Dispersion Modeling Analysis for General James M. Gavin Source Area: 2010 SO_2 NAAQS: Response to U.S. EPA 120-Day Letter

Introduction

The United States Environmental Protection Agency (U.S. EPA) established a new National Ambient Air Quality Standard (NAAQS) for SO_2 on June 22, 2010, of 75 ppb, as the 99^{th} percentile of maximum daily values, averaged over three years. In addition, U.S. EPA revoked the primary annual and 24-hour standards.

On August 5, 2013 (75 FR 47191), effective October 4, 2013, U.S. EPA promulgated the initial SO_2 nonattainment areas for the newly established SO_2 standard across the country. On March 2, 2015, the U.S. District Court for the Northern District of California accepted as an enforceable order an agreement between the U.S. EPA and Sierra Club and the Natural Resources Defense Council to resolve litigation concerning the deadline for completing designations. The court's order directs U.S. EPA to complete designations in three steps: the first by July 2, 2016; the second by December 31, 2017 and the third by December 31, 2020. As part of the first round of designations, U.S. EPA has identified areas with newly monitored violations of the standard, or areas that contain stationary sources that emitted more than 16,000 tons of SO_2 in 2012 or emitted more than 2,600 tons of SO_2 and had an emission rate of at least 0.45 lbs SO_2/MMBtu in 2012. The U.S. EPA has identified two facilities in Ohio as meeting one or more of these criteria: the General James M. Gavin Plant and the W.H. Zimmer Generating Station.

On September 16, 2015, Ohio EPA submitted a five factor analysis for both source areas, inclusive of refined dispersion modeling. On February 16, 2016, U.S. EPA submitted to Ohio a 120-day letter indicating concurrence with Ohio's recommendation of Attainment for the W.H. Zimmer Generating source area, and non-concurrence with Ohio's recommendation of Attainment for the General James M. Gavin/Kyger Creek source area, based on Ohio EPA's use of the beta LOWWIND3 option. Ohio EPA is therefore submitting revised modeling that does not utilize this option. Note that Ohio EPA disagrees with U.S. EPA's stance on the use of this option, and is providing as a part of our comments an expanded statistical analysis for this source area, as well as two additional source areas, that shows improved model performance when the LOWWIND3 option is utilized, without the introduction of under-predictive bias.

Per U.S. EPA's guidance (December 2013 *Draft SO_2 NAAQS Designations Modeling Technical Assistance Document* (herein referred to as "Modeling TAD")), "The primary objective of the modeling would be to determine whether an area currently meets the SO_2 NAAQS, and thereby indicate the designation process for the area". Ohio EPA is including this refined dispersion modeling analysis as a portion of the five-factor approach recommended by U.S. EPA in defining designation areas.

The dispersion modeling analysis was conducted for the 2012-2014 period, using actual hourly variable emissions from the General James M. Gavin facility, as well as the

Kyger Creek Station facility, located 2.5 kilometers to the southwest of the General James M. Gavin plant. This was done per the Modeling TAD, in which U.S. EPA recommends modeling the most recent 3 years of actual emissions.

Temporally varying emissions were modeled to determine the contribution of emissions from each source in the modeling domain. Ohio EPA attempted to use variable emissions at the finest temporal scale available for each unit. Hourly variable emissions data for the 2012-2014 period were submitted to Ohio EPA by American Electric Power for all SO_2 sources at both the General James M. Gavin and Kyger Creek facilities. (Appendix B of Ohio's September 16, 2015 recommended designation submittal)

Modeling Approach

Per U.S. EPA's Modeling TAD,

> "Since the purpose here pertains to designations, this guidance supports analyses of existing air quality rather than analyses of emissions limits necessary to provide for attainment. Consequently, the guidance in this TAD differs in selected respects from the guidance published in Appendix W. These differences include:
>
> - Placement of receptors only in areas where it is feasible to place a monitor vs. all ambient air locations (NSR, PSD, and SIP)
> - Use of the most recent 3 years of actual emissions (designations) vs. maximum allowable emissions (NSR, PSD, and SIP)
> - Use of 3 years of meteorological data (designations) vs. one to five years (NSR, PSD, and SIP)
> - Use of actual stack height for designations using actual emissions vs. Good Engineering Practice (GEP) stack height for other regulatory applications (NSR, PSD, and SIP)"

Ohio EPA incorporated the differences listed above and followed Appendix W guidance where applicable to modeling for designation purposes. The averaging period for the 2010 SO_2 NAAQS is the 99th percentile of maximum monitored daily values, averaged over three years. Per the Modeling TAD, three years of National Weather Service data is sufficient to allow the modeling to simulate a monitor. Thus, the modeled form of the standard is expressed as the 99th percentile of maximum daily values averaged over three years (herein referred to as "design value") for the purposes of designation.

The recommended dispersion model for modeling for SO_2 designations is the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) modeling system. There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using United States Geological Survey (USGS) Digital Elevation Data. Additionally, Ohio EPA utilized the AERMINUTE module to incorporate 1-minute ASOS meteorological data into the hourly surface input file. Ohio EPA utilized the most up-to-date versions of AERMOD and the associated preprocessors available at the time of the attainment modeling analyses. These are as follows: AERMOD version 15181, AERMET version 15181, AERMINUTE version 14337, and AERMAP version 11103.

As the purpose of the modeling demonstration, per the Modeling TAD, is to simulate a monitor(s), Ohio EPA conducted a model performance evaluation using monitor data recorded at site 30-105-0003 and actual emissions, years 2012-2014, to ensure that model results presented the most accurate representation of ground-level impacts. This analysis is presented in the technical support document accompanying this submittal. However, as Ohio EPA's initial modeling formulation (demonstrated to be superior to the default regulatory version for this source area in the accompanying technical support document) was rejected by U.S. EPA, Ohio EPA is submitting this revised dispersion modeling analysis, using AERMOD in the regulatory default mode with default meteorological data, with the understanding that the results are over-predictive and not representative of actual ground level concentrations in this source area.

Meteorological Data

In order to generate meteorological input data for use with AERMOD, AERMET, along with AERMINUTE and AERSURFACE preprocessing for the modeling domain was conducted to generate the surface (.sfc) and profile (.pfl). Ohio EPA used the AERMINUTE pre-processing module. This module accepts as input 1-minute ASOS meteorological surface observations, calculates an hourly average for each hour in the modeled time period, and substitutes any missing values from the co-located ISHD surface data. Use of AERMINUTE reduces the number of calm hours present in the input files, and these enhanced hourly files are therefore considered more representative of local meteorological conditions.

Meteorological data from 2012-2014 from the Huntington, WV surface station (Station # 3860) located at the Huntington Tri-State Airport and the Pittsburgh, PA upper air station (Station # 94823) located at the Greater Pittsburgh International Airport were used in these analyses. These sites were determined to be representative of Gallia County, OH and the surrounding region. AERSURFACE was run using twelve sectors and monthly surface characteristics, centered on the location of the meteorological station. Monthly Bowen ratios were determined by comparing monthly precipitation values against the most recent 30-year precipitation values recorded at the Huntington surface station. For this revised modeling, Ohio EPA has utilized a reprocessed 2014 meteorological dataset, to address unrealistic, and in some instances, non-physical convective and mechanical mixing heights. This methodology is detailed in the technical support document accompanying this submittal.

Background

In Ohio's original September 16, 2015 modeling, a very conservative 10 ppb fixed background was applied to all modeled concentrations in the General James M. Gavin/Kyger Creek source area. Since that submittal, Ohio EPA has reanalyzed the use of fixed background concentrations, and has found that variable background profiles offer a more realistic assessment of background, more consistent with the intent of Data Requirements Rule. As such, Ohio EPA applied a seasonal/hourly variable background profile in this source area, as described in the technical support document accompanying this submittal.

Emission Sources

The two SO_2 emission sources at the General James M. Gavin facility were included in the designation modeling analysis as two egress points. The five SO_2 sources at Kyger Creek Station were treated as two separate egress points, with Units 1 and 2 sharing a common stack, and Units 3, 4, and 5 sharing another. Variable emissions for all sources were included in the model via the HOUREMIS input pathway, years 2012-2014. Ohio EPA utilized the 1-hour SO_2 design value output option internal to the AERMOD code to simplify post processing and eliminate the need to generate large hourly output files. The relevant release point parameters for the emission units included in the analysis are presented in Table 1, below. All emissions sources included in the modeling were treated as point sources.

Ohio EPA, via outreach and consultation with American Electric Power, identified erroneous emissions data resulting from faults in the continuous emissions monitors at the facilities, Part 75 data substitutions, and other variables which contribute to erroneous emissions data. A full description of the derivation of accurate hourly emission rates, release point temperatures, and exit velocities are provided in Appendix B of Ohio's recommended designation submittal.

As part of the five factor analysis described in Ohio's recommended designation submittal, Ohio determined that there were 65,681 TPY of actual SO_2 emissions in 2014 from Ohio and West Virginia sources within 50 kilometers of the General James M. Gavin facility from facilities that might potentially need to be modeled under the requirements of the Data Requirements Rule. 50,621 TPY of actual 2014 SO_2 emissions are within Gallia County itself and were explicitly modeled. The Appalachian Power Phillip Sporn Station in Mason County, West Virginia ceased operations as of June 1, 2015, as described in Appendix I of Ohio's recommended designation submittal. This shutdown accounted for a reduction of 10,649 tons from 2014, or 16% from the area surrounding the General James M. Gavin facility. The Ohio Valley Electric Company Kyger Creek Station, located within 2.5 kilometers of the General James M. Gavin facility in Gallia County, was explicitly modeled. The remaining large source located in West Virginia, the Appalachian Power Mountaineer Plant, is not expected to cause a significant concentration gradient in the source area that is not accounted for by background, based on meteorology, distance, and emissions.

Examination of a composite wind rose (Figure 1), years 2012-2014, from the Huntington meteorological station would indicate that the predominant wind directions are unlikely to carry emissions from sources other than Kyger Creek Station to the General James M. Gavin source area.

