



AERSURFACE User's Guide

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AERSURFACE User's Guide

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PREFACE

This document provides a technical description and user instructions for the AERSURFACE tool, designed to aid in obtaining realistic and reproducible surface characteristic values for AERMET, the meteorological processor for AERMOD. Portions of the AERSURFACE User's Guide were modified with the release of AERSURFACE version 13016 (01/16/2013), including Section 2.1 containing updated information regarding accessing NLCD data, and Table A-3 containing modified surface roughness values for a few land cover categories.

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1.0 INTRODUCTION

When applying the AERMET meteorological processor (EPA, 2004a) to process meteorological data for the AERMOD model (EPA, 2004b), 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, together with albedo and other meteorological observations, is used for determining planetary boundary layer parameters for convective conditions driven by the surface sensible heat flux. Further details regarding the AERMOD model formulations and their dependence on surface characteristics are provided in Cimorelli, *et al.* (2004).

The AERSURFACE tool has been developed to aid users in obtaining realistic and reproducible surface characteristic values, including albedo, Bowen ratio, and surface roughness length, for input to AERMET. The tool uses publicly available national land cover datasets and look-up tables of surface characteristics that vary by land cover type and season. This user's guide provides a technical description of the AERSURFACE tool, including information on the data used by AERSURFACE to provide these surface characteristics for AERMET. Detailed user instructions for application of AERSURFACE are also provided.

2.0 TECHNICAL DESCRIPTION OF AERSURFACE

2.1 DESCRIPTION OF USGS LAND COVER DATA

AERSURFACE requires the input of land cover data from the U.S. Geological Survey (USGS) National Land Cover Data 1992 archives (NLCD92), which it uses to determine the land cover types for the user-specified location. AERSURFACE matches the NLCD92 land cover categories to seasonal values of albedo, Bowen ratio, and surface roughness. Values of surface characteristics are calculated based on the land cover data for the study area and output in a format for input into AERMET Stage 3.

The USGS NLCD92 data utilized by AERSURFACE provide land cover data at a spatial resolution of 30 meters, mapped using an Albers Conic Equal Area projection, and based on a 21-category classification scheme applied over the continental U.S. A list of the 21 land cover categories in NLCD92 is shown in Table 2-1. More information on this data can be found at the USGS Land Cover Institute (LCI) website: <http://landcover.usgs.gov/natl/landcover.php>. The NLCD92 data can be downloaded in two different forms: 1) complete files by state; and 2) files for a user-specified domain of arbitrary size and location from a “seamless data server.” AERSURFACE supports both forms of the NLCD92 data.

Table 2-1: USGS NLCD92 Land Cover Categories

Classification	Class Number	Land Cover Category
Water	11	Open Water
	12	Perennial Ice/Snow
Developed	21	Low Intensity Residential
	22	High Intensity Residential
	23	Commercial/Industrial/Transportation
Barren	31	Bare Rock/Sand/Clay
	32	Quarries/Strip Mines/Gravel Pits
	33	Transitional
Forested Upland	41	Deciduous Forest
	42	Evergreen Forest
	43	Mixed Forest
Shrubland	51	Shrubland
Non-natural Woody	61	Orchards/Vineyards/Other
Herbaceous Upland	71	Grasslands/Herbaceous
Herbaceous Planted/Cultivated	81	Pasture/Hay
	82	Row Crops
	83	Small Grains
	84	Fallow
	85	Urban/Recreational Grasses
Wetlands	91	Woody Wetlands
	92	Emergent Herbaceous Wetlands

The state NLCD92 data files can be accessed through the following website, which includes two formats (TIF and BIN) for each state (except for Alaska and Hawaii), as well as an NLCD92 legend and other user files: <http://edcftp.cr.usgs.gov/pub/data/landcover/states/>. The state NLCD filenames are of the form “statename.nlcd.tif.gz” for the “TIF format”, more accurately referred to as the GeoTIFF format, and “statename.nlcd.bin.gz” for the BIN format. The “.gz” extension on the filenames indicates that the files are in compressed form (due to their large size). The state files must be uncompressed, using public domain or commercial software that supports the “gzip” compression format. These two formats for state NLCD data are essentially equivalent. However, as discussed in Section 3.0, the TIF format requires less user input when running the AERSURFACE program, and can also be visualized through various public domain and commercial software products. The USGS provides a free data viewer, called “dlgv32 PRO”, which can be downloaded from the following website: <http://mcmweb.er.usgs.gov/drc/dlgv32pro/>.

The NLCD92 data can also be downloaded as seamless data for user-specified domains from the Multi-Resolution Land Characteristics (MRLC) Consortium (<http://www.mrlc.gov>) at the following link: <http://www.mrlc.gov/viewerjs/>. AERSURFACE supports data extracted through the MRLC Consortium Viewer in the GeoTIFF format. The NLCD92 data downloaded from the viewer is a compressed file (with a “.zip” file extension) that contains several data files. The only file needed to run AERSURFACE is the file with the “.tif” file extension. The MRLC Consortium Viewer also offers the advantage that users can download only the data needed for a particular application, and thus the file sizes will be considerably smaller than the state NLCD data. For sites located near state boundaries, the use of seamless NLCD data may be the only option for successfully applying AERSURFACE. The MRLC Consortium Viewer also allows users to visualize the land cover data, which can be overlaid with other geographic information for reference purposes, such as state and county boundaries, roadways and waterways, as well as topographic information.

Users should note that the MRLC Consortium Viewer also offers access to several types of data other than the NLCD92 data, including National Elevation Data (NED) and the newer 2001 and 2006 NLCD data. AERSURFACE currently does not support the 2001 or 2006 NLCD data. Users should take care to ensure that they are downloading the correct type of data for use with AERSURFACE, which is labeled as “NLCD 1992 Land Cover.”

Several options are available regarding the types of data to display on the MRLC Consortium Viewer, as well as types of data to download. Users should become familiar with the options available for navigating the seamless server and extracting the data needed for AERSURFACE. In addition to navigating and accessing the correct type of data for the desired domain, the user may also need to make adjustments to their web browser settings in order to successfully download the data. This may include disabling “pop-up blockers,” as well as modifying other settings. Users experiencing difficulties with accessing NLCD92 data through the MRLC Consortium Viewer are encouraged to review the user support information available through the MRLC website or request assistance through their own computer user support group. It should also be noted that the information presented here is accurate as of the date shown in the page footer; however, since web-based data sources often change over time, the links provided above may become obsolete in the future.

