APPENDIX D

DISPERSION FACTOR CALCULATIONS

When developing SSLs for the outdoor inhalation of fugitive dusts and volatiles using the simple site-specific approach, site managers may want to calculate air dispersion factors (Q/C) that reflect the site location/climate and site size. This appendix provides information regarding the calculation of such "site-specific" dispersion factors (Q/C), which can be used in lieu of default values provided in this document.

These Q/C values should be used in conjunction with the Particulate Emission Factor (PEF) and Volatization Factor (VF) equations provided for outdoor workers under the commercial/industrial scenario (Section 4.2.3) and for off-site residents under the construction scenario in (Section 5.3.2).

The soil screening process presented in this guidance includes three receptor- and pathway-specific Q/C values for which site managers can calculate site-specific values using the information presented in this appendix. These include:

- **Q/C_{wind}:** The dispersion factor for fugitive dusts emitted from soils; used to derive commercial/industrial SSLs for the outdoor worker/landscaper receptor.

- **Q/C_{vol}:** The dispersion factor for volatiles emitted from soils; used to derive commercial/industrial SSLs for the outdoor worker/landscaper receptor.

- **Q/C_{off}:** The dispersion factor for fugitive dusts emitted from soils; used to derive construction SSLs for the off-site resident receptor.

The equations for calculating these dispersion factors all take the general form of Equation D-1. The specific instructions for calculating each of these receptor-specific dispersion factors are presented below. Site managers should use the map shown in Exhibit D-1 to identify their climate zone and refer to the relevant lookup table (Exhibits D-2 through D-4) to identify the appropriate values for the constants A, B, and C. To evaluate the dispersion factor, the ISC3 dispersion model was used to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. These data were used to generate the best-fit curve equation for predicting air concentration as a function of site size. CURVEFIT was used to determine the best fit equation and the resulting default values for constants A, B, and C.[1] This program performs a least squares curve fit on X (site size), Y (concentration data). Curves are fitted and Equation coefficients, Correlation Coefficient, and Best Fit parameters are computed. It was determined that a log normal distribution had the highest correlation coefficient when comparing site size to the concentration data. For additional information regarding the derivation of the dispersion modeling conducted, please refer to Appendix E of this document or to Section 2.4.3 in the *Technical Background Document* of the 1996 *Soil Screening Guidance*.

Equation D-1

GENERAL FORM FOR CALCULATING RECEPTOR- AND PATHWAY-SPECIFIC DISPERSION FACTORS (Q/C)

$$Q / C = A \times \exp\left[\frac{(\ln A_{site} - B)^2}{C}\right]$$

Parameter/Definition (Units)

Q/C: Inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source or at the boundary of the source* (g/m^2-s per kg/m^2)

A, B, C: Constants based on air dispersion modeling for specific climate zones

A_{site}: Areal extent of the site or contamination (acres)**

* Q/C_{wind} and Q/C_{vol} are calculated for concentrations at the center of the source. Only Q/C_{off} is calculated for the concentration at the site boundary in the direction of the prevailing wind.

** Site size can range from 0.5 to 500 acres.

---

[1] CURVEFIT Version 2.11 A July 29, 1988 by Thomas S. Cox.

Q/C_{wind} (Outdoor Worker - Fugitive Dusts)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 16.2302
B = 18.7762
C = 216.1080

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{wind} of 93.77.

Exhibit D-2 presents values for the constants for use in the calculation of site-specific values of Q/C_{wind}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{wind}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{wind} can then be used with Equation 4-5 in Chapter 4 of this guidance to calculate an appropriate PEF value. This is used in calculating SSLs for the inhalation of fugitive dusts pathway using Equations 4-3 and 4-4.

Q/C_{vol}(Outdoor Worker - Volatiles)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 11.9110
B = 18.4385
C = 209.7845

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{vol} of 68.18.

Exhibit D-3 presents values for the constants for use in the calculation of site-specific values of Q/C_{vol}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{vol}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{vol} can then be used with Equation 4-8 from Chapter 4 of this guidance to calculate an appropriate VF value. This is used in calculating SSLs for the inhalation of volatiles pathway using Equations 4-6 and 4-7.

Q/C_{off} (Offsite Residents - Fugitive Dusts)

Dispersion modeling yielded the following default values for use in Equation D-1, above:

A = 11.6831
B = 23.4910
C = 287.9969

These represent the 90th percentile values for these constants based on the 29 meteorological stations modeled. Using these values and a site area (A_{site}) of 0.5 acres, produces a default Q/C_{off} of 89.03.

Exhibit D-4 presents values for the constants for use in the calculation of site-specific values of Q/C_{off}. Values are presented for each of the 29 meteorological stations used in the dispersion model analysis. To calculate site-specific Q/C_{off}, site managers first select the values of these constants from the most appropriate monitoring station. The value of Q/C_{off} can then be used with Equation 5-9 in Chapter 5 of the guidance to calculate an appropriate PEF value. This is used in calculating SSLs for the inhalation of fugitive dusts pathway using Equations 5-7 and 5-8.

Exhibit D-1

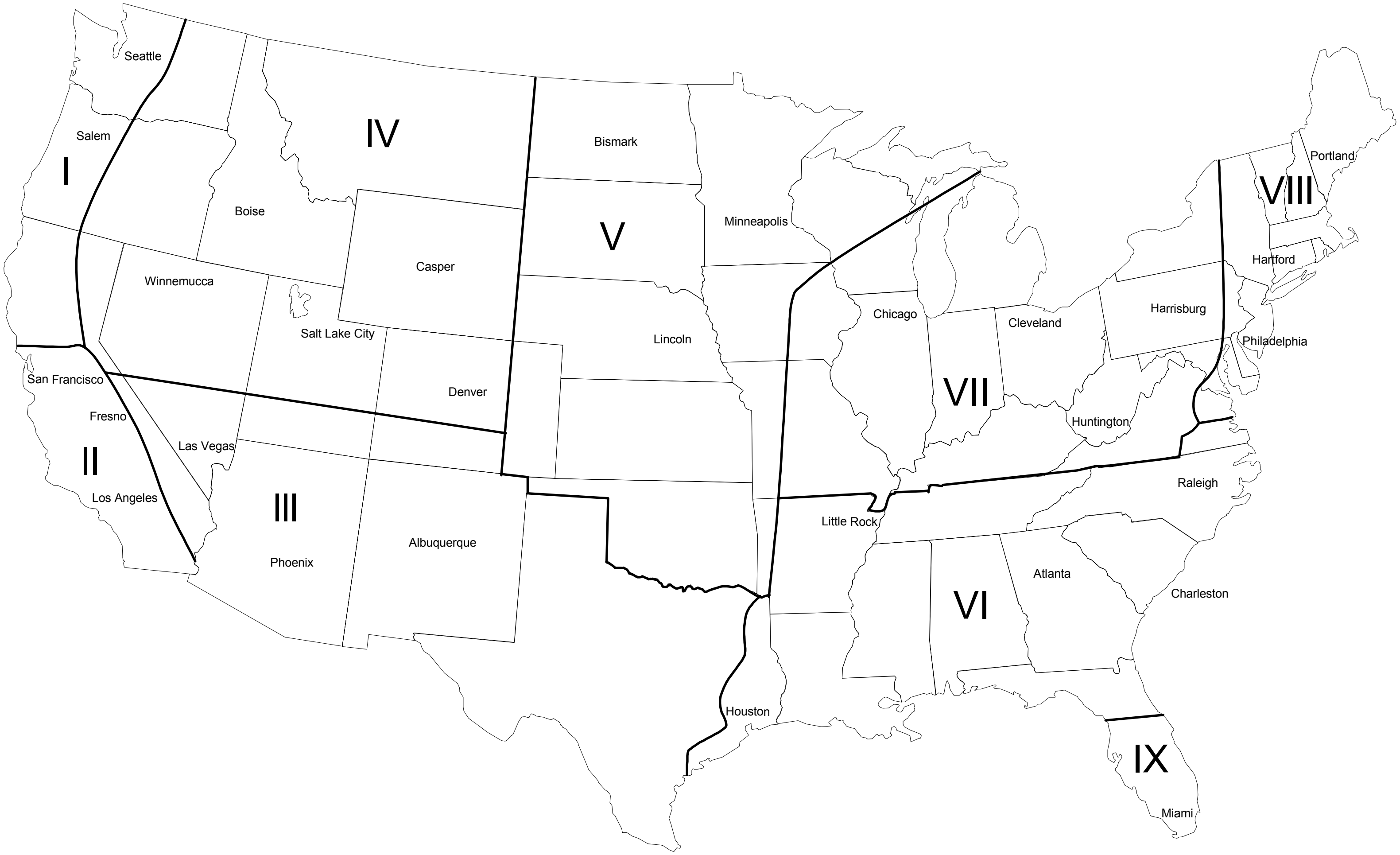
Seattle
Salem
I
Boise
IV
Bismark
V
Minneapolis
Casper
Winnemucca
Salt Lake City
Lincoln
Chicago
Cleveland
Harrisburg
Hartford
Portland
VIII
Philadelphia
San Francisco
Fresno
Denver
VII
Huntington
Las Vegas
II
Los Angeles
III
Little Rock
Raleigh
Albuquerque
Phoenix
Atlanta
Charleston
VI
Houston
IX
Miami

Exhibit D-2

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C_{wind}

$$Q / C_{wind} = A \times \exp\left[\frac{\left(\ln A_{site} - B\right)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Zone 2			
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Zone 3			
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Zone 4			
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	7.1414	31.1794	382.6078
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Zone 5			
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Zone 6			
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Zone 7			
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Zone 8			
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Zone 9			
Miami, FL	12.1960	19.0645	215.3923