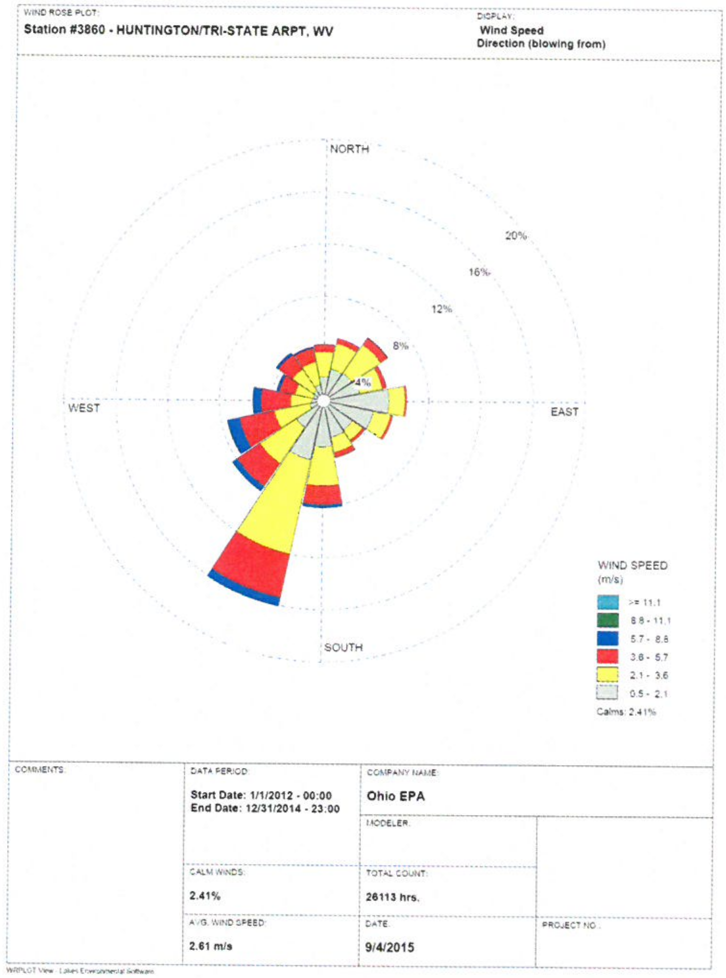

Figure 1: Huntington wind rose, 2012-2014.

	Source ID	Source Description	Easting (X)	Northing (Y)	Base Elevation	Stack Height	Temperature	Exit Velocity	Stack Diameter	SO2
			(m)	(m)	(m)	(m)	(K)	(m/s)	(m)	(lb/hr)
General James M. Gavin	UNIT1	Unit 1 main boiler	403277.18	4310126.46	172.8	252.98	Variable	Variable	12.80	Variable
	UNIT2	Unit 2 main boiler	403345.18	4310254.46	172.8	252.98	Variable	Variable	12.80	Variable
Kyger Creek Station	CS12	Units 1 and 2	402257.17	4308093.45	178.6	252.98	Variable	Variable	7.53	Variable
	CS35	Units 3, 4, and 5	402248.17	4308099.45	178.6	252.98	Variable	Variable	9.20	Variable

Table 1: Modeled source parameters, General James M. Gavin and Kyger Creek Station, 2012-2014.

Analysis

The designation modeling analysis consisted of a single modeling run, years 2012-2014. The results of this analysis are to be used to inform the designation process for the area surrounding the General James M. Gavin facility.

<u>Receptors</u>

A total of 34,225 receptors were included in the modeling domain. 50 meters spacing was used along the fenceline of both the General James M. Gavin and Kyger Creek facilities, and a 50 meters spacing to 2 km from the fenceline was used. The large, dense grid around the facility was informed by screen modeling to ensure that the point of maximum impact would be located within this dense grid. 100 meters spacing was used within 3 km of the fenceline, 250 meters spacing was used to 8 km from the fenceline, and a 500 meters spacing was used to 15 km from the fenceline. Beyond 10 km, a 1000 meters spacing was used to 25 km distant, and a 2000 meters spacing was used to 50 km. A discrete receptor was also included at the location of the monitor, 39-105-0003. Figure 2 shows the location of the facilities (center) as well as the receptor grid used. Also shown in Figure 2 are the borders of Gallia County and the western portion of Meigs County (north).

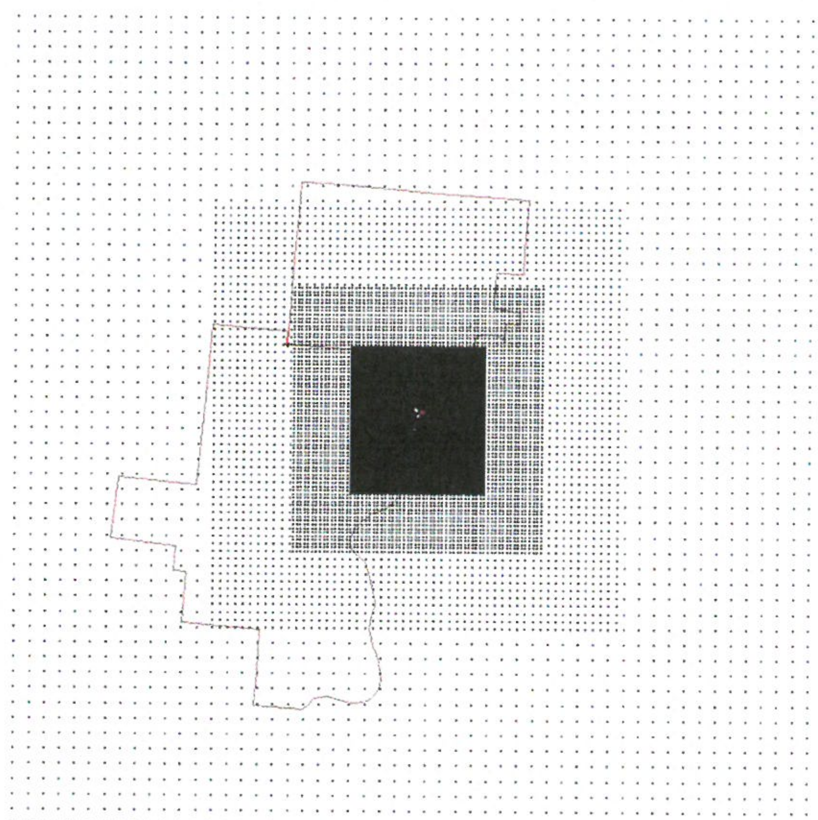

Figure 2: Receptor grid, facilities, and designation boundaries, General James M. Gavin source area.

Results

The dispersion modeling analysis evaluated the impact of the General James M. Gavin and Kyger Creek Station facilities as a design value when modeled using hourly variable SO_2 emissions. Any maximum impact exceeding 196.2 $\mu g/m^3$ would represent a modeled exceedance. For this analysis, the maximum modeled 3-year design value, years 2012-2014, was 193.87795 $\mu g/m^3$, including background. Thus, no exceedance of the standard was modeled. The maximum modeled concentration, 193.87795 $\mu g/m^3$, or 74.1 ppb, including background, is located approximately 1,200 meters from the fenceline of Kyger Creek Station and approximately 1,800 meters from the main SO_2 source at Kyger Creek Station.

The dispersion modeling analysis for the designation of the area surrounding the General James M. Gavin facility demonstrates no modeled exceedances of the 2010 SO_2 standard based on the 2012-2014 period. Further, dispersion modeling performed with the AERMOD model accounts for multiple aspects of the five-factor analysis emphasized by U.S. EPA in designating areas as originally submitted by Ohio EPA on September 16, 2015.

State of Ohio 2010 Revised Sulfur Dioxide National Ambient Air Quality Standard: Response to U.S. EPA 120-day Letters: Technical Support Document for the General James M. Gavin/Kyger Creek Station Power Plant Source Area

History

The United States Environmental Protection Agency (U.S. EPA) promulgated the revised National Ambient Air Quality Standard (NAAQS) for sulfur dioxide (SO_2) on June 2, 2010. U.S. EPA replaced the 24-hour and annual standards with a new short-term one-hour standard of 75 parts per billion (ppb). The new one-hour SO_2 standard was published on June 22, 2010 (75 FR 35520) and became effective on August 23, 2010. The standard is based on the three-year average of the annual 99th percentile of one-hour daily maximum concentrations.

On August 15, 2013, U.S. EPA published (78 FR 47191) the initial SO_2 nonattainment area designations for the one-hour SO_2 standard across the country (effective October 4, 2013). On March 2, 2015, the U.S. District Court for the Northern District of California accepted as an enforceable order an agreement between the U.S. EPA and Sierra Club and the Natural Resources Defense Council to resolve litigation concerning the deadline for completing designations. The court's order directs U.S. EPA to complete designations in three steps: the first by July 2, 2016; the second by December 31, 2017 and the third by December 31, 2020. As part of the first round of designations, U.S. EPA has identified areas with newly monitored violations of the standard, or areas that contain stationary sources that emitted more than 16,000 tons of SO_2 in 2012 or emitted more than 2,600 tons of SO_2 and had an emission rate of at least 0.45 lbs SO_2/MMBtu in 2012. The U.S. EPA has identified two facilities in Ohio as meeting one or more of the emissions thresholds: the General James M. Gavin Plant and the W.H. Zimmer Generating Station. Ohio EPA submitted recommended designations for both the W.H. Zimmer and General James M. Gavin source areas on September 16, 2015.

Requirements

Pursuant to section 107(d) of the Clean Air Act (CAA), U.S. EPA must initially designate areas as either "unclassifiable", "attainment", or "nonattainment" for the 2010 one-hour SO_2 standard. Since the original 2011 state submittals of designation recommendations and pursuant to the March 2, 2015 court order, new information may be relevant for future designations. CAA Section 107(d) does not require states to submit updated recommendations. However, U.S. EPA will consider such information. For the round of designations to be completed by July 2, 2016, U.S. EPA requested that states submit updated recommendations and supporting information for consideration by September 18, 2015. If U.S. EPA intends to modify any state's designation recommendation, original or updated, the state will be notified no later than 120 days prior to promulgating the final designations. For the designations due to be promulgated on or before July 2, 2016, this notification will occur no later than March 2, 2016. Ohio EPA received U.S. EPA's 120-day letter on February 16, 2016. This letter indicated that Ohio had until April 19, 2016 to provide comments.

General James M. Gavin and Kyger Creek Source Area:

Ohio's September 16, 2015 submission for the General James M. Gavin and Kyger Creek source area recommended a designation of Attainment for the entirety of Gallia County and the townships of Bedford, Columbia, Rutland, Salem, Salisbury, and Scipio in Meigs County, based on a five factor analysis inclusive of refined dispersion modeling. Pierce Township itself was designated non-attainment on August 5, 2013 [78 FR 47191].

