies, and no chemical conversion of the pollutants (i.e., secondary formation of $PM_{2.5}$ or formation of ozone).

Stability Category

Dispersion of pollutants depends, at least in part, on the stability of the environment into which the pollutants are released. In an unstable atmosphere, the pollutants tend to rise unhindered unless acted upon by some other force (i.e., incoming air mass). Conversely, in a stable atmosphere, the pollutants tend to remain at or near the height of the release point, and are assumed to travel downwind until they reach the ground. Pasquill (1961) used the strength of incoming sunlight (i.e., insolation) and cloud cover to represent atmospheric stability, and divided the possible meteorological conditions into six categories, A, B, C, D, E, and F, where A is the most unstable environment and F is the most stable. The Pasquill stability categories are summarized in ***Table 2***.

Stability classes A, B, and C, reflect unstable atmospheric conditions; category D reflects neutral stability characteristics; and categories E and F reflect stable conditions, where F reflects the most extreme stable conditions and is rarely used in research. The stability class E was selected for the BOEM analysis as this is the only stable category valid for the conditions for wind speeds of 2 *m/s* under a nighttime thinly overcast sky (or at least one-half sky cover).

Horizontal Wind Velocity ($\bar{u}$)

The mean wind speed of 2 *m/s* to 3 *m/s* is related to the "E" Pasquill stability class. Because pollutant concentrations increase with lower wind speeds, the lower of the range was selected for this analysis to reflect the most conservative case. Thus, a mean wind speed, $\bar{u}$, of 2 *m/s* is applied to this analysis.

Dispersion Coefficients

As the pollutants travel within the plume in the downwind direction, and throughout the distance to χ, the plume expands to some size in the *z*- and *y*-direction. The degree to which the plume expands with distance in the vertical and horizontal directions is defined by the dispersion coefficients σ_y and σ_z (each in *m*). The σ_y and σ_z coefficients are each a function of the atmospheric stability and turbulence category, and the downwind distance, χ, from the air pollution source.

Vertical and crosswind dispersion occur according to the Gaussian (normal) distribution and are constants to a given downwind distance, χ, where the expansion of the plume assumes an expanding conical plume implicitly requiring homogeneous turbulence throughout the *x*, *y*, and *z*-dimensions of the plume. Pasquill (as cited in Beychok, 2005) developed graphs of the values for σ_y and σ_z, by distance, χ, and by stability category, A, B, C, D, E, and F. The graphs were revised by Turner (1961) (as cited in Beychok, 2005) and are reproduced in ***Figure 2*** and ***Figure 3***.

When using the graph for the vertical coefficient, σ_z, find the distance, χ, on the y-axis and follow the line up to the intersection with the appropriate stability category line, and read the value of σ_z from the y-axis. The idealized Gaussian Equation requires the ratio of σ_y to σ_z be constant throughout dispersion. Larger values of σ_y and σz indicate lower concentrations at the receptors because of the larger volume allowed for dispersion within the larger plume.

Table 2. Pasquill Stability and Turbulence Categories.

Surface wind speed (*m/s*) at 10*m*	**Day**			**Night**	
	Incoming Solar Insolation				
	Strong	**Moderate**	**Slight**	**Thinly overcast or ≥ 4/8 low cloud cover**	**≤ 3/8 cloud cover**
< 2	A	A-B	B	--	--
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Note: Solar insolation is the amount of solar radiation energy received on a given surface area during a given time.
Sources: Pasquill (1961); Pasquill, as cited in Vallero (2008), and Turner (1961).

The users of these plots should understand that the graphs are based on field experimental data that make them appropriate only for environments germane to the test conditions, i.e., level terrain in open, rural areas. The BOEM analysis assumes the surface of the water, in the Gulf of Mexico and the Chukchi and Beaufort Seas of the Arctic Ocean adjacent to Alaska, where in Alaska the water is often a frozen surface, reflects a level open surface, without any complex terrain, and that the Pasquill plots of σ_y and σ_z are valid for this analysis.

Dispersion Coefficients in Equation Form

To improve the accuracy of predicting σ_y and σ_z without using the graphs, the curves on the graphs have been converted into analytical equations by researchers using various approaches. Such equations allow the calculation of C_χ without the need for graphs. The two schemes considered for this analysis are after Martin (1976) and McMullen (as cited in Beychok, 2005).

Martin Scheme - The magnitude of the dispersion coefficients can be estimated using the equations reported by Martin (1976). Martin's equations for horizontal (σ_y) and vertical (σ_z) dispersion coefficients are:

$$\sigma_y = ax^b$$
$$\sigma_z = cx^d + f$$

where, the factor variable, *a*, is dependent on the stability category for calculating σ_y; and *b*, is always assumed to be 0.894 for σ_y. The variables *c*, *d*, and *f* for σ_z depend on the stability category and whether the source is located less than, or greater than, one kilometer from the receptor. Thus, the value of σ_z is calculated using two sets of variables, one when the distance to the receptor, χ, is less than 1 *km*, and another when χ is equal to or greater than 1 *km*.