2.2 ASSIGNMENT OF SURFACE CHARACTERISTICS BY LAND COVER CATEGORY

Each of the 21 land cover categories in the NLCD92 archive is linked within AERSURFACE to a set of seasonal surface characteristics. These values of seasonal surface characteristics are provided in Appendix A. Table A-1 provides the seasonal albedo values, Table A-2 has the seasonal Bowen ratio values for three categories of surface moisture (average, dry and wet), and Table A-3 lists the seasonal surface roughness values. These values are based on data reported in the literature and the tables include information and references regarding their derivation. A more detailed explanation of the NLCD92 21 land cover categories is presented in Appendix B to provide a better understanding of the surface types included within each category.

The values of seasonal surface characteristics by land cover category were developed for the continental U.S. for the five seasonal categories listed in Table 2-2. These seasonal categories are the same as those used by the AERMOD model (EPA, 2004b) for the gas deposition algorithms (GDSEASON keyword). The user is given the option of choosing which months belong to which seasonal category for their specific location if they choose to output monthly or annual surface characteristics for AERMET. This option will allow a more state-specific estimate, and in many cases be more reflective of the true nature of the site. Otherwise, the user can select to use the program's default setting which assigns the months of March, April, and May to seasonal category 5 ("Transitional spring with partial green coverage or short annuals"); June, July, and August to seasonal category 1 ("Midsummer with lush vegetation"); and September, October, and November to seasonal category 2 ("Autumn with unharvested cropland"). The user will also be asked whether the location experiences continuous snow cover in the winter. If the area does experience continuous snow cover, then the default seasonal category 4 ("Winter with continuous snow on ground") will include the months of December, January, and February. If the area does not experience continuous snow cover, then the months of December, January, and February will be paired with surface characteristic values listed with seasonal category 3 ("Late autumn after frost and harvest, or winter with no snow").

Some locations may never experience significant periods of continuous snow cover, while other locations may experience continuous snow cover for a period of one or more months during the year. AERSURFACE will prompt the user regarding whether the study area experiences continuous snow cover for at least one month during the year to allow for an appropriate designation of seasonal categories 3 and 4 for the specific application. Further details regarding these user options are provided in Section 3.0.

Table 2-2: Seasonal Category Descriptions

<i>Seasonal Category</i>	<i>Season Description</i>	<i>Default Month Assignments</i>
1	Midsummer with lush vegetation	Jun, Jul, Aug
2	Autumn with unharvested cropland	Sep, Oct, Nov
3	Late autumn after frost and harvest, or winter with no snow	Dec, Jan, Feb
4	Winter with continuous snow on ground	Dec, Jan, Feb
5	Transitional spring with partial green coverage or short annuals	Mar, Apr, May

Because the 21 land cover classification system of NLCD92 was applied across the continental U.S., there are instances where the surface characteristic values for two areas of the U.S. may differ, although the land cover type is the same. There are also categories that cover several surface types for which albedo, roughness, and/or Bowen ratio may be quite different. To address these issues, Land Cover Classes 23, 31, and 51 are each split into two separate categories in Tables A-1, A-2, and A-3, and the values used for each of these categories are determined by the user’s responses to questions about the location. These questions and how the user response will affect the output are explained below:

- *“Is this site at an airport?”*

The answer to this question will affect the Commercial/Industrial/Transportation category (Class 23) which covers both transportation land cover (e.g. roadways and airport runways) and commercial and industrial areas (e.g. industrial parks). If the site is at an airport, AERSURFACE will use surface characteristics that reflect an area more dominated by transportation land cover. If the user answers “No” to the above question, AERSURFACE will choose higher surface roughness values that are more representative of an area dominated by buildings associated with commercial and industrial land cover. To represent this split, the Commercial/Industrial/Transportation category is broken out into two categories in Tables A-1, A-2, and A-3: “site at airport” and “not at airport”.

- *“Is this site in an arid region?”*

The answer to this question will affect the Shrubland (Class 51) and the Bare Rock/Sand/Clay (Class 31) categories. These two categories may appear in the NLCD92 data in both desert and non-arid regions of the U.S., two climatologically different areas which will have quite different surface characteristic values. If the user answers “Yes,” AERSURFACE will use the seasonal surface characteristics for the Shrubland and Bare Rock/Sand/Clay categories that are more representative of a desert area. Therefore, in general, the albedo and Bowen ratio will be higher and the surface roughness lower. Otherwise, AERSURFACE will use the seasonal surface characteristics for the non-arid area. In Tables A-1, A-2, and A-3, these categories are broken out and labeled “arid region” and “non-arid region”. (Note: If the user specifies that the location experiences continuous snow cover for at least one month during the year, the program assumes that the area is non-arid and will not offer this prompt.)

- “Characterize the surface moisture condition at the site relative to climatological normals, to be applied for all periods. Enter ‘A’ for Average, ‘W’ for Wet, or ‘D’ for Dry.”

The answer to this question will dictate the value of the Bowen ratio. If the user answers average, the average Bowen ratio values will be used; if the user answers wet, the wet Bowen ratio values will be used; and, if the user answers dry, the dry Bowen ratio values will be used for each land cover category. The surface moisture condition for the site may vary depending on the meteorological data period for which the surface characteristics will be applied. The current version of AERSURFACE applies the surface moisture condition for the entire data period. Therefore, if the surface moisture condition varies significantly across the data period, then AERSURFACE may need to be applied multiple times to account for those variations. The surface moisture condition can be determined by comparing precipitation for the period of data to be processed to the 30-year climatological record, selecting “wet” conditions if precipitation is in the upper 30th-percentile, “dry” conditions if precipitation is in the lower 30th-percentile, and “average” conditions if precipitation is in the middle 40th-percentile.

2.3 AERSURFACE CALCULATION METHODS

Determining effective surface characteristics for the purpose of processing meteorological data for use with the AERMOD model presents many challenges. AERMOD is a steady-state plume model which assumes spatially uniform meteorological conditions across the modeling domain for each hour of meteorology, while land cover across the domain is typically very heterogeneous. A sound understanding of the important physical processes represented in the AERMOD model algorithms (Cimorelli, *et al.*, 2004) 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 recommendations for determining surface characteristics presented in Section 3.1 of the AERMOD Implementation Guide (EPA, 2008) have been incorporated into AERSURFACE. These recommendations are briefly summarized below:

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.
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. 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.

