Validation Testing of the Area-Source Technique Using EPA Method TO-16

Conference Paper · March 2016

Timothy Minnich
Minnich and Scotto, Inc.

Validation Testing of the Area-Source Technique Using EPA Method TO-16

Final Extended Abstract # 31
Presented at the conference:
Air Quality Measurement Methods and Technology
March 15-17, 2016
Chapel Hill, NC

Timothy R. Minnich,[1] Robert L. Scotto,[1] Stephen H. Perry,[2] Olga Pikelnaya,[3] Andrea Polidori,[3] Laki Tisopulos,[3] Susan Stuver,[4] Jesse Alonzo[4]; [1]Minnich and Scotto, Inc., Freehold, New Jersey, [2]Kassay Field Services, Inc., Mohrsville, Pennsylvania, [3]South Coast Air Quality Management District, Diamond Bar, California, [4]Texas A&M University, Institute of Renewable Natural Resources, San Antonio, Texas

INTRODUCTION

The need to develop accurate methods for quantifying air pollutant emissions rates from fugitive-type industrial sources is becoming increasingly important, both in this country and abroad. Presented are two sets of validation test results for the area-source technique, a mass-balance emission-rate measurement method applicable to most small ground-level sources. In each study, a tracer gas was released at known emission rates, with coincident measurements of onsite meteorology and downwind tracer-gas concentrations.

A RAM2000 G2 open-path FTIR spectrometer (EPA Method TO-16), manufactured by Kassay Field Services, Mohrsville, Pennsylvania, was employed for all tracer-gas measurements. All emission-rate work reported on herein was performed by Minnich and Scotto, as part of the Kassay team.

The first study discussed, led by TAMU/IRNR and referred to as the South Texas study (Dimmit County, November 4-5, 2015), involved the controlled release of sulfur hexafluoride (SF_6) from locations near a compressor/condensate-tank complex and an assembly of gas-gathering pipelines, both configurations typical of the oil and gas industry.[1] The second study discussed, sponsored by the SCAQMD, was carried out first (October 12-13, 2015) and involved the controlled release of propane from a large parking lot at Anaheim Stadium; it was part of a larger R&D effort to evaluate four optical remote sensing (ORS) techniques (separate contractors) for the measurement of emission rates from a variety of industrial source types.[2] In each study, the emission rates were measured using the area-source technique and compared to the known release rates. All tracer releases were modeled as a circular area source with a 1-meter radius.

The area-source technique quantifies gaseous contaminant emissions from ground-level area-type sources, such as oil and gas production well-pad components, wastewater lagoons and ponds, landfills, and hazardous waste sites. Developed by EPA's Environmental Response Team in the early 1990s to derive emission factors during pilot-scale Superfund remediations,[3-6] the area-source technique is intended for use with optical remote sensing (ORS) – either FTIR, UV, or TDL open-path spectroscopy – in which a path-integrated concentration (PIC) is generated in the cross-plume dimension, i.e., a "whole-plume" approach. Parameterization of plume transport and dispersion within the microscale region between the source and the downwind measurement path, via sophisticated surface-based meteorological monitoring, obviates the need for measuring contaminant concentrations or meteorological parameters in the vertical dimension.[3]

The analysis reduces to one of conservation of mass, as the extent of the pollutant's lateral and vertical dispersion is accounted for. The area-source technique involves the 15-minute-averaged cross-plume measurement of source attribution, and the subsequent back-calculation of a coincident emission rate (mass per time) based on Gaussian dispersion relationships inherent in most EPA air dispersion models; in this case, the model is AERMOD, EPA's Guideline Gaussian air dispersion model. Sometimes referred to as inverse modeling, this back-calculated emission rate can be thought of as the "snapshot" (15-minute-averaged) emission rate required to yield the measured downwind path-integrated concentration under the atmospheric conditions near the source during that precise 15-minute period.

Gaussian models assume that pollutants from a source exhibit a Gaussian distribution in the horizontal and vertical dimensions as the plume is transported downwind. Another type of model employed to back-calculate emission rates is the Lagrangian stochastic model, commonly referred to as backward-Lagrangian stochastic (bLS) modeling.[7, 8] Lagrangian models follow pollution plume parcels in a random walk fashion using a moving frame of reference; they yield dispersion calculations at receptors by computing the statistics of the trajectories of a large number of such parcels as they move from their initial location. Another ORS-based method for measuring emission rates is the vertical radial plume mapping (VRPM) method, in which the mass flux of pollutants is measured, via multiple non-intersecting beam paths, downwind of an emission source.[9] Although comparisons of the bLS and VRPM approaches with the area-source technique is beyond the scope of this paper, the latter method is logistically easiest to implement, especially with the use of specialized emissions-calculation software (discussed below).