U.S. EPA's February 16, 2016 120-day letter and accompanying technical support documents (TSD) indicate non-concurrence with Ohio's recommended designation of Attainment for this source area, based primarily on Ohio's usage of the LOWWIND3 beta option in the refined dispersion modeling analysis portion of Ohio's five-factor analysis. It should be noted that Ohio EPA submitted a request to utilize both the beta u* adjustment (ADJ_U*) and LOWWIND3 options to U.S. EPA Region 5 on December 7, 2015. No mention of this request was made in the 120-day letter or in the accompanying technical support documents, nor has U.S. EPA responded to Ohio EPA regarding the outcome of this request. Ohio EPA is again providing this request as Appendix A of this submittal, as much of the content is relevant to the information presented in this submittal. The remainder of U.S. EPA's 120-day letter and TSD for this source area indicates that U.S. EPA did not find flaw with the remainder of Ohio EPA's modeling approach. Therefore, Ohio EPA is providing in this TSD supplementary information that further supports a designation of Attainment for the General James M. Gavin and Kyger Creek source area. This information includes a statistical analysis of model performance in this source area specifically addressing the beta LOWWIND3 option beyond that provided on December 7, 2015; the derivation of a temporally varying background profile to replace the overly-conservative fixed 10 ppb background used in Ohio's September 16, 2015 submittal; and a discussion of new meteorological data for 2014 based on serious flaws discovered in that data as originally submitted to U.S. EPA on September 16, 2015. In addition to this TSD, you will find additional Attainment modeling accompanying Ohio EPA's comments.

Meteorological Data Issues:

As Ohio EPA was preparing additional modeling to further support our recommendation and address U.S. EPA's concerns in the 120-day letter, Ohio EPA discovered issues associated with the 2014 meteorological data used in our September 16, 2015 submittal. In the course of performing the model performance evaluation presented in this document, Ohio EPA noted multiple periods in the 2014 AERMOD surface meteorological input data when unrealistic, non-physical, and unexplained values for both the convective and mechanical mixing heights were present. These periods corresponded, in many cases, to elevated modeled ground level impacts not related to emission rate increases at either facility included in the modeling domain or changes in other stack parameters that might be associated with elevated model concentrations. Further examination revealed that in 2014, the meteorological data at the Huntington, WV surface station (Station # 3860) located at the Huntington Tri-State Airport had significant periods of missing cloud cover data. A total of 1,285 cloud cover substitutions were performed via the AERMET meteorological data processor for the 2014 .SFC file, which was used in Ohio's September 16, 2015 modeling analysis. Absent substitution of these missing cloud cover data, the 2014 meteorological data failed to meet the 90% completeness criteria required by U.S. EPA for regulatory purposes.

Superficially, these cloud cover substitutions did not appear to affect the meteorological inputs in a significant or meaningful manner, and these same substitutions did not appear to influence the 2012 or 2013 meteorological data. However, it was also observed that the majority of those periods demonstrating unusual and, in some cases, non-physical, convective and mechanical mixing heights identified in the data corresponded to periods where a large number of cloud cover substitutions were present in the .SFC input file. In addition to the large number of hours with missing cloud cover data, Ohio EPA observed that there were multiple hours in the Huntington data where observed cloud cover was reported as zero, but that conditions at other nearby airports indicate that cloud cover was present. To avoid these non-physical results, and to utilize as much "real" measured cloud cover data as possible, Ohio EPA re-processed the meteorological data for 2014 using a different methodology than that described in Ohio's September 16, 2015 submission. Note that these issues were not observed in 2012 and 2013, and therefore the original 2012 and 2013 surface data used in Ohio's September 2015 submission were used in all modeling exercises and analyses conducted for these comments.

At the time of this submittal, Ohio EPA has not had time to specifically diagnose the source of these erroneous data or to determine if there were malfunctions of the instrumentation at the Huntington surface site during 2014. Such issues could arise from errors within the raw 2014 Integrated Surface Hourly Data (ISHD), within the AERMET substitution algorithm itself, or from the large number of substituted data itself. It should be noted that an examination of the substitution algorithms in the FORTRAN code of the AERMET processor was performed by Ohio EPA, and it does not appear that the issues are related to coding errors. As a full examination of all variables was not possible in the time available for Ohio EPA to provide these comments, the only course of action available was to develop a methodology to correct the issues and identify the source of the erroneous data at a later date.

The methodology developed by Ohio EPA to process the 2014 meteorological data for input into the AERMOD model was designed to maximize the number of measured cloud cover data points in the AERMET input, and to avoid the use of the missing cloud cover interpolation component of AERMET. As a first step, Ohio EPA compiled hourly surface data for the Huntington surface station from "ISD-Lite" data, which represent a subset of the full ISD data and designed to provide the most frequently used hourly meteorological data in a more accessible format. Additionally, Ohio EPA collected the same data from the Mason County Airport (WBAN #63876) which is located approximately 2.6 kilometers to the East of the Gavin/Kyger Creek facilities and from the Charleston-Yeager Airport (WBAN #13866) located approximately 75 kilometers to southeast of the sources. Note that the Huntington surface station is located at a similar distance of approximately 72 kilometers to the southwest of the sources. Ohio EPA then compiled hourly temperature, dew point, sea-level pressure, wind direction, wind speed, and sky cover data from the Huntington surface station into a comma-delimited format. To supplement the hourly cloud cover data, Ohio EPA substituted any missing cloud cover data in the Huntington meteorology with data from both the Mason and Charleston stations, if available. Preference was given to the Mason surface station, but this data had a similarly incomplete cloud cover record for 2014. In addition, Ohio EPA replaced cloud cover values of zero with non-zero values form the Charleston airport, if available. This was done primarily to address situations in which cloud cover was observed at nearby surface stations, but extended periods of no cloud cover were reported during the same time period at the Huntington surface station. Note here that Charleston was selected for this substitution, as the cloud cover data record at the Mason surface station is also missing a substantial number of values. Lastly, rather than utilize the cloud cover substitution algorithms in AERMET, Ohio EPA performed valid-hour-before/valid-hour-after averaging to replace any remaining missing cloud cover data. Missing data periods longer than four hours were treated as missing data.

The hourly comma delimited file created following the above procedure was treated as an onsite meteorological station in AERMET. To ensure a complete data record, Ohio EPA utilized the full 2014 ISHD record at the Huntington surface station as the secondary surface station, and allowed substitution of all other missing meteorological parameters in the onsite data. As with 2012 and 2013, upper air soundings from the Pittsburgh, PA upper air station (Station # 94823) located at the Greater Pittsburgh International Airport were used. The resultant 2014 surface file therefore represents meteorological conditions at the Huntington surface station (as is the case for 2012 and 2013), maximizes the use of "real" measured cloud-cover data, and avoids the need to utilize the cloud cover substitution algorithm to generate a 90% complete meteorological record.

The .SFC input file generated in the manner described above did not demonstrate the same non-physical and un-realistic convective and mechanical mixing heights observed in the original 2014 data. It should be noted here that the modified met data processing described above increased the 4th highest maximum daily value modeled in 2014 by approximately 10 micrograms/cubic meter from that modeled using the original meteorology.

Model Performance Evaluation:

Ohio EPA conducted model performance analyses using 2012 to 2014 actual emissions from the General James M. Gavin Plant and the Kyger Creek Station, modeling the impact of these facilities at the location of monitor 39-195-0003. This monitor is located 13 km to the Northeast of the General James M. Gavin plant in Pomeroy, Ohio, and was sited to monitor the combined impact of emissions from the General James M. Gavin and Kyger Creek Station facilities. While not located in a "hot-spot" of maximum or near-maximum ground level impacts, this monitoring location is situated such that the prevailing winds of the source area, which originate primarily in the south-west, frequently carry emissions from both facilities to the monitor location, and is therefore considered highly representative of relative ground level impacts in the area resulting from the emissions of these facilities. Further, 13 kilometers is well within the limitations of the AERMOD modeling system. Ohio EPA therefore considers accurate modeling at this location to be critical to assessing the performance of the AERMOD model in this source area.

Page 28 of U.S. EPA's TSD states that "an application-specific statistical performance evaluation is conducted" at "representative air quality monitors that are appropriately sited for the given application". Further clarification on this comment was given verbally to Ohio EPA on a March 3, 2016 phone call. That clarification indicated that a single monitor was likely insufficient for such a statistical analysis, in particular for a location where maximum ground level concentrations are not observed. To address concerns expressed by U.S. EPA that the use of a single monitor not located in a "hot-spot" to characterize model performance is likely insufficient to completely address model performance (concerns which Ohio EPA strongly disagrees with), Ohio EPA has performed the same statistical evaluation of model performance for two additional locations where there are both nearby and distant monitors which can be used for an expanded comparison of model performance under default and beta model formulations. The statistical analyses for these additional source areas are provided as Appendix B to this submittal. Ohio EPA demonstrates in this document that although monitor 39-105-0003 is not located at a point of maximum impact, it is situated such that the prevailing winds of the region transport emissions from the General James M. Gavin and Kyger Creek stations. Lastly, verbal clarification from U.S. EPA indicated that the monitor was located approximately 13 kilometers distant from the source area, and thus potentially too distant to be considered representative. Ohio EPA has serious concerns with U.S. EPA's stance on this, as AERMOD is intended to be accurate within 50 kilometers of a source. If modeled results at a point 13 kilometers distant are viewed with skepticism by U.S. EPA, this would indicate a significant degree of uncertainty in all modeled results that must be accounted for when designating any source area based on modeling alone.

Pursuant to identifying the most appropriate modeling techniques for this source area, Ohio EPA performed modeling over the 2012 to 2014 period with the General James M. Gavin and Kyger Creek sources using AERMOD under three different parameter formulations – one with the beta friction velocity (ADJ_U*) option enabled, the second with both ADJ_U* and the beta low wind (LOWWIND3) option enabled, and a third with the default options – no beta options enabled. To evaluate the validity and performance of the three formulations, Ohio EPA performed a comparison of the modeled values from each formulation at the location of the Pomeroy SO_2 ambient air quality monitor, with the monitor values. For these analyses, focus was placed on the highest 20% of the maximum daily values, which contain the information from which the monitored and modeled design values are calculated.