Exhibit D-3

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C$_{vol}$

$$Q / C_{vol} = A \times \exp\left[\frac{\left(\ln A_{site} - B\right)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Zone 2			
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Zone 3			
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Zone 4			
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Zone 5			
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Zone 6			
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Zone 7			
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Zone 8			
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Zone 9			
Miami, FL	12.1960	19.0645	215.3923

Exhibit D-4

VALUES FOR THE CONSTANTS (A, B, AND C) FOR CALCULATING Q/C$_{off}$

$$Q / C_{off} = A \times \exp\left[\frac{(\ln A_{site} - B)^2}{C}\right]$$

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	14.5609	21.9974	265.3198
Seattle, WA	18.5578	21.5469	269.0431
Zone 2			
Fresno, CA	11.5554	22.2571	268.0331
Los Angeles, CA	15.7133	21.8997	269.8244
San Francisco, CA	13.1994	23.6414	283.5307
Zone 3			
Albuquerque, NM	17.8252	22.8701	274.1261
Las Vegas, NV	12.1784	24.5606	296.4571
Phoenix, AZ	11.6831	23.5910	287.9969
Zone 4			
Boise, ID	12.2294	23.8156	286.4807
Casper, WY	18.4275	22.9015	280.6949
Denver, CO	12.0770	22.5621	272.5685
Salt Lake City, UT	11.3006	25.8655	321.3924
Winnemucca, NV	16.5157	21.2894	252.8634
Zone 5			
Bismarck, ND	18.8928	22.2274	268.2849
Lincoln, NE	17.6897	22.7826	273.2907
Minneapolis, MN	20.2352	22.3129	271.1316
Zone 6			
Atlanta, GA	15.8125	23.7527	288.6108
Charleston, SC	19.2904	21.9679	265.0506
Houston, TX	18.9273	20.1609	242.9736
Little Rock, AR	15.4094	21.7198	261.8926
Raleigh, NC	15.4081	21.8656	261.3267
Zone 7			
Chicago, IL	20.1837	21.6367	264.0685
Cleveland, OH	13.4283	24.5328	302.1738
Harrisburg, PA	17.2968	22.2917	272.9800
Huntington, WV	12.1521	21.1970	252.6964
Zone 8			
Hartford, CT	15.3353	21.6690	261.7432
Philadelphia, PA	16.4927	22.2187	268.3139
Portland, ME	13.2438	23.2754	277.8473
Zone 9			
Miami, FL	17.7682	21.3218	253.6436

APPENDIX E

DETAILED SITE-SPECIFIC APPROACHES FOR DEVELOPING INHALATION SSLs

This appendix presents suggested methods of calculating SSLs for inhalation pathways using a detailed site-specific approach. The detailed site-specific approach is the most rigorous of the three approaches to SSL development and requires the largest amount of site-specific data. EPA generally recommends that site managers use the simple site-specific approach, which represents a reasonable balance between cost and site-specificity. This method is the focus of the soil screening guidance documents. However, the detailed site-specific approach allows a site manager to model more complex site conditions and employ less conservative assumptions than those used in the simple site-specific approach. For example, a detailed approach could be used to model volatilization of contaminants from either surface and subsurface (i.e., buried) soils, while the simple site-specific modeling conservatively assumes all contamination is located at the soil surface. If such modeling would produce SSLs more appropriate for site conditions and thus result in a substantial savings in cleanup costs, the detailed site-specific approach would be a reasonable choice for developing SSLs, despite the added cost and effort.

This appendix focuses on development of SSLs for the inhalation pathways (i.e., inhalation of outdoor volatiles and fugitive dust) because exposure modeling for these pathways can be complex and more detailed approaches that incorporate additional site-specific information may be useful in soil screening evaluations. Detailed modeling of the migration to ground water pathway can also be complex and useful in the soil screening process. Information on detailed site-specific approaches to this pathway are discussed in the *Technical Background Document* to EPA's 1996 *Soil Screening Guidance*.

The remainder of this appendix consists of two parts. The first presents a detailed site-specific approach for developing inhalation SSLs under the commercial/industrial or non-residential exposure scenario. The second section discusses a detailed site-specific approach for developing inhalation SSLs under the construction exposure scenario.

INHALATION SSLs FOR THE NON-RESIDENTIAL EXPOSURE SCENARIO

This section presents methods appropriate for the detailed site-specific approach to developing SSLs for the inhalation of volatiles and fugitive dust in outdoor air pathways. In describing these methods, it focuses on their application to the commercial/industrial exposure scenario; however, these methods could be applied to residential or other non-residential scenarios as well.

Detailed Site-Specific Approach to Developing Outdoor Inhalation of Volatiles SSLs for the Outdoor Worker/Landscaper

The key difference between a detailed and a simple site-specific approach to developing SSLs for the inhalation of volatiles in the outdoor air pathway is the use of a more rigorous model. The Exposure Model for Soil Organic Fate and Transport (EMSOFT), can be used to estimate the average emissions of volatiles from soil. This model, which is largely based on the work of Jury et al. (1983, 1990), estimates volatile emissions from both surface and subsurface soil contamination. It provides a one-dimensional analytical solution to mass transfer from soil to outdoor air. The major advantages of using EMSOFT rather than the infinite source model and mass balance approaches used in the simple site-specific SSL approach described in Section 4.3.2 of this guidance are that EMSOFT:

- Handles both surface and subsurface sources of emissions.
- Accounts for a finite source of emissions.
- Accounts for subsurface water convection (e.g., leaching).
- Accounts for a soil-to-air boundary layer which impedes emissions of contaminants with relatively low Henry's law constants.
- Provides time-averaged emissions over the exposure duration.

The EMSOFT model is available at no charge from the U.S. EPA National Center for Environmental Assessment (NCEA) web site at: http://www.epa.gov/ncea/emsoft.htm.

If the site is comprised of areas with both surface and subsurface soil contamination, the EMSOFT model can be used to calculate the unit emission flux for each area independently. The unit emission flux is calculated based on an initial soil concentration of 1 mg/kg or 1×10^{-6} g/g. This is subsequently used to reverse-calculate the SSL for inhalation of volatiles.

When using the EMSOFT model for calculating SSLs, set the model options as follows:

A. Calculation Options

- Check the box for "Time-Averaged Flux."

B. Calculation Control

- Set "Time Period for Averaging and Printing Flux and Soil Concentration Results" equal to the exposure duration in units of days.

- Set "Depth (D1)..." equal to any value > 0 but < the depth to the bottom of soil contamination.

- Set "Depth (D2)..." equal to the same value as "Depth (D1)."

C. Chemical Data

- Set the value of the "Half Life" equal to 1,000,000 days; this will eliminate calculation of transformation processes such as biodegradation.

- Set the value of the "Number of Layers" equal to 1.

D. Soil Properties

- Set the value of each soil property equal to an appropriate long-term average value. EMSOFT assumes homogeneous soil properties from the soil surface to an infinite depth; therefore, the selection of the soil properties values will have a significant effect on calculated emissions.

E. Physical Constants

- Set the value of the "Porewater Flux" to the appropriate long-term average value for the site. For worst-case conditions, set the value equal to zero.

- Set the value of the "Boundary Layer Thickness" to the appropriate value or to the default value of 0.5 cm.

F. Layer Properties

- Set the value of the "Cover Thickness" to the appropriate site-specific value. For surface contamination, set this value equal to zero. The "cover" should consist only of clean uncontaminated soil.

- Set the value of the "Layer Thickness" equal to the appropriate site-specific value. If the depth to the bottom of soil contamination is unknown, estimate the thickness of the contaminated layer as the depth from the soil surface to the top of the water table minus the depth from the soil surface to the top of soil contamination. If an infinitely thick layer of soil contamination is preferred, set the value of the "Layer Thickness" equal to a very large value (e.g., 1,000,000 cm).

- Set the value of the "Contaminant Concentration" equal to 1.0 mg/kg.

Equation E-1 along with the appropriate EMSOFT model results for areas of surface and subsurface soil contamination, are used to calculate the SSLs for outdoor inhalation of volatiles.

Equation E-1

$$VF = Q/C_{vol} \times \frac{1}{<J_T^s>} \times 0.1\ \mathrm{mg\text{-}m^2/g\text{-}cm^2} \times 86{,}400\ \mathrm{s/day} \times 10^{-6}\ \mathrm{g/g}$$

where:

VF = Volatilization factor (m^3/kg)

Q/C_{vol} = Inverse of the ratio of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)

$< J_T^s >$ = Total EMSOFT time-averaged unit emission flux; sum of results for both surface and subsurface soils (g/m^2-s).

The dispersion factor (Q/C_{vol}) used in Equation E-1 was evaluated using the Industrial Source Complex (ISC3) dispersion model to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 national sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. The ISC3 model run was set up using the regulatory default options. Other selected options are identified in Exhibit E-1. These data were then used to generate a best-fit curve equation for predicting air concentration as a function of site size. Equation E-2 represents the best-fit curve equation for calculating the dispersion factor for emissions of volatiles. The default *A*, *B*, and *C* constants in Equation E-2 represent the 90th percentile of the 29 national sites with regard to dispersion. This equation is used to calculate the long-term dispersion factor for on-site exposure to volatile emissions from soils.

Equation E-2

$$Q/C_{vol} = A \times \exp\left[\frac{(\ln A_c - B)^2}{C}\right]$$

where:

Q/C_{vol} = Inverse of the ratio of the geometric mean air concentration to the volatilization flux at the center of a square source (g/m^2-s per kg/m^3)

A = Constant; default = 11.9 110

B = Constant; default = 18.4385

C = Constant: default = 209.7845

A_c = Areal extent of site soil contamination (acres).