Earlier work on application of the area-source technique was based on the ISCST3 Model, as the more sophisticated AERMOD was not yet available. To our knowledge, formal validation of this technique using either dispersion model, until now, has never been attempted.

All results presented are based solely on AERMOD[10, 11] and supported by e-Calc©, Minnich and Scotto's Windows-based software to calculate, in real time, contaminant emission rates based on the area-source technique (using AERMOD).[1, 12] E-Calc employs the EPA regulatory version of AERMOD in order to maintain the model's legal Guideline status. The generation of input files requires event-specific meteorological data together with emissions-characterization and monitoring configuration data. E-Calc computes wind-speed profiles and dispersion coefficients based on surface characteristics, solar insolation, and statistical data treatments such as the standard deviations of the vertical wind speed and horizontal wind direction. It should be noted that successful employment of the area-source technique does not depend upon use of e-Calc, as all AERMOD software coding resides in the public domain.

EXPERIMENTAL DESIGN

South Texas Study

SF_6 was released continually from ground-level locations simulating a compressor/condensate tank complex on the first day (November 4), and an assembly of gas-gathering pipelines on the second day (November 5). The FTIR beam height was about 1 meter above grade on each day.

On the first day, the SF_6 was released atop a 4-meter berm near the compressor/condensate tank complex to simulate release from an immediately adjacent tank top. The FTIR beam path was oriented normal to a wind blowing from 135 degrees (a southeast wind direction), and the acceptable wind-direction range was between 90 and 180 degrees. The pathlength was 85 meters (downwind normal distance of 39 meters).

On the second day, the SF_6 was released from an area of flat terrain, in close proximity to the gas-gathering pipelines. The beam path was oriented normal to a wind blowing from 150 degrees (a south-southeast wind direction), and the acceptable wind-direction range was between 105 and 195 degrees. The pathlength was 118 meters (downwind normal distance of 32 meters).

SCAQMD Study

Over the two-day study, propane was released at varying emission rates from a scissors-type lift from pre-designated heights of 3.0, 6.4, and 7.9 meters. Neither the Kassay team nor the other contractors were privy to the emission-rate values, only when the emission rates were changed.

On the first day (October 12), the FTIR beam path was oriented normal to a wind blowing from 230 degrees (a southwest wind direction), and the acceptable wind-direction range was between 185 and 275 degrees; the pathlength was 136 meters (downwind normal distance of 33 meters).

On the second day (October 13), the beam-path orientation and acceptable wind-direction range were the same as the first day; however, the pathlength was 153 meters (downwind normal distance of 23 meters). The beam height was about 1 meter above ground on each day.

RESULTS

South Texas Study

Table 1 presents the mean actual-vs.-predicted SF_6 emission rates for each valid 15-minute monitoring event for the South Texas study. The number of 15-minute events comprising each measurement campaign is shown, together with the mean actual and predicted emission rates (mg/s), as well as the predicted-to-actual (P/A) ratios (%). As noted above, all tracer-gas releases were from ground-level.

Table 1. Mean Actual-vs.-Predicted SF_6 Emission Rates: South Texas Study

No. of Events	Mean SF_6 Emission Rate: AERMET-Derived z_o			Mean SF_6 Emission Rate: z_o = 0.05 Meter		
	Actual (mg/s)	Predicted (mg/s)	P-to-A Ratio (%)	Actual (mg/s)	Predicted (mg/s)	P-to-A Ratio (%)
NOVEMBER 4, 2015 — Measurement Campaign 1 — Compressor/Condensate Tank Complex						
4	125.3	205.2	163.8	125.3	171.8	137.1
NOVEMBER 5, 2015 — Measurement Campaign 2 — Gas-Gathering Pipelines						
16	108.7	166.1	152.8	108.7	134.6	123.9

An important parameter for wind profiling in AERMOD is the surface roughness length (z_o), which is related to the height of the obstacles to the wind flow. The EPA defines z_o as, "the [greatest] height above the ground at which the horizontal wind velocity is typically zero."[13] Values range from less than 0.001 meter over a calm water surface to 1 meter or more over a forest or urban area. Incorporation of surface roughness allows for the calculation of friction velocity, which is used directly in AERMOD to simulate plume dispersion and transport.