As described previously in Ohio EPA's December 7, 2015 request to utilize the LOWWIND3 beta option (Appendix A), the concentrations modeled at the location of the Pomeroy SO_2 monitor were over-predictive under all model formulations, prior to the inclusion of a background. For the analyses presented here, Ohio EPA again did not include background in the statistical analysis portion of the model evaluation, as the inclusion of background serves only to inflate the bias and error statistics in a non-meaningful way and does not benefit the comparison of one model formulation to another.

Graphical Evaluation of Model Performance:

Model performance was assessed using modeled estimates of concentration at a receptor placed at the location of ambient air quality monitor 39-105-0003. Although this monitor is not located in a modeled "hot-spot", or area of maximum impact, this monitor was sited specifically to monitor emissions from the General James M. Gavin and Kyger Creek power plants based on previous maximum impact modeling. Figure 1 shows the location of monitor 39-105-0003 in relationship to the General James M. Gavin and Kyger Creek facilities. Also included in this figure is a composite wind rose, years 2012 to 2014 from the Huntington surface station. The 3-year composite wind rose is shown superimposed on the location of the monitor.

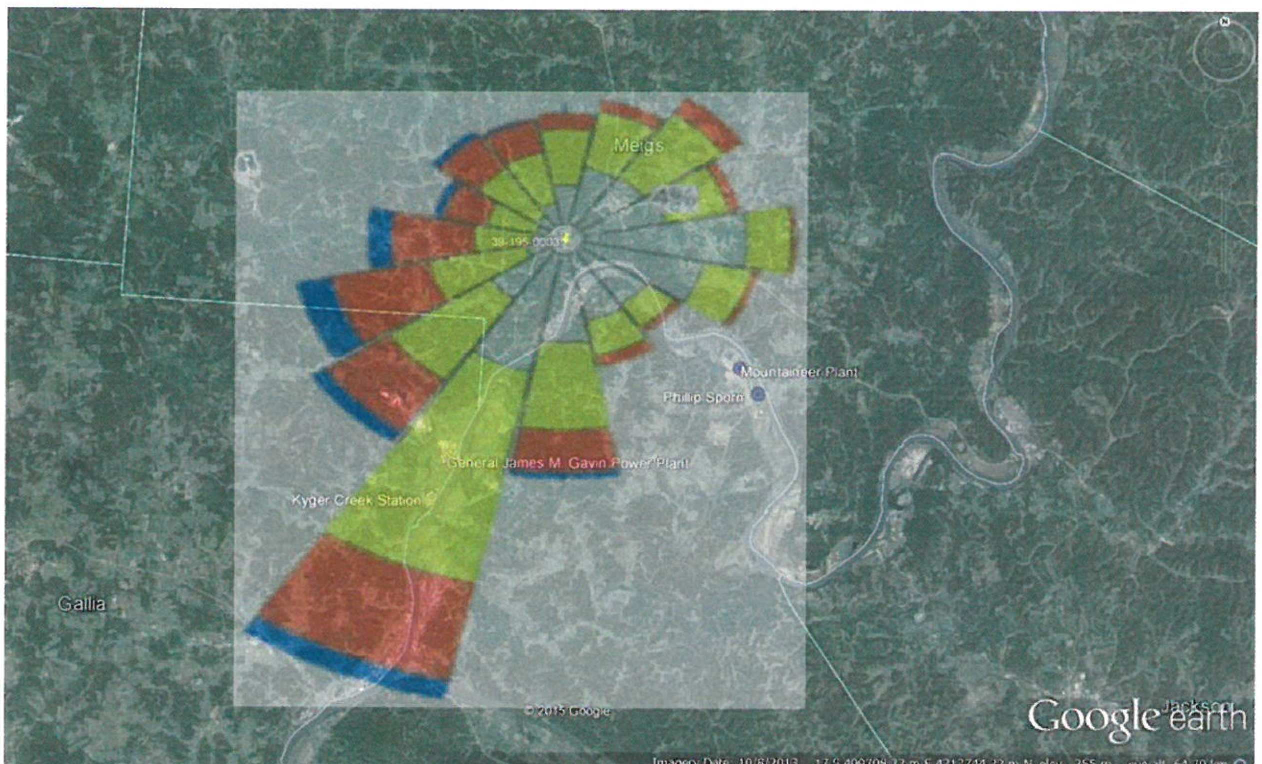

Figure 1: Location of General James M. Gavin and Kyger Creek power plants, monitor 39-105-0003, with 2012-2014 composite wind rose from Huntington, WV surface station.

Figure 1 clearly demonstrates that monitor 39-105-0003 is well sighted to monitor emissions from the General James M. Gavin and Kyger Creek power plants, with respect to the prevailing winds of the area. Thus, as previously stated, Ohio EPA believes that model performance at this monitor is a strong indicator of model performance in the entirety of the source area.

As an initial evaluation of model performance, Ohio EPA plotted modeled vs. monitor concentrations for the top 20% of maximum daily values, for each year 2012 to 2014. Note that the data are not paired in time. These data, without background, are shown in Figures 2-4, below. For comparative purposes, Ohio EPA has included in each figure 2:1, 1:1, and 1:2 lines, as well as an indication of the 99th percentile maximum daily value for each year recorded at monitor 39-105-0003. Figure 5 presents the highest 20% of the maximum daily values, averaged over three years (form of the standard) in the same manner as for the annual datasets.

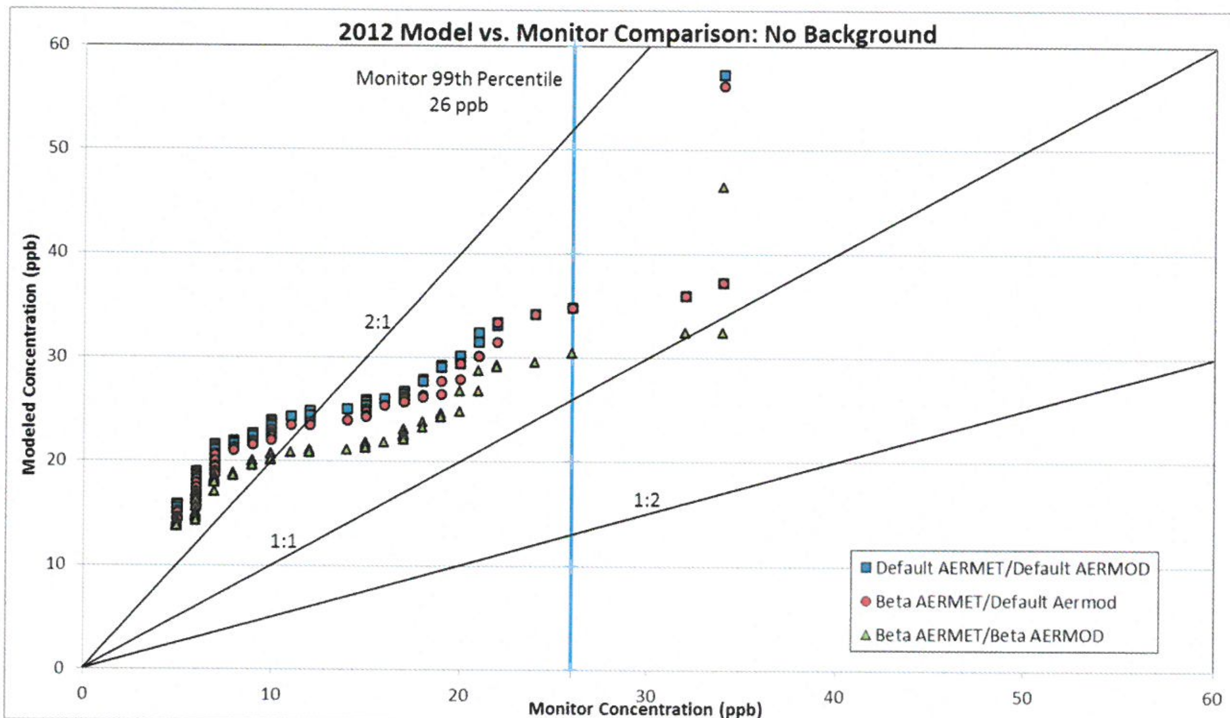

Figure 2: 2012 Model vs. Monitor Comparison, under various model formulations.

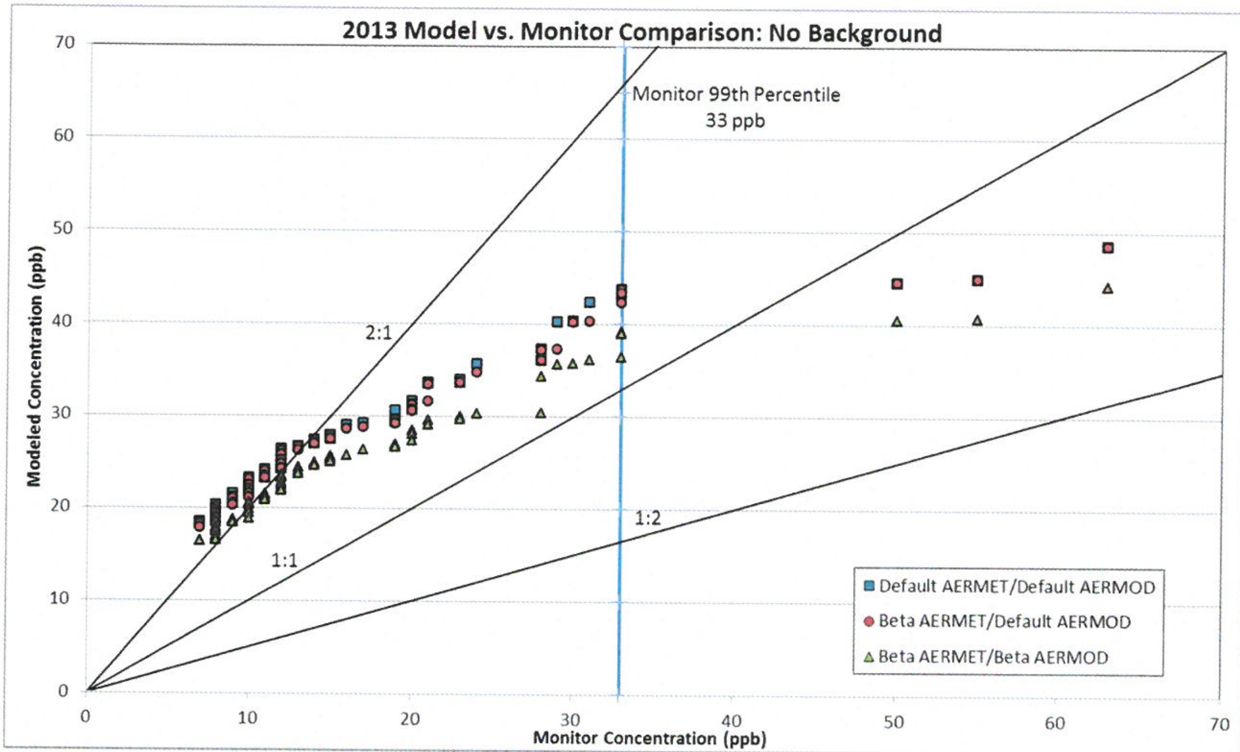

Figure 3: 2013 Model vs. Monitor Comparison, under various model formulations.