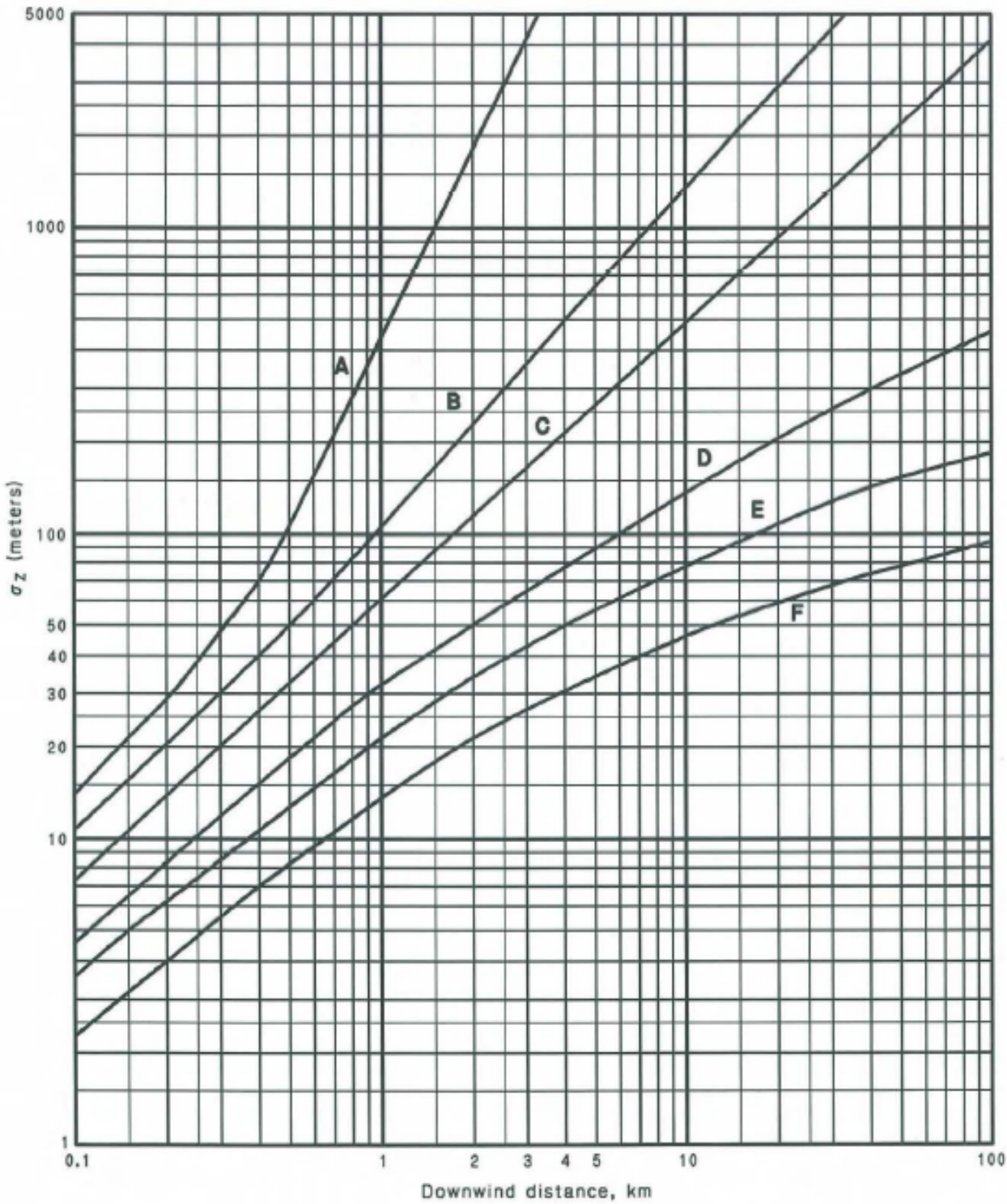


Figure 2. Turner's Version of Pasquill's Vertical Dispersion Coefficient σ_z. Given as a function of downwind distance from the source (rural values).
Source: Beychok, 2005.

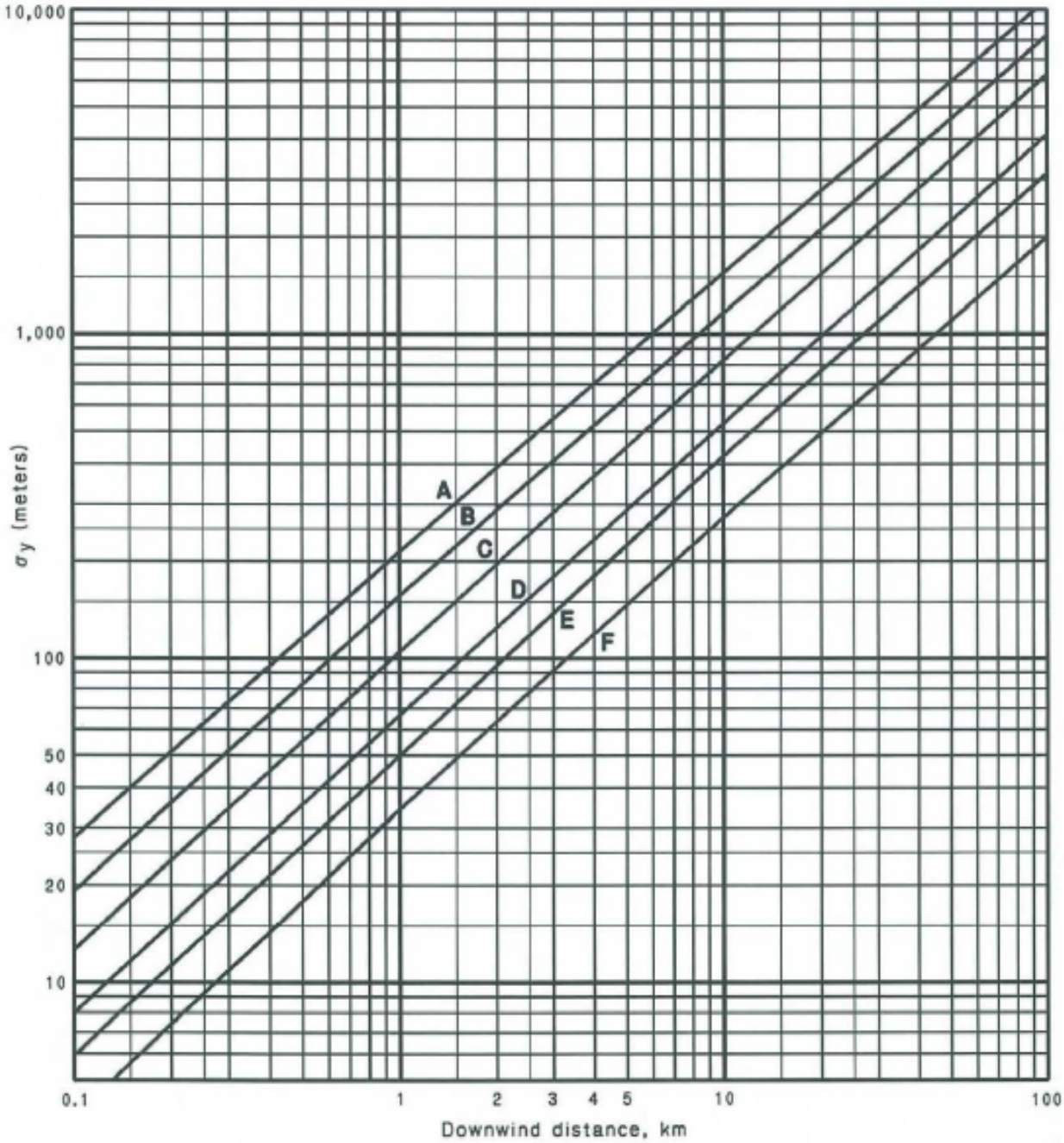


Figure 3. Turner's Version of Pasquill's Horizontal Dispersion Coefficient, σ_y. Given as a function of downwind distance from the source (rural values).

Source: Beychok, 2005.

This accounts for a "bump" in a graph of the σ_z values at 1 *km*, after which the equation "readjusts."

The Martin scheme was used for the air quality analysis in BOEM's Final Supplemental Environmental Impact Statement for Oil and Gas Lease Sale 193 (LS193 Final SEIS); the Record of Decision was issued March 31, 2015. The values of the variables for the Martin scheme equations are shown in ***Table 3*** for each of the Pasquill stability categories.

Table 3. Martin Scheme for Calculating Dispersion Coefficients

Pasquill's Stability and Turbulence Category	σ_y Variables (for any distance, χ, from the source)		σ_z Variables (given the distance, χ, from the source)					
			χ < 1.0 kilometer			χ ≥ 1.0 kilometer		
	a	*b*	*c*	*d*	*f*	*c*	*d*	*f*
A	213	0.894	440.8	1.041	9.27	459.7	2.094	-9.6
B	156	0.894	106.6	1.149	3.3	108.2	1.098	2
C	104	0.894	61	0.911	0	61	0.911	0
D	68	0.894	33.2	0.725	-1.7	44.5	0.516	-13
E	50.5	0.894	22.8	0.675	-1.3	55.4	0.305	-34
F	34	0.894	14.35	0.74	-0.35	62.6	0.18	-48.6

Martin's equations for horizontal (σ_y) and vertical (σ_z) dispersion coefficients are $\sigma_y = ax^b$ and $\sigma_z = cx^d + f$

Source: Martin, D.O. 1976. "Comment on 'The Change of Concentration Standard Deviations with Distance'."

where, σ is the rural dispersion coefficient, sigma, expressed in *m*

χ is the downwind distance, converted to kilometers (*km)*,

e is the "natural" exponential, where $\text{EXP}^a = 2.71828^a$, and

ln(χ) is the "natural" logarithm, or base-*e*, denoted as "*ln*(χ),"

where the stability of the atmosphere is considered to be after Pasquill, and the solution is assumed to representative of an average time of 1-hour, which is consistent with EPA dispersion models used for regulatory compliance.