Representative z_o values in the upwind area of interest can be determined by: (a) employing the procedure based on surrounding land use (via USGS data) per AERMET, AERMOD's meteorological preprocessor; or (b) simply assigning an appropriate value from look-up tables. In general, it is preferable to use the AERMET-derived value when the upwind area of influence acting upon the source is large, e.g., where stack emissions from a large power plant are modeled. Conversely, use of the "look-up" option for z_o assignment (herein also referred to as the "adjusted" z_o option) may lead to more accurate results when the upwind area of influence is more limited, as is the case of South Texas study.

Predicted emission rates shown in Table 1 are based z_o values determined via each of the above two options. The site-specific z_o values calculated by AERMET ranged between 0.132 and 0.134 meter, depending on the actual wind direction and the resultant upwind terrain. The adjusted z_o value assigned was 0.05 meter, based on recommendations by the Texas Commission on Environmental Quality (TCEQ) for relatively flat terrain with sparse, short vegetation.[14]

Table 1 shows that the adjusted z_o value (0.05 meter) yielded superior results as compared to the AERMET-derived z_o values. For the compressor/condensate tank complex, the P/A ratios were 137.1 vs. 163.8 percent (where 100 percent is a perfect mean prediction). For the gas-gathering pipelines, the P/A ratios were 123.9 vs. 152.8 percent. Although not shown, the P/A ratios for the adjusted z_o treatment evidenced strong event-to-event reproducibility, ranging between 128.3

and 145.8 percent for the compressor/condensate tank complex (mean of 137.1 percent over four events), and between 103.8 and 139.3 percent for the gas-gathering pipelines (mean of 123.9 percent over sixteen events).

Figures 1 and 2 show, for each 15-minute monitoring event, the predicted and actual emission rates for the AERMET-derived z_o values and the adjusted z_o value (0.05 meter), respectively, for the South Texas study (both sources combined). Also depicted are the coefficients of variation (CV) of the root-mean-square deviations (RMSD), and the coefficients of determination (r^2).

Figure 1. P/A Emission Rates for the South Texas Study: AERMET-Derived z_o

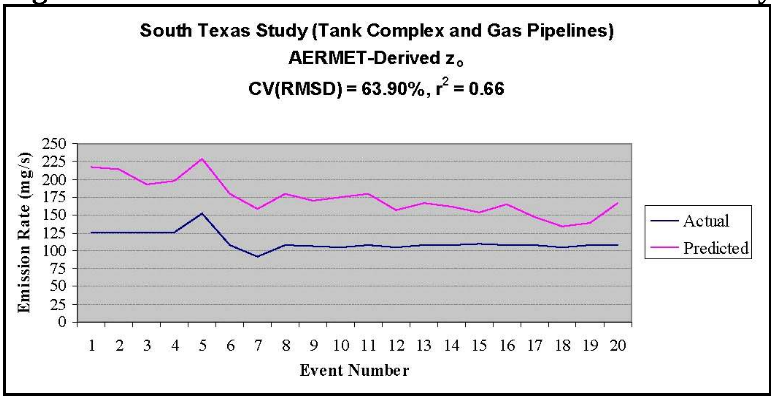
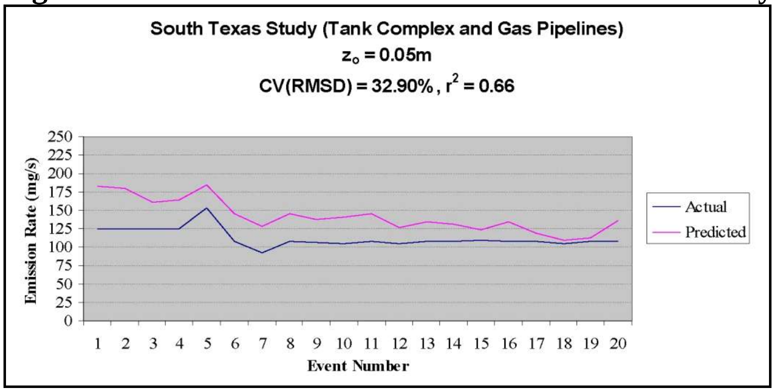


Figure 2. P/A Emission Rates for the South Texas Study: z_o = 0.05m



We also elected to examine whether we could improve upon the P/A ratio still further by assigning an adjusted z_o value of 0.01 meter for each source.

