ADEC Guidance re AERMET Geometric Means

How to Calculate the
Geometric Mean Bowen Ratio and the
Inverse-Distance Weighted Geometric Mean Surface Roughness Length
in Alaska

Alaska Department of Environmental Conservation
Air Permits Program
Revised June 17, 2009

April 7, 2009 Note: ADEC revised this guidance to correct mathematical errors found in Tables 2 and 3. Other than these corrections, this revision is identical to the original April 23, 2008 version of this guidance.

June 17, 2009 Note: ADEC added clarification regarding the approach for when the land classification is homogeneous.

INTRODUCTION

This guidance describes alternative methods for determining the "geometric mean Bowen Ratio" and the "inverse-distance weighted geometric mean surface roughness length" needed by AERMET, for those situations where AERSURFACE is not a viable option.

BACKGROUND

The January 9, 2008 *AERMOD Implementation Guide* issued by the U.S. Environmental Protection Agency (EPA) states:

- 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 …" and
- 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."

EPA has also released a computer program (AERSURFACE) to calculate these values from the U.S. Geological Survey (USGS) National Land Cover Data 1992 archives (NLCD92) – see http://landcover.usgs.gov/natllandcover.php for additional information regarding the NLCD92 data set. Unfortunately, the NLCD92 database is not available for all of Alaska, which means AERSURFACE is not a viable tool for those areas. Availability is changing though, which means the website should be checked for the current status.

When AERSURFACE cannot be run, the geometric means must be hand-calculated from the estimated fractions of the surface characteristics found within a given area. Since land fractions must be used for this estimate rather than a gridded database, the land fraction must be used to weight all surface parameters, including the Bowen Ratio. The recommended approach for making these calculations is based on the following principals and equations.

The geometric mean of a data set $[x_1, x_2, \ldots, x_n]$ is given by the equation:

(*Eq 1*) $$\text{Geometric Mean} = (x_1 \cdot x_2 \cdot \ldots \cdot x_n)^{1/n}$$

The weighted geometric mean ($\bar{x}$) is given by the equation:

(*Eq 2*) $$\bar{x} = [(x_1)^{w_1} \cdot (x_2)^{w_2} \cdot \ldots \cdot (x_n)^{w_n}]^{1/\Sigma(w)}$$

where w_i is the weighted value for each data point.

The weighted geometric mean can also be expressed as:

(*Eq 3*) $$\bar{x} = \left(\prod_{i=1}^{n} x_i^{w_i} \right)^{1/\sum_{i=1}^{n} w_i} = \exp\left(\frac{\sum_{i=1}^{n} w_i \ln(x_i)}{\sum_{i=1}^{n} w_i} \right)$$

SUGGESTED METHOD

- Use EPA's stated guidance for determining the applicable areas/sectors for calculating the Bowen Ratio and Surface Roughness Length.
- Use photographs, site visits, maps, etc., to determine the types of land classifications for the given area/sector.
- Estimate the fraction of land that each classification covers within the given area/sector. When assessing the surface roughness length, also estimate the approximate distance (in kilometers) to the centroid of each classification.
- Put the above values in a table, along with the seasonal Bowen Ratio or Surface Roughness Length (as applicable) associated with each classification.
- When calculating the geometric mean Bowen ratio, weight each value by the applicable land fraction.
- When calculating the inverse weighted geometric mean surface roughness length, weight each value by the applicable land fraction divided by the distance.

Example Calculation – Bowen ratio

The land within a 10 km by 10 km domain centered on the meteorological tower can be classified as indicated in Table 1. The area of each classification, the fraction of the total area and the associated Bowen ratio (*B*) for a given season (winter), are also shown.