The variables I, J, and K required to calculate σ_y and σ_z are shown in ***Table 4***.

The equations are presented on the University of Washington Website with example solutions, *see* http://courses.washington.edu/cee490/DISPCOEF4WP.htm

A handy method of verifying the math for the equations is provided on a California State University (Northridge) Website: http://www.csun.edu/~vchsc006/469/ccccc.html.

Table 4. McMullen Scheme for Calculating Dispersion Coefficients.

Pasquill Stability Class	Variables I, J, and K for σ_z			Variables I, J, and K for σ_y		
	I	**J**	**K**	**I**	**J**	**K**
A	6.035	2.1097	0.277	5.357	0.8828	-0.0076
B	4.694	1.0629	0.0136	5.058	0.9024	-0.0096
C	4.11	0.9201	-0.002	4.651	0.9181	-0.0076
D	3.414	0.7371	-0.0316	4.23	0.9222	-0.0087
E	3.057	0.6794	-0.045	3.922	0.9222	-0.0064
F	2.621	0.6564	-0.054	3.533	0.9191	-0.007

Source: Beychok. 2005. "The Fundamentals of Stack Gas Dispersion."

McMullen Scheme - The values of σ_y and σ_z can also be estimated using equations developed by McMullen (as cited in Beychok, 2005). McMullen developed the following equation, which is valid for both coefficients, except for the application of different variable values, depending on the Pasquill stability category:

$$\sigma = e^{\left[(I+J\,(ln(x))) + \left(K\,(ln(x^2))\right)\right]}$$

Comparison of the Martin and McMullen Schema

A comparison of the values of the σ_y and σ_z dispersion coefficients using the Martin scheme as compared to the McMullen scheme is provided in ***Table 5***. The method used to calculate the dispersion coefficients of σ_y and σ_z under the Martin scheme limits the width of the plume and the vertical height of the plume when compared with the dispersion coefficients under the McMullen scheme, given the same conditions. Thus, the Martin scheme would result in higher concentrations for a given emission rate. Likewise, under the Martin scheme, the maximum allowable emission rate would be 5.80% lower when compared with the McMullen scheme, given the conditions described in Table 5. ***Thus, the Martin scheme is the more conservative of the two approaches***.

Extrapolating Time-Averaged Concentrations

The solution of the Gaussian Equation predicts the 1-hour average pollutant concentration. However, BOEM is requiring lessees and operators to address air quality standards for average concentrations over periods of 1-hour, 3-hours, 8-hours, 24-hours, and annually (30 CFR § 550.303(d)). BOEM has followed conversion factors in the EPA AERSCREEN User's Guide (2011) to calculate average concentrations for these other periods:

- 3-hour average is the same as the 1-hour average;
- 8-hour average is the 1-hour average multiplied by 0.9;
- 24-hour average is the 1-hour average multiplied by 0.6; and
- Annual average is the 1-hour average multiplied by 1.0.

Table 5. Comparison of the McMullen and Martin Schema for Dispersion Coefficients

Scheme	**Coefficients** (when χ = 30 *km* and Stability Class E)			**Maximum Allowable Rate of Emissions** (where $C\chi$ = 1.00 $\mu g/m^3$ is not exceeded, and H = 10 *m*, $\bar{u}$ = 2 *m/s*, c = 20 *st.mi*, and stability category E)	
	σ_y (*m*)	σ_z (*m*)	$\sigma_y * \sigma_z$ (m^2)	Q_p (*g/s*)	Q_p (*s. tons/y*)
McMullen (1960)	1178.645	130.745	1.50^{E+5}	0.9463	32.91757
Martin (1976) (LS193 Final SEIS)	1125.007	125.717	1.41^{E+5}	0.8914	31.00784
Difference	-23.64	-5.03	-0.087^{E+5}	-0.055	-1.910
Percent Difference	-2.06%	-3.85%	-5.82%	-5.80%	-5.80%

Statute miles is *st. mi*.

Note: χ = 32.1868 *km* (32,186 *m* or ~20.0 *st.mi)*.

Plume Rise Variables

In using the Gaussian Dispersion Equation, BOEM assumes there is no plume rise, which results in a more conservative, higher solution to the equation for the maximum allowable rate of emissions.

LIMITATIONS OF THE ANALYSIS

Beychok (2005) cautions users that applying the Gaussian Dispersion Equation is only valid when assuming the constraints listed with the literature. The dynamic process of dispersion, which includes the diffusion in the y- and z- dimension, and the wind speed, cannot be stated with absolute certainty. Neither can the stability of the atmosphere be duplicated using just six categories of meteorological conditions, i.e., A, B, C, D, E, and F. In addition, it is not likely that each of the constraints, wind speed, stability, and diffusion, would remain constant throughout the plume and during the time required to reach the receptor. Beychok states the Pasquill dispersion coefficients could easily have an uncertainty range of plus or minus 25 percent.

Beychok recognized that as the EPA updates its dispersion models, even when based on Gaussian theory, they would be far more accurate than the modeling of a single point-source. Indeed, current models include techniques such as stack downwash, modeling the land-sea interface, photochemical analysis, and the use of multi-year historical meteorological data that calculates σ_y and σ_z for each of the 8,760 hours of each year, for multiple years.

Despite the limitations of the Gaussian methodology, BOEM believes this method can be very useful in predicting the maximum allowable emissions rates below which emissions would not have the potential to exceed air quality standards and adversely impact onshore air quality.

METHOD OF THE ANALYSIS

This analysis derives equations to calculate thresholds for the maximum allowable rate of emissions that would not exceed the values in *Table 1*, based on the distance from the receptor, whether the receptor is located at the shoreline, the seaward boundary, or any other receptor location. Equations are derived for each SIL whereby lessees and operators can calculate the maximum allowable emission rates that would not exceed the values in *Table 1*, for each applicable pollutant, given the distance of their source or sources from the receptor location.

Determining the Variables and Constants

BOEM coded the Gaussian Dispersion Equation in a Microsoft Excel spreadsheet for calculation of the maximum rate of emissions, Q_p, which would not exceed the significance levels in *Table 1* at a distance, χ, given the conditions indicated in ***Table 6.***

Table 6. Variables for the Analysis of Q_p.