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 above should be followed unless case-by-case justification can be provided for an alternative method.

3.0 AERSURFACE USER INSTRUCTIONS

3.1 RUNNING AERSURFACE

The AERSURFACE program was written in Fortran and can be run interactively from the command prompt. The program can be executed by navigating to the folder containing the AERSURFACE executable (aersurface.exe), and typing “aersurface” (without the quotes) at the command prompt. The program can also be executed from Windows Explorer by double-clicking on the aersurface.exe file. In the interactive mode, the user responds to a series of prompts to identify the input and output filenames and specify options for processing the land cover data.

Alternatively, the AERSURFACE program can be run by redirecting the responses to prompts from a separate text file. Running AERSURFACE using an input file through redirection is accomplished by typing “aersurface <aersurface.dat” (without the quotes) from the command prompt, or by including the same command as part of a batch file. The input filename used for redirected input is arbitrary. However, each time the AERSURFACE program is executed it automatically creates an input file called “AERSURFACE.DAT” containing the user responses for that application. Since the “AERSURFACE.DAT” file is automatically overwritten each time AERSURFACE is executed, the user may wish to copy the file to another name for later use. The AERSURFACE.DAT file created by AERSURFACE also includes annotations describing each of the inputs.

3.2 INTERACTIVE USER PROMPTS

AERSURFACE is designed to lead the user through several prompts to specify the necessary information regarding the location of interest. A listing of these prompts is provided below, with additional description regarding each input.

The first prompt the user will encounter is:

- *“Enter INPUT filename and extension (*.tif or *.bin) for land cover data file (include path if needed). Enclose with quotes if path or filename contains spaces. Linux users include quotes to accommodate forward slash in path. (132 character limit)”*

The user should enter the filename for the NLCD92 input data file. The file should be either a GeoTIFF (*.tif) or binary (*.bin) format. State files are available in either the *.tif or *.bin format, while the default format for seamless files is GeoTIFF. If input data from the seamless data server are used, only the *.tif file is needed for input to AERSURFACE. If the input data file is in the *.bin format (state files only), the user will also be prompted to enter the 2-character postal code for the state in which their site is located. If the *.bin data is for California or Texas, the user will be asked to specify more information about their site location in relation to the state land cover data files, since the

NLCD92 provides multiple land cover data files to cover these states. Note that filenames are case-sensitive for Linux systems.

- *“Enter name of OUTPUT file for the surface characteristics formatted for AERMET Stage 3 input. AERSURFACE.DAT and ‘*.LOG’ are not accepted output filenames. Enclose with quotes if the path or filename contains spaces. Linux users include quotes to accommodate forward slash in path. (132 character limit).”*

AERSURFACE will output a file with this user-specified name which will contain surface characteristics values in a format for use in AERMET Stage 3. AERSURFACE will not give this file an extension, although the user may specify an extension when naming the file at the prompt. However, the extension “.log” will not be allowed since AERSURFACE will automatically output another file with the same prefix as the user-specified output file and the extension “.log”, which will document the user’s response to the program’s prompts and other details of the program’s calculations. This is discussed in more detail in Section 3.4.

- *“Enter the type of coordinate used to define the center of the study area. ‘UTM’ for Universal Transverse Mercator coordinates; ‘LATLON’ for Latitude and Longitude coordinates. (Note: User responses are not case-sensitive.)”*

This prompt asks the user to enter the type of coordinates to be used for the site center. The coordinates input to AERSURFACE should be based on the location of the meteorological tower (measurement site) for the meteorological data to be processed with the output surface characteristics. AERSURFACE uses these coordinates to extract land cover data for the area of interest from the NLCD92 data file. If the user enters “UTM”, the user will be asked to enter the UTM Easting and Northing coordinates (in meters) and the UTM zone. If the user chooses “LATLON”, the user will be prompted to enter the latitude and the longitude (in decimal degrees), using a negative number for west longitude. The user must also specify the horizontal reference datum (NAD83 or NAD27) for the input coordinates for either UTM or LATLON coordinates. The NLCD92 data are based on the NAD83 horizontal datum, and AERSURFACE will convert the input coordinates to NAD83 if needed. The NAD Grid conversion files (conus.las and conus.los) must be included in the local folder for NAD27 conversions. Coordinates for airport locations are generally provided in the NAD83 datum.

NOTE: Significant discrepancies have been identified between station coordinates reported by the National Climatic Data Center (NCDC) and the actual location of the meteorological instrument tower for National Weather Service (NWS) sites. Discrepancies of several hundred meters up to a few kilometers are common, which could significantly compromise the representativeness of AERSURFACE calculations, especially for surface roughness. Users are encouraged to verify the coordinates of the meteorological tower before applying AERSURFACE.

- *“Enter the radius (in km) of the study area used for surface roughness (0.1 – 5.0 km). The recommended default value is 1 km.”*

The user should enter the distance from the center of the site location that will be used in calculating the effective surface roughness length. The current recommended default is 1km. If a radius other than the recommended default value of 1km is used, it is recommended that this choice be documented and justified in a modeling protocol prior to conducting the modeling. AERSURFACE will not accept values outside of the range from 0.1 to 5.0 km, inclusive. AERSURFACE uses this information, along with the coordinates of the center of the study area, to extract a subsection of land cover data from the NLCD92 data file.

- *“Do you want to define the surface roughness length for multiple sectors?”*

The user is given the option of defining the surface roughness length for multiple sectors, up to a maximum of 12. If the user opts to use multiple sectors, AERSURFACE will prompt for the number of sectors to be used to characterize the area, and the starting direction (in whole degrees) of each sector. An input of 0° will correspond with true North. The minimum sector width allowed by AERSURFACE is 30 degrees. If the user selects the maximum of 12 sectors, AERSURFACE will automatically define 30-degree sectors starting with 0° (North).