Exhibit E-1
OPTIONS SELECTED IN THE ISCST3 MODELING

Option description
Regulatory default option.
Emission Flux was set to 1 g/m^2-sec.
Discrete receptor locations were established for site boundaries and out to at least 1000 meters.
Terrain elevations were not considered.
Rural Mode.
Default wind profile exponent values.
Default vertical potential temperature gradient values.
The downwind distance plume rise option was used.
Buoyancy-induced dispersion was used.
The wind system measurement height was set to ten meters.
No down wash considerations for area/line sources.
Program control parameters, receptors, and source input data were output with the results.
Concentrations during calm wind speed hours set to zero.
Averaging times were set to annual.

Exhibit E-2 shows the values of the A, B, and C constants for Equation E-2 for each of the 29 national sites. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

Exhibit E-2

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C$_{vol}$

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	14.9421	17.9869	205.1782
Atlanta, GA	14.8349	17.9259	204.1516
Bismarck, ND	15.0235	18.2526	207.3387
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Charleston, SC	13.7674	18.0441	204.8689
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Denver, CO	11.3612	19.3324	221.2167
Fresno, CA	10.2152	19.2654	220.0604
Harrisburg, PA	15.5169	18.4248	211.7679
Hartford, CT	12.5907	18.8368	215.4377
Houston, TX	13.6482	18.1754	206.7273
Huntington, WV	9.9253	18.6636	211.8862
Las Vegas, NV	13.3093	19.8387	230.1652
Lincoln, NE	14.1901	18.5634	210.5281
Little Rock, AR	12.4964	18.4476	210.2128
Los Angeles, CA	11.9110	18.4385	209.7845
Miami, FL	12.1960	19.0645	215.3923
Minneapolis, MN	16.2302	18.7762	216.1080
Philadelphia, PA	14.0111	19.6154	225.3397
Phoenix, AZ	10.2871	18.7124	212.2704
Portland, ME	10.4660	20.9077	238.0318
Raleigh, NC	12.3675	18.6337	212.7284
Salem, OR	12.3783	18.9683	218.2086
Salt Lake City, UT	13.2559	19.2978	221.3379
San Francisco, CA	13.8139	20.1624	234.2869
Seattle, WA	14.2253	18.8366	218.1845
Winnemucca, NV	12.8784	17.9804	204.1028

Once the Q/C and VF factors have been calculated, SSLs for inhalation exposure to volatile contaminants in outdoor air by the outdoor worker can be calculated using Equations 4-6, 4-7, and 4-9 in Chapter 4 of this guidance document. Equations 4-6 and 4-7 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively. Equation 4-9 calculates C_{sat}, which serves as a ceiling for SSLs calculated using a VF model. If the SSL calculated using Equation 4-6 or 4-7 exceeds C_{sat} and the contaminant is liquid at soil temperatures (see Appendix C, Exhibit C-3), the SSL is set at C_{sat}. The SSL calculated using these equations represents the screening level for both surface and subsurface soils.

Detailed Site-Specific Approach to Developing Fugitive Dust Inhalation SSLs for Outdoor Workers

The simple site-specific fugitive dust equations (Equations 4-3 and 4-4 in this guidance document) are also used to calculate fugitive dust SSLs for the outdoor worker for carcinogenic and non-carcinogenic contaminants, respectively, under the detailed site-specific approach. The particulate emission factor (*PEF*) represents an estimate of the relationship between the concentration of contaminant in soil to the concentration of contaminant in air (as a consequence of particle suspension). The *PEF* is calculated using either the "unlimited reservoir" model from Cowherd et al. (1985) or the "emission factor" model from EPA's Compilation of Air Pollution Factors (1985), as appropriate for site-specific conditions. The "unlimited reservoir" model is the same model used in the simple site-specific approach and calculates emissions based on an unlimited reservoir of erodible particles. This assumes that the surface material consists of dry finely divided soils. The "emission factor" model assumes a "limited reservoir" of erodible particles that are completely suspended in air after a single soil disturbance; subsequent emissions are a function of the number of disturbances per year. The user is advised to review the appropriate sections of Cowherd et al. (1985) for a discussion of when to use these different models. Both models can be used to calculate the PM_{10} emission flux due to wind erosion. When using the "unlimited reservoir" model as given in Cowherd et al. (1985), the wind erosion emission flux of PM_{10} (given as E_{10}) is calculated in units of mg/m^2-h and must be converted to units of g/m^2-s. When using the EPA model, the "emission factor" or flux is calculated in units of g/m^2-yr and must be converted to units of g/m^2-s. The *PEF* is then calculated using Equation E-3.

Equation E-3

$$PEF = Q/C_{wind} \times \frac{1}{J_w}$$

where:

PEF = Particulate emission factor (m^3/kg)
Q/C_{wind} = Inverse of the ratio of the geometric mean air concentration to the emission flux at the center of a square source (g/m^2-s per kg/m^3)
J_w = PM_{10} emission flux (g/m^2-s).

For a detailed site-specific analysis, the air dispersion factor Q/C_{wind} is not based on an assumed exposure area of 0.5 acres. The exposure area for commercial/industrial land use may range in size from less than one acre to hundreds of acres. For this reason, the value of Q/C_{wind} is calculated as a function of site size.

To evaluate the dispersion factor for wind erosion, the ISC3 dispersion model was used to estimate the maximum annual average on-site air concentration for the 29 national sites previously modeled for the *1996 SSG*. Maximum annual average air concentrations for the 29 sites were estimated for a series of square site sizes ranging from 0.5 to 500 acres; the emission flux was set equal to 1 g/m^2-s. These data were used to generate a best-fit curve equation for predicting air concentration as a function of site size. Equation E-4 represents the best-fit curve equation for calculating the dispersion factor for wind erosion. The default *A*, *B*, and *C* constants in Equation E-4 represent the 90th percentile of the 29 national sites with regard to emissions and dispersion in that both are a function of meteorology. Equation E-4 is used to calculate the long-term dispersion factor for on-site exposure to emissions from wind erosion.

Equation E-4

$$Q/C_{wind} = A \times \exp\left[\frac{(\ln A_S - B)^2}{C}\right]$$

where: Q/C_{wind} = Inverse of the geometric mean air concentration to the emission flux at the center of a square source (g/m^2-s per kg/m^3)

A = Constant; default = 16.2302

B = Constant; default = 18.7762

C = Constant; default = 216.1080

A_S = Areal extent of site surface contamination (acres).

Exhibit E-3 shows the values of the *A*, *B*, and *C* constants for Equation E-4 for each of the 29 national sites. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

Exhibit E-3

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C_{wind}

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	14.9421	17.9869	205.1782
Atlanta, GA	14.8349	17.9259	204.1516
Bismarck, ND	15.0235	18.2526	207.3387
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	7.1414	31.1794	382.6078
Charleston, SC	13.7674	18.0441	204.8689
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Denver, CO	11.3612	19.3324	221.2167
Fresno, CA	10.2152	19.2654	220.0604
Harrisburg, PA	15.5169	18.4248	211.7679
Hartford, CT	12.5907	18.8368	215.4377
Houston, TX	13.6482	18.1754	206.7273
Huntington, WV	9.9253	18.6636	211.8862
Las Vegas, NV	13.3093	19.8387	230.1652
Lincoln, NE	14.1901	18.5634	210.5281
Little Rock, AR	12.4964	18.4476	210.2128
Los Angeles, CA	11.9110	18.4385	209.7845
Miami, FL	12.1960	19.0645	215.3923
Minneapolis, MN	16.2302	18.7762	216.1080
Philadelphia, PA	14.0111	19.6154	225.3397
Phoenix, AZ	10.2871	18.7124	212.2704
Portland, ME	10.4660	20.9077	238.0318
Raleigh, NC	12.3675	18.6337	212.7284
Salem, OR	12.3783	18.9683	218.2086
Salt Lake City, UT	13.2559	19.2978	221.3379
San Francisco, CA	13.8139	20.1624	234.2869
Seattle, WA	14.2253	18.8366	218.1845
Winnemucca, NV	12.8784	17.9804	204.1028

INHALATION SSLs FOR THE CONSTRUCTION EXPOSURE SCENARIO

This section presents methods appropriate for the detailed site-specific approach to developing construction-specific SSLs for the inhalation of volatiles and fugitive dust in outdoor air pathways. These SSLs reflect the increased inhalation exposures likely to result due to construction activities such as excavation and vehicle traffic on temporary, unpaved roads. This section first describes methods for evaluating the short-term inhalation exposures experienced by a construction worker and then presents methods for evaluating increased inhalation exposures to off-site residents living at the site boundary.

Detailed Site-Specific Approach to Developing Subchronic Inhalation SSLs for Construction Workers

For the construction worker exposure scenario, the primary assumption is that a commercial/industrial building or group of buildings will be constructed at the site. Additional assumptions are that the building or group of buildings will be constructed within the area of residual soil contamination and that the total time of construction is less than one year. As discussed in the guidance document, the short exposure duration of the construction worker constitutes a subchronic exposure that should be evaluated using subchronic toxicity values (denoted here and in the guidance document as HBL_{sc}). See Section 5.3.1 of the guidance document for suggestions on how to determine appropriate HBL_{sc} values.

The dynamic processes inherent in construction activities are likely to increase emissions of both volatiles and particulate matter from affected soils. Modeling studies have shown that high emissions of volatiles can occur from both excavation of contaminated soils and from undisturbed surface soil contamination. In the case of particulate matter, traffic on contaminated unpaved roads typically accounts for the majority of emissions, with wind erosion, excavation soil dumping, dozing, grading, and tilling operations contributing lesser emissions. The following approach can be used to estimate SSLs for construction activities based on subchronic inhalation exposures of the construction worker.