Figures 3 and 4 show, for each 15-minute monitoring event, the predicted and actual emission rates for the adjusted z_o value of 0.01 meter for compressor/condensate tank complex (Day 1, Campaign 1) and the gas-gathering pipelines (Day 2, Campaign 2), respectively, for the South Texas study.

Figure 3. P/A Emission Rates for the South Texas Study: Tank Complex, z_o = 0.01m

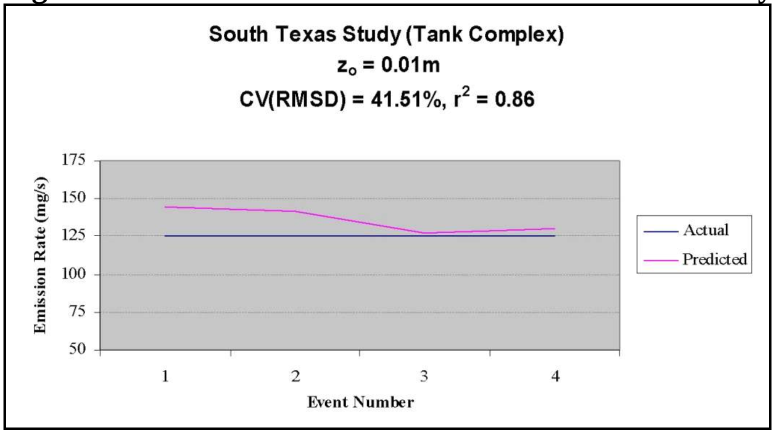
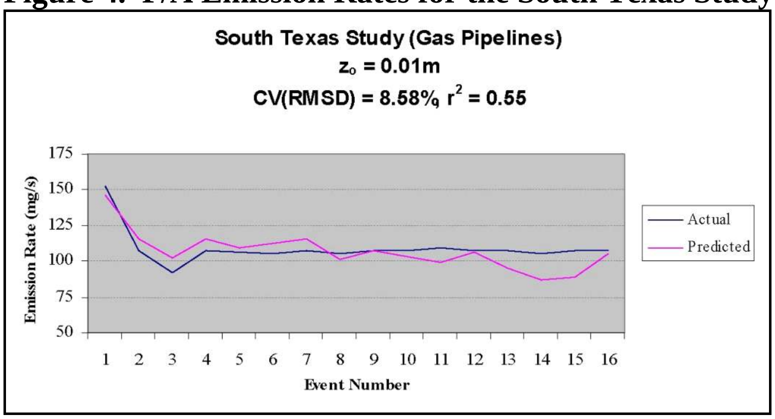


Figure 4. P/A Emission Rates for the South Texas Study: Gas Pipelines, z_o = 0.01m



SCAQMD Study

Table 2 presents the mean actual-vs.-predicted emission rates for each valid 15-minute monitoring event for the SCAQMD study. As with Table 1, the number of 15-minutes events comprising each measurement campaign is shown, together with the mean actual and predicted emission rates, as well as the P/A ratios. In this study, however, the tracer-gas release height was 3 meters, and measurement campaigns were denoted by changes in the propane emission rate.

As mentioned earlier, the SCAQMD study included tracer-gas releases from heights greater than 3 meters. The Kassay team, however, did not participate in these other releases, as the area-source technique is not intended to be applied to elevated sources. As it turned out, even the 3-meter release height proved problematic, especially during the second day (refer to the P/A ratio column for the 3-meter release treatment, which also employed an adjusted z_o value of 0.05 meter, based on professional judgement for a parking lot with scattered upwind obstructions).

Table 2. Mean Actual-vs.-Predicted Propane Emission Rates: SCAQMD Study

No. of Events	Mean Propane Emission Rate: 3-Meter Release (z_o = 0.05 Meter)			Mean Propane Emission Rate: Ground-Level Release Simulation (z_o = 0.25 Meter)		
	Actual (mg/s)	Predicted (mg/s)	P-to-A Ratio (%)	Actual (mg/s)	Predicted (mg/s)	P-to-A Ratio (%)
OCTOBER 12, 2015 – Measurement Campaign 1						
1	4,773.85	3,797.5	79.5	4,773.85	4,388.64	91.9
Measurement Campaign 2						
4	1,603.21	908.7	56.7	1,603.21	1,088.29	67.9
Measurement Campaign 3						
4	3,215.64	2,751.6	85.6	3,215.64	3,139.25	97.6
Measurement Campaign 4						
4	4,817.45	3,269.5	67.9	4,817.45	3,746.99	77.8
OCTOBER 13, 2015 – Measurement Campaign 5						
4	3,858.67	5,318.8	137.8	3,858.67	3,473.79	90.0
Measurement Campaign 6						
3	6,673.82	14,583.2	218.5	6,673.82	6,479.18	97.1