- *Define the temporal resolution of surface characteristic outputs (ANNUAL, SEASONAL or MONTHLY) .*

The reference surface characteristics used in AERSURFACE are stored as seasonal values for each land cover category based on the following seasonal categories:

*Late autumn after frost and harvest, or winter with no snow
 Winter with continuous snow on the ground
 Transitional spring (partial green coverage, short annuals)
 Midsummer with lush vegetation
 Autumn with unharvested cropland*

SEASONAL surface characteristics output implies the following seasonal definitions based on AERMET:

*Dec, Jan, Feb for Winter (snow-covered or no snow)
 Mar, Apr, May for Spring
 Jun, Jul, Aug for Summer
 Sep, Oct, Nov for Fall*

Months can be reassigned to different seasonal categories for ANNUAL or MONTHLY output, including

*the option to specify continuous snow cover for one or more months.
Months cannot be reassigned for SEASONAL output, and Winter will assume either continuous snow cover or no snow cover for all three months, depending on the user response to the subsequent prompt.*

Enter 'A' for ANNUAL, 'S' for SEASONAL, or 'M' for MONTHLY:

This prompt allows the user to specify the temporal resolution of the surface characteristic outputs, based on the options supported by AERMET.

- *Does the site experience continuous snow cover for at least one month? {for ANNUAL or MONTHLY outputs}
or
Does the site experience continuous snow cover for most of the winter? {for SEASONAL outputs}*

Enter 'Y' for Yes or 'N' for No

Because the surface characteristics are affected by snow cover, this question is asked of the user to determine whether surface characteristics for continuous snow cover should be used. The wording of this prompt will vary as shown depending on the temporal resolution for outputs specified by the user. For the ANNUAL or MONTHLY output options, the user may specify which months are assumed to experience continuous snow cover. For SEASONAL output, continuous snow cover will be assumed for all winter months if the user answers Yes to this prompt.

- *****
The default month-to-season associations in AERSURFACE will be as follows (where 1=Jan, 2=Feb, 3=Mar, etc.):

*Winter with continuous snow on the ground: 12, 1, 2
or, {depending on response to snow cover prompt}
Late autumn after frost and harvest, or winter with no snow: 12, 1, 2*

Transitional spring (partial green coverage, short annuals): 3, 4, 5

Midsummer with lush vegetation: 6, 7, 8

Autumn with unharvested cropland: 9, 10, 11

*Would you like to reassign the months to different seasons?
Enter 'Y' to reassign or 'N' to use the default assignments.*

This prompt is only offered if MONTHLY or ANNUAL output has been selected. If the user opts to reassign the months to different seasons, the user will be prompted to enter the months for each of the applicable seasonal categories in Table 2-2. If the user indicates that continuous snow cover occurs, the prompts will include all five seasonal categories, otherwise the “Winter with continuous snow on the ground” category will be omitted. If the user opts to not reassign the months to different seasons, or if the user chooses the SEASONAL output option at the previous prompt, the default AERSURFACE month-to-season associations will be used.

The following prompt is provided if the user elects to reassign months:

- *****
Assign months to seasons by entering a space or comma-delimited list, e.g., to assign Nov, Dec, and Jan, enter "11 12 1" (without the quotes). To skip a season enter "0" (no quotes). Enter "-9" to restart month-season assignments.

You will be prompted for the following seasonal categories:

Late autumn after frost and harvest, or winter with no snow

Winter with continuous snow on the ground

Transitional spring (partial green coverage, short annuals)

Midsummer with lush vegetation

Autumn with unharvested cropland

- *“Is this site at an airport?”*

See discussion in Section 2.2.

- *“Is this site in an arid region?”*

See discussion in Section 2.2. (**Note:** If the user specifies that the location experiences continuous snow cover for at least one month during the year, the program assumes that the area is not arid and will skip this prompt.)

- *“Characterize the surface moisture condition at the site relative to climatological normals, to be applied for all periods. Enter ‘A’ for Average, ‘W’ for Wet, or ‘D’ for Dry.”*

See discussion in Section 2.2.

3.3 AERSURFACE ERROR HANDLING

When performing the surface characteristic calculations, if AERSURFACE determines that more than 10% of the land cover in any one sector for surface roughness or within the entire domain for albedo and Bowen ratio falls within the “Transitional” land cover category, a warning will be issued to the user. This is because the “Transitional” land cover category represents an area that is dynamically changing from one land cover to another, and since the NLCD92 data were collected between 1991 and 1992, the current land cover for that area will most likely differ (see Appendix B.) If this warning message is generated, it is recommended that the user take a closer look at the land cover in the area to determine whether the land cover data can be supplemented with more current land cover data. To assist in this, the warning message will include the percentage of the area in the “Transitional” category, and also the sector in which this occurs in the case of surface roughness.

AERSURFACE will also issue a warning if more than 10% of the land cover in any one sector for surface roughness or the entire domain for albedo and Bowen ratio is labeled as “Missing” or “Outside Boundary.” When this occurs for more than 90% of the area in any one sector, AERSURFACE will not continue with its calculations and the program will end. If this occurs, the user may want to investigate the land cover data, and decide if they are able to supplement the missing data with current land cover data. However, this problem can also occur if the user specified site is too close to the state boundary for a state NLCD file or the edge of the data domain for seamless data. If the application site is too close to the boundary of a state file, then the user should acquire seamless data for the proper domain. If the application site is too close to the edge of the seamless data file, then a larger domain of seamless data should be acquired.

3.4 FILE DESCRIPTIONS

As mentioned in Section 3.1, AERSURFACE will always create a text file called “AERSURFACE.DAT” that contains the annotated user responses to the program prompts. The AERSURFACE.DAT file can be renamed and/or modified for use in rerunning AERSURFACE with redirected input. In modifying the input file, users should be aware that modifications to certain prompts may alter the input requirements for AERSURFACE.

Based on the name specified by the user, AERSURFACE outputs two files. The user-specified output filename will contain the surface characteristics formatted for input into AERMET Stage 3. The other file, which will have the same prefix as the user-specified output file with an extension of “.log”, will contain the following information: a summary of the user’s responses to the AERSURFACE prompts; an extraction of land cover data from the user specified location for both the albedo/Bowen ratio domain and the surface roughness domain; and a tally of the number of land cover grid cells for each of the 21 land cover categories for the albedo/Bowen

ratio domain, and for each of the sectors for the surface roughness domain. This file is supplied to aid the user in better understanding the data being used by AERSURFACE and to help quality assure the program's outputs.

In addition to the AERMET Stage 3 output and the log file, AERSURFACE creates two text files containing the extracted land cover data for the albedo/Bowen ratio and surface roughness domains, respectively. These files are named "albedo_bowen_domain.txt" and "roughness_domain.txt". These domain files contain the same extracted land cover data that is included in the log file, but also include several records at the top of the file containing the Albers coordinates for the lower left corner of the domain and horizontal resolution of the data. These domain files can be imported into mapping software, such as ArcGIS, to visualize the extracted land cover data to further assist with interpretation and quality assurance of the data.