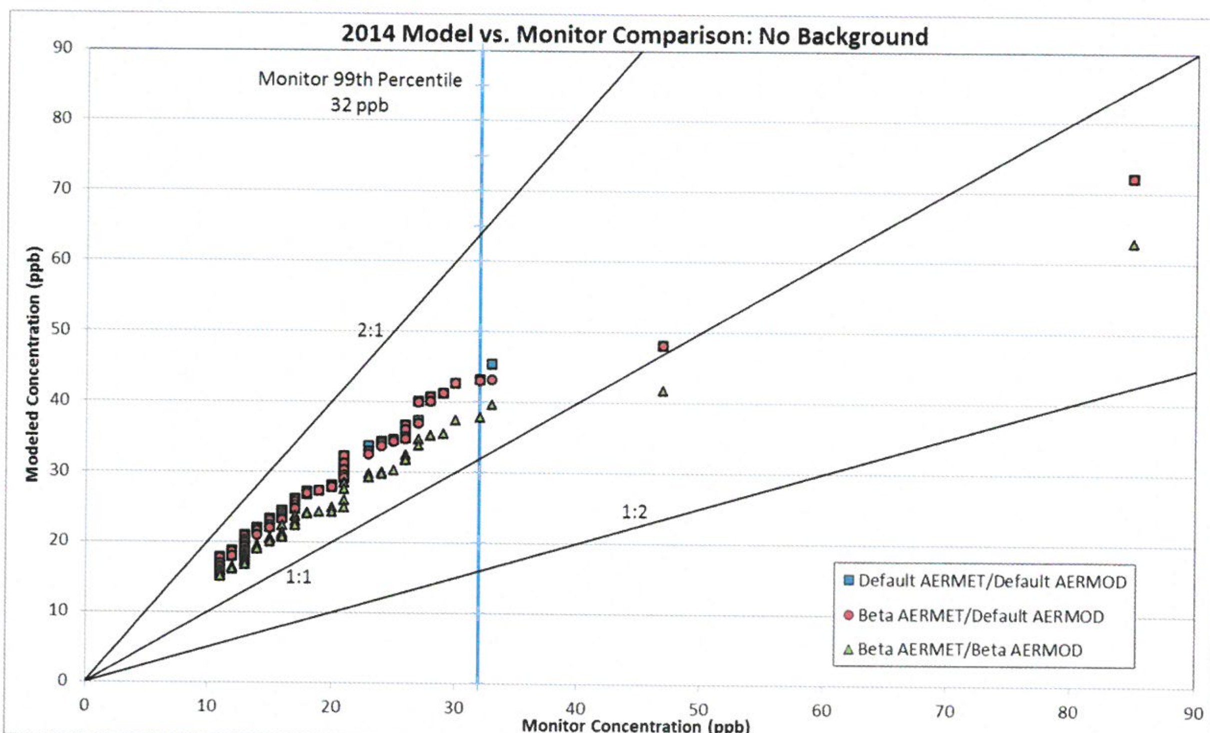

Figure 4: 2014 Model vs. Monitor Comparison, under various model formulations.

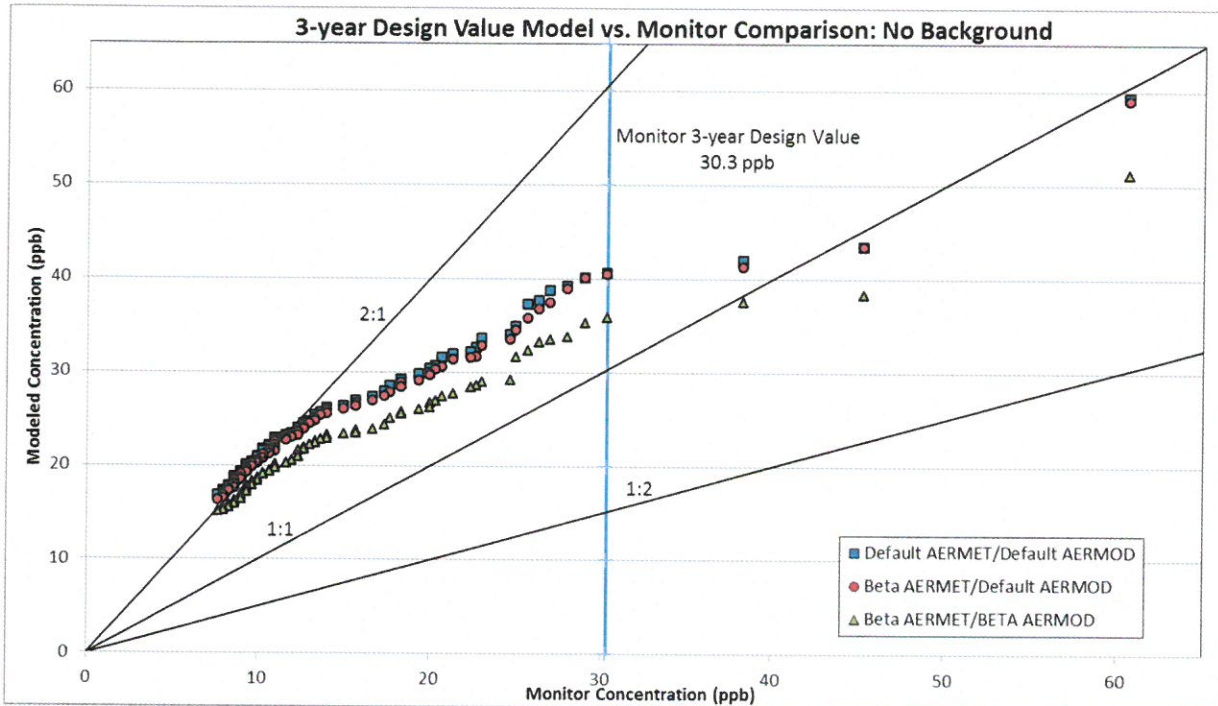

Figure 5: 2012-2014 Model vs. Monitor Design Value Comparison, under various model formulations.

Figures 2-5 demonstrate that model performance is over-predictive under all model formulations for this source area at the location of monitor 39-105-0003, even in the absence of background concentration. There is also only minor improvement in model performance with the ADJ_U* option enabled, which is consistent with previous evaluations of tall-stack sources, as described in Appendix A of this submittal and the references contained therein. Across all three years, model performance is improved significantly when the LOWWIND3 beta option is enabled, without the introduction of under-predictive bias. This is particularly true and critical at the 99th percentile level. The data in Figure 5 indicates excellent performance of the AERMOD model at the 99th percentile level and below, with modeled results within approximately 5 to 6 ppb of the 1:1 line. There is a considerable decrease in model performance below approximately 15 ppb, but concentrations at this level in this source area are not critical to characterizing ambient air quality with respect to the 2010 1-hour SO_2 standard.

Statistical Evaluation of Model Performance:

Although Ohio EPA provided compelling evidence of improved model accuracy in the General James M. Gavin/Kyger Creek source area in both the September 16, 2015 recommended designation submittal and in Ohio's December 7, 2015 request to utilize beta ADJ_U* and LOWWIND3 options, the limited time and resources available to submit these documents necessarily limited Ohio's ability to provide an in-depth statistical analysis to quantify model performance under the various model formulations.

Therefore, Ohio EPA is providing the following statistical analysis to supplement the information presented in the aforementioned documents.

Ohio EPA selected several well-established statistical measures which have been used frequently to assess model performance[1,2]. A brief description of each metric is provided below, with the analysis after.

Normalized mean bias

$$NMB = \frac{\sum_{i=1}^{N}(Model_i - Obs_i)}{\sum_{i=1}^{N} Obs_i} \times 100\%$$

Bias indicates systematic distortion in one direction as percent deviation in predicted values from observed values. Normalized mean bias (NMB) is constructed by normalizing absolute mean bias by observation mean, which avoids over-inflating the observed range of values. The metric has a range of -100% to +∞ and is asymmetric, tending to weight over-predictions more than under-predictions. A model with low bias would return a NMB approaching zero.

Normalized mean error

$$NME = \frac{\sum_{i=1}^{N}|Model_i - Obs_i|}{\sum_{i=1}^{N} Obs_i} \times 100\%$$

Coupled with NMB, normalized mean error (NME) is a measure of precision that normalizes mean absolute error relative to observations. The metric has a range of zero to +∞.

Mean fractional bias

$$FBIAS = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(Model_i - Obs_i)}{\left(\frac{Model_i + Obs_i}{2}\right)}\right) \times 100\%$$

Mean fractional bias (FBIAS) has an added advantage to the similar mean normalized bias in its symmetry, equally weighting positive and negative bias estimates. Each prediction-observation set is normalized by the average of the model and observation prior to calculating the mean. The metric has a range of -200% to 200% with FBIAS approaching zero indicating low bias.

Mean fractional error

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[1] Environmental Protection Agency. (2007). *Guidance on the use of models and other analyses for demonstrating attainment of air quality goals for ozone, $PM_{2.5}$, and regional haze* (EPA Publication No. 454-B-07-002). Research Triangle Park, NC: U.S. Environmental Protection Agency.

[2] Boyan, J. & Russell, A. G. (2006) PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models. *Atmospheric Environment*, 20, 4946-4959.

$$FERROR = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|Model_i - Obs_i|}{\left(\frac{Model_i + Obs_i}{2}\right)}\right) \times 100\%$$

Similar to FBIAS, mean fractional error (FERROR) bounds maximum error, preventing a few data points from dominating the metric. The metric has a range of zero to 200%.

