United States Environmental Protection Agency

AERMOD Implementation Guide

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AERMOD Implementation Guide

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
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Preface

This document provides information on the recommended use of AERMOD to address specific issues and concerns related to the implementation of AERMOD for regulatory applications. The following recommendations augment the use of experience and judgment in the proper application of dispersion models. Advanced coordination with reviewing authorities, including the development of modeling protocols, is recommended for regulatory applications of AERMOD.

Acknowledgments

The AERMOD Implementation Guide has been developed through the collaborative efforts of EPA OAQPS, EPA Regional Office, State and local agency dispersion modelers, through the activities of the AERMOD Implementation Workgroup. The efforts of all contributors are gratefully acknowledged.

Contents

1.0 What's new in this document

Revisions dated April 17, 2018:

The following section has been affected by this revision:

3.4 USE OF PROGNOSTIC METEOROLOGICAL MODEL DATA AS INPUTS TO AERMOD

This section addresses the use of prognostic meteorological model data as inputs to the AERMOD modeling system using the Mesoscale Model Interface (MMIF) program.

2.0 Document background and purpose

2.1 Background (10/19/07)

In April 2005, the AERMOD Implementation Workgroup (AIWG) was formed in anticipation of AERMOD's promulgation as a replacement for the Industrial Source Complex (ISCST3) model. AERMOD fully replaced ISCST3 as the regulatory model on December 9, 2006 (EPA, 2005a), after a one-year grandfather period. The primary purpose for forming the AIWG was to develop a comprehensive approach for dealing with implementation issues for which guidance is needed. A result of this initial AIWG was the publication of the first version of the AERMOD Implementation Guide on September 27, 2005.

In 2007, a new AIWG was formed as a standing workgroup to provide support to EPA's Office of Air Quality Planning and Standards (OAQPS). This document represents the combined efforts of AIWG and OAQPS in relation to the implementation of the AERMOD regulatory model.

2.2 Purpose (10/19/07)

This document provides information on the recommended use of AERMOD to address a range of issues and types of applications. Topics are organized based on implementation issues, with additional information as appropriate on whether they impact the modules of the AERMOD modeling system (AERMOD, AERMET, and AERMAP) or related programs (AERSURFACE, AERSCREEN, and BPIPPRM). The document contains a section which highlights changes from the previous version. This is located in Section 1 of the document for use as a quick reference. Each section is also identified with the date (mm/dd/yy) that it was added or last updated. Only sections with substantive changes or new recommendations are identified with new revision dates. Revision dates are not updated for sections with only minor edits to clarify the wording or to correct typographical errors.

The recommendations contained within this document represent the current best use practices as determined by EPA, through the implementation of AIWG. The document is not intended as a replacement of, or even a supplement to the *Guideline on Air Quality Models*

(EPA, 2017). Rather, it is designed to provide consistent, technically sound recommendations to address specific issues and concerns relevant to the regulatory application of AERMOD. As always, advance coordination with the reviewing authorities on the application of AERMOD is advisable. Modeling protocols should be developed, and agreed upon by all parties, in advance of any modeling activity.

3.0 Meteorological data and processing

3.1 Determining surface characteristics (01/09/08)

When applying the AERMET meteorological processor (EPA, 2018a) to prepare the meteorological data for the AERMOD model (EPA, 2018b), the user must determine appropriate values for three surface characteristics: surface roughness length $\{z_o\}$, albedo $\{r\}$, and Bowen ratio $\{B_o\}$. The surface roughness length is related to the height of obstacles to the wind flow and is, in principle, the height at which the mean horizontal wind speed is zero based on a logarithmic profile. The surface roughness length influences the surface shear stress and is an important factor in determining the magnitude of mechanical turbulence and the stability of the boundary layer. The albedo is the fraction of total incident solar radiation reflected by the surface back to space without absorption. The daytime Bowen ratio, an indicator of surface moisture, is the ratio of sensible heat flux to latent heat flux and is used for determining planetary boundary layer parameters for convective conditions driven by the surface sensible heat flux. This section provides recommendations regarding several issues associated with determining appropriate surface characteristics for AERMOD modeling applications.

3.1.1 Meteorological data representativeness considerations (01/09/08)

When using National Weather Service (NWS) data for AERMOD, data representativeness can be thought of in terms of constructing realistic planetary boundary layer (PBL) similarity profiles and adequately characterizing the dispersive capacity of the atmosphere. As such, the determination of representativeness should include a comparison of the surface characteristics (i.e., z_o, B_o and r) between the NWS measurement site and the source location, coupled with a determination of the importance of those differences relative to predicted concentrations. Site-specific meteorological data are assumed by definition to be representative of the application site; however, the determination of representativeness of site-specific data for AERMOD applications should also include an assessment of surface characteristics of the measurement and source locations and cannot be based solely on proximity. The recommendations presented in this section for determining surface characteristics for AERMET apply to both site-specific and non-site-specific (e.g. NWS) meteorological data.

The degree to which predicted pollutant concentrations are influenced by surface parameter differences between the application site and the meteorological measurement site depends on the nature of the application (i.e., release height, plume buoyancy, terrain influences, downwash considerations, design metric, etc.). For example, a difference in z_o for one application may translate into an unacceptable difference in the design concentration, while for another application the same difference in z_o may lead to an insignificant difference in design concentration. If the reviewing agency is uncertain as to the representativeness of a meteorological measurement site, a site-specific sensitivity analysis may be needed in order to quantify, in terms of expected changes in the design concentration, the significance of the differences in each of the surface characteristics.