Variable	Description	Value and/or Units
C_x	Pollutant concentration, solution to the Gaussian Equation.	In grams per cubic meter (g/m^3), for each pollutant and averaging period, and can be converted to micrograms per cubic meter ($\mu g/m^3$) for comparison to ***Table 1*** values
χ	Downwind distance from the source	In meters (*m*), ranging from 500 *m* to 370 *km* (~200 *nm*) in increments of 500 *m* to 1,500 *m*, in increments of one-half mile from 1.0 miles to 15 miles, and every mile thereafter
$\bar{u}$	Average lowest daily wind speed	2.0 *m/s*
H	Height of the emission source stack above the surface	10 *m*
σ_y *and* σ_z	Dispersion coefficients, expresses the pollutant plume in terms of expanding width and depth of the plume, with distance, χ, from the source	in *m*, using the Martin scheme and variables in *Table 3*, for stability category "E"
Stability Category	Moderately stable atmosphere	E

For this analysis, the value of χ, the distance in meters, is given for the range from 500 *m* to 371,758 *m* (371.76 *km*) or approximately 200 nautical miles (*nm*), the extent of the U.S. Exclusive Economic Zone (EEZ). The math used for the calculation of σ_y and σ_z can be verified using various online dispersion coefficient "calculators," and in particular the calculator available from the California State University of Northridge, http://www.csun.edu/~vchsc006/469/ccccc.html. Once the value of Q_p is found, the solutions are randomly checked against an online calculator provided by A.J. Design Software to verify the solutions to the Gaussian Equation in *Figure 1*. http://www.ajdesigner.com/phpdispersion/emission_source_ground_equation.php#ajscroll

Building the Derived Equation for the Rate of Emissions, Q_p

Once the values of σ_y and σ_z are calculated, the Gaussian Dispersion Equation can be solved for Q_p, the rate of emissions in mass per unit of time (*g/s* or *s.tons/yr*) where the target values of $C\chi$ for each pollutant and averaging period are the values given in *Table 1*. For purposes of the derivation, the denominator of the Dispersion Equation in *Figure 1*, ($\pi\ \sigma_y\ \sigma_z\ \bar{u}$), is considered one term, "A," and the exponential factor, (e^x), is considered a separate term, "B." Given these substitutions, the Gaussian Equation in *Figure 1* is solved for Q_p, as follows:

$$C_x = \frac{Q_p}{A} * B$$

$$C_x = Q_p * \frac{B}{A} \quad \text{so that,}$$

$$Q_p = C_x \times \frac{A}{B} \quad \text{therefore,}$$

$$Q_p = \frac{C_x\ A}{B}$$

Thus, the maximum allowable emissions rate, Q_p, is calculated using the equation above, in the Microsoft Excel program for each SIL (i.e. $C\chi$) provided in *Table 1*. The variable assignments given in *Table 6* are applied along with the Martin scheme for calculating dispersion coefficients for Pasquill's stability and turbulence category "E", for σ_y and σ_z in *Table 3*.

It is then a simple matter to calculate the maximum emissions rate by multiplying the value from the appropriate $C\chi$ by "A," then dividing the product by "B." In this derivation, the values for "A" and "B" only change relative to the distance from the source, χ, and reflect a 1-hour average concentration. Other averaging periods are calculated using the conversion rates under "*Extrapolating Time-Averaged Concentrations,*" provided in a previous section.

Threshold Equations

Once the first equation solving for Q_p was complete, the method was repeated for each SIL, and for each value of χ ranging from 500 *m* to 371,758 *m*. The solution, Q_p, was converted to "E," emissions in *s.tons/y*, and "*d*" is substituted for the many values of χ, ranging from 0.2 *nm* (500 *m*, 0.5 *km*, or 0.31 *st.mi*) to ~200 *nm* (371,758 *m*, 371.758 *km*, or 231 *st.mi*). An equation to estimate the maximum allowable maximum emission rate based on distance from a target, which would not exceed the applicable SIL, was derived by graphing, for each SIL, the ratio of E:*d* using Excel graphing features. The resultant curves were assigned a "power regression" line to get the best possible fit to the E:*d* curve, which Excel generates as an equation for the regression line. The equation to the regression line becomes the threshold equation for each SIL, as shown in ***Table 9***.

Table 9. Threshold Exemption Equations for Predicting the Maximum Rate of Emissions, E, in *s.tons/yr*, at a distance, *d*, from the Receptor

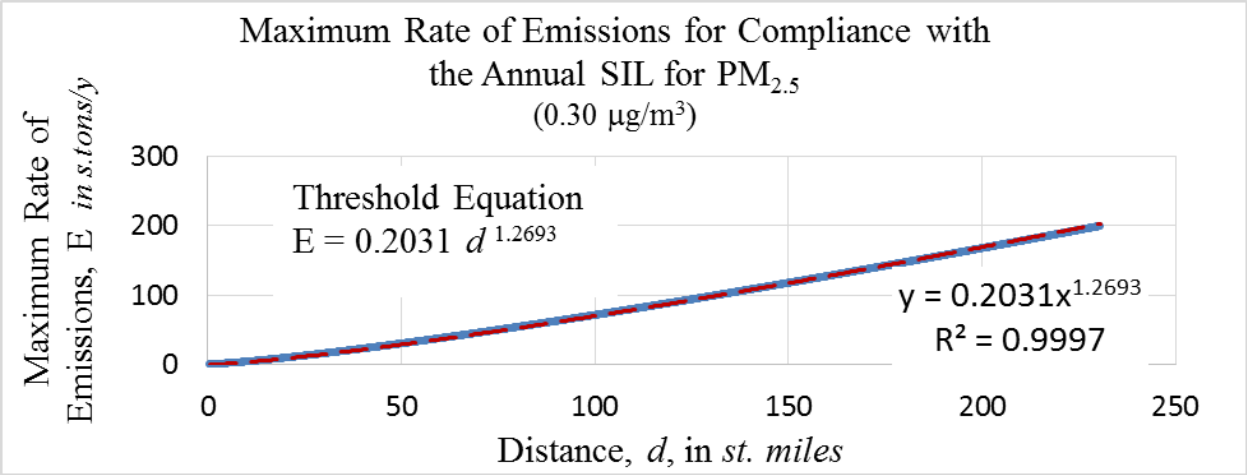
Threshold Equation (*d* is in *st.miles*, E is in *s.tons/y*)	**Pollutant and Averaging Period**	**Maximum Allowable Concentration (SILs)**
$E = 0.2031(d^{1.2693})$	Annual $PM_{2.5}$	0.30 μg/m^3
$E = 0.677\ (d^{1.2693})$	Annual NO_x, SO_x, and PM_{10}	1.0 μg/m^3
$E = 0.8124\ (d^{1.2693})$	24-hr $PM_{2.5}$	1.20 μg/m^3
$E = 3.3851\ (d^{1.2693})$	24-hr SO_2 and PM_{10}	5.0 μg/m^3
$E = 16.926\ (d^{1.2693})$	3-hr SO_2	25.0 μg/m^3
$E = 338.51(d^{1.2693})$	8-hr CO	500.0 μg/m^3
$E = 1354\ (d^{1.2693})$	1-hr CO	2,000.0 μg/m^3

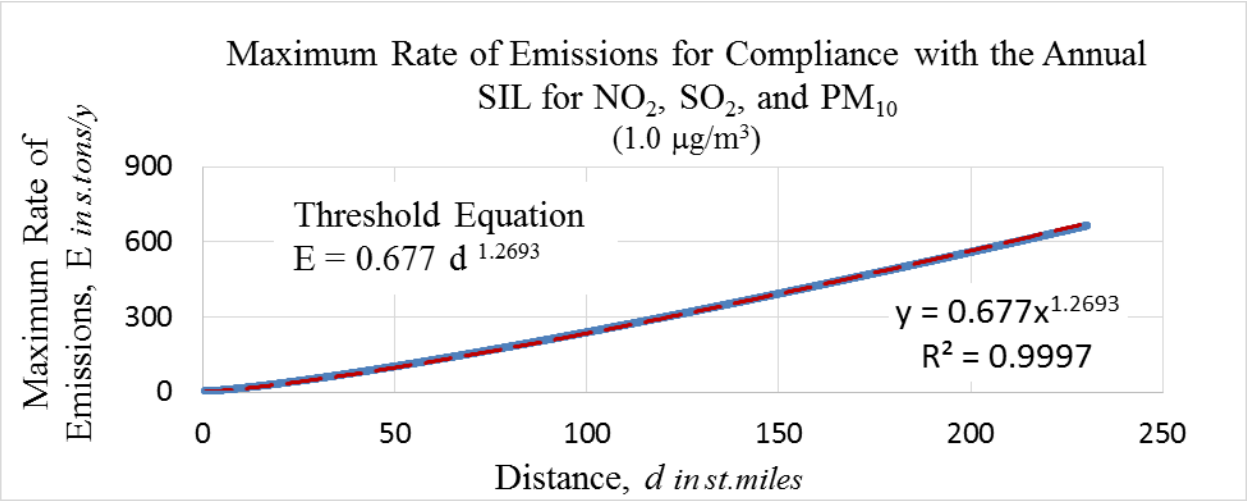
Given the conditions H = 10 *m*; $\bar{u}$ = 2.0 *m/s*; and applying Pasquill stability category E.