At the time, we thought that the plume centerline would be brought to the ground immediately upon the tracer-gas release. The logic was that the solid volume created by the fully collapsed scissors-lift structure from which the propane was released would cause the air to flow up over it and then down the other side, as opposed to passing right through it (as it did when the lift was extended for the other releases). Such was not the case, however. As discussed in the user's manual for implementing the Building Profile Input Program for the Plume Rise Enhancement Model,[15] we subsequently determined the collapsed structure to be insufficient to cause a significant wake effect.

Based on the above downwash issue, we decided to re-run e-Calc for all 20 individual monitoring events using a ground-level release simulation (instead of the actual release height of 3 meters), with three separate determinations of z_o: (a) the AERMET-derived values (which ranged between 0.319 and 0.556 meter); (b) an adjusted value of 0.05 meter; and (c) an adjusted value of 0.25 meter. For the ground-level release simulation in Table 2, emission rates are based on the z_o value of 0.25 meter, as it performed best overall.

Results of this re-analysis showed that the ground-level release simulation with z_o set to 0.25 meter provided significant overall improvement for all campaigns.

Figures 5 and 6 show, for each 15-minute monitoring event, the predicted and actual emission rates for the 3-meter release treatment (adjusted z_o value of 0.05 meter) and the ground-level release simulation (adjusted z_o value of 0.25 meter), respectively, for the SCAQMD study.

Figure 5. P/A Emission Rates for the SCAQMD Study: 3m Release Height and z_o = 0.05m

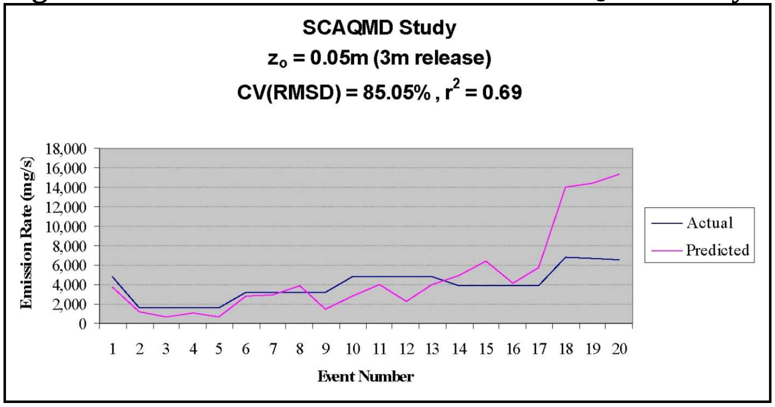
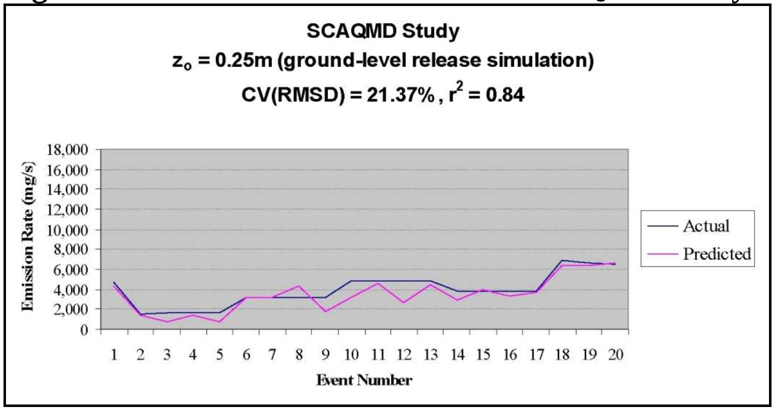


Figure 6. P/A Emission Rates for the SCAQMD Study: 0m Release Height and z_o = 0.25m



SUMMARY AND CONCLUSIONS

In general, the area-source technique, using AERMOD, is shown to be a very promising method for quantifying emission rates for small industrial sources.