Volatile Emissions from Subsurface Soil Contamination

Because of the relatively short exposure duration of the construction worker, the emission model used to estimate volatile emissions from undisturbed subsurface soils should take into consideration the time that has elapsed since the time of initial soil contamination. If an estimate of the elapsed time can be made with significant certainty, this value may be used as the starting point for estimating time-averaged emissions during construction. Typically, however, this time period cannot be estimated with a high degree of certainty. In such cases, it is assumed that sufficient time has elapsed such that the volatile emissions at the soil surface have reached near steady-state conditions. The time required for the volatile emissions from subsurface soil contamination to reach near steady-state conditions is estimated by Equations E-5 and E-6 (API, 1998).

Equation E-5

$$\tau_{ss} \cong \frac{R_v \theta_a d^2}{D_A}$$

where: τ_{ss} = Time required to reach near steady-state (s)
R_v = Vapor-phase retardation factor (unitless)
2_a = Soil air-filled porosity (cm^3/cm^3)
d = Depth to top of soil contamination (cm)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document.

Equation E-6

$$R_v = 1 + \frac{\theta_w}{\theta_a H'} + \frac{\rho_b K_d}{\theta_a H'}$$

where: R_v = Vapor-phase retardation factor (unitless)
θ_w = Soil water-filled porosity (cm^3/cm^3)
2_a = Soil air-filled porosity (cm^3/cm^3)
H' = Henry's law constant (unitless)
ρ_b = Soil dry bulk density (g/cm^3)
K_d = Soil-water partition coefficient (cm^3/g).

Equation E-7 (from Jury et al., 1990) is used to calculate the unit emission flux at the soil surface. The "unit" emission flux assumes an initial soil contaminant concentration of 1 mg/kg or 10^{-6} g/g-soil. This equation should be run for a minimum of 100 time-steps, starting at time = τ_{ss} (or, if available, the actual elapsed time since initial soil contamination) and extending to the end of the duration of construction *(T)* in units of seconds.

Equation E-7

$$J_{sub} = \rho_b \left(\frac{D_A}{\pi\tau}\right)^{1/2} \left[\exp\left(-\frac{d^2}{4D_A t}\right) - \exp\left(-\frac{(d+W)^2}{4D_A t}\right)\right] \times 10^4\,\mathrm{cm^2/m^2}$$

where:
J_{sub} = Unit emission flux from subsurface soils at each time-step (g/m^2-s)
ρ_b = Soil dry bulk density (g/cm^3)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document
t = Elapsed time at the end of each time-step (s)
d = Depth to top of soil contamination (cm)
W = Thickness of subsurface contaminated soil (cm).

If the depth to the bottom of soil contamination is unknown, the value of the thickness of contaminated soil (W) is calculated as the depth to the top of the water table minus the depth to the top of soil contamination (d). In addition, the 100 time-steps using Equation E-7 are of equal intervals. These calculations can be performed easily using a PC-based spreadsheet program. Please note that the EMSOFT model cannot presently be used for these calculations because the averaging time period always begins at time = 0 and cannot be changed to time = τ_{ss} or any other value. For a relatively short exposure duration such as for construction, beginning the time period at t = 0 will underpredict the time-averaged unit emission flux in some cases.

From these data, Equation E-8 is used to estimate the cumulative unit mass emitted from undisturbed subsurface soil contamination using a trapezoidal approximation of the integral.[1] To ensure that the total unit mass of each subsurface contaminant emitted does not exceed the total unit initial mass in soil, a mass-balance is performed using Equations E-8 and E-9.

If the cumulative unit mass emitted from subsurface soils (M_{sub}) exceeds the total unit initial mass of subsurface contamination (M^T_{sub}), Equation E-7 may be rerun with a smaller time-step interval and a greater number of time-steps until the unit mass emitted is less than the total unit initial mass. As a more conservative alternative, the value of M_{sub} may be set equal to the value of M^T_{sub}.

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[1] For a more complete description of the tapezoidal approximation and example calculations, see *Calculus and Analytic Geometry*, pages 178-180 (Thomas, 1968).

Equation E-8

$$M_{sub} = \left[\frac{h}{2}\left(J_0 + 2J_1 + 2J_2 + \ldots + 2J_{n-1} + J_n\right)\right] \times A_{sub}$$

where:

M_{sub} = Cumulative unit mass emitted from undisturbed subsurface soils (g)

h = Constant time-step interval (s), $h = \mathrm{T}/100$

T = Total time of construction (s)

J_0 = Unit emission flux at time = 0 (g/m^2-s), set time zero = τ_{ss} or = the actual elapsed time since initial soil contamination

$J_{1,2 \ldots n}$ = Unit emission flux at time-step J_1 and each succeeding time-step where n = 100 (g/m^2-s)

A_{sub} = Areal extent of site with undisturbed subsurface soil contamination (m^2).

NOTE: In Microsoft® Excel, the formula for M_{sub} can be written as:
= (((*T*/100)/2)*(J_0+ 2*SUM(J_1:J_{n-1}) + J_n))*A_{sub}

Equation E-9

$$M^T{}_{sub} = \rho_b \times A_{sub} \times W \times 10^{-2}\ \mathrm{m/cm} \times 10^6\ \mathrm{cm^3/m^3}$$

where:

$M^T{}_{sub}$ = Total unit initial mass of subsurface contamination, (g)

ρ_b = Soil dry bulk density (g/cm^3)

A_{sub} = Areal extent of site with undisturbed subsurface soil contamination (m^2)

W = Thickness of subsurface contaminated soil (cm).

Volatile Emissions from Surface Soil Contamination and from Excavation

Volatile emissions from both surface soil contamination and from excavation of areas with subsurface contamination are calculated assuming that contamination begins at the soil surface. The cumulative unit mass emitted from areas of the site where surface contamination is found and from site areas where subsurface contamination is expected to be excavated are added to the cumulative unit mass emitted from subsurface soil contamination. The unit mass emitted from all three of these areas of the site are then totaled and divided by the product of the total area of contamination and the total duration of construction. In this manner, the emissions from all three site areas are averaged over the total areal extent of contamination and over the duration of construction which is also the exposure duration.

Equation E-10 (from Jury et al., 1990) is used to calculate the unit emission flux from surface soil contamination. As with Equation E-7, the unit emission flux assumes an initial soil contaminant concentration of 1 mg/kg or 10^{-6} g/g-soil. This equation should be run for a minimum of 100 time-steps, starting at time = τ_{ss} (or, if available, the actual elapsed time since initial soil contamination) and extending to the end of the duration of construction (T) in units of seconds. If the time to reach near steady-state is used, the value of τ_{ss} for surface soil contamination should be set equal to that of subsurface soil contamination as calculated by Equations E-5 and E-6. If subsurface soil contamination is not present at the site, a best estimate should be made of the time since surface soil contamination last occurred and this value substituted for the value of τ_{ss}.

Equation E-10

$$J_{surf} = \rho_b \left(\frac{D_A}{\pi t} \right)^{1/2} \left[1 - \exp\left(-\frac{L^2}{4 D_A t} \right) \right] x\, 10^4 \text{ cm}^2/\text{m}^2$$

where:

J_{surf} = Unit emission flux from surface soils at each time-step (g/m^2-s)
ρ_b = Soil dry bulk density (g/cm^3)
D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document
t = Elapsed time at the end of each time-step (s)
L = Depth to the bottom of soil contamination (cm).

From these data, Equation E-11 is used to estimate the cumulative unit mass emitted from undisturbed surface soil contamination using a trapezoidal approximation of the integral. To ensure that the total unit mass of each surface contaminant emitted does not exceed the total unit initial mass in soil, a mass-balance is performed using Equations E-11 and E-12.

Equation E-11

$$M_{surf} = \left[\frac{h}{2}\left(J_0 + 2J_1 + 2J_2 + ... + 2J_{n-1} + J_n\right)\right] \times A_{surf}$$

where: M_{surf} = Cumulative unit mass emitted from undisturbed surface soils (g)
h = Constant time-step interval (s), $h = T/100$
T = Total time of construction (s)
J_0 = Unit emission flux at time = 0 (g/m^2-s), set time zero = τ_{ss} or = the actual elapsed time since initial soil contamination
$J_{1,2...n}$ = Unit emission flux at time-step J_1 and each succeeding time-step where n = 100 (g/m^2-s)
A_{surf} = Areal extent of site with undisturbed surface soil contamination (m^2).

Equation E-12

$$M^T{}_{surf} = \rho_b \times A_{surf} \times L \times 10^{-2} \text{ m/cm} \times 10^6 \text{ cm}^3/\text{m}^3$$

where: $M^T{}_{surf}$ = Total unit initial mass of surface contamination (g)
ρ_b = Soil dry bulk density (g/cm^3)
A_{surf} = Areal extent of site with undisturbed surface soil contamination (m^2)
L = Depth to the bottom of soil contamination (cm).

If the cumulative unit mass emitted from surface soils (M_{surf}) exceeds the total unit initial mass of surface contamination ($M^T{}_{surf}$), Equation E-10 may be rerun with a smaller time-step interval and a greater number of time-steps until the unit mass emitted is less than the total unit initial mass. As a more conservative alternative, the value of M_{surf} may be set equal to the value of $M^T{}_{surf}$.

Equation E-13 (from Jury et al., 1984) is used to calculate the cumulative unit mass emitted from the areal extent of excavation.