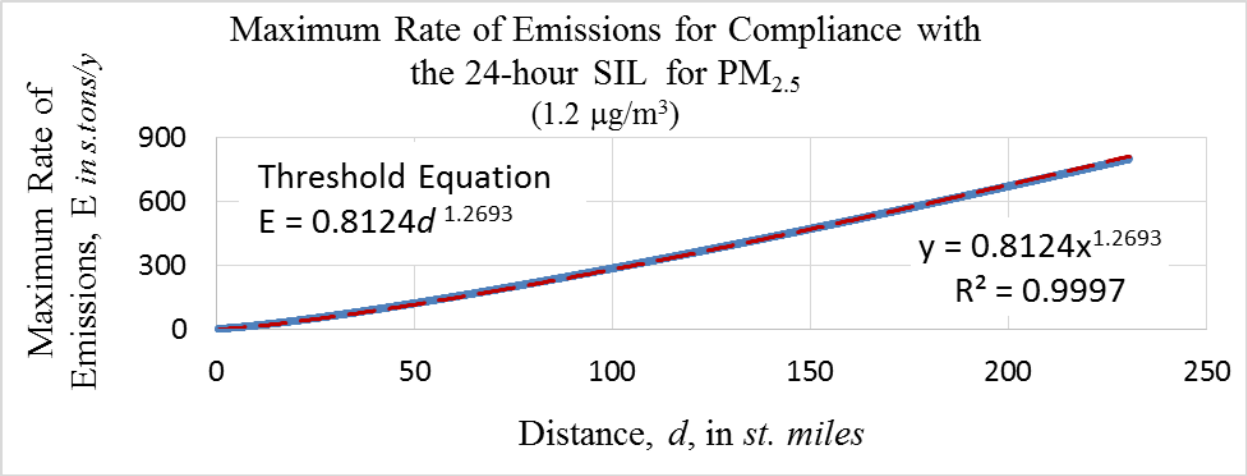
When creating the regression line, Excel calculates how well the line "fits" the E:*d* curve, in other words, how effectively the power regression equation can be used to replicate the original curve. The measure of the fit is calculated within the Excel algorithm and expressed by the value R^2, or the "R-squared value, which is the square of the correlation coefficient. The higher the value of R^2 the more accurate the replication of the original curve from which the equation was derived. The maximum possible R^2 value is 1.0, or 100%. Each curve plotted for the analysis has an R^2 value of .9997, or a "fit" of 99.97% of the points that form each curve.

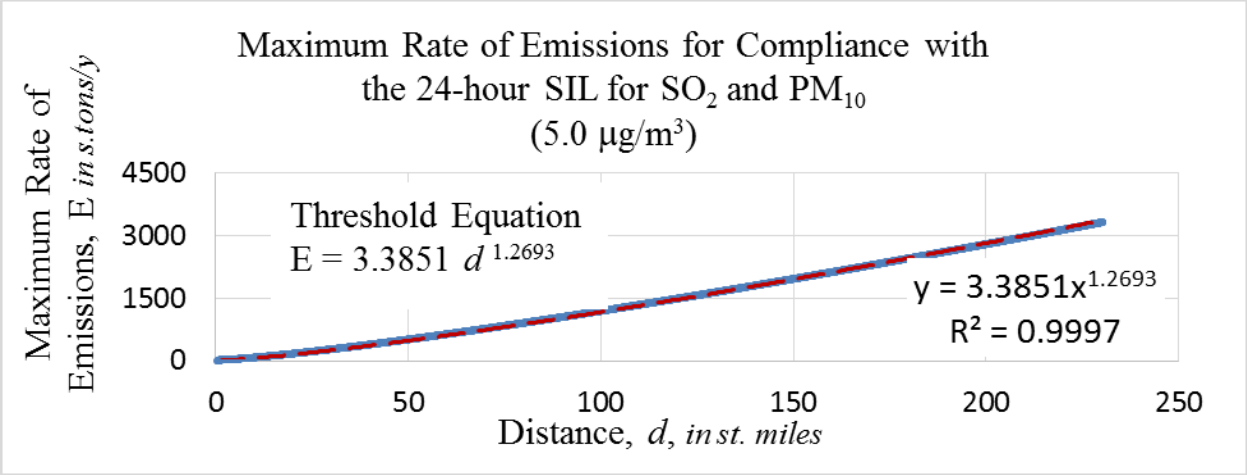
The equations in *Table 9* are in the form of the equation, $y = ax^b$, the equation of a regression line. Notice that the "*a*" variable in each equation changes with each curve while the exponent, "*b*", remains the same, 1.2693. This occurs because the Gaussian Equation is idealized, causing the shape of the curve to be the same for each equation. Only the position of the curve on the y-axis changes with each equation.

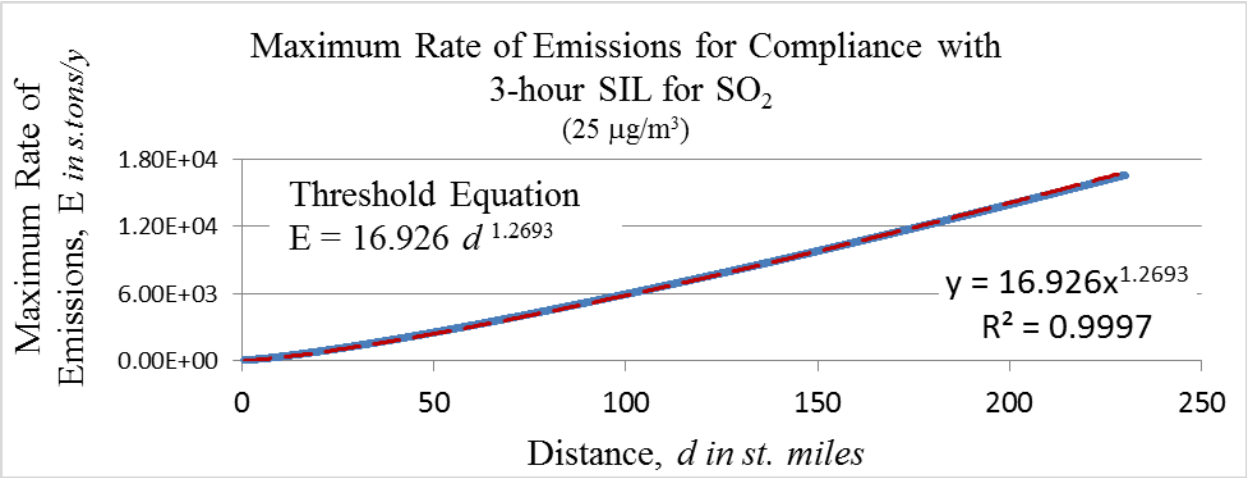
The following graphs show the plots of distance, *d*, against the calculated maximum rate of emissions, E, calculated using an Excel spreadsheet under the conditions in *Table 6*. Each graph shows the power regression line, the equation to the regression line, which is shown as the SIL threshold equation. There is a graph for each of the SIL threshold equations in *Table 9*. Note that each graph has a different scale for the vertical y-axis, representing the maximum rate of emissions, E. The graphs cover the range from ~0.5 *st.mi* (~0.43 *nm*) to 230 *st.mi* (~200 *nm*).