Normalized mean square error

$$NMSE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(Model_i - Obs_i)^2}{\overline{Model} \times \overline{Obs}}\right)$$

$$\overline{Model} = \frac{1}{N}\sum_{i=1}^{N} Model_i$$

$$\overline{Obs} = \frac{1}{N}\sum_{i=1}^{N} Obs_i$$

Normalized mean square error (NMSE) is a measure of scatter and reflects both random and systematic error. Normalization by the product of prediction and observation means prevents bias towards over- or under-predicting models.

In addition to the above statistical metrics, Ohio EPA also determined mean bias and error for each data set, which measure the average bias and error of model predictions expressed in units of concentration (ppb). As stated above, Ohio EPA is presenting these data without the addition of background concentration, as this does not aid in the inter-comparison of the various model formulations. Tables 1-3 present the above model vs. monitor statistics for each year 2012 to 2014 under each model formulation. The primary focus of these analyses was the highest 20% of modeled and monitored maximum daily values. Table 4 presents the same statistics, but calculated based on the highest 20% of maximum daily values at the monitor location, averaged over three years, consistent with the form of the design value. Again, these data are presented in the absence of a background concentration. The nomenclature used in these tables to indicate model formulation is as follows: Default AERMOD/Default AERMET refers to AERMOD with no LOWWIND corrections and AERMET without the beta ADJ_U* option; Default AERMOD/Beta AERMET refers to AERMOD with no LOWWIND corrections enabled and meteorological input processed in AERMET with the beta ADJ_U* correction enabled; Beta AERMOD/Beta AERMET refers to AERMOD with the LOWWIND3 option enabled and with meteorological input processed with the ADJ_U* option enabled.

Table 1: 2012 Statistical evaluation of model performance, under various model formulations.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2012	Mean Bias (ppb)	11.51	10.62	8.38
	Mean Error (ppb)	11.51	10.62	8.43
	Normalized Mean Bias(%, -100 to ∞)	100.10	92.34	72.87
	Normalized Mean Error(%, 0 to ∞)	100.10	92.34	73.26
	Mean Fractional Bias(%, -200 to +200)	74.32	70.91	61.87
	Mean Fractional Error(%, 0 to 200)	74.32	70.91	62.00
	Normalized Mean Square Error	0.53	0.45	0.29

Table 2: 2013 Statistical evaluation of model performance, under various model formulations.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2013	Mean Bias (ppb)	11.30	10.97	8.39
	Mean Error (ppb)	11.73	11.40	9.05
	Normalized Mean Bias(%, -100 to ∞)	72.46	70.30	53.79
	Normalized Mean Error(%, 0 to ∞)	75.22	73.06	58.03
	Mean Fractional Bias(%, -200 to +200)	60.83	59.71	50.60
	Mean Fractional Error(%, 0 to 200)	61.71	60.59	52.02
	Normalized Mean Square Error	0.34	0.32	0.21

Table 3: 2014 Statistical evaluation of model performance, under various model formulations.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2014	Mean Bias (ppb)	8.18	8.02	5.25
	Mean Error (ppb)	8.18	8.02	5.39
	Normalized Mean Bias(%, -100 to ∞)	44.73	43.86	28.69
	Normalized Mean Error(%, 0 to ∞)	44.73	43.86	29.49
	Mean Fractional Bias(%, -200 to +200)	37.50	36.93	26.47
	Mean Fractional Error(%, 0 to 200)	37.50	36.93	26.80
	Normalized Mean Square Error	0.15	0.14	0.06

Table 4: 2012-2014 Statistical evaluation of model performance, under various model formulations.

2012-2014 3-year Average	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	10.33	9.87	7.34
	Mean Error (ppb)	10.39	9.92	7.56
	Normalized Mean Bias(%, -100 to ∞)	68.29	65.23	48.50
	Normalized Mean Error(%, 0 to ∞)	68.65	65.59	49.95
	Mean Fractional Bias(%, -200 to +200)	55.89	54.17	44.51
	Mean Fractional Error(%, 0 to 200)	56.01	54.30	45.04
	Normalized Mean Square Error	0.29	0.27	0.16

The statistics presented in Tables 1-4 demonstrate that the model is biased towards over-prediction under all formulations, even in the absence of background concentration. The statistics also indicate a clear improvement in both bias and error for all years, as well as the three year average, when the beta options are included. This improvement is most critical in the three year average data presented in Table 4, which shows an improvement of 19.79% in the normalized mean bias, and an 18.7% improvement in the normalized mean error using the ADJ_U* and LOWWIND3 options. Mean bias improves 2.99 ppb, and mean error improves 2.83 ppb. While these differences seem relatively minor, it must be noted that the purpose of this modeling is to characterize ambient air quality, treating each receptor as a surrogate for an ambient air quality model. These differences are therefore highly relevant and indicative of improved model performance. The goal of any modeling conducted to inform SO_2 designations should be the most accurate and un-biased modeling possible. In this source area, the most accurate and un-biased modeled estimates of ambient air quality are achieved via the AERMOD model with the LOWWIND3 option enabled, coupled with meteorological data processed with the ADJ_U* option.

Given the over-predictive bias at the monitor location in this source area in the absence of background, it is obvious and not unexpected that inclusion of any background would further increase the over-predictive bias of the model, regardless of model formulation. As a consequence of these analyses, Ohio EPA understands that a carefully chosen background, informed by the statistical assessment of model performance presented in this document, as well as other relevant variables, is necessary to minimize over-predictive bias.

Background Revision:

In Ohio's September 16, 2015 recommended designation submittal for the General James M. Gavin and Kyger Creek source area, modeling was performed using a fixed background of 10 ppb, derived conservatively from monitor 39-105-0003 in Meigs County, Ohio. At the time of submittal, Ohio EPA understood that a fixed background was overly conservative. This is due in large part to both the lack of other sources of SO_2 besides the General James M. Gavin and Kyger Creek stations close enough to impact monitor 39-105-0003, or located such that prevailing winds would carry emissions to this monitor location. A fixed background also lacks any of consideration of temporal variation observed in hourly monitor data. Simply put, Ohio EPA believes that the vast majority of SO_2 ambient concentrations recorded at monitor 30-105-0003 originate from emissions from the General James M. Gavin and Kyger Creek facilities. Considering the results the statistical analyses presented above, which indicate that the model is over-predictive even in the absence of a background, Ohio EPA believes that it is still necessary to include background in this modeling to maintain a measure of conservatism, provided that the background is carefully considered and informed by the multiple statistical analyses performed at the monitoring location, the meteorology of the source area, and the temporal distribution of concentrations recorded at the monitoring location. While Ohio EPA believes that monitor 39-105-0003 is impacted almost exclusively by emissions from the General James M. Gavin and Kyger Creek facilities, and that use of data from this monitor has strong potential to introduce "double-counting" in the modeled results, it is also believed that with careful consideration of wind direction, temporal distribution of minimum and maximum monitor values, and the statistical analyses in this document, this monitor can serve as an adequate indicator of background values in this source area.

The monitor is approximately 13 kilometers to the Northeast of the General James M. Gavin Power Plant (Gavin) (see Figure 1, above). According to the EPA March 1, 2011 Memorandum[3], selection of regional background sources to be included in a modeling analysis should focus on the area within about 10 kilometers of the project location in most cases. The nearest significant contributor to regional SO_2 concentrations is Mountaineer Power Plant near New Haven, WV. This power plant is approximately 16 kilometers East-Northeast of Gavin and approximately 12 kilometers to the Southeast of the background monitor. Because of the distance between this source and the General James M. Gavin plant, as well as being primarily downwind of Gavin and nearer to the background monitor than to Gavin, it would be expected to produce only a minimal background influence at the location of the Gavin and Kyger sources and would be conservatively captured by the background monitor. As such, no additional sources were modeled for consideration of regional background.

According to the *Guideline on Air Quality Models*[4] and the proposed changes to Appendix W[5], the background concentration at the monitor should be determined by excluding values when the source in question is impacting the monitor. The Pomeroy monitor falls directly in line with both the Gavin and Kyger plants, and so values at the monitor were excluded for hours when the wind direction was coming from within a 60

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[3] http://www.epa.gov/scram001/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2 NAAQS_FINAL_03-01-2011.pdf.

[4] 40 CFR Appendix W to Part 51

[5] 80 FR 45373. (July 29, 2015).

degree sector centered on the Gavin and Kyger plants. After the exclusion of the hours of monitoring data within the 60 degree sector encompassing the plants, all remaining hours at the Pomeroy monitor were used to generate an initial background profile, based conservatively on the 99th percentile monitored concentrations. The EPA March 1, 2011 Memorandum suggests that when considering standards based on the annual distribution of daily maximum 1-hour values, diurnal patterns of ambient impacts may play a significant role in pairing modeled and monitored concentrations, and a temporally varying background may be most appropriate. This was deemed to be the case here. A temporally (by hour of day and season) varying background was then determined according to that guidance and used in this case. The resulting concentrations of the initial background profile are shown in Figure 6.

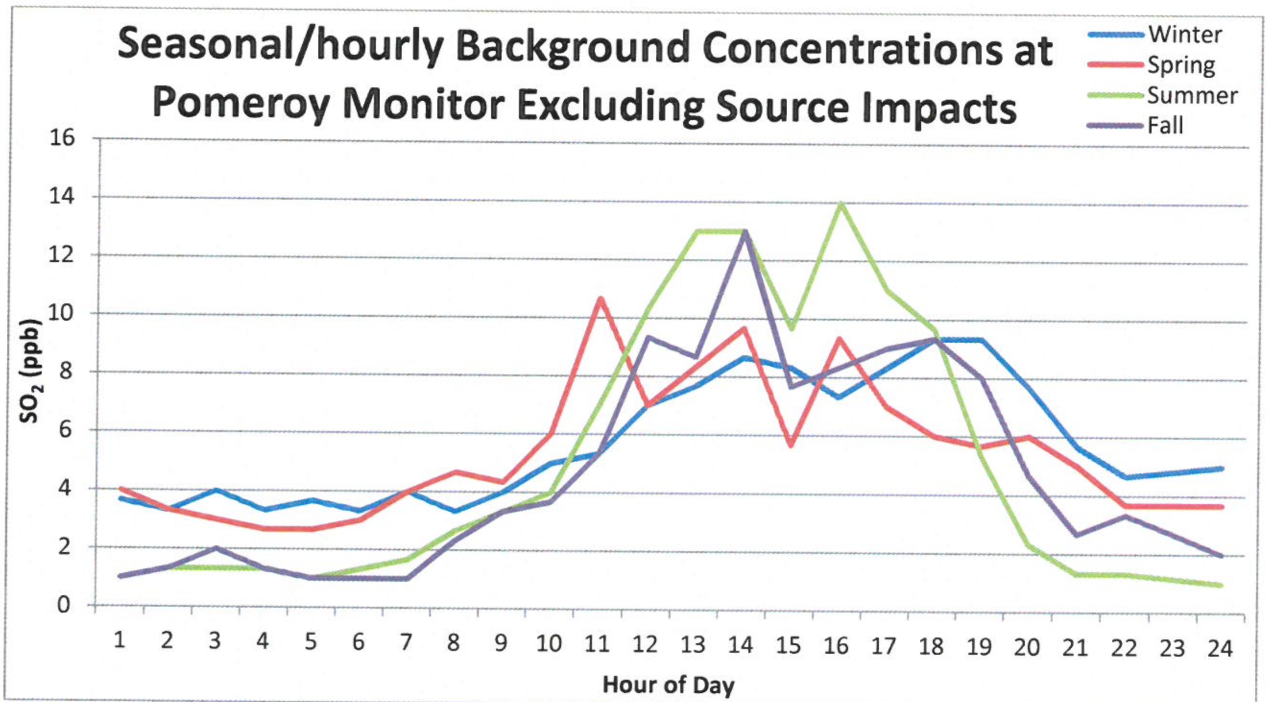

Figure 6: Initial season/hourly varying background profile, based on 99th percentile monitor values.