Equation E-13

$$M_{excvav} = \frac{2\rho_b D_A T_E}{(\pi D_A T_E)^{1/2}} x10^4 \, \mathrm{cm}^2/\mathrm{m}^2 \, x \, A_{excav}$$

where: M_{excav} = Cumulative unit mass emitted from excavation (g)

ρ_b = Soil dry bulk density (g/cm^3)

D_A = Apparent diffusivity (cm^2/s), Eq. 4-8 in Chapter 4 of this guidance document

T_E = Duration of excavation (s); T_E ends when the excavation is covered by an impermeable material

A_{excav} = Areal extent of excavation (m^2).

Equation E-13 operates under the assumption of an infinitely deep emission source. This should not be problematic, however, for the relatively short duration of excavation. Equation E-13 differs from Equations E-7 and E-10 in that excavation is assumed to expose subsurface soil contamination to the atmosphere at time = 0. That is to say that excavation is assumed to instantaneously uncover the subsurface contamination. The duration of the excavation event ends when the areal extent of excavation is covered by an impermeable material (e.g., a concrete slab).

The total time-averaged unit emission flux from undisturbed subsurface soils, undisturbed surface soils, and from excavation is calculated using Equation E-14.

Equation E-14

$$< J_T >= \frac{\left(M_{sub} + M_{surf} + M_{excav}\right)}{A_c \times T}$$

where: $< J_T >$ = Total time-averaged unit emission flux (g/m^2-s)

M_{sub} = Cumulative unit mass emitted from undisturbed subsurface soils (g)

M_{surf} = Cumulative unit mass emitted from undisturbed surface soils (g)

M_{excav} = Cumulative unit mass emitted from excavation (g)

A_c = Areal extent of site soil contamination (m^2)

T = Duration of construction (s).

Calculation of the Soil-to-Air Volatilization Factor for the Construction Scenario

Because the exposure duration during construction is typically less than one year (i.e., subchronic), the dispersion factor must also reflect the same time period. The on-site subchronic dispersion factor for a ground-level area emission source, Q/C_{sa}, was derived by employing the EPA SCREEN3 dispersion model to predict the maximum 1-h. average on-site unit concentration for a ground-level area source of emissions. Identical dispersion modeling was performed for square site sizes ranging 0.5 to 500 acres. A best curve was then fit to the paired data of maximum concentration and site size to predict the value of Q/C_{sa} This resulted in Equation E-15 for calculating the subchronic on-site dispersion factor for area sources.

Equation E-15

$$Q/C_{sa} = A \times \exp\left[\frac{(\ln A_c - B)^2}{C}\right]$$

where: Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the volatilization flux at the center of a square emission source (g/m^2-s per kg/m^3)
A = Constant; default = 2.4538
B = Constant; default = 17.5660
C = Constant; default = 189.0426
A_c = Areal extent of site soil contamination (acres).

The value of Q/C_{sa} must be corrected for the averaging time represented by the duration of construction. To accomplish this, a best curve was fit to the EPA correction factors for converting 1-h. average concentrations to 3-h., 8-h., and 24-h. averages (U.S. EPA, 1992). In addition, a fourth data point was included representing the correction factor for converting the SCREEN3 1-h. average concentration to an annual average concentration. The median concentration was computed as the geometric mean of all 29 national sites as determined using the ISC3 dispersion model. This resulted in Equation E-16 for estimating the dispersion correction factor for averaging times less than one year.

Equation E-16

$$F_D = 0.1852 + \frac{5.3537}{t_c} + \frac{-9.6318}{t_c^{\ 2}}$$

where:
F_D = Dispersion correction factor (unitless)
t_c = Duration of construction (hr),
$t_c = T$ in units of hours.

The subchronic soil-to-air volatilization factor for the exposure of the construction worker is calculated by Equation E-17.

Equation E-17

$$VF_{sc} = Q/C_{sa} \times \frac{1}{F_D} \times \frac{1}{< J_T >}$$

where:
VF_{sc} = Subchronic soil-to-air volatilization factor (m^3/kg)
Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the volatilization flux at the center of a square emission source (g/m^2-s per kg/m^3), Eq. E-15
F_D = Dispersion correction factor (unitless), Eq. E-16
$< J_T >$ = Total time-averaged unit emission flux, Eq. E-14.

Once these values have been calculated, the SSL for subchronic on-site inhalation exposure to volatile emissions during construction can be calculated using Equations 5-12, 5-13, and 5-16 in Chapter 5 of this guidance document. Equations 5-12 and 5-13 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively, and Equation 5-16 calculates C_{sat}, which is an upper bound on SSLs calculated using the VF model. If the SSL calculated using Equation 5-12 and 5-13 exceed C_{sat} and the contaminant is liquid at soil temperatures (see Appendix C, Exhibit C-3), the SSL is set at C_{sat}. The value of the SSL calculated by these equations represents the soil screening level for all three areas of soil contamination, i.e., surface soils, subsurface soils, and areas of excavation.

Fugitive Dust Emissions During Construction

The construction worker is assumed to be exposed to contaminants in the form of particulate matter with an aerodynamic particle diameter of less than 10 microns (PM_{10}). Fugitive dust emissions are generated by construction vehicle traffic on temporary unpaved roads. In addition, fugitive dust emissions are generated by other construction activities such as excavation, soil dumping, dozing, grading, and tilling operations as well as from wind erosion of soil surfaces. Reasonable maximum exposure (RME) of the construction worker to unpaved road emissions occurs in proximity to the road(s). RME for wind erosion emissions and emissions from other construction activities are assumed to occur at the center of the emission source. The ambient air dispersion of emissions, therefore, is different for these two classes of emission sources. For this reason, the subchronic exposure SSL for unpaved road traffic and the subchronic exposure SSL for other construction activities (including wind erosion) are calculated separately.

The following fugitive dust emission equations represent approximations of actual emissions at a specific site. Sensitive emission model parameters include the soil silt content and moisture content. Silt is defined as soil particles smaller than 75 micrometers (Fm) in diameter and can be measured as that proportion of soil passing a 200-mesh screen, using the American Society for Testing and Materials (ASTM) Method C-136. Soil moisture content is defined on a percent gravimetric basis [(g-water/g-soil) x 100] and should be approximated as the mean value for the duration of the construction project. In general, soil silt and moisture content are the most sensitive model parameters for which default values have been assigned, however, site-specific values will produce more accurate modeling results. Other emission model parameters have not been assigned default values and are typically defined on a site-specific basis. These parameters include the total distance traveled by construction site vehicles, mean vehicle weight, average vehicle speed, and the area of soil disturbance.

Fugitive Dust Emissions from Unpaved Road Traffic

The subchronic particulate emission factor for unpaved road traffic (PEF_{sc}) is calculated using Equation E-18 (EPA, 19895). Equation E-18 differs from Equation 5-5 in Chapter 5 of this document in that it contains the unabridged equation for PM_{10} emissions from traffic on unpaved roads. Equation E-18 therefore allows the user to enter a site-specific value for each variable.

Equation E-18

$$PEF_{sc} = Q/C_{sr} \times \frac{1}{F_D} \times \frac{T \times A_R}{\dfrac{2.6 \times (s/12)^{0.8} (W/3)^{0.4}}{(M_{dry}/0.2)^{0.3}} \times \left[\dfrac{(365 - p)}{365}\right] \times 281.9 \times \Sigma VKT}$$

where: PEF_{sc} = Subchronic particulate emission factor for unpaved road traffic (m^3/kg)

Q/C_{sr} = Inverse of the ratio of the 1-h. geometric mean air concentration to the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3), Eq. E-19

F_D = Dispersion correction factor (unitless), Eq. E-16

T = Total time over which construction occurs (s)

A_R = Surface area of contaminated road segment (m^2), $A_R = L_R \times W_R \times 0.092903\ m^2/ft^2$

s = Road surface silt content (%), default = 8.5 %

W = Mean vehicle weight (tons)

M_{dry} = Road surface material moisture content under dry, uncontrolled conditions (%), default = 0.2 %

p = Number of days per year with at least 0.01 inches of precipitation (Exhibit E-1)

ΣVKT = Sum of fleet vehicle kilometers traveled during the exposure duration (km)

L_R = Length of road segment (ft) L_R = square root of site surface contamination configured as a square

W_R = Width of road segment (ft), default = 20 ft.

Equation E-18 operates under the assumption of a road surface silt content of 8.5 percent as the mean value for "construction sites – scraper routes" (see Table 13.2.2-1 of EPA, 1985). In addition, the surface material moisture content under dry conditions is assumed to be 0.2 percent as the default value (see Section 13.2.2 of EPA, 1985).