3.5 EXAMPLE TEST CASE

An example AERSURFACE test case was run for the Raleigh/Durham (RDU) airport located in North Carolina. The input and output files for this test case are packaged with the AERSURFACE code. Figure 3-1 shows the input data file associated with this test case, called "rdu_seamless.dat". The center of study area was located at the NWS meteorological station tower at the airport (latitude in decimal degrees: 35.89194; longitude in decimal degrees: -78.78194). The test case uses the SEASONAL output option with the default month assignments and no continuous snow cover. An average surface moisture condition was assumed, with non-arid conditions. The option to vary surface roughness outputs by sector was selected with three sectors defined. Figure 3-2 shows the sectors selected for this test case. Sector 1 was selected to start at 0°, Sector 2 at 90°, and Sector 3 at 225°. Figure 3-3 shows the output appearing in the file "rdu_seamless.out", formatted for input into Stage 3 of AERMET. The extracted albedo/Bowen ratio and surface roughness domains and sectors are also shown in Figure 3-4, overlaid on the seamless NLCD data file. The airport runways, terminals and other structures are clearly visible on this figure as NLCD category 23, Commercial/Industrial/Transportation. The large open areas surrounding the airport runways and terminals show up as category 85, Urban Recreational Grasses.

```

"rdu_seamless.tif"          ** Land use data file
"rdu_seamless.out"         ** Output file with sfc values for AERMET Stage 3
LATLON                     ** Coordinate type (UTM, LATLON)
    35.891940              ** Latitude
    -78.781940            ** Longitude
NAD83                       ** Datum
    1.0                    ** Study radius for surface roughness (km)
Y                           ** Vary by sector? (Y/N)
    3                      ** Number of sectors
    0                      ** Start of sector 1
    90                     ** Start of sector 2
    225                    ** Start of sector 3
S                           ** Temporal resolution (A=ANNUAL, M=MONTHLY, S=SEASONAL)
N                           ** Continuous snow cover most of the winter? (Y/N)
Y                           ** Airport? (Y/N)
N                           ** Arid region? (Y/N)
A                           ** Surface Moisture (A=Average, W=Wet, D=Dry)

```

Figure 3-1. Contents of rdu_seamless.dat File for RDU Seamless Test Case

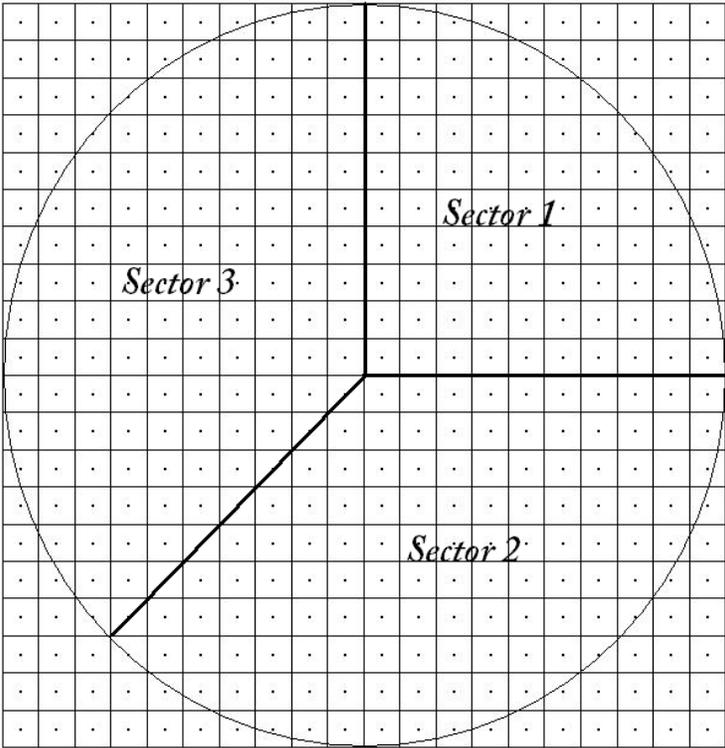


Figure 3-2. Diagram of User-specified Radius and Sector Definitions Overlaid on Land Cover Grid Cells

```

** Generated by AERSURFACE, dated 13016
** Generated from "rdu_seamless.tif"
** Center Latitude (decimal degrees):    35.891940
** Center Longitude (decimal degrees):   -78.781940
** Datum: NAD83
** Study radius (km) for surface roughness:  1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11
**
  FREQ_SECT SEASONAL  3
  SECTOR   1    0  90
  SECTOR   2   90 225
  SECTOR   3  225 360
**
  SITE_CHAR Season  Sect  Alb    Bo    Zo
  SITE_CHAR  1      1    0.15  0.85  0.027
  SITE_CHAR  1      2    0.15  0.85  0.025
  SITE_CHAR  1      3    0.15  0.85  0.166
  SITE_CHAR  2      1    0.14  0.63  0.037
  SITE_CHAR  2      2    0.14  0.63  0.032
  SITE_CHAR  2      3    0.14  0.63  0.206
  SITE_CHAR  3      1    0.15  0.36  0.046
  SITE_CHAR  3      2    0.15  0.36  0.038
  SITE_CHAR  3      3    0.15  0.36  0.240
  SITE_CHAR  4      1    0.15  0.85  0.037
  SITE_CHAR  4      2    0.15  0.85  0.032
  SITE_CHAR  4      3    0.15  0.85  0.215