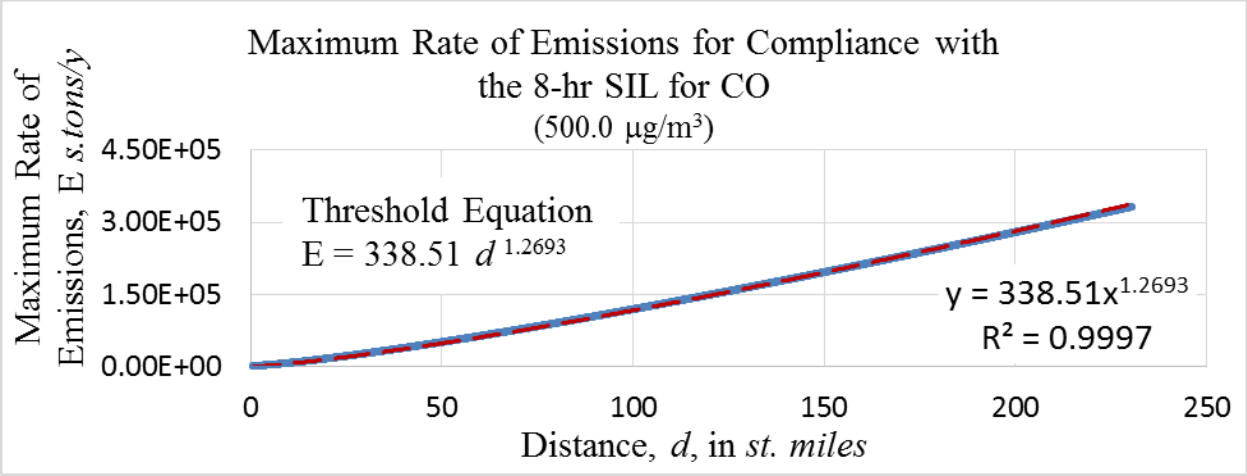

Maximum Rate of Emissions for Compliance with the Annual SIL for PM2.5
(0.30 µg/m3)
Threshold Equation
E = 0.2031 d 1.2693
y = 0.2031x1.2693
R² = 0.9997
Maximum Rate of Emissions, E in s.tons/y
Distance, d, in st. miles
0
100
200
300
0
50
100
150
200
250

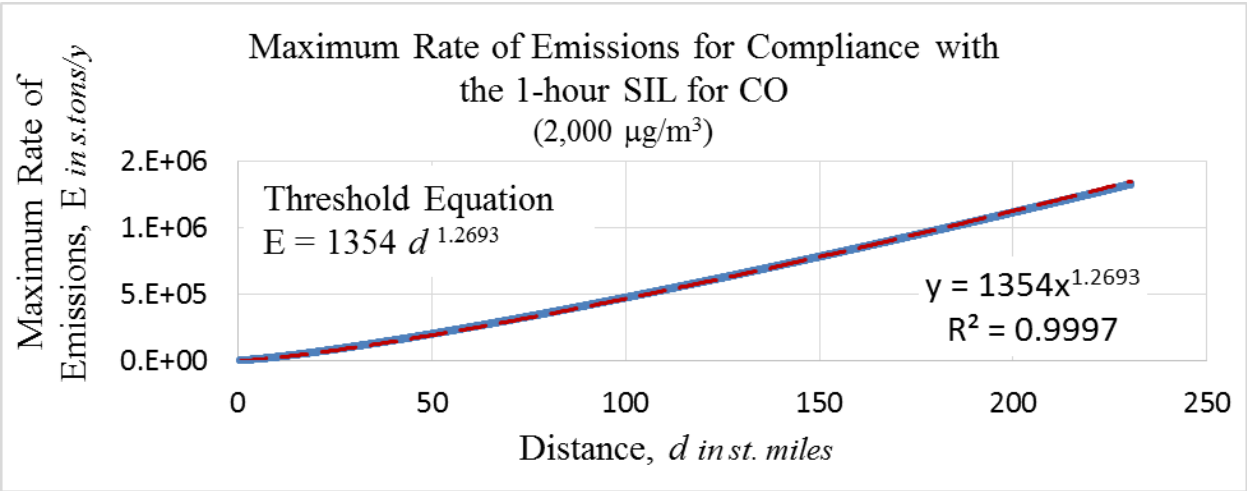

Maximum Rate of Emissions for Compliance with the Annual SIL for NO2, SO2, and PM10
(1.0 µg/m3)
Threshold Equation
E = 0.677 d 1.2693
y = 0.677x1.2693
R² = 0.9997
Maximum Rate of Emissions, E in s.tons/y
Distance, d in st.miles
0
300
600
900
0
50
100
150
200
250


Maximum Rate of Emissions for Compliance with the 24-hour SIL for PM2.5
(1.2 µg/m3)
Threshold Equation
E = 0.8124d 1.2693
y = 0.8124x1.2693
R² = 0.9997
Maximum Rate of Emissions, E in s.tons/y
Distance, d, in st. miles
0
300
600
900
0
50
100
150
200
250


Maximum Rate of Emissions for Compliance with
the 24-hour SIL for SO_2 and PM_{10}
(5.0 µg/m³)
Maximum Rate of Emissions, E in s.tons/y
4500
3000
1500
0
Threshold Equation
E = 3.3851 d 1.2693
y = 3.3851x1.2693
R² = 0.9997
0
50
100
150
200
250
Distance, d, in st. miles