If the proposed meteorological measurement site's surface characteristics are determined to NOT be representative of the application site, it may be possible that another nearby meteorological measurement site may be representative of both meteorological parameters and surface characteristics. Failing that, it is likely that site-specific meteorological data will be required.

3.1.2 Methods for determining surface characteristics (01/09/08)

Several sources of data may be utilized in determining appropriate surface characteristics for use in processing meteorological data for AERMOD. This may include printed topographic and land use, land cover (LULC) maps available from the U. S. Geological Survey (USGS), aerial photos from web-based services, site visits and/or site photographs, and digitized databases of land use and land cover data available from USGS. A sound understanding of the important physical processes represented in the AERMOD model algorithms and the sensitivity of those algorithms to surface characteristics is needed in order to properly interpret the available data and make an appropriate determination. The temporal representativeness of the source(s) of land cover data used relative to the meteorological data period to be processed should be considered as part of this assessment.

The availability of high resolution digitized land cover databases provides an opportunity to apply systematic procedures to determine surface characteristics based on an objective analysis of the gridded land cover data across a domain. A proper analysis of such data must take into consideration the relationship between surface characteristics and the meteorological measurements on which the surface characteristics will be applied. While the following discussion offers specific recommendations regarding the methods for determining surface characteristics from digitized land cover data, the general principles on which these recommendations are based are also applicable to determining surface characteristics from other sources of non-digitized land use and land cover data.

Based on model formulations and model sensitivities, the relationship between the surface roughness upwind of the measurement site and the measured wind speeds is generally the most important consideration. The effective surface roughness length should be based on an upwind distance that captures the net influence of surface roughness elements on the measured wind speeds needed to properly characterize the magnitude of mechanical turbulence in the approach flow. A number of studies have examined the response of the atmosphere to abrupt changes in the surface roughness, and provide some insight into the relationship between measured winds and surface roughness [e.g., Blom and Warenta (1969), Businger (1986), Högström and Högström (1978), Horst and Weil (1994), Irwin (1978), Rao, et al. (1974), and Taylor (1969)]. Such changes in surface roughness result in the development of an internal boundary layer (IBL) which grows with distance downwind of the roughness change, and defines the layer influenced by the transition in surface roughness. The size and structure of the IBL is very complex, even for idealized cases of uniform roughness upwind and downwind of the transition. The IBL is also affected by the magnitude and direction of the roughness change and the stability of the upstream flow. The IBL generally grows more slowly for stable conditions than for neutral or unstable approach flow, and will also tend to grow more slowly for rough-to-smooth transitions than for smooth-to-rough transitions. The relationship between surface roughness and measured wind speeds is even more complex in real world applications given the typically patchy nature of the heterogeneity of surface roughness elements.

The recommended upwind distance for surface roughness should take into account the fact that surface roughness effects in AERMOD are more important for stable atmospheric conditions than for neutral/unstable conditions, and that meteorological monitoring sites are typically characterized by open (low roughness) exposures in order to accommodate recommended siting criteria (EPA, 2000). For typical measurement programs, including NWS stations, the reference wind measurements will be taken for an anemometer height of approximately 10 meters above ground. An upwind distance based on the recommended siting criterion of at least 10 times the height of nearby obstacles (EPA, 2000), which would correspond to a distance of about 100m for typical obstacles such as trees and 2-3 story buildings, is considered inadequate for this purpose. However, the previous recommendation to use an upwind distance of 3 kilometers for surface roughness is considered too large because the boundary layer up to typical measurement heights of 10m will generally respond to changes in roughness length over much shorter distances. Including land cover information across an upwind distance that is too large could misrepresent the amount of mechanical turbulence present in the approach flow and bias model results, especially for low-level releases.

The recommended upwind distance for processing land cover data to determine the effective surface roughness for input to AERMET is 1 kilometer relative to the meteorological tower location. This recommended distance is considered a reasonable balance of the complex factors cited in the discussion above. If land cover varies significantly by direction, then surface roughness should be determined based on sector. However, the width of the sectors should be no smaller than a 30-degree arc. Further information on the definition of sectors for surface roughness is provided in the AERMET user's guide (EPA, 2018a). Exceptions to the recommended default distance of 1 kilometer for surface roughness may be considered on a case-by-case basis for applications involving site-specific wind speed measurements taken at heights well above 10m, in situations with significant discontinuities in land cover just beyond the recommended 1 kilometer upwind distance, or for sites with significant terrain discontinuities (e.g., the top of a mesa or a narrow, steep valley). Another factor that may need to be considered in some cases for determining an effective surface roughness length is the potential contribution of nearby terrain or other significant surface expression, not reflected in the land cover data, to the generation of mechanical turbulence. Use of a non-default distance for surface roughness estimation, or modification of surface roughness estimates to account for terrain/surface-expression effects, should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the modeling analysis.

The dependence of meteorological measurements and plume dispersion on Bowen ratio and albedo is very different than the dependence on surface roughness. Effective values for Bowen ratio and albedo are used to estimate the strength of convective turbulence during unstable conditions by determining how much of the incoming radiation is converted to sensible heat flux. These estimates of convective turbulence are not linked as directly with tower measurements as the linkage between the measured wind speed and the estimation of mechanical turbulence intensities driven by surface roughness elements. While local surface characteristics immediately upwind of the measurement site are very important for surface roughness, effective values of Bowen ratio and albedo determined over a larger domain are more appropriate.