The number of days with at least 0.01 inches of rainfall can be estimated using Exhibit E-4. Mean vehicle weight *(W)* can be estimated by assuming the numbers and weights of different types of vehicles. For example, assume that the daily unpaved road traffic consists of 20 two-ton cars and 10 twenty-ton trucks. The mean vehicle weight would then be:

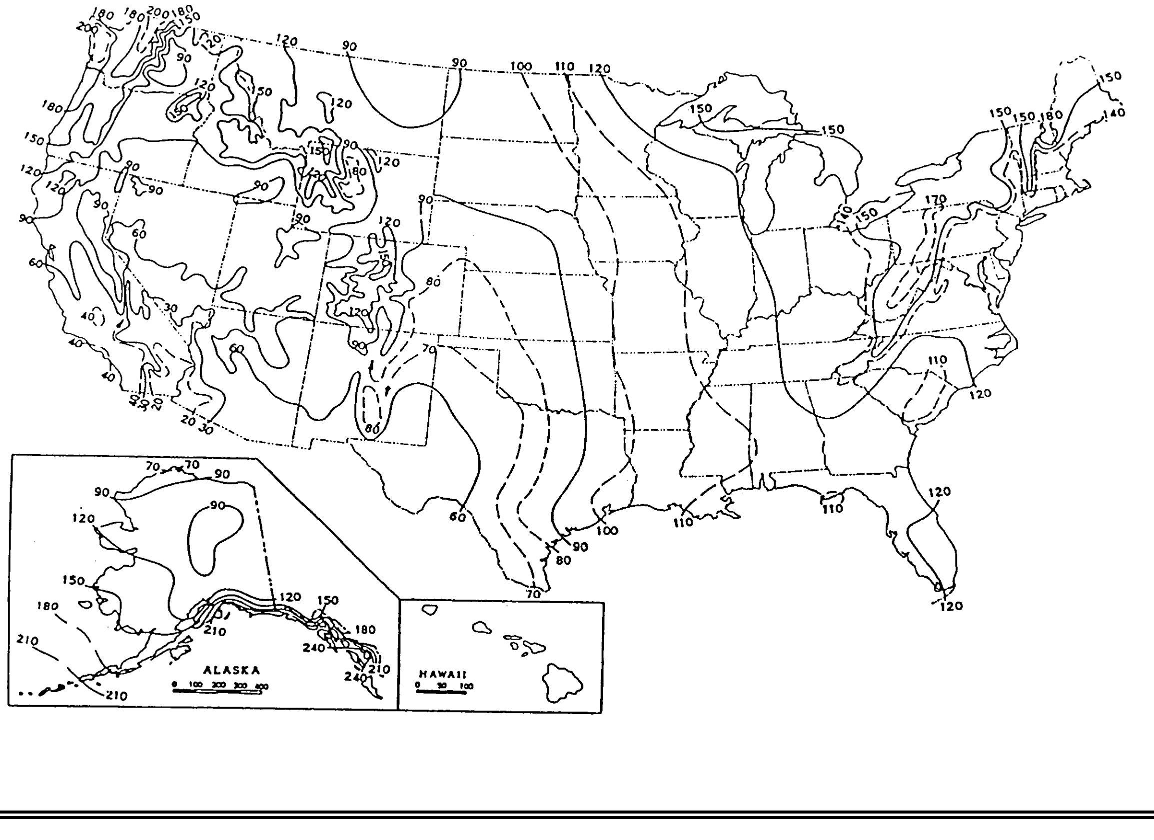
$$W = [(20 \text{ cars x } 2 \text{ tons/car}) + (10 \text{ trucks x } 20 \text{ tons/truck})]/30 \text{ vehicles} = 8 \text{ tons}$$

The sum of the fleet vehicle kilometers traveled during construction *(ΣVKT)* can be estimated based on the size of the area of surface soil contamination, the configuration of the unpaved road, and the amount of vehicle traffic on the road. For example, if the area of surface soil contamination is 0.5 acres (or 2,024 m^2), and one assumes that this area is configured as a square with the unpaved road segment dividing the square evenly, the road length would be equal to the square root of 2,024 m^2 (45 m or 0.045 km). Assuming that each vehicle travels the length of the road once per day, 5 days per week for a total of 6 months, the total fleet vehicle kilometers traveled would be:

$$\Sigma VKT = 30 \text{ vehicles} \times 0.045 \text{ km/day} \times (52 \text{ wks/yr} \div 2) \times 5 \text{ days/wk} = 175.5 \text{ km.}$$

Exhibit E-4

MEAN NUMBER OF DAYS WITH 0.01 INCH OR MORE OF ANNUAL PRECIPITATION



The subchronic dispersion factor for on-site exposure to unpaved road traffic, Q/C_{sr}, was derived by using the ISC3 dispersion model with a meteorological data set that mimics that of the SCREEN3 dispersion model. A straight road segment was situated such that the road bisected the site configured as a square. A series of square sites ranging in size from 0.5 to 500 acres with their associated road segments were modeled. A series of receptors were placed along each road segment and the road emissions were set equal to 1 g/m^2-s. The final on-site 1-h. average unit concentration was calculated as the mean of these receptors.

The subchronic dispersion factor for on-site exposure to unpaved road traffic is calculated using Equation E-19.

Equation E-19

$$Q/C_{sr} = A \times \exp\left[\frac{(\ln A_S - B)^2}{C}\right]$$

where: Q/C_{sr} = Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3)
A = Constant; default = 12.9351
B = Constant; default = 5.7383
C = Constant; default = 71.7711
A_S = Areal extent of site surface contamination (acres).

Once these values have been calculated, the SSL for subchronic on-site inhalation exposure to particulate matter emissions from unpaved road traffic during construction can be calculated using Equations 5-7 and 5-8 in Chapter 5 of this guidance document. Equations 5-7 and 5-8 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively.

Fugitive Dust Emissions from Other Construction Activities

Other than emissions from unpaved road traffic, the construction worker may also be exposed to particulate matter emissions from wind erosion, excavation soil dumping, dozing, grading, and tilling or similar operations. These operations may occur separately or concurrently and the duration of each operation may be different. For these reasons, the total unit mass emitted from each operation is calculated separately and the sum is normalized over the entire area of contamination and over the entire time during which construction activities take place.

Equation E-20 is used to calculate the unit mass emitted from wind erosion of contaminated soil surfaces (from Cowherd et al., 1985).

Equation E-20

$$M_{wind} \text{ ' } 0.036 \times (1 \& V) \times \left(\frac{U_m}{U_t} \right)^3 \times F(x) \times A_{surf} \times ED \times 8{,}760\, hr/yr$$

where: M_{wind} = Unit mass emitted from wind erosion (g)
V = Fraction of vegetative cover (unitless), default = 0
U_m = Mean windspeed during construction (m/s), default = 4.69 m/s (EPA, 1996)
U_t = Equivalent threshold value of windspeed at 7 m (m/s), default = 11.32 m/s (EPA, 1996)
$F(x)$ = Function dependent on U_m/U_t derived from Cowherd et al. (1985) (unitless), default = 0.194 (EPA, 1996)
A_{surf} = Areal extent of site with surface soil contamination (m^2)
ED = Exposure duration (yr).

The unit mass emitted from the dumping of excavated soils can be calculated using Equation E-21 (from EPA, 1985).

Equation E-21

$$M_{excav} \text{ ' } 0.35 \times 0.0016 \times \frac{\left(\frac{U_m}{2.2} \right)^{1.3}}{\left(\frac{M}{2} \right)^{1.4}} \times \rho_{soil} \times A_{excav} \times d_{excav} \times N_A \times 10^3\, g/kg$$

where: M_{excav} = Unit mass emitted from excavation soil dumping (g)
0.35 = PM_{10} particle size multiplier (unitless) (EPA, 1985)
U_m = Mean windspeed during construction (m/s), default = 4.69 m/s (EPA, 1996)
M = Gravimetric soil moisture content (%), default = 12 %, EPA (1985) Table 13.2.4-1, mean value for municipal landfill cover

ρ_{soil} = In situ soil density (includes water) (Mg/m^3), default = 1.68 Mg/m^3

A_{excav} = Areal extent of excavation (m^2)

d_{excav} = Average depth of excavation (m)

N_A = Number of times soil is dumped (unitless), default = 2.

Equation E-22 (from EPA, 1985) is used to calculate the unit mass emitted from dozing operations.

Equation E-22

$$M_{doz} = 0.75 \times \frac{0.45(s)^{1.5}}{(M)^{1.4}} \times \frac{\Sigma VKT}{S} \times 10^3\, g/kg$$

where:

M_{doz} = Unit mass emitted from dozing operations (g)

0.75 = PM$_{10}$ scaling factor (unitless)

s = Soil silt content (%), default = 6.9 %, EPA (1985) Table 11.9-3, mean value for overburden

M = Gravimetric soil moisture content (%), default = 7.9 %, EPA (1985) Table 11.9-3, mean value for overburden

ΣVKT = Sum of dozing kilometers traveled (km)

S = Average dozing speed (kph), default = 11.4 kph, EPA (1985) Table 11.9-3, mean value for graders.

The unit mass emitted from grading operations is calculated by Equation E-23 (from EPA, 1985).

Equation E-23

$$M_{grade} = 0.60 \times 0.0056(S)^{2.0} \times \Sigma VKT \times 10^3\, g/kg$$

where:

M_{grade} = Unit mass emitted from grading operations (g)

0.60 = PM$_{10}$ scaling factor (unitless)

S = Average grading speed (kph), default = 11.4 kph, EPA (1985) Table 11.9-3 mean value for graders

ΣVKT = Sum of grading kilometers traveled (km).

Finally, Equation E-24 (from EPA, 1992a) is used to calculate the unit mass emitted from tilling or similar operations.

Equation E-24

$$M_{till} = 1.1(s)^{0.6} \times A_{till} \times 4{,}047\,m^2/acre \times 10^{-4}\,ha/m^2 \times 10^3\,g/kg \times N_A$$

where: M_{till} = Unit mass emitted from tilling or similar operations (g)

s = Soil silt content (%), default = 18 %
EPA (1992a) Section 2.6.1.1

A_{till} = Areal extent of tilling (acres)

N_A = Number of times soil is tilled (unitless), default = 2.

The total time-averaged unit emission flux from wind erosion, excavation soil dumping, dozing, grading, and tilling operations is calculated by Equation E-25.