To determine the impact of the variable background shown in Figure 1 on model performance with respect to bias and error, Ohio EPA performed the same statistical analyses presented previously in this document on the highest 20% of maximum daily values at the monitor location, averaged over three years, consistent with the form of the design value. The results of this analysis are shown in Table 5.

Table 5: 2012-2014 Statistical evaluation of model performance, under various model formulations, with initial background profile based on 99th percentile values.

2012-2014 3-year Average with Initial Background	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	16.06	15.70	13.17
	Mean Error (ppb)	16.06	15.70	13.22
	Normalized Mean Bias(%, -100 to ∞)	106.15	103.78	87.02
	Normalized Mean Error(%, 0 to ∞)	106.15	103.78	87.35
	Mean Fractional Bias(%, -200 to +200)	74.38	73.39	66.19
	Mean Fractional Error(%, 0 to 200)	74.38	73.39	66.30
	Normalized Mean Square Error	0.56	0.54	0.39

The results of the statistical analysis shown in Table 5 indicate that the initial variable background determined by Ohio EPA from the 99th percentile values introduces approximately 6 ppb, on average, of additional bias and error in the model data at the monitor location. These data can be compared to those presented in Table 4, above, and replicated here (below) for convenience.

2012-2014 3-year Average	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	10.33	9.87	7.34
	Mean Error (ppb)	10.39	9.92	7.56
	Normalized Mean Bias(%, -100 to ∞)	68.29	65.23	48.50
	Normalized Mean Error(%, 0 to ∞)	68.65	65.59	49.95
	Mean Fractional Bias(%, -200 to +200)	55.89	54.17	44.51
	Mean Fractional Error(%, 0 to 200)	56.01	54.30	45.04
	Normalized Mean Square Error	0.29	0.27	0.16

The results of the statistical analysis indicate that Ohio EPA's initial variable background profile, based on 99th percentile monitored values, is overly conservative. To mitigate to some degree the error and bias introduced solely by the initial variable background, Ohio EPA revised the initial variable background, as informed by the statistics presented in Tables 4 and 5. Specifically, it is demonstrated that this background introduces ~38% bias and error in modeled daily maximum values, independent of model performance or formulation. Therefore, Ohio EPA reduced the seasonally varying background values initially based on 99th percentile values by 38%. Any background value calculated to be less than 1 via this process was replaced with a value of 1 ppb. Ohio EPA understands that while this process will not mitigate fully the bias and error introduced by background in this source area, some degree of improvement is anticipated. The results of Ohio EPA's statistical analysis of the variable background are presented in Table 6.

Table 6: 2012-2014 Statistical evaluation of model performance, under various model formulations, with final variable background profile.

2012-2014 3-year Average with Final Background	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	13.69	13.29	10.73
	Mean Error (ppb)	13.68	12.29	10.84
	Normalized Mean Bias(%, -100 to ∞)	90.48	87.81	70.93
	Normalized Mean Error(%, 0 to ∞)	90.48	87.81	71.63
	Mean Fractional Bias(%, -200 to +200)	67.41	66.17	58.03
	Mean Fractional Error(%, 0 to 200)	67.41	66.17	57.27
	Normalized Mean Square Error	0.45	0.42	0.28

The data in Table 6 shows that the final variable background profile derived by Ohio EPA from data recorded at monitor 39-105-0003 introduces significantly less bias and error than the initial profile, which was conservatively compiled from 99th percentile values. Figure 7 presents Ohio EPA's final variable background.

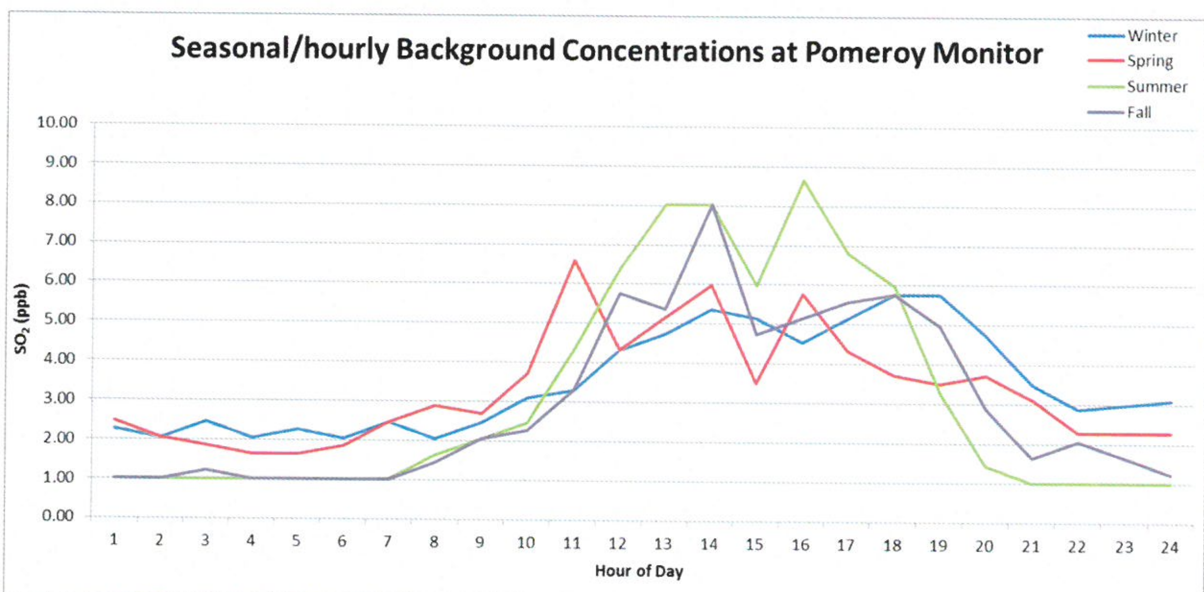

Figure 7: Final season/hourly varying background profile.

As a final evaluation of Ohio's temporally varying background profile, Figure 8 shows the model vs. monitor comparison of the top 20% of maximum daily values inclusive of the variable background. The modeled data presented in Figure 8 were derived from AERMOD in the default configuration (no LOWWIND corrections enabled) and with default meteorological data (no ADJ_U* option enabled).

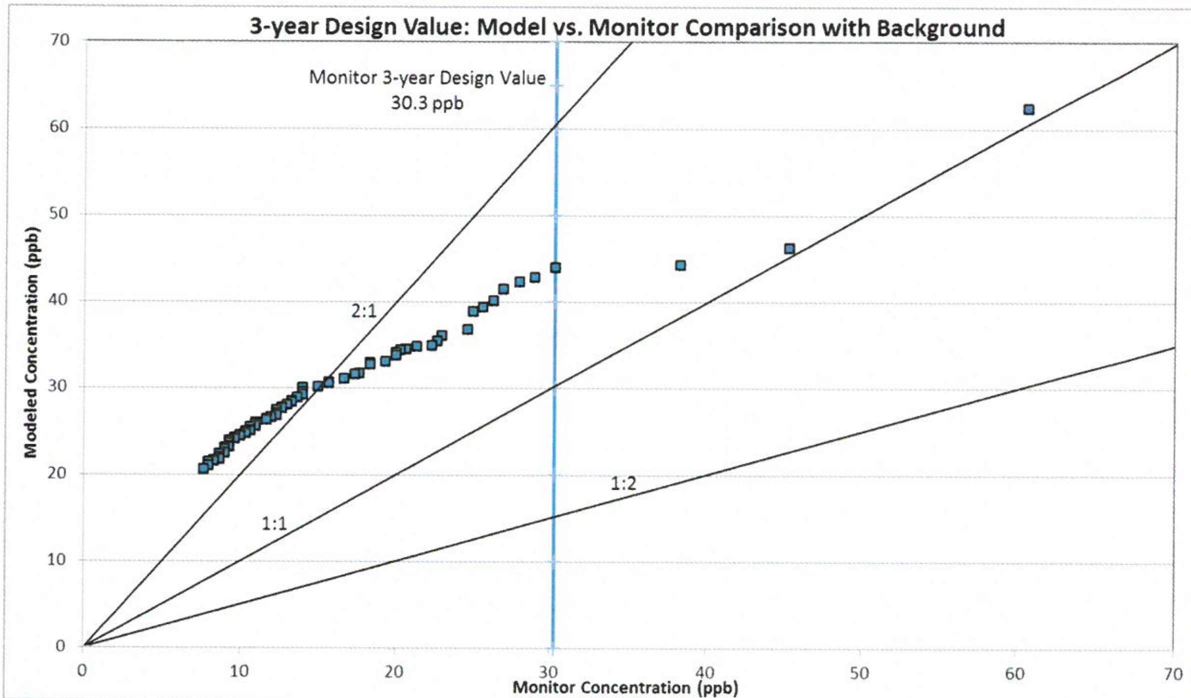

Figure 8: 2012-2014 three year design value, model vs. monitor, inclusive of variable background, with full regulatory default AERMET and AERMOD.