The recommended approach for processing digitized land cover data to determine the effective Bowen ratio and albedo for input to AERMET is to average the surface characteristics across a representative domain without any direction or distance dependency. The recommended default domain is a 10km by 10km region centered on the measurement site. Use of the measurement location to define the domain is likely to be adequate for most applications. However, a domain representative of the application site may be more appropriate for some applications, particularly if the majority of sources are elevated releases. The use of an alternative domain for Bowen ratio and albedo should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the modeling analysis.

Beyond defining the appropriate domains to use for processing digitized land cover data, additional considerations are needed regarding the computational methods for processing of the data. Due to the fact that the width of a sector increases with distance from the measurement site, the land cover further from the site would receive a higher effective weight than land cover closest to the site if a direct area-weighted averaging approach were used to calculate an effective surface roughness. An inverse-distance weighting is recommended for determining surface roughness from digitized land cover data in order to adjust for this factor, since the length of an arc (across a sector) is proportional to the distance from the center. In addition, a geometric mean is recommended for calculating the effective surface roughness due to the fact that the AERMOD formulations are dependent on the $ln(z_o)$. Note that the arithmetic average of the *ln*(z_o) is mathematically equivalent to the geometric mean of z_o. Since the Bowen ratio represents the ratio between sensible heat flux and latent heat flux, the use of a geometric mean is also recommended for calculating effective values of Bowen ratio. Geometric means are more appropriate for calculating "average" values of ratios; for example, the "average" for Bowen ratios of 0.5 and 2.0 should be 1.0, which is accomplished with the use of a geometric mean. A simple arithmetic average is recommended for calculating effective values of albedo.

These recommendations for determining surface characteristics supersede previous recommendations and should be followed unless case-by-case justification can be provided for an alternative method. The recommendations described above are briefly summarized below:

3.1. The determination of the **surface roughness length** should be based on an inverse-distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.

3.2. The determination of the **Bowen ratio** should be based on a simple unweighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10km by 10km region centered on the measurement site.

3.3. The determination of the **albedo** should be based on a simple unweighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as defined for Bowen ratio, with a default domain defined by a 10km by 10km region centered on the measurement site.

An important aspect of determining surface characteristics from digitized land cover data is the assignment of surface characteristic values for each of the parameters (surface roughness, Bowen ratio and albedo) to the land cover categories contained in the dataset. Several references are available to guide those assignments, including Sections 4.7.7 and 5.4 of the AERMET user's guide (EPA, 2018a), Garrett (1992), Gifford (1968), Oke (1978), Randerson (1984), and Stull (1988). Due to the somewhat subjective nature of this process, and the fact that specific land cover categories may include a wide range of values for some surface characteristics, the methods and assumptions used to assign surface characteristics based on land cover categories should be thoroughly documented and justified.

3.1.3 Use of AERSURFACE for determining surface characteristics (01/09/08)

EPA has developed a tool called AERSURFACE (EPA, 2008) that can be used as an aid in determining realistic and reproducible surface characteristic values, including albedo, Bowen ratio, and surface roughness length, for input to AERMET, the meteorological processor for AERMOD. The current version of AERSURFACE supports the use of land cover data from the USGS National Land Cover Data 1992 archives (NLCD92). The NLCD92 archive provides land cover data at a spatial resolution of 30 meters based on a 21-category classification scheme applied consistently over the continental U.S. AERSURFACE incorporates look-up tables of representative surface characteristic values by land cover category and seasonal category. Further details regarding application of the AERSURFACE tool are provided in the AERSURFACE User's Guide (EPA, 2008).

The AERSURFACE tool incorporates the recommended methods for determining surface characteristics from digitized land cover data described in Section 3.1.2. While the AERSURFACE tool is not currently considered to be part of the AERMOD regulatory modeling system, i.e. the use of AERSURFACE is not required for regulatory applications of AERMOD, the recommended methodology described in Section 3.1.2 should be followed unless case-by-case justification can be provided for an alternative method.

3.2 Selecting upper air sounding levels (10/19/07)

The AERMET meteorological processor requires full upper air soundings (radiosonde data) representing the vertical potential temperature profile near sunrise in order to calculate convective mixing heights. For AERMOD applications within the U.S., the early morning sounding, nominally collected at 12Z (or UTC/GMT), is typically used for this purpose. Upper air soundings can be obtained from the Radiosonde Data of North America CDs for the period 1946 through 1997, which are available for purchase from the National Climatic Data Center (NCDC). Upper air soundings for the period 1994 to the present are also available for free download from the Radiosonde Database Access website (http://raob.fsl.noaa.gov/).

Both of these sources of upper air data offer the following three options for specifying which levels of upper air data to extract:

1) all levels,
2) mandatory and significant levels, or
3) mandatory levels only.

Options 1 and 2 are both acceptable and should provide equivalent results when processed through AERMET. The use of mandatory levels only, Option 3, will not provide an adequate characterization of the potential temperature profile, and is not acceptable for AERMOD modeling applications.