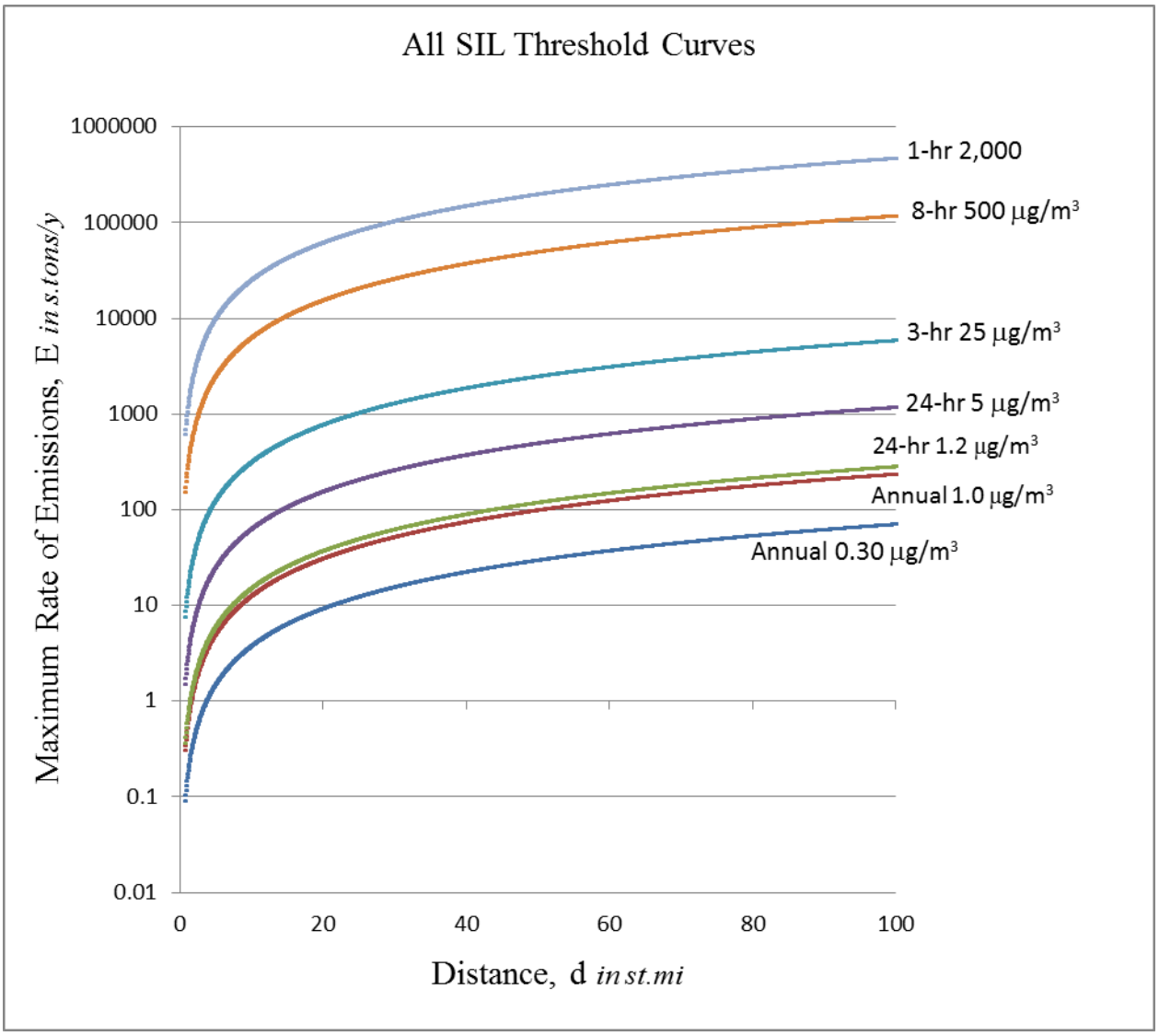

Maximum Rate of Emissions for Compliance with
3-hour SIL for SO_2
(25 µg/m³)
Maximum Rate of Emissions, E in s.tons/y
1.80E+04
1.20E+04
6.00E+03
0.00E+00
Threshold Equation
E = 16.926 d 1.2693
y = 16.926x1.2693
R² = 0.9997
0
50
100
150
200
250
Distance, d in st. miles


Maximum Rate of Emissions for Compliance with
the 8-hr SIL for CO
(500.0 µg/m³)
Maximum Rate of Emissions, E s.tons/y
4.50E+05
3.00E+05
1.50E+05
0.00E+00
Threshold Equation
E = 338.51 d 1.2693
y = 338.51x1.2693
R² = 0.9997
0
50
100
150
200
250
Distance, d, in st. miles

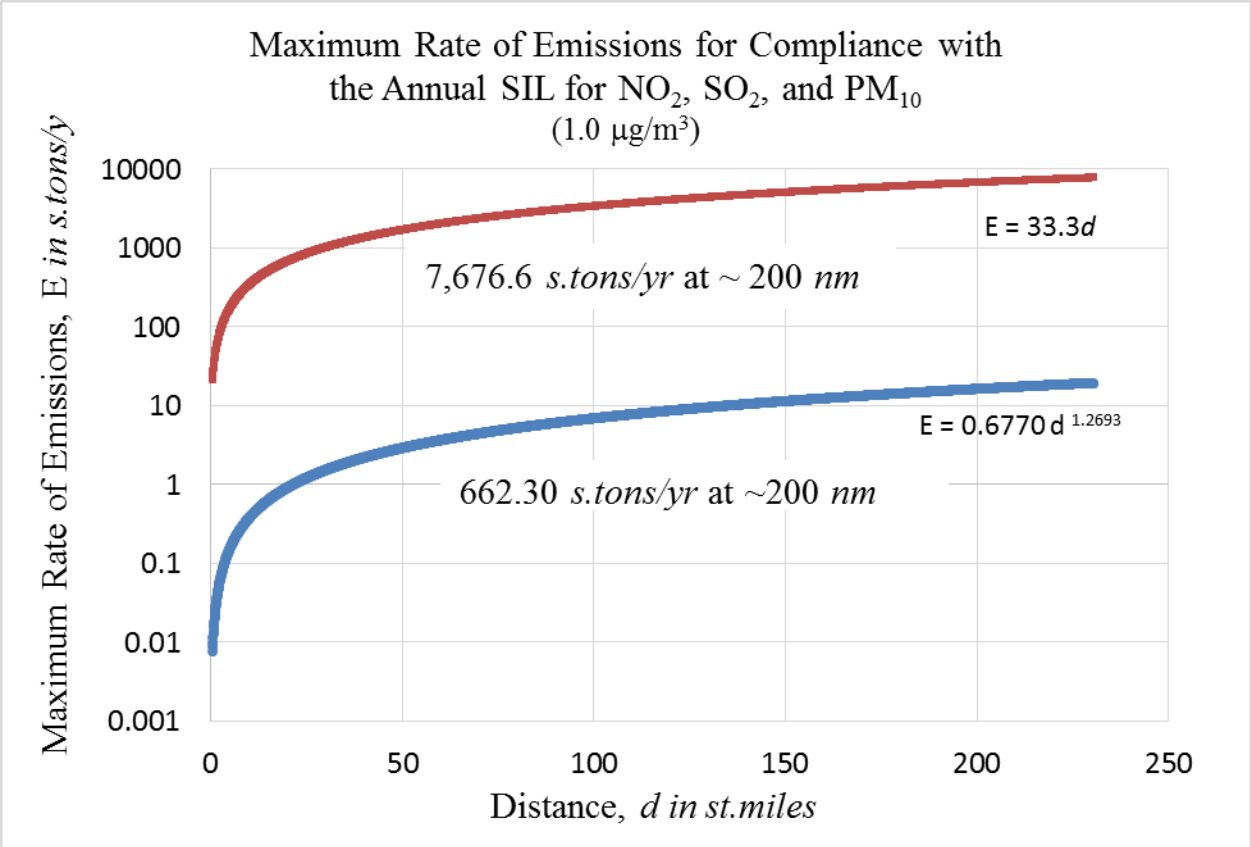


This graph of "All SIL Threshold Curves" illustrates the curves of each equation relative to their position on the scale of the y-axis of the maximum rate of emissions. The graph depicts the maximum rate of emissions in *s.tons/y* against the distance in *st.mi* for each SIL, where the SIL for each equation is labeled for each curve. Note all the curves maintain the same shape but are at different positions on the vertical y-axis. In order to visualize all the curves on one graph, the axis scales are converted to logarithmic scale. This is necessary to visualize all the curves on one graph; otherwise the five lowest curves would overlap and be obscured. Use of the logarithmic scale accounts for the change in shape of each curve as compared to the graphs above.