```

Figure 3-3. Contents of rdu_seamless.out File for RDU Seamless Test Case

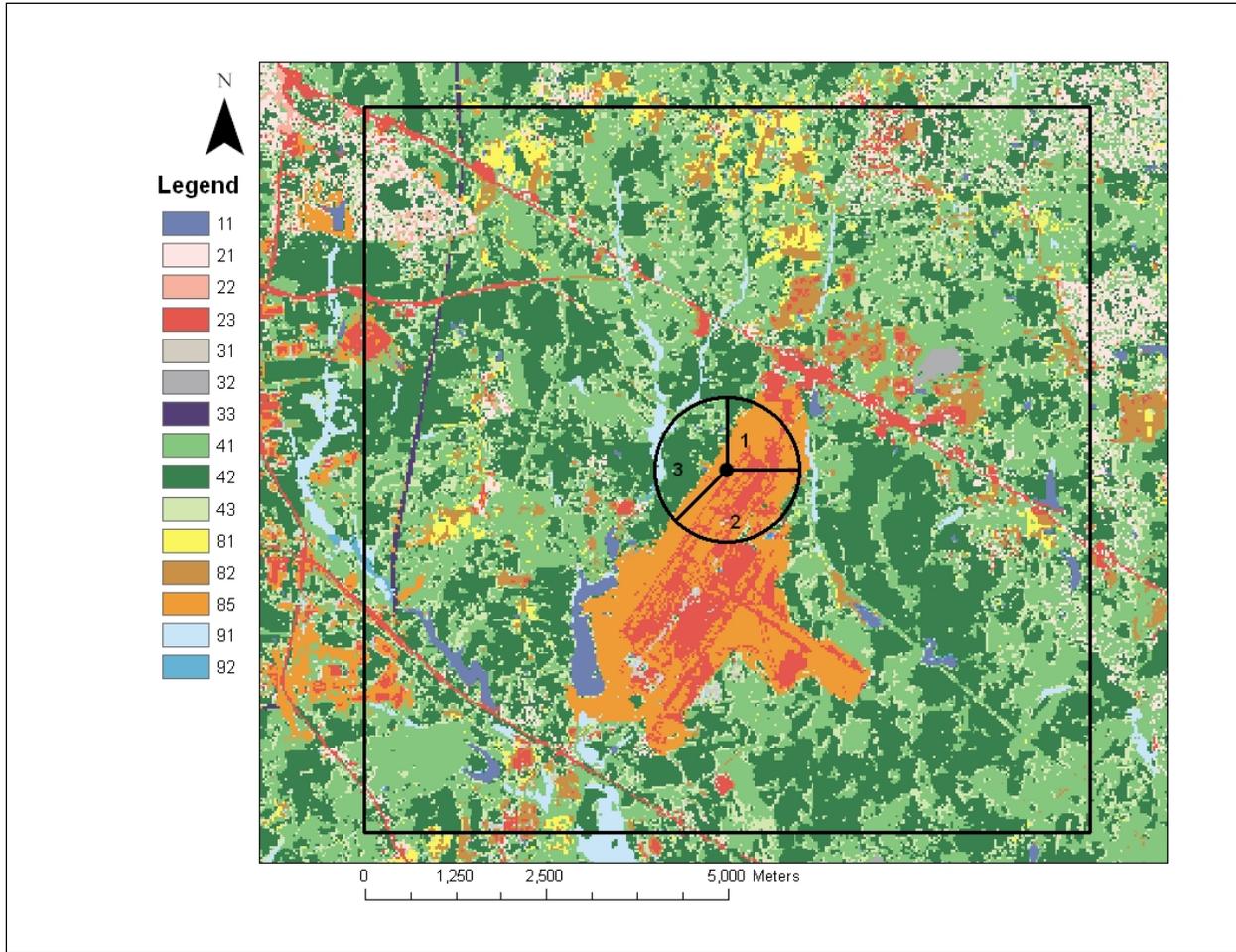


Figure 3-4. NLCD Plot for the RDU Seamless Test Case, Showing Albedo/Bowen Ratio Domain, and Surface Roughness Domain and Sectors

4.0 REFERENCES

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APPENDIX A. SURFACE CHARACTERISTICS TABLES

Tables A-1 through A-3 provide the values of albedo, Bowen ratio, and surface roughness, respectively, based on the NLCD92 land cover categories. Each table includes a column containing references used in estimating the values for each surface characteristic parameter and each land cover category. As explained in Section 2.0, more than one value of surface characteristics may be listed for certain land cover categories depending on user responses to specific prompts regarding the site location.

Table A-1. Seasonal Values of Albedo for the NLCD92 21-Land Cover Classification System

Class Number	Class Name	Seasonal Albedo Values ¹					Reference
		1	2	3	4	5	
11	Open Water	0.1	0.1	0.1	0.1	0.1	AERMET ^{2,3}
12	Perennial Ice/Snow	0.6	0.6	0.7	0.7	0.6	Stull & Garratt ⁴
21	Low Intensity Residential	0.16	0.16	0.18	0.45	0.16	(22+43+85)/3 ⁵
22	High Intensity Residential	0.18	0.18	0.18	0.35	0.18	Stull ⁶ & AERMET ⁷
23	Commercial/Industrial/Transp (Site at Airport)	0.18	0.18	0.18	0.35	0.18	Stull ⁶ & AERMET ⁷
	Commercial/Industrial/Transp (Not at Airport)	0.18	0.18	0.18	0.35	0.18	Stull ⁶ & AERMET ⁷
31	Bare Rock/Sand/Clay (Arid Region)	0.2	0.2	0.2	NA	0.2	Garratt ⁸
	Bare Rock/Sand/Clay (Non-arid Region)	0.2	0.2	0.2	0.6	0.2	Garratt ⁸ & AERMET ⁷
32	Quarries/Strip Mines/Gravel	0.2	0.2	0.2	0.6	0.2	Garratt ⁸ & AERMET ⁷
33	Transitional	0.18	0.18	0.18	0.45	0.18	same as 84 ⁹
41	Deciduous Forest	0.16	0.16	0.17	0.5	0.16	Stull ⁶ & AERMET ⁷
42	Evergreen Forest	0.12	0.12	0.12	0.35	0.12	Stull ⁶ & AERMET ⁷
43	Mixed Forest	0.14	0.14	0.14	0.42	0.14	(41+42)/2 ¹⁰
51	Shrubland (Arid Region)	0.25	0.25	0.25	NA	0.25	Stull ⁶
	Shrubland (Non-arid Region)	0.18	0.18	0.18	0.5	0.18	Estimate ¹¹ & AERMET ⁷
61	Orchards/Vineyards/Other	0.18	0.18	0.18	0.5	0.14	Estimate ¹²
71	Grasslands/Herbaceous	0.18	0.18	0.2	0.6	0.18	AERMET ²
81	Pasture/Hay	0.2	0.2	0.18	0.6	0.14	AERMET ^{2,13}
82	Row Crops	0.2	0.2	0.18	0.6	0.14	AERMET ^{2,13}
83	Small Grains	0.2	0.2	0.18	0.6	0.14	AERMET ^{2,13}
84	Fallow	0.18	0.18	0.18	0.6	0.18	Garratt ⁸
85	Urban/Recreational Grasses	0.15	0.15	0.18	0.6	0.15	Estimate ¹⁴
91	Woody Wetlands	0.14	0.14	0.14	0.3	0.14	Stull ⁶ & AERMET ⁷
92	Emergent Herbaceous Wetlands	0.14	0.14	0.14	0.3	0.14	Stull ⁶ & AERMET ⁷

¹ Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals

² Estimate based on AERMET User's Guide, Table 4-1.