3.3 Processing site-specific meteorological data for urban applications (01/09/08)

The use of site-specific meteorological data obtained from an urban setting may require some special processing if the measurement site is located within the influence of the urban heat island and site-specific turbulence measurements are available (e.g., σ_θ and/or σ_w). As discussed in Section 5.4, the urban algorithms in AERMOD are designed to enhance the turbulence levels relative to the nearby rural setting during nighttime stable conditions to account for the urban heat island effect. Since the site-specific turbulence measurements will reflect the enhanced turbulence associated with the heat island, site-specific turbulence measurements should not be used when applying AERMOD's urban option, in order to avoid double counting the effects of enhanced turbulence due to the urban heat island.

As also discussed in Section 5.4, the AERMOD urban option (URBANOPT) should be selected for urban applications, regardless of whether the meteorological measurement site is located in an urban setting. This is due to the fact that the limited surface meteorological measurements available from the meteorological measurement program (even with measured turbulence) will not adequately account for the meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms.

3.4 Use of prognostic meteorological model data as inputs to AERMOD (04/17/2018)

In recent years, interest has grown in the use of prognostic meteorological data, such as the Weather Research and Forecasting (WRF) model to create inputs for dispersion modeling with AERMOD. This is especially true in locations where it can be difficult to find an adequately representative NWS station or cost-prohibitive or infeasible to set up a site-specific meteorological monitoring tower. As part of the recent update to the Guideline on Air Quality Models (EPA,2017), the use of prognostic data is allowed for regulatory applications of AERMOD where it is cost-prohibitive or not feasible to collect site-specific data and there is no representative NWD or comparable station nearby. EPA developed the Mesoscale Model Interface Program, or MMIF for processing prognostic meteorological data for AERMOD (Environ, 2014). For more information see Section 8.4.5 of the Guideline and the MMIF guidance document (EPA, 2018d) that offers recommendations on the use of prognostic data and MMIF.

4.0 Terrain data and processing

4.1 Modeling sources with terrain-following plumes in sloping terrain (01/09/08)

Under the regulatory default mode (DFAULT option on the MODELOPT keyword), for all situations in which there is a difference in elevation between the source and receptor, AERMOD simulates the total concentration as the weighted sum of 2 plume states (Cimorelli, *et al.*, 2004): 1) a horizontal plume state (where the plume's elevation is assumed to be determined by release height and plume rise effects only, and thereby allowing for impingement if terrain rises to the elevation of the plume); and, 2) a terrain-responding plume state (where the plume is assumed to be entirely terrain following).

For cases in which receptor elevations are lower than the base elevation of the source (i.e., receptors that are down-slope of the source), AERMOD will predict concentrations that are less than what would be estimated from an otherwise identical flat terrain situation. While this is appropriate and realistic in most cases, for cases of down-sloping terrain where expert judgment suggests that the plume is terrain-following (e.g., down-slope gravity/drainage flow), AERMOD will tend to underestimate concentrations when terrain effects are taken into account. AERMOD may also tend to underestimate concentrations relative to flat terrain results for cases involving low-level, non-buoyant sources with up-sloping terrain since the horizontal plume component will pass below the receptor elevation. Sears (2003) has examined these situations for low-level area sources, and has shown that as terrain slope increases the ratio of estimated concentrations from AERMOD to ISC (which assumes flat terrain for area sources) decreases substantially.

To avoid underestimating concentrations in such situations, it may be reasonable in cases of terrain-following plumes in sloping terrain to apply the non-DFAULT option to assume flat, level terrain. This determination should be made on a case-by-case basis, relying on the modeler's experience and knowledge of the surrounding terrain and other factors that affect the air flow in the study area, characteristics of the plume (release height and buoyancy), and other factors that may contribute to a terrain-following plume, especially under worst-case meteorological conditions associated with the source. The decision to use the non-DFAULT option for flat terrain, and details regarding how it will be applied within the overall modeling analysis, should be documented and justified in a modeling protocol submitted to the appropriate reviewing authority prior to conducting the analysis.

4.2 AERMAP DEM array and domain boundary (09/27/05)

Section 2.1.2 of the AERMAP User's Guide (EPA, 2018c) states that the DEM array and domain boundary must include all terrain features that exceed a 10% elevation slope from any given receptor. The 10% slope rule may lead to excessively large domains in areas with considerable terrain features (e.g., fjords, successive mountain ranges, etc). In these situations, the reviewing authority may make a case-by-case determination regarding the domain size needed for AERMAP to determine the critical dividing streamline height for each receptor.

4.3 Terrain elevation data sources for AERMAP (03/19/09)

AERMAP has been revised (beginning with version 09040) to support processing of terrain elevations from the National Elevation Dataset (NED) developed by the U.S. Geological Survey (USGS, 2002). The revised AERMAP program supports the use of NED data in the GeoTIFF format. AERMAP still supports terrain elevations in the DEM format, and has also been enhanced to process DEM files of mixed format (e.g., 7.5-minute and 1-degree DEM files) in the same run. AERMAP currently does not support processing of elevation data in both the DEM format and the GeoTIFF format for NED data in the same run.