Equation E-25

$$<J'_T> = \frac{M_{wind} + M_{excav} + M_{doz} + M_{grade} + M_{till}}{A_c \times T}$$

where: $<J'_T>$ = Total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads (g/m^2-s)

M_{wind} = Unit mass emitted from wind erosion (g)

M_{excav} = Unit mass emitted from excavation soil dumping (g)

M_{doz} = Unit mass emitted from dozing operations (g)

M_{grade} = Unit mass emitted from grading operations (g)

M_{till} = Unit mass emitted from tilling operations (g)

A_c = Areal extent of site soil contamination (m^2)

T = Duration of construction (s).

The subchronic particulate emission factor for the construction worker due to construction activities other than unpaved road traffic is calculated by Equation E-26.

Equation E-26

$$PEF'_{sc} = Q/C_{sa} \times \frac{1}{F_D} \times \frac{1}{\langle J'_T \rangle}$$

where: PEF'_{sc} = Subchronic particulate emission factor for construction activities other than traffic on unpaved roads (m^3/kg)

Q/C_{sa} = Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux at the center of the square emission source (g/m^2-s per kg/m^3), Eq. E-15

F_D = Dispersion correction factor (unitless), Eq. E-16

$\langle J'_T \rangle$ = Total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads (g/m^2-s), Eq. E-25.

Once these values have been calculated, the construction worker subchronic exposure SSLs for particulate matter emissions due to traffic on unpaved roads and due to other construction activities are calculated separately using Equations 5-3 and 5-4 in Chapter 5 this guidance document. Equations 5-3 and 5-4 are used to calculate SSLs for carcinogenic and non-carcinogenic effects, respectively. With values of the SSL for unpaved road traffic and the SSL for other construction activities, the lowest of the two SSLs should be used.

Particulate Matter Case Example

The following represents a theoretical case example illustrating the use of the previously cited equations for determining the SSL for unpaved road traffic and the SSL for other construction activities. The case example site consists of a 5-acre square area contaminated with hexavalent chromium (chromium VI). Contamination occurs in both surface and subsurface soils. Construction activities are anticipated to include unpaved road traffic, excavation soil dumping, dozing, grading, and tilling. In addition, wind erosion of the construction site is expected. Actual soil excavation will encompass one acre of soil to a depth of one meter. Likewise, one acre will be tilled twice for landscaping purposes. Dozing and grading operations are expected to cover the entire 5 acres.

SSL for Unpaved Road Traffic

From Equation E-18, the width of the road segment *(W_R)* is assumed to be 20 ft. The length of the road segment *(L_R)* is calculated as the square root of the area of the 5-acre site configured as a square:

$$L_R = (5 \text{ acres x } 43{,}560 \text{ ft}^2/\text{acre})^{0.5} = 467 \text{ ft.}$$

Therefore, the area of the road segment (A_R) is the product of the width and length of the road segment and a conversion factor of 0.092903 m^2/ft^2:

$$A_R = 20 \text{ ft x } 467 \text{ ft x } 0.092903 \text{ m}^2/\text{ft}^2 = 867 \text{ m}^2.$$

The total time period over which traffic will occur is estimated to be 6 months. Therefore, the value of T is calculated by:

$$T = (52 \text{ wks/yr} \div 2) \text{ x } 5 \text{ days/wk x } 8 \text{ hrs/day x } 3{,}600 \text{ s/hr} = 3{,}744{,}000 \text{ s.}$$

From Exhibit E-1, the value of the number of days with at least 0.01 inches of precipitation *(p)* is determined to be 70 days. Assuming that 30 vehicles per day travel the entire length of the road segment, the sum of the fleet vehicle kilometers traveled during the exposure duration *(ΣVKT)* is calculated by:

$$\Sigma VKT = 30 \text{ vehicles x } 467 \text{ ft/day x } (52 \text{ wks/yr} \div 2) \text{ x } 5 \text{ days/wk} \div 3{,}281 \text{ ft/km} = 555 \text{ km.}$$

For a square 5-acre site, the value of Q/C_{sr} is calculated to be 16.40 g/m^2-s per kg/m^3 from Equation E-19. Assuming that the overall duration of construction is 6 months or 4,380 hours *(t_c)*, the value of the dispersion correction factor *(F_D)* is calculated to be 0.186 from Equation E-16. Finally, the values of the road surface silt content *(s)* and the dry road surface moisture content *(M_{dry})* in Equation E-18 are set equal to the default values of 8.5 % and 0.2 %, respectively. The value of the mean vehicle weight *(W)* in Equation E-18 is assumed to be 8 tons.

From these data, the value of the subchronic particulate emission factor for unpaved road traffic *(PEF_{sc})* is calculated by Equation E-18:

$$PEF_{sc} = 16.40 \times \frac{1}{0.186} \times \frac{3{,}744{,}000 \times 867}{\frac{2.6 \times (8.5/12)^{0.8} (8/3)^{0.4}}{(0.2/0.2)^{0.3}} \times [(365-70)/365] \times 281.9 \times 555}$$

$$PEF_{sc} = 7.74 \times 10^5 \ m^3/kg.$$

With a value of the PEF_{sc} for chromium VI (a carcinogenic contaminant), the construction worker subchronic exposure soil screening level for unpaved road traffic is calculated by Equation 5-3:

$$SSL_{sc} = \frac{TR \times AT \times 365\, days/yr}{URF \times 1{,}000\, \mu g/mg \times EF \times ED \times (1/PEF_{sc})}$$

$$SSL_{sc} = \frac{10^{-6} \times 70 \times 365}{(1.2 \times 10^{-2}) \times 1{,}000 \times 130 \times 1 \times (1/7.74 \times 10^{5})}$$

$$SSL_{sc} = 13 \;\; mg/kg.$$

SSL for Wind Erosion and Other Construction Activities

The particulate emission factor for wind erosion and for construction activities other than unpaved road traffic *(PEF'_{sc})* is calculated using Equations E-20 through E-26. In each of these equations, the default values are used for each variable assigned a default value. In Equation E-20, the value of the areal extent of the site with surface soil contamination *(A_{surf})* is assigned a value of 5 acres or 20,235 m^2. In Equation E-21, the value of the areal extent of excavation *(A_{excav})* is set equal to 1 acre or 4,047 m^2, and the value of the average depth of excavation *(d_{excav})* is set equal to 1 meter. In Equation E-24, the value of the areal extent of tilling *(A_{till})* is also set equal to 1 acre or 4,047 m^2. The values of the sum of dozing and grading kilometers traveled in Equations E-22 and E-23 *(ΣVKT)* are each calculated assuming that the entire 5 acres are dozed and graded three times over the duration of construction. Assuming that the dozing and grading blades each have a length of 8 ft (2.44 m) and that one dozing or grading pass across the length of the site is equal to the square root of the site area (142 m), the value of ΣVKT is calculated by:

$$\Sigma VKT = ((142m/2.44m) \times 142m \times 3)/1{,}000\, m/km$$

$$\Sigma VKT = 24.79\, km.$$

From Equation E-15, the value of the dispersion factor *(Q/C_{sa})* for a square 5-acre site is calculated to be 9.44 g/m^2-s per kg/m^3. The value of the dispersion correction factor *(F_D)* is calculated from Equation E-16 as 0.186 based on a value for the duration of construction *(t_c)* equal to 6 months or 4,380 hours.

The total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads *($<J_T'>$)* is calculated by Equation E-25:

$$<J_T'> = \frac{(8.80 \times 10^4 g) + (1.66 \times 10^3 g) + (7.37 \times 10^2 g) + (1.08 \times 10^4 g) + (5.04 \times 10^3 g)}{20{,}235\, m^2 \times 3{,}744{,}000\, s}$$

$$<J_T'> = 1.40 \times 10^{-6}\, g/m\text{-}s.$$

From these data, the value of the subchronic particulate emission factor for construction activities other than unpaved road traffic *(PEF'_{sc})* is calculated by Equation E-26:

$$PEF'_{sc} = 9.44 \times \frac{1}{0.186} \times \frac{1}{1.40 \times 10^{-6}}$$

$$PEF'_{sc} = 3.61 \times 10^{7}\, m^{3}/kg.$$

With a value of the PEF'_{sc} for chromium VI, the construction worker subchronic exposure SSL for construction activities other than unpaved road traffic is calculated by Equation 5-3:

$$SSL_{sc} = \frac{TR \times AT \times 365\, days/yr}{URF \times 1{,}000\, \mu g/mg \times EF \times ED \times (1/PEF'_{sc})}$$

$$SSL_{sc} = \frac{10^{-6} \times 70 \times 365}{(1.2 \times 10^{-2}) \times 1{,}000 \times 130 \times 1 \times (1/3.61 \times 10^{7})}$$

$$SSL_{sc} = 590\, mg/kg.$$

Because the SSL for unpaved road traffic (13 mg/kg) is less than the SSL for construction activities other than unpaved road traffic (590 mg/kg), the final value of the SSL_{sc} is set equal to the value for unpaved road traffic.

Inhalation SSLs for the Off-site Resident[2]

The off-site resident receptor refers to a receptor who does not live on the site. The major assumption is that the relevant exposure point is located at the site boundary. Dispersion modeling has shown that an exposure point at the site boundary will always experience the highest off-site air concentration from the ground-level nonbuoyant type of site emission sources considered for this analysis. This receptor will experience volatile and particulate matter emissions from the site both during construction and after construction is completed. In some cases, the magnitude of the emissions during construction may exceed that of post-construction even though the post-construction exposure duration is considerably longer.

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[2] The approach described in this section can also be applied to other off-site receptors, such as an off-site commercial/industrial worker.