The geometric mean Bowen ratio ($\bar{B}$) would therefore be:

(*Eq 4*) $$\bar{B} = [(0.5)^{0.57} \cdot (6)^{0.37} \cdot (6)^{0.02} \cdot (0.5)^{0.02} \cdot (0.5)^{0.01} \cdot (0.1)^{0.01}]^{1/1}$$

$$\bar{B} = \mathbf{1.30}$$

Table 1 – Bowen Ratio Example

Land Cover Category	Area (km^2)	Fraction of Total Area	Bowen Ratio
Evergreen Forest	57	0.57	0.5
Shrubland	37	0.37	6
Bare Rock/Sand/Clay	2	0.02	6
Quarries/Strip Mines/Gravel Pits	2	0.02	0.5
Low Intensity Residential	1	0.01	0.5
Open Water	1	0.01	0.1
TOTAL	100	1.00	

Example Calculation – Surface Roughness Length

The land within a 1-km radius of the meteorological tower can be divided into sectors. One of the sectors has the classifications indicated in Table 2. The area of each classification, the fraction of the total area, the distance between the meteorological tower and the centroid of each classification are also shown, along with the inverse of the distance, the weighting value (fraction divided by distance), and the associated surface roughness (s_z) for a given season (summer).

Table 2 – Surface Roughness Length Example

Land Cover Category	Area (km^2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	s_z (m)
Evergreen Forest	1.26	0.40	0.66	0.61	1.3
Shrubland	0.79	0.25	0.13	1.92	0.15
Low Intensity Residential	0.63	0.20	0.74	0.27	0.54
Open Water	0.46	0.15	0.23	0.65	0.001
TOTAL	3.14	1.00		3.45	

The inverse-distance weighted geometric mean surface roughness length $\overline{s_z}$ would therefore be:

(Eq 5) $$\overline{s_z} = [(1.3)^{0.61} \cdot (0.15)^{1.92} \cdot (0.54)^{0.27} \cdot (0.001)^{0.65}]^{(1/3.45)}$$

$$\overline{s_z} = \mathbf{0.094}$$

The surface roughness length could also be calculated using the logarithmic approach. In this case, the table could be expanded to include the natural logarithm of each surface roughness length; and the product of the weighting and natural logarithm; as illustrated in Table 3.

Table 3 – Alternative Surface Roughness Length Example

Land Cover Category	Area (km^2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	s_z (m)	Ln (s_z)	Wt · Ln (s_z)
Evergreen Forest	1.26	0.40	0.66	0.61	1.3	0.262	0.160
Shrubland	0.79	0.25	0.13	1.92	0.15	-1.897	-3.642
Low Intensity Residential	0.63	0.20	0.74	0.27	0.54	-0.616	-0.166
Open Water	0.46	0.15	0.23	0.65	0.001	-6.908	-4.490
TOTAL	3.14	1.00		3.45			-8.139

In this case, the inverse-distance weighted geometric mean surface roughness length $\overline{s_z}$ would be calculated as:

(Eq 6) $$\overline{s_z} = \exp(-8.139 / 3.45)$$

$$\overline{s_z} = \mathbf{0.095}$$ (*note: the difference in values is due to round-off error*)

ADDITIONAL COMMENTS

Albedo should be based on an arithmetic mean, weighted by land-fraction, of the values found in a 10 km by 10 km domain centered on the meteorological measurement site. As stated in EPA's AERMOD Implementation Guide, albedo has no direction or distance dependency (i.e., no sector or inverse-distance weighting).

In all cases, the surface characteristics should be calculated on a monthly basis rather than a quarterly or annual basis. Applicants will also need to document and justify their selected values. Justification can include, but is not limited to: maps, photographs, and published reports/studies of local surface characteristics.

The surface characteristics provided by EPA in the AERMET and AERSURFACE User Guides may be used when local data is unavailable (which is the typical case). *However, be aware that EPA used different assumptions in reporting the winter Bowen Ratio values in these two documents.* In the AERMET User's Guide, EPA assumed continuous snow cover. In the AERSURFACE User's Guide, EPA assumed some snow melt occurs during the day. Therefore, for most parts of Alaska, the values reported in the AERMET User's Guide may be more appropriate than the values reported in the AERSURFACE User's Guide.

If the land-use classification is homogeneous (e.g., all tundra), then the surface roughness length, Bowen ratio, and albedo for the given classification and month can be used without going through the calculations provided in this guidance.

The Department encourages applicants to provide their proposed values in a modeling protocol prior to conducting the modeling analysis. This step allows the Department to review and approve the proposed approach prior to incurring the expense of conducting the actual modeling analysis.