The USGS DEM archives are now static and will not be updated in the future, while the NED data are being actively supported and checked for quality. Therefore, NED represents a more up-to-date and improved resource for terrain elevations for use with AERMAP. Due to a number of problems that have been encountered with DEM data, AERMOD users are encouraged to transition to the use of NED data as soon as practicable. Problems encountered with DEM data include incorrect geo-referencing information for entire DEM files and elevations that reflect the tops of buildings and trees in some cases. The use of NED data should avoid these issues, and provides additional advantages over the use of DEM data, including the ability to download a single NED file to cover the entire modeling domain of interest, with a consistent horizontal resolution and reference datum (generally NAD83). Some applications of

AERMAP using DEM data may involve inconsistent reference datums for adjacent DEM files, which can result in receptors being located within gaps between files due to the datum shift. Gaps may also occur within DEM files generated by various software tools to convert from one format to another when a NAD conversion is involved, e.g., converting1-degree DEM data to the 7.5-minute DEM format to fill areas not covered by available 7.5-minute data. The AERMAP User's Guide Addendum (EPA, 2009) provides a more detailed discussion of issues associated with gaps between DEM files or within DEM files, and describes how these cases are handled by AERMAP.

While NED is considered an improvement in the quality and consistency of elevation data for use with AERMAP, there are some issues associated with the GeoTIFF format supported by AERMAP that users should be aware of. The main issue of importance to AERMAP users is that the NED GeoTIFF files currently available from the USGS Seamless Data Server do not include the GeoKey specifying the units for the elevation data. The USGS documentation for NED data (USGS, 2002) indicates that elevations are in units of meters and are provided in floating point format. AERMAP will therefore assume units of meters if the elevation units GeoKey is absent. However, non-standard (i.e., non-USGS) NED data in GeoTIFF format may not be in units of meters. AERMAP provides an option for users to specify elevation units in these cases. However, users must exercise caution in using such data unless the correct units can be confirmed. The AERMAP User's Guide Addendum (EPA, 2009) provides a more detailed discussion of these and other potential issues associated with the GeoTIFF format supported for NED data.

The NED elevation data are currently available for the conterminous United States, Hawaii, Puerto Rico, and the Virgin Islands at a horizontal resolution of 1 arc-second (approximately 30 meters), and at a resolution of 2 arc-seconds for Alaska. Higher resolution NED elevation data at 1/3rd arc-second (about 10 meters) are available for most areas outside of Alaska, and even 1/9th arc-second data (about 3 meters) are available for some areas. These higher resolution data may become more widely available in the future. The appropriate horizontal resolution for the input terrain data and receptor network should be determined in consultation with the reviewing authority based on the specific needs of the project. Higher resolutions for both the terrain data and receptor network may be necessary in areas with significant terrain relief than for areas with relatively flat terrain. While acceptable, using the highest resolution elevation data available for determining receptor elevations and hill height scales may not always be justified. Since spatial coverage of terrain data for some resolutions may not be complete, it is also worth noting that use of a single resolution across the domain has advantages, and AERMAP places some restrictions on the order of DEM or NED file inputs when mixed resolution data are used.

Regardless of the receptor and terrain data resolutions used in AERMAP, it is advisable to check the accuracy of receptor elevations and hill height scales being input to AERMOD for significant terrain features that are likely to be associated with peak concentrations based on proximity and elevation in relation to the sources. Elevations for fenceline or other nearby receptors located within areas that have been altered due to facility construction may require special consideration since these changes in local topography may not be reflected in the USGS terrain files. Use of receptor elevations derived from plant survey data may be an acceptable alternative in these cases. The option available in AERMAP for the user to provide elevations may be utilized to determine hill height scales for these special cases, rather than the default option of determining elevations and hill height scales based on the input terrain data. However, care should be exercised to ensure that the hill height scales determined by AERMAP are also representative of the modified topography. If alternative data sources and/or methods are used to estimate receptor elevations, users must recognize that receptor elevations input to AERMOD should represent the best estimate of the actual terrain elevation at the receptor location. Use of a "conservative" estimate of the maximum elevation in the vicinity of the receptor location, such as the maximum within a "grid cell" centered on the receptor, is not appropriate for use in AERMOD based on the formulation of the terrain algorithms in the model, and may not result in a conservative estimate of concentrations.

Beginning with the version dated 09040, AERMAP can also process terrain elevations derived from the Shuttle Radar Topography Mission (SRTM) since they are available in the same GeoTIFF format as NED data from the USGS Seamless Data Server. SRTM elevation data is also available for most of the U. S. at 1 arc-second and 3 arc-second resolutions from various sources. However, SRTM elevations represent the height of the "reflective surface" for the radar signal, and therefore include the heights of obstacles such as buildings and trees (USGS, 2009). NED data represents the ground ("bare earth") elevation, which is a more appropriate input for determining receptor elevations and hill height scales for use in AERMOD. AERMOD users should therefore avoid the use of SRTM data to determine elevations for use in AERMOD. However, SRTM data are also available at 3 arc-second resolution for most of the globe, and may be the only practical alternative for applications beyond the U. S. While AERMAP can process both NED and SRTM data in GeoTIFF format in the same run, the only situation that might warrant such an approach would be applications along a border that extends beyond the domain covered by the NED data. The SRTM elevation data are typically based on the WGS84 horizontal datum, rather than the NAD83 datum used for most NED data. While AERMAP treats the WGS84 and NAD83 datums as equivalent, AERMAP will issue a warning message for any terrain file input as NED data that is not in the NAD83 datum to flag the possibility that non-NED data (or non-standard NED data) are being used.