Volatile Emissions

Simple site-specific inhalation SSLs due to volatile emissions that are calculated for the on-site outdoor worker are considered to be protective of the off-site resident for two primary reasons. First, the volatile emission model used in the simple site-specific analyses for off-site receptors operates under the assumption that soil contamination begins at the soil surface. This assumption equates to worst-case conditions in terms of the magnitude of emissions. Second, dispersion modeling has shown that for a square area emission source the on-site air concentration will always be higher than the off-site air concentration. Preliminary emission and dispersion modeling has shown that considering the greater exposure frequency and longer exposure duration of the off-site residential receptor, the resulting SSLs are typically lower than those of the on-site outdoor worker by less than 30 percent. However, one must consider the relative uncertainty in these analyses. The uncertainty is a function of several variables. First, the actual geometry of a site may not closely resemble a square. Second, the emission model assumes that volatiles are emitted uniformly across the entire areal extent of the site, whereas emissions from actual sites may be heterogeneous with respect to both strength and location. Finally, the dispersion factor for the off-site receptor assumes that it is located at the emission source boundary as an upper bound estimate; in reality, this may or may not be the case. For these reasons, the difference in the on-site outdoor worker and off-site residential SSLs is considered to be negligible.

Particulate Matter Emissions

The off-site resident is exposed to particulate matter emissions both during site construction and after construction is complete. During site construction, this receptor is assumed to be exposed to particulate matter emissions from unpaved road traffic, excavation soil dumping, dozing, grading, and tilling operations as well as emissions from wind erosion. After construction, the receptor is assumed to be exposed only to fugitive dust emissions from wind erosion. Although the construction exposure duration is considerably shorter than the post-construction exposure duration, the magnitude of emissions during construction may be higher than that due to wind erosion alone. For this reason, the total unit mass emitted from all construction activities and the total unit mass emitted from wind erosion are summed and normalized over the entire site area and over the total exposure duration of the off-site resident receptor.

The unit masses of each contaminant emitted during construction from wind erosion, excavation soil dumping, dozing, grading, and tilling operations are calculated using Equations E-20 through E-24. The post-construction unit mass emitted due to wind erosion (M^{pc}_{wind}) is calculated using Equation E-20. In this case, the value of the exposure duration *(ED)* in Equation E-20 must be changed to reflect a long-term exposure (i.e., 30 years for residential or 25 years for commercial/industrial exposure). In addition, the default value of the fraction of vegetative cover *(V)* in Equation E-20 is changed from 0 to 0.5 for post-construction exposure. The unit mass emitted from traffic on unpaved roads (M_{road}) is calculated by Equation E-27.

Equation E-27

$$M_{road} = \frac{2.6 \times (s/12)^{0.8}\,(W/3)^{0.4}}{(M_{dry}/0.2)^{0.3}} \times [(365 - p)/365] \times 281.9 \times \Sigma VKT$$

where each variable has been defined previously in Equation E-18.

The total time-averaged unit emission flux for the off-site receptor is calculated by Equation E-28.

Equation E-28

$$<J_T^{off}> = \frac{(M_{road} + M_{wind} + M_{excav} + M_{doz} + M_{grade} + M_{till} + M_{wind}^{pc})}{A_{site} \times ED \times 3.1536E{+}07\; s/yr}$$

where:

$<J_T^{off}>$ = Total time-averaged PM_{10} unit emission flux for the off-site receptor (g/m^2-s)

M_{road} = Unit mass emitted from unpaved roads (g)

M_{wind} = Unit mass emitted from wind erosion (g)

M_{excav} = Unit mass emitted from excavation soil dumping (g)

M_{doz} = Unit mass emitted from dozing operations (g)

M_{grade} = Unit mass emitted from grading operations (g)

M_{till} = Unit mass emitted from tilling operations (g)

M^{pc}_{wind} = Post-construction unit mass emitted from wind erosion (g)

A_{site} = Areal extent of site (m^2)

ED = Exposure duration (yr).

Equation E-28 combines the unit mass emitted from construction activities and from wind erosion and normalizes these emissions across the entire site area and the exposure duration of the off-site receptor. Because the emission source geometry at an actual site is unknown, spreading the total emissions across the entire site facilitates calculation of the dispersion factor such that the receptor is located at the point of maximum annual average concentration at the site boundary. This concentration represents the maximum concentration at the point of public access.

The particulate emission factor for the exposure of the off-site receptor is calculated by Equation E-29.

Equation E-29

$$PEF_{off} = Q/C_{off} \times \frac{1}{<J_T^{off}>}$$

where: PEF_{off} = Particulate emission factor for the off-site receptor (m^3/kg)

Q/C_{off} = Inverse of the ratio of the geometric mean air concentration at the emission flux at the site boundary (g/m^2-s per kg/m^3), Eq. E-30

$<J_T^{off}>$ = Total time-averaged PM$_{10}$ unit emission flux for the off-site receptor (g/m^2-s), Eq. E-28.

The dispersion factor for the off-site resident, Q/C_{off}, was derived by using EPA's ISC3 dispersion model to predict the maximum annual average unit concentration at the boundary of a series of square ground-level area emissions sources. Site sizes ranged from 0.5 to 500 acres. A best curve was fit to the paired data of maximum concentration and site size to predict the value of $(Q/C)_{off}$. This resulted in Equation E-30 for calculating the dispersion factor.

The dispersion factor for the off-site resident, Q/C_{off}, is therefore calculated using Equation E-30.

Equation E-30

$$Q/C_{off} = A \times \exp\left[\frac{(\ln A_{site} - B)^2}{C}\right]$$

where: Q/C_{off} = Inverse of the ratio of the geometric mean air concentration at the emission flux at the site boundary (g/m^2-s per kg/m^3)

A = Constant; default = 11.6831

B = Constant; default = 23.4910

C = Constant; default = 287.9969

A_{site} = Areal extent of the site (acres).

Exhibit E-5 shows the values of the *A, B,* and *C* constants used in Equation E-30 for each of the 29 meteorological stations used in the dispersion modeling analysis. The appropriate constants for the most representative meteorological station may be used instead of the default constants, or a more refined dispersion modeling analysis may be performed for the actual site using EPA's ISC3 model.

With a calculated value of the off-site receptor particulate emission factor (PEF_{off}), the inhalation soil screening level is calculated using Equations 5-3 and 5-4 in Chapter 5 of the supplemental soil screening guidance document, as appropriate.

Exhibit E-5

VALUES FOR THE A, B, AND C CONSTANTS FOR CALCULATING Q/C$_{off}$

Meteorological Station	A Constant	B Constant	C Constant
Albuquerque, NM	17.8252	22.8701	274.1261
Atlanta, GA	15.8125	23.7527	288.6108
Bismarck, ND	18.8928	22.2274	268.2849
Boise, ID	12.2294	23.8156	286.4807
Casper, WY	18.4275	22.9015	280.6949
Charleston, SC	19.2904	21.9679	265.0506
Chicago, IL	20.1837	21.6367	264.0685
Cleveland, OH	13.4283	24.5328	302.1738
Denver, CO	12.0770	22.5621	272.5685
Fresno, CA	11.5554	22.2571	268.0331
Harrisburg, PA	17.2968	22.2917	272.9800
Hartford, CT	15.3353	21.6690	261.7432
Houston, TX	18.9273	20.1609	242.9736
Huntington, WV	12.1521	21.1970	252.6964
Las Vegas, NV	12.1784	24.5606	296.4751
Lincoln, NE	17.6897	22.7826	273.2907
Little Rock, AR	15.4094	21.7198	261.8926
Los Angeles, CA	15.7133	21.8997	269.8244
Miami, FL	17.7682	21.3218	253.6436
Minneapolis, MN	20.2352	22.3129	271.1316
Philadelphia, PA	16.4927	22.2187	268.3139
Phoenix, AZ	11.6831	23.4910	287.9969
Portland, ME	13.2438	23.2754	277.8473
Raleigh, NC	15.4081	21.8656	261.3267
Salem, OR	14.5609	21.9974	265.3198
Salt Lake City, UT	11.3006	25.8655	321.3924
San Francisco, CA	13.1994	23.6414	283.5307
Seattle, WA	18.5578	21.5469	269.0431
Winnemucca, NV	16.5157	21.2894	252.8634

REFERENCES

API (American Petroleum Institute). 1998. *Assessing the Significance of Subsurface Contaminant Vapor Migration to Enclosed Spaces, Site-Specific Alternatives to Generic Estimates*. Publication No. 4674. American Petroleum Institute, Washington, DC.

Cowherd, C.G., G. Muleski, P. Engelhart, and D. Gillette. 1985. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*. EPA/600/8-85/002. Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996. *Soil Screening Guidance: User's Guide*. Second Edition. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. Publication 9355.4-23.

EPA (U.S. Environmental Protection Agency). 1992a. Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures, EPA-450/2-92-004. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA (U.S. Environmental Protection Agency). 1992. *Workbook of Screening Techniques for Assessing Impacts of Toxic Air Pollutants (Revised)*. EPA-454/R-92-024. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

EPA (U.S. Environmental Protection Agency). 1985. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, and Supplements*. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Jury, W.A., W.J. Farmer, and W.F. Spencer. 1984. Behavior assessment model for trace organics in soil: II. Chemical classification and parameter sensitivity. *J. Environ. Qual*. 13 (4): 567-572.

Jury, W.A., D. Russo, G. Streile, and H.E. Abd. 1990. Evaluation of volatilization by organic chemicals residing below the soil surface. *Water Resources Research* 26 (1): 13-20.

Jury, W.A., W.F. Spencer, and W.J. Farmer. 1983. Behavior assessment model for trace organics in soil: I. Model description. *J. Environ. Qual.* 12(4): 558-564.

Thomas, G. B. 1968. *Calculus and Analytic Geometry, 4th edition*. Addison-Wesley, New York. Pages 178-180.