³ We assume no freeze of the water and no seasonal changes in albedo.

⁴ Estimate based on Stull, Table C-7 and Garratt, Table A8. Assume fresher snow and more ice in seasonal categories 3 & 4 and older snow in seasonal categories 1, 2, & 5.

⁵ Assume an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses."

⁶ Estimate based on Stull, Table C-7.

⁷ Estimate based on AERMET User's Guide, Table 4-1 albedo value for winter with continuous snow cover.

⁸ Estimate based on Garratt, Table A8.

⁹ Assume "Transitional" is similar to Class 84: "Fallow". A warning will be issues to the user if this category appears in more than 10% of the land cover data.

¹⁰ Estimate based on the average of Classes 41 and 42.

¹¹ Estimate based on the non-arid shrubland having more vegetation than the arid-region shrubland.

¹² Estimate based Class 51: "Shrubland (non-arid region)" for seasonal categories 1, 2 & 4 and AERMET User's Guide ("Cultivated Land") for seasonal categories 3 & 5.

¹³ Estimate based on AERMET User's Guide; assume more vegetation in summer and soil being wetter in spring than in fall.

¹⁴ Estimate based on AERMET User's Guide ("Cultivated Land") for seasonal category 3 & 4, and Garratt, Table A8 for seasonal categories 1, 2 & 5.

Table A-2. Seasonal Values of Bowen Ratio for the NLCD92 21-Land Cover Classification System

Class Number	Class Name	Seasonal Bowen Ratio ¹ – Average					Seasonal Bowen Ratio ¹ - Wet					Seasonal Bowen Ratio ¹ - Dry					Reference	
		1	2	3	4 ²	5	1	2	3	4 ²	5	1	2	3	4 ²	5		
11	Open Water	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	AERMET&Oke ₃
12	Perennial Ice/Snow	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	AERMET&Oke ₃
21	Low Intensity Residential	0.8	1	1	0.5	0.8	0.6	0.6	0.6	0.5	0.6	2	2.5	2.5	0.5	2	Estimate ⁴	
22	High Intensity Residential	1.5	1.5	1.5	0.5	1.5	1	1	1	0.5	1	3	3	3	0.5	3	AERMET&Oke ₃	
23	Commercial/Industrial/Transp (Site at Airport)	1.5	1.5	1.5	0.5	1.5	1	1	1	0.5	1	3	3	3	0.5	3	AERMET&Oke ₃	
	Commercial/Industrial/Transp (Not at Airport)	1.5	1.5	1.5	0.5	1.5	1	1	1	0.5	1	3	3	3	0.5	3	AERMET&Oke ₃	
31	Bare Rock/Sand/Clay (Arid Region)	4	6	6	NA	3	1.5	2	2	NA	1	6	10	10	NA	5	AERMET&Oke ₃	
	Bare Rock/Sand/Clay (Non-arid Region)	1.5	1.5	1.5	0.5	1.5	1	1	1	0.5	1	3	3	3	0.5	3	AERMET&Oke ₃	
32	Quarries/Strip Mines/Gravel	1.5	1.5	1.5	0.5	1.5	1	1	1	0.5	1	3	3	3	0.5	3	AERMET&Oke ₃	
33	Transitional	1	1	1	0.5	1	0.7	0.7	0.7	0.5	0.7	2	2	2	0.5	2	Estimate ⁵	
41	Deciduous Forest	0.3	1	1	0.5	0.7	0.2	0.4	0.4	0.5	0.3	0.6	2	2	0.5	1.5	AERMET&Oke ₃	
42	Evergreen Forest	0.3	0.8	0.8	0.5	0.7	0.2	0.3	0.3	0.5	0.3	0.6	1.5	1.5	0.5	1.5	AERMET&Oke ₃	
43	Mixed Forest	0.3	0.9	0.9	0.5	0.7	0.2	0.35	0.35	0.5	0.3	0.6	1.75	1.75	0.5	1.5	(41+42)/2 ⁶	
51	Shrubland (Arid Region)	4	6	6	NA	3	1.5	2	2	NA	1	6	10	10	NA	5	AERMET&Oke ₃	
	Shrubland (Non-arid Region)	1	1.5	1.5	0.5	1	0.8	1	1	0.5	0.8	2.5	3	3	0.5	2.5	Estimate ⁷	
61	Orchards/Vineyards/Other	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃	
71	Grasslands/Herbaceous	0.8	1	1	0.5	0.4	0.4	0.5	0.5	0.5	0.3	2	2	2	0.5	1	AERMET&Oke ₃	
81	Pasture/Hay	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃	
82	Row Crops	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃	
83	Small Grains	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃	

84	Fallow	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃
85	Urban/Recreational Grasses	0.5	0.7	0.7	0.5	0.3	0.3	0.4	0.4	0.5	0.2	1.5	2	2	0.5	1	AERMET&Oke ₃
91	Woody Wetlands	0.2	0.2	0.3	0.5	0.2	0.1	0.1	0.1	0.5	0.1	0.2	0.2	0.2	0.5	0.2	Estimate ⁷
92	Emergent Herbaceous Wetlands	0.1	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.5	0.1	0.2	0.2	0.2	0.5	0.2	AERMET&Oke ₃

¹ Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals.

² Values for seasonal category 4 are based on the AERMET User's Guide (EPA, 2004a) and Oke (1978), Tables 4-2a-c, Bowen ratio values for winter with continuous snow cover, except for class 11 with the assumption the water does not freeze.

³ Values for seasonal categories 1, 2, 3 & 5 are based on AERMET User's Guide (EPA, 2004a), Tables 4-2a-c and Oke (1978).

⁴ Estimate based on composition being an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses."

⁵ Estimate based on the Bowen ratio of "Transitional" being between the Bowen ratio of Classes 31 and 71.

⁶ Assume "Mixed Forest" is composed of equal parts of "Deciduous Forest" and "Evergreen Forest."

⁷ Estimate based on comparison to Bowen ratio for other classes.