Given the number of options available for elevation data inputs to AERMAP, and the range of issues associated with elevation data, users are encouraged to clearly document the source of elevation data used for AERMOD applications in the modeling protocol, including the resolution and horizontal reference datum for the data and any pre-processing that might have been done, such as converting from one format to another. Since the NED data are being checked for quality and updated as needed, AERMAP users should also consider acquiring updated terrain files on a periodic basis before use in regulatory modeling applications. If the option to provide receptor elevations to AERMAP is utilized, rather than using the default option of determining elevations based on the input terrain data, the sources and methods used to determine the provided elevations should be clearly documented along with a justification for use of that option.

4.4 Manually entering terrain elevations in AERMAP (03/19/09)

AERMAP currently does not have the capability of accepting hand-entered terrain data in an "xyz" format. AERMAP only accepts terrain data from digitized elevation files in the DEM or NED/GeoTIFF formats. Therefore, if no DEM or NED/GeoTIFF data are available for a particular application, terrain elevations may need to be determined through other means. One option may be to manually enter gridded terrain elevations in a form that mimics the DEM data format. Instructions for how to accomplish this can be found on the SCRAM web site http://www.epa.gov/scram001/ in a document titled “On inputting XYZ data into AERMAP.” As noted in Section 4.3, if alternative sources and/or methods are used to estimate receptor elevations, users must recognize that receptor elevations input to AERMOD should represent the best estimate of the actual terrain elevation at the receptor location, and these alternative sources and methods should be documented in the modeling protocol. As also noted in Section 4.3, SRTM elevation data in GeoTIFF format is available for most of the globe, which may provide another alternative source of elevation data for use in AERMAP. However, SRTM data represents the heights of obstacles, such as buildings and trees, rather than ground elevations, and should be used with caution and only as a last resort.

4.5 Use of AERMAP to determine source elevations (03/19/09)

AERMAP includes the capability of estimating terrain elevations for sources based on the same data and procedures used to estimate receptor elevations. However, the requirements for determining source elevations are somewhat different than the requirements for determining receptor elevations since a greater emphasis is placed on the accuracy of elevations at specific locations in the case of sources. While the accuracy of specific receptor elevations is also important, the main focus for receptors should be on how well the terrain features are defined by the receptor network as a whole, which is based on both the accuracy of the terrain data and the horizontal resolution of the receptor network. As noted in Section 4.3, it is advisable to check the accuracy of receptor elevations and hill height scales for significant terrain features that are likely to be associated with peak concentrations. These accuracy checks should also account for the relative elevation differences between the source and receptor since that will determine the elevation of the plume in relation to the terrain.

Given the issues and uncertainties associated with estimating the elevation at a specific location, and the potential sensitivity of AERMOD model results to differences in the relative elevations of sources and nearby receptors, users are discouraged from relying solely on AERMAP-derived source elevations in regulatory applications of AERMOD, especially for emission sources within the facility being permitted. These concerns are particularly important with newer facilities since regrading associated with construction of the facility may not be reflected in the digitized terrain data. Source elevations based on a reliable plant survey are generally considered to be the preferred option. If AERMAP-derived source elevations are used for the permitted facility, then some effort should be made to verify the accuracy of the elevations based on other reliable information, such as up-to-date topographic maps, taking into account adjustments for the horizontal datum if necessary. Use of AERMAP-derived elevations for other background sources included in the modeled inventory is generally of less concern than their use for the permitted facility, depending on the complexity of the terrain and the distances between sources within the modeled inventory. To facilitate proper review, the modeling protocol should clearly document the data and method(s) used to determine source elevations for input to AERMOD.

5.0 Urban applications

5.1 Urban/rural determination (08/03/2015)

The URBANOPT keyword on the CO pathway in AERMOD, coupled with the URBANSRC keyword on the SO pathway, should be used to identify sources to be modeled using the urban algorithms in AERMOD (EPA, 2018b). To account for the dispersive nature of the "convective-like" boundary layer that forms during nighttime conditions due to the urban heat island effect, AERMOD enhances the turbulence for urban nighttime conditions over that which is expected in the adjacent rural, stable boundary layer, and also defines an urban boundary layer height to account for limited mixing that may occur under these conditions. The magnitude of the urban heat island effect is driven by the urban-rural temperature difference that develops at night. AERMOD currently uses the population input on the URBANOPT keyword as a surrogate to define the magnitude of this differential heating effect. Details regarding the adjustments in AERMOD for the urban boundary layer are provided in Section 5. 8 of the AERMOD model formulation document (Cimorelli, *et al.*, 2004).

Section 7.2.2.1 of the *Guideline on Air Quality Models* (EPA, 2017) provides the basis for determining the urban/rural status of a source. For most applications the Land Use Procedure described in Section 7.2.3(c) is sufficient for determining the urban/rural status. However, there may be sources located within an urban area, but located close enough to a body of water or to other non-urban land use categories to result in a predominately rural land use classification within 3 kilometers of the source following that procedure. Users are therefore cautioned against applying the Land Use Procedure on a source-by-source basis, but should also consider the potential for urban heat island influences across the full modeling domain. Furthermore, Section 7.2.3(f) of Appendix W recommends modeling all sources within an ***urban complex*** using the urban option even if some sources may be defined as rural based on the procedures outlined in Section 7.2.3. Such an approach is consistent with the fact that the urban heat island is not a localized effect, but is more regional in character.