The graph "Comparing Curves for Compliance" shows the difference in the maximum rate of emissions allowable under the current threshold equation, E = 33.3*d* (30 CFR § 550.303(d)) as compared to the threshold calculated for this analysis for the maximum rate of emissions of NO_2, SO_2, and PM_{10}, $E = 0.6770\ d^{1.2693}$. As an example, at a distance of 230 *st.mi* (200 *nm)* the range of the allowable rate of emissions differs by 7,014.3 *s.tons/y*. This would be expected as the idealized variables BOEM used for the Gaussian Equation reflects a stable environment and low winds for maximum concentrations at the receptor.


All SIL Threshold Curves
Maximum Rate of Emissions, E in s.tons/y
1000000
100000
10000
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
Distance, d in st.mi
1-hr 2,000
8-hr 500 µg/m³
3-hr 25 µg/m³
24-hr 5 µg/m³
24-hr 1.2 µg/m³
Annual 1.0 µg/m³
Annual 0.30 µg/m³

Comparing Curves for Compliance



BIBLIOGRAPHY

Abdel-Rahman, A.A. 2008. "On the Atmospheric Dispersion and Gaussian Plume Model." *Waste Management, Water Pollution, Air Pollution, Indoor Climate*, 2nd International Conference, Corfu, Greece, October 26-28, 2008.

Arya, S. P. 1999. Air Pollution Meteorology and Dispersion. Oxford University Press, Inc.: New York, New York.

Beychok, M. R. 2005. "Fundamentals of Stack Gas Dispersion," 4th ed. Milton R. Beychok: Newport Beach, California.

Martin, D.O. 1976. "Comment on 'The Change of Concentration Standard Deviations with Distance'." Journal of the Air Pollution Control Association. 26:2, 145-147. doi: 10.1080/00022470.1976.10470238. The equations for the Martin σ_y and σ_z dispersion coefficients are provided on the University of Washington Website at http://courses.washington.edu/cee490/DISPCOEF4WP.htm

Pasquill, F. 1961. "The Estimation of the Dispersion of Windborne Material." Meteor. Mag. 90:1,063. pp 34-49, February 1961.

Turner, D.B. 1961. "Workbook of Atmospheric Dispersion Estimates." U.S. EPA Publication AP-26. Revised 1970, 5th printing 1972.

U.S. Environmental Protection Agency (USEPA). August 23, 2010. Memorandum from USEPA Air Quality Policy Division, Acting Director Anna Marie Wood to "Regional Air Division Directors." "*General Guidance for Implementing the 1-hour SO_2 National Ambient Air Quality Standard in Prevention of Significant Deterioration Permits, Including an Interim 1-hour SO_2 Significant Impact Level*."

U.S. Environmental Protection Agency (USEPA). March 2011. "AERSCREEN User's Guide." EPA-454/B-11-001. EPA Air Quality Assessment Division: Research Triangle Park, North Carolina.

Vallero, D. 2008. Fundamentals of Air Pollution. 4th ed. Academic Press: New York: New York.

ACRONYMS, SYMBOLS, AND UNITS OF MEASURE

ACRONYM	DESCRIPTION
AERMOD	American Meteorological Society/EPA Regulatory Model for simulation of air pollutant dispersion
AERSCREEN	American Meteorological Society/EPA Regulatory Model for performing screening simulation of air pollutant dispersion
CFR	Code of Federal Regulations
CO	Carbon monoxide
EPA	U.S. Environmental Protection Agency
EEZ	U.S. Exclusive Economic Zone
LS193 Final SEIS	BOEM Final Supplemental Environmental Impact Statement for Oil and Gas Lease Sale 193 for the Chukchi Sea Outer Continental Shelf (OCS)
NO_2	Nitrogen dioxide
$PM_{2.5}$	Fine particulate matter
PM_{10}	Coarse particulate matter
SIL	Significant Impact Level, as given in the table at 40 CFR § 51.165(b)(2)
SO_2	Sulfur dioxide

SYMBOL	DESCRIPTION
A	Pasquill stability and turbulence category (*see* Table 2); or the denominator of the Gaussian Equation, where A = ($\pi\ \sigma_y\ \sigma_z\ \bar{u}$)
a	Variable for Martin sigma values (*see* Table 3); or variable used in the equation of an Excel power regression line in the form $y = ax^b$ (*see* Table 9)
B	Pasquill stability and turbulence category (*see* Table 2); or the exponential function of the Gaussian Dispersion Equation, where B = exp [-1/2 (H^2/σ_z^2)]
b	Variable for Martin sigma values (*see* Table 3); or variable used in the equation of an Excel power regression line in the form $y = ax^b$ (*see* Table 9)
C	Pasquill stability and turbulence category (*see* Table 2)
C_x	Pollutant concentration in $\mu g/m^3$, solution to the Gaussian Equation at a distance, x meters
c	Variable for Martin sigma values (*see* Table 3)
D	Pasquill stability and turbulence category (*see* Table 2)
d	Variable for Martin sigma values (*see* Table 3); or distance from the source in *st.mi*, used in the threshold equation, for example, E = 0.2031 ($d^{1.2693}$), where E is the rate of emissions in *s.tons/yr* (*see* Table 9)
E	Pasquill stability and turbulence category (*see* Table 2); or the solution of the emission exemption threshold rate equation, for example, E = 0.2031 ($d^{1.2693}$), where *d* is the distance from the target in *st.mi* and the solution, E, is in *s.tons/yr* (*see* Table 9)

SYMBOL	DESCRIPTION
e	Natural exponent, where e^1 is a value approximately 2.718, no units
F	Pasquill stability and turbulence category (*see* Table 2)
f	Variable for Martin sigma values (*see* Table 3)
H	Height of the emission source stack above the surface, in *m*
I	Variable for McMullen sigma values (*see* Table 4)
J	Variable for McMullen sigma values (*see* Table 4)
K	Variable for McMullen sigma values (*see* Table 4)
π	Pi, a value of approximately 3.14, no units
Q_p	Maximum allowable rate of emissions, in *g/s*, per pollutant, *p*, or *s.tons/y*
R^2	R-squared value, which is the square of the correlation coefficient, indicating how well a regression line "fits" a plotted curve, maximum value is 1.00 or 100%
σ_y	Sigma dispersion horizontal coefficient, expresses expansion of a plume in the y-direction, in *m*
σ_z	Sigma dispersion vertical coefficient, expresses expansion of a plume in the z-direction, in *m*
$\bar{u}$	Average wind speed, in *m*
χ or x	Downwind distance from the source, in *m*, except when used to calculate sigma values when χ is entered in *km*

UNITS OF MEASURE	DESCRIPTION
g	grams
g/s	grams per second
μ	micro, a metric unit meaning 1,000,000, as in micrograms, μg, or 10^{-6} *g*
m	meters
m/s	meters per second
$\mu g/m^3$	micrograms per cubic meter, mass of pollutant per volume of air
km	kilometer, or 1,000 meters, or 10^3 *m*
s.tons/y	short tons per year, rate of emissions in weight over time, where a short ton = 2,000 pounds
nm	nautical miles, where 1*nm* = 1.1508 *st.mi*
st.mi	statute miles, where 1 *st.mi* = 1.6093 *km*