Table A-3. Seasonal Values of Surface Roughness (m) for the NLCD92 21-Land Cover Classification System

Class Number	Class Name	Seasonal Surface Roughness ¹ (m)					Reference
		1	2	3	4	5	
11	Open Water	0.001	0.001	0.001	0.001	0.001	Stull ²
12	Perennial Ice/Snow	0.002	0.002	0.002	0.002	0.002	Stull ²
21	Low Intensity Residential	0.40	0.40	0.30	0.30	0.40	50% 22 + 25% 43+ 25% 85 ³
22	High Intensity Residential	1	1	1	1	1	AERMET ⁴
23	Commercial/Indust/Transp (Site at Airport)	0.07	0.07	0.07	0.07	0.07	10% 22 & 90% 31 ⁵
	Commercial/Industrial/Transp (Not at Airport)	0.7	0.7	0.7	0.7	0.7	90% 22 & 10% 31 ⁵
31	Bare Rock/Sand/Clay (Arid Region)	0.05	0.05	0.05	NA	0.05	Slade ⁶
	Bare Rock/Sand/Clay (Non-arid Region)	0.05	0.05	0.05	0.05	0.05	Slade ⁶
32	Quarries/Strip Mines/Gravel	0.3	0.3	0.3	0.3	0.3	Estimate ⁷
33	Transitional	0.2	0.2	0.2	0.2	0.2	Estimate ⁸
41	Deciduous Forest	1.3	1.3	0.6	0.5	1	AERMET ⁴
42	Evergreen Forest	1.3	1.3	1.3	1.3	1.3	AERMET ⁴
43	Mixed Forest	1.3	1.3	0.9	0.8	1.1	50% 41 & 50% 42 ⁹
51	Shrubland (Arid Region)	0.15	0.15	0.15	NA	0.15	50% 51 (Non-Arid) ¹⁰
	Shrubland (Non-arid Region)	0.3	0.3	0.3	0.15	0.3	AERMET ⁴
61	Orchards/Vineyards/Other	0.3	0.3	0.1	0.05	0.2	Garratt ¹¹
71	Grasslands/Herbaceous	0.1	0.1	0.01	0.005	0.05	AERMET ⁴
81	Pasture/Hay	0.15	0.15	0.02	0.01	0.03	Garratt ¹¹ & Slade ¹²
82	Row Crops	0.2	0.2	0.02	0.01	0.03	Garratt ¹¹ & Slade ¹²
83	Small Grains	0.15	0.15	0.02	0.01	0.03	Garratt ¹¹ & Slade ¹²
84	Fallow	0.05	0.05	0.02	0.01	0.02	31 & 81,82,83 ¹³
85	Urban/Recreational Grasses	0.02	0.015	0.01	0.005	0.015	Randerson ¹⁴
91	Woody Wetlands	0.5	0.5	0.4	0.3	0.5	50% 43 & 50% 92 ¹⁵
92	Emergent Herbaceous Wetlands	0.2	0.2	0.2	0.1	0.2	AERMET ⁴

¹ Values are listed for the following seasonal categories: 1 - Midsummer with lush vegetation; 2 - Autumn with unharvested cropland; 3 - Late autumn after frost and harvest; or winter with no snow; 4 - Winter with continuous snow on ground; 5 - Transitional spring with partial green coverage or short annuals

² Estimate based on Stull, Fig 9.6. We have specified a larger roughness than the AERMET "calm open sea" roughness value because we have assumed that most of the water is closer to land and will experience waves and be closer to the shoreline, increasing roughness.

³ Assume 50% "High Intensity Residential" (22), 25% "Mixed Forest" (43), and 25% "Urban/Recreational Grasses" (85), using a weighted geometric mean value.

⁴ Based on the AERMET User's Guide (EPA, 2004a), Table 4-3.

⁵ For airport sites, assume 90% of land cover is "Transportation" with roughness similar to Class 31 (Bare Rock/ Sand/ Clay) and 10% is "Commercial/Industrial" with roughness similar to Class 22 (High Intensity Residential). For non-airport, assume 10% of land cover is "Transportation" and 90% is "Commercial/Industrial". Weighted geometric mean values are used.

⁶ Estimate based on Slade, Table 3-1, assuming the surface is not completely level due to inclusion of some larger rocks.

⁷ Estimate reflecting "significant surface expression"

⁸ Estimate reflecting significant mix of different land cover classes. A warning will be issued to the user if this category appears in more than 10% of the land cover data.

⁹ Assume "Mixed Forest" is 50% "Deciduous Forest" and 50% "Evergreen Forest", using a weighted geometric mean value.

¹⁰ Assume arid region would have approximately 50% less vegetation than a non-arid region.

¹¹ Estimate based on Garratt, Table A6.

¹² Estimate based on Slade, Table 3-1

¹³ Based on class 31 ("Bare Rock/Sand/Clay") for seasonal categories 1 & 2 and 81, 82, 83 ("Pasture/Hay", "Row Crops" & "Small Grains") for seasonal categories 3, 4, & 5, with seasonal category 5 having a more similar amount of vegetation to seasonal category 3 and, therefore, the same roughness.

¹⁴ Estimate based on Randerson, Table 5.4

¹⁵ Assume 50% Mixed Forest (43) and 50% Emergent Herb Wetlands (92), using a weighted geometric mean value.

APPENDIX B. DESCRIPTIONS OF NLCD92 LAND COVER CATEGORIES

The following information, taken from the USGS documentation on the NLCD92, provides more detailed descriptions of the 21 land cover categories in NLCD92.

Water

All areas of open water or permanent ice/snow cover.

Open Water - All areas of open water; typically 25 percent or greater cover of water (per pixel).

Perennial Ice/Snow - All areas characterized by year-long cover of ice and/or snow.

Developed

Areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.

High Intensity Residential - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to 100 percent of the cover.

Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren

Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

Bare Rock/Sand/Clay - Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.

Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression.

Transitional - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).

Forested Upland

Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.

Shrubland

Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Non-natural Woody

Areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25-100 percent of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.

Orchards/Vineyards/Other - Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.

Herbaceous Upland

Upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

Planted/Cultivated

Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

Row Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

Small Grains - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

Fallow - Areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.

Urban/Recreational Grasses - Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.

Wetlands

Areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al. *Woody Wetlands* - Areas where forest or shrubland vegetation accounts for 25-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for 75-100 percent of the cover and the soil or substrate is periodically saturated with or covered with water.