Another aspect of the urban/rural determination that may require special consideration on a case-by-case basis relates to tall stacks located within or adjacent to small to moderate size urban areas. In such cases, the stack height, or effective plume height for very buoyant plumes, may extend above the urban boundary layer height. The urban boundary layer height, z_{iuc}, can be calculated from the population input on the URBANOPT keyword, *P*, based on Equation 104 of the AERMOD formulation document (Cimorelli, *et al.*, 2004):

$$z_{iuc} = z_{iuo} \left(P/P_0\right)^{1/4} \qquad (1)$$

where z_{iu0} is the reference height of 400 meters corresponding to the reference population, P_0, of 2,000,000.

Prior to version 15181 of AERMOD, application of the urban option for these types of sources may have artificially limited the plume height resulting in anomalously high concentrations. Use of the urban option may not have been appropriate for such sources, since the actual plume was likely to be transported over the urban boundary layer and not be affected by urban enhanced dispersion. However, the potential for such anomalous results has been mitigated beginning with version 15181 of AERMOD, which has incorporated a formulation bug fix that modifies the treatment of plume rise for urban sources. Beginning with version 15181, AERMOD emulates the plume rise approach used for penetrated plumes during convective conditions if the initial plume height estimate is greater than or equal to the urban mixing height. With the introduction of this formulation bug fix in version 15181 of AERMOD a more thorough case-specific justification will be needed, in consultation with the appropriate reviewing authority, to support excluding these elevated sources from application of the urban option.

5.2 Selecting population data for AERMOD's urban mode (10/19/07)

For relatively isolated urban areas, the user may use published census data corresponding to the Metropolitan Statistical Area (MSA) for that location. For urban areas adjacent to or near other urban areas, or part of urban corridors, the user should attempt to identify that part of the urban area that will contribute to the urban heat island plume affecting the source(s). If this approach results in the identification of clearly defined MSAs, then census data may be used as above to determine the appropriate population for input to AERMOD. Use of population based on the Consolidated MSA (CMSA) for applications within urban corridors is not recommended, since this may tend to overstate the urban heat island effect.

For situations where MSAs cannot be clearly identified, the user may determine the extent of the area, including the source(s) of interest, where the population density exceeds 750 people per square kilometer. The combined population within this identified area may then be used for input to the AERMOD model. Users should avoid using a very fine spatial resolution of population density for this purpose as this could result in significant gaps within the urban area due to parks and other unpopulated areas, making it more difficult to define the extent of the urban area. Population densities by census tract should provide adequate resolution in most cases, and may still be finer resolution than desired in some cases. Since census tracts vary in size and shape, another acceptable approach would be to develop gridded estimates of population data based on census block or block group data. In such cases, a grid resolution on the order of 6 kilometers is suggested. Plotting population density with multiple "contour" levels, such as 0-500, 500-750, 750-1000, 1000-1500, etc., may also be beneficial in identifying which areas near the edge of the urban complex to include even though the population density may fall below the 750 threshold. The user should also bear in mind that the urban algorithms in AERMOD are dependent on population to the one-fourth power, and are therefore not highly sensitive to variations in population. Population estimates to two significant figures should be sufficiently accurate for application of AERMOD.

5.3 Optional urban roughness length – URBANOPT keyword (10/19/07)

The URBANOPT keyword on the CO pathway in AERMOD (EPA, 2018b) includes an optional parameter to specify the urban surface roughness length. The urban surface roughness parameter is used to define a reference height for purposes of adjusting dispersion for surface and low-level releases to account for the enhanced turbulence associated with the nighttime urban heat island. This optional urban roughness length is <u>not</u> used to adjust for differences in roughness length between the meteorological measurement site, used in processing the meteorological data, and the urban application site. Details regarding the adjustments in AERMOD for the urban boundary layer, including the use of the urban roughness length parameter, are provided in Section 5. 8 of the AERMOD model formulation document (Cimorelli, *et al.*, 2004).

The default value of 1 meter for urban surface roughness length, assumed if the parameter is omitted, is considered appropriate for most applications. Any application of AERMOD that utilizes a value other than 1 meter for the urban roughness length should be considered as a non-regulatory application, and would require appropriate documentation and justification as an alternative model, subject to Section 3.2 of the *Guideline on Air Quality Models* (EPA, 2017). The use of a value other than 1 meter for the urban surface roughness length will be explicitly treated as a non-DFAULT option in the next update to the AERMOD model.

5.4 Meteorological data selections for urban applications (01/09/08)

5.4.1 Urban applications using NWS meteorological data (01/09/08)

When modeling urban sources, the urban algorithms in AERMOD are designed to enhance the turbulence levels relative to the nearby rural setting during nighttime stable conditions to account for the urban heat island effect (Cimorelli, *et al.*, 2004). For urban applications using representative NWS meteorological data the AERMOD urban option (URBANOPT) should be selected (EPA, 2018b), regardless of whether the NWS site is located in a nearby rural or an urban setting. This is due to the fact that the limited surface meteorological measurements available from NWS stations will not account for the enhanced turbulence or other meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms. The determination of surface characteristics for processing NWS meteorological data for urban applications should conform to the recommendations presented in Section 3.1.

5.4.2 Urban applications using site-specific meteorological data (01/09/08)

In most cases, site-specific meteorological data used for urban applications should be treated in a manner similar to NWS data described in Section 5.4.1, regardless of whether the measurement site is located in a nearby rural or an urban setting. That is, the AERMOD urban option should be selected and the surface characteristics should be determined based on the recommendations in Section 3.1. This is due to the fact that the limited surface meteorological measurements available from the meteorological measurement program will not adequately account for the meteorological characteristics of the urban boundary layer included in the AERMOD urban algorithms. However, if the measurement site is located in an urban setting and site-specific turbulence measurements are available (e.g., σ_θ or σ_w), some adjustments to the meteorological data input to AERMOD may be necessary, as discussed in Section 3.3.