For the South Texas study, as evidenced in Table 1, the overall performance of the area-source technique was judged excellent, especially when a more appropriate z_o value of 0.05 meter was assigned instead of the AERMET-derived values. Performance improved even more when a z_o value of 0.01 meter was assigned (Figures 3 and 4).

For the SCAQMD study, as evidenced in Table 2, the overall performance of the area-source technique was judged only fair for the 3-meter tracer-gas release treatment and an assigned z_o

value of 0.05 meter. However, when the release was simulated to be ground-level and a z_o value of 0.25 meter was assigned, performance was judged excellent (Figures 5 and 6), despite the fact the method is intended for ground-level sources only.

REFERENCES

1. *Quality Assurance Project Plan (Rev. 0), Validation Testing of the Area-Source Technique Using AERMOD for Oil-and-Gas-Industry Pollutant Sources in Support of Eventual OTM Designation*, prepared for Texas A&M University, Institute of Renewable Natural Resources, Minnich and Scotto, Inc., September 28, 2015.

2. *Request for Proposals, Application and Development of Advanced Optical Remote Sensing Technologies to Characterize and Quantify Fugitive and Stack Emissions from Refineries and Other Sources, #P2015-07,* South Coast Air Quality Management District, Diamond Bar, California, September 5, 2014.

3. *Field Standard Operating Procedure for the Use of Open-Path FTIR Spectroscopy at Hazardous Waste Sites (preliminary draft)*; US Environmental Protection Agency, National Environmental Response Team (ERT), Edison, New Jersey, March 1992.

4. *A Method for Estimating VOC Emission Rates from Area Sources Using Remote Optical Sensing*; Scotto, R.L., Minnich, T.R.; A&WMA/USEPA International Symposium on the Measurement of Toxic and Related Air Pollutants; Durham, North Carolina; May 1991.

5. *Remote Sensing of VOCs: A Methodology for Evaluating Air Quality Impacts During Remediation of Hazardous Waste Sites*; Minnich, T.R., Scotto, R.L., Leo, M.R., Solinski, P.J.; pp. 247-255 of Sampling and Analysis of Airborne Pollutants, Winegar, E.D. and Keith, L.H., editors, Lewis Publishers, Boca Raton, Florida, 1993.

6. *Use of Open-Path FTIR Spectroscopy to Address Air Monitoring Needs During Site Remediations*; Minnich, T.R. Scotto, R.L.; pp. 79-92 of Remediation Journal, Summer 1999, John Wiley & Sons, Inc.

7. *Backward-Time Lagrangian Stochastic Dispersion Models and Their Application to Estimate Gaseous Emissions*; Journal of Applied Meteorology, 34 (1995): 1320-1332.

8. An Introduction to WindTrax, Thunder Beach Scientific, http://thunderbeachscientific.com/downloads/introduction.pdf.

9. *Optical Remote Sensing for Emission Characterization from Non-point Sources*; U.S. EPA Other Test Method 10 (OTM-10), Final ORS Protocol, June 14, 2006.

10. *User's Guide for the AMS/EPA Regulatory Model – AERMOD*; USEPA, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711, EPA-454/B-03-001, September 2004.

11. *Addendum, User's Guide for the AMS/EPA Regulatory Model – AERMOD* (EPA-454/B-03-001); USEPA, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 27711, February 2011.

12. *Quality Assurance Project Plan (Rev. 0), Application of the Area-Source Technique for Measuring Emission Rates from Small Sources*, SCAQMD Request for Proposal #P2015-07, Project 2: Quantification of Gaseous Emissions from Gas Stations, Oil Wells, and Other Small Point Sources, prepared by Minnich and Scotto, Inc., August 28, 2015.

13. *AERMOD: Description of Model Formulation*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emissions Monitoring and Analysis Division, Research Triangle Park, North Carolina, p. 75, EPA-454/R-03-004, September 2004.

14. *AERMOD Training, Understanding the Key Surface Characteristics Used by AERMET*, PowerPoint Presentation (undated), Texas Commission of Air Quality, http://www.cabq.gov/airquality/documents/pdf/tceqsfcroughnessguidance.pdf.

15. *User's Guide to the Building Profile Input Program*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Technical Support Division, Research Triangle Park, North Carolina, 27711, October 1993, EPA-454/R-93-038 (Revised April 21, 2004).