6.0 Source characterization

6.1 Capped and horizontal stacks (12/20/2016)

Beginning with version 16216, AERMOD includes regulatory options for modeling capped and horizontal stacks using the POINTCAP and POINTHOR source types, respectively. For capped and horizontal sources that are not subject to building downwash, the options are consistent with the approach that was approved by the Model Clearinghouse in July 1993 (see Appendix A). This approach uses an effective stack diameter to maintain the flow rate to maintain plume buoyancy, while suppressing plume momentum by setting the exit velocity to 0.001 m/s. For capped and horizontal sources that are subject to building downwash, the options have been adapted to account for the PRIME algorithm. Since the PRIME component in AERMOD incorporates a numerical plume rise algorithm that simulates the full trajectory of the plume, AERMOD sets the initial plume trajectory angle as horizontal for the POINTHOR option. For the POINTCAP option, AERMOD assigns the initial diameter of the plume to be 2 times the actual stack diameter to account for initial spread of the plume associated with the cap. AERMOD also assigns the initial horizontal velocity of the plume for the POINTCAP option to be the initial exit velocity specified by the user divided by 4.

6.2 Use of area source algorithm in AERMOD (09/27/05)

Because of issues related to excessive run times and technical issues with model formulation, the approach that AERMOD uses to address plume meander has not been implemented for area sources. As a result, concentration predictions for area sources may be overestimated under very light wind conditions (i.e., $u \ll 1.0$ m/s). In general, this is not expected to be a problem for meteorological data collected using standard wind instruments since instrument thresholds are generally too high. However, the problem could arise with meteorological data derived from very low threshold instruments, such as sonic anemometers. While not currently accepted for regulatory applications of AERMOD, this problem has also arisen when data from a gridded meteorological model was used to drive AERMOD. Meteorological grid models can at times produce extremely light winds. During such conditions time-averaged plumes tend to spread primarily as a result of low frequency eddy translation rather than eddy diffusion. AERMOD treats this meander effect by estimating the concentration from two limiting states: 1) a coherent plume state that considers lateral diffusive turbulence only (the mean wind direction is well defined) and 2) a random plume state (mean wind direction is poorly defined) that allows the plume to spread uniformly, about the source, in the x-y plane. The final concentration predicted by AERMOD is a weighted sum of these two bounding concentrations. Interpolation between the coherent and random plume concentrations is accomplished by assuming that the total horizontal “energy” is distributed between the wind’s mean and turbulent components.

In order to avoid overestimates for area sources during light wind conditions, it is recommended that, where possible, a volume source approximation be used to model area sources. This approach can be applied with confidence for situations in which the receptors are displaced from the source. However, for applications where receptors are located either directly adjacent to, or inside the area source, AERMOD’s area source algorithm will need to be used. For these circumstances, caution should be exercised if excessive concentrations are predicted during extremely light wind conditions. On a case-by-case basis, the reviewing authority should decide whether such predictions are unrealistic. One possible remedy would be to treat such hourly predictions as missing data.

It is EPA’s intention to correct this problem. A version of AERMOD that includes meander for area sources will be developed as soon as practicable.

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Appendix A. EPA Model Clearinghouse memorandum dated July 9, 1993

July 9, 1993

MEMORANDUM

SUBJECT: Proposal for Calculating Plume Rise for Stacks with Horizontal Releases or Rain Caps for Cookson Pigment, Newark, New Jersey

FROM: Joseph A. Tikvart, Chief
Source Receptor Analysis Branch, TSD (MD-14)

TO: Ken Eng, Chief
Air Compliance Branch, Region II

In response to your request, the Model Clearinghouse has reviewed your proposal for treating horizontal and capped stacks at Cookson Pigment so that the model (SCREEN or ISC2) will properly treat plume rise from the Cookson Pigment stacks. We concur in principle with the approach, with some relatively minor changes.

First, the analysis provided by New Jersey Department of Environmental Protection is technically correct. We suggest, however, that the exit velocity for horizontal and capped stacks be set to a lower figure than 0.1 m/s. A 0.1 m/s exit velocity may still result in significant momentum plume rise being calculated, even though these kinds of sources should have zero momentum rise. We therefore suggest setting the stack exit velocity to a lower value, such as .001.

For horizontal stacks that are not capped, we suggest turning stack tip downwash off, whether there are buildings or not. Stack tip downwash calculations are inappropriate for horizontal stacks.

For vertical stacks that are capped, turn stack tip downwash off and reduce the stack height by three times the actual stack diameter. The cap will probably force stack tip downwash most of the time. The maximum amount of the stack tip downwash (as calculated in ISC2) is three times the stack diameter. Reducing the stack height by this amount, while turning off the stack tip downwash option, causes the maximum stack tip downwash effect. The resulting concentrations may err slightly on the high side. For stacks with small diameters, such as those at Cookson Pigment, the error should be quite small. Note, however, that this approach may not be valid for large diameter stacks (say, several meters).

cc: A. Colecchia
D. Wilson

United States Environmental Protection Agency	Office of Air Quality Planning and Standards Air Quality Assessment Division Research Triangle Park, NC	Publication No. EPA-454/B-18-003 April, 2018