The 10 ppb fixed background utilized in modeling for Ohio's September 16, 2015 recommended designation submittal indicated a modeled design value at the monitor location of 41 ppb, or 11 ppb greater than the actual 2012 to 2014 monitored design value of 30 ppb. The variable background derived by Ohio EPA and considered here yield a modeled design value at the monitor location of 43 ppb. While this is slightly greater than the value modeled in the original submittal, Ohio EPA believes that the variable profile derived for this submittal is far more realistic and appropriate, given the consideration of additional factors to inform its development.

Conclusions:

This TSD details Ohio EPA's derivation of a new, variable background concentration profile for the General James M. Gavin/Kyger Creek source area, to replace the fixed value of 10 ppb as used in Ohio's September 16, 2015 recommended designation submittal, the corrective measures taken to remedy unrealistic and non-physical convective and mechanical mixing heights observed in the original 2014 meteorological data, and a statistical analysis of model performance. The statistical analysis conducted in the source area indicates that the most accurate AERMOD formulation for this source area is AERMOD with the LOWWIND3 option enabled, and meteorological data processed with the ADJ_U* option. Under all model formulations, the model is over-predictive, even in the absence of background concentration. Although this analysis can only be conducted at a single monitor in this source area, Ohio EPA has demonstrated that this monitor is well situated to represent the impacts of emissions from the General James M. Gavin and Kyger Creek power plants, despite not being located at a point of maximum impact. And further, in Appendix B, Ohio EPA has demonstrated improved model performance without the introduction of under-predictive bias in two additional source areas where multiple monitors are present. The results of these analyses are used to inform additional modeling performed for this source area that is being submitted as a part of Ohio's comments.

AERMOD Low Wind Speed Correction Options Analysis and Request: 1-hour Sulfur Dioxide Data Requirements Rule Modeling

Ohio EPA

December, 2015

Introduction

Under both the March 2, 2015 Consent Decree and the August 21, *2015 Data Requirements Rule for the 2010 1-Hour Sulfur Dioxide (SO2) Primary National Ambient Air Quality Standard (NAAQS); Final Rule*, states are tasked with modeling actual SO_2 emissions for the purposes of designation. U.S. EPA has stated multiple times that the purpose of this modeling is to treat each receptor in the modeling domain as a surrogate for an ambient air quality monitor. As such, Ohio EPA has, as part of what Ohio considers best modeling practice, included receptors in the location(s) of actual ambient air quality monitors in those source areas for which Ohio has completed designations modeling. These efforts, as well as multiple presentations, peer reviewed publications, and U.S. EPA documents, indicate that there is a tendency for AERMOD to overpredict ground level impacts under conditions of low wind speed, even in cases where the meteorology does not contain a significant number of low wind periods. To address these concerns, U.S. EPA has, beginning with AERMOD version 12345, included various beta model options that compensate for the performance issues of AERMOD under low wind conditions. Recently, U.S. EPA proposed that the beta u* adjustment (ADJ_U*) option of AERMET, as well as the LOWWIND3 option of AERMOD, be incorporated as regulatory default components of the AERMOD modeling system.

Ohio EPA's experience, as well as a substantial and growing body of research, indicates that these options improve the accuracy of AERMOD without the introduction of underprediction bias. This improved accuracy is of critical importance to states tasked with determining the most accurate and realistic assessment of actual air quality via modeling for the purposes of designation. Further, the form and stringency of the 1-hour SO_2 standard is such that a relatively few hours of each year modeled can drive unrealistic and overly conservative design values.

Ohio EPA is therefore requesting the use of ADJ_U* and LOWWIND3 AERMOD options for designations modeling in the State of Ohio. Pursuant to this request, Ohio EPA is providing here information to support this request. It should be noted here that U.S. EPA Region 5 conveyed to Ohio EPA staff that a request would include:

1. An email requesting the use of these options
2. Source information (stack heights, exit velocities)
3. Information on the terrain in each modeling domain
4. Analysis/description of representative meteorological data
5. Results of model performance evaluations conducted
6. Reference to past evaluations and publications

Previous Evaluations of Model Performance

Ohio EPA understands that there is a substantial and growing body of research and evaluation with respect to methodologies to alleviate and correct for the overly-conservative performance of AERMOD under low wind conditions. The following represents a summary of those evaluations and milestones leading to the proposed incorporation of the u* adjustment (ADJ_U*) and LOWWIND3 treatment as default regulatory components of the AERMOD modeling system. While not intended to represent a complete bibliography of the development of these options, Ohio EPA believes the following section presents an adequate and relatively complete summary of the major evaluations and publications justifying the use of these options in most modeling applications. Further, Ohio EPA contends that the presentations and evaluations described below demonstrate substantial improvements to the accuracy of the AERMOD modeling system without introduction of underprediction bias. As states are tasked, under both the Consent Decree and Data Requirements Rule, to conduct air quality modeling to assess current air quality for the purposes of designations for the 2010 1-hour SO_2 standard (treating receptor locations as surrogates for ambient air quality monitoring) it is critical that the most accurate modeling approach be considered and implemented for these modeling analyses.

U.S. EPA initially noted at the 2007 Regional, State, and Local Modelers' Workshop issues with AERMOD's performance under low wind conditions[1]. These performance issues became significantly more challenging and apparent to the modeling community with the promulgation of the 2010 1-hour SO_2 and NO_2 standards. In response to these challenges, the American Petroleum Institute (API) and the Utility Air Regulatory Group (UARG) commissioned a study of AERMOD's performance under low wind speeds. The results of this study were presented by AECOM at the 10th Annual Modeling Conference in 2012[2]. This study utilized existing research-grade meteorological databases and tracer study results to evaluate the performance of AERMOD under low wind conditions. The results of this study indicated that AERMOD underpredicts u* under low wind conditions, and as a consequence, tends to overpredict concentrations under those conditions. Further, the study also demonstrated improved model performance when the minimum value for sigma-v was increased from 0.2 meters/second. The study was submitted to U.S. EPA with recommendations that an alternative u* formulation and an adjustment to the minimum sigma-v value be incorporated into AERMOD.

Starting with AERMOD version 12345, U.S. EPA, in response to these concerns, incorporated various beta options to adjust the formulation of u* under low wind speed conditions. These adjustments to u* are based on a 2011 publication which presented a rigorous examination of AERMOD predictions against observed values from two historical field studies[3]. This publication concluded that adjustments to u* resulted in a reduction in model bias, but did not completely eliminate overprediction bias. Further, the study presented a rigorous mathematical framework for adjustments to the u* formulation. In the 2012 AERMOD User's Guide Addendum, U.S. EPA presented Q-Q plots of observed versus model-predicted concentrations using two historic field-study data sets analyzed by U.S. EPA. The results presented by U.S. EPA in this document indicate that there is lower mean bias in modeled concentrations, and results were free from underprediction at both study sites, when the beta u* formulation was utilized. As a consequence of the multiple validation studies and the peer reviewed publication of Qian and Venkatram in 2011, U.S. EPA has indicated on multiple occasions that the beta u* adjustment option is not considered an alternative model as described in Appendix W[4].

AERMOD version 12345 also introduced beta options LOWWIND1 and LOWWIND2, which adjust the minimum wind speed and sigma-v values, as well as the meander component of AERMOD. Although not as rigorously analyzed as the u* adjustment, the LOWWIND options fulfilled the additional recommendations presented in Paine, Connors, and Szembeck, 2012.

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1 Brode, R (2007). AERMOD Implementation Workgroup Highlights. Presented at the 2007 EPA R/S/L Modelers' Workshop. Virginia Beach, VA, May 2007.

2 Paine, R; Connors, J; Szembek, C (2012) Low Wind Speed Evaluation Study. Presented at EPA's 10th Modeling Conference. Raleigh, NC, March, 2012.

3 Qian, W; Venkatram, A (2001). *Performance of Steady-State Dispersion Models Under Low Wind-Speed Conditions*. Boundary Layer Meteorology, 138: 475-491.

4 http://www3.epa.gov/scram001/models/aermod/20130626-Statement_on_Beta_Options.pdf

Ongoing evaluations of the performance of AERMOD under low wind conditions and the various beta options incorporated into AERMOD since version 12345 have been conducted. The most recent updated version of AERMOD, version 15181, was released concurrently with a significantly updated and revised proposed Appendix W. This version of AERMOD continued the inclusion of the u* adjustment as a beta option, as well as an updated beta low wind speed adjustment option, LOWWIND3, which blended the approach of the previous LOWWIND1 and LOWWIND2 options. U.S. EPA is proposing that both the u* and LOWWIND3 options be incorporated as regulatory default options in a future version of AERMOD. Concurrent with the proposed revisions to Appendix W and the release of AERMOD version 15181, U.S. EPA hosted the 11th Modeling Conference in August of 2015. Several presentations given at this conference, both by U.S. EPA and the public, demonstrate the improvement of the AERMOD modeling system under low wind conditions and support the proposed incorporation of the u* adjustment and LOWWIND3 option as default regulatory components. U.S. EPA presented model performance results, using the beta u* option and AERMOD version 14134, based on the 1993 Cordero Rojo surface mine study. These results demonstrated a significant improvement over the default regulatory options. In the same presentation, U.S. EPA presented updated model evaluation studies using AERMOD version 15181 and the 1974 Oak Ridge and Idaho Falls tracer studies. These tracer studies were based on low-level release tracer studies. In each instance, model performance was demonstrated to be significantly improved using various combinations of the u* and LOWWIND3 options[5]. Ohio EPA notes that U.S. EPA had presented similar conclusions for the same field study databases prior to the 11th Modeling Conference, conducted using AERMOD version 14134 for all three field study evaluations referenced above[6].

Also important to Ohio EPA's request to utilize the beta u* and LOWWIND options was an updated evaluation of the North Dakota and Gibson Generating Station tall stack database with the u* and LOWWIND2 options using AERMOD version 14134, presented at the 11th Modeling Conference[7]. The results presented indicate an overall performance increase against measured concentrations with tall stack sources. Additionally, the results indicate that the performance of AERMOD with tall stacks in elevated terrain is substantially improved by use of both the u* and LOWWIND options. As the majority of sources in Ohio necessitating modeling under the SO_2 Data Requirements Rule are tall-stack type sources located in the elevated terrain of the Ohio River valley, these findings are of particular interest to Ohio EPA. Lastly, the study indicates that the LOWWIND3 option introduced in AERMOD version 15181 (and proposed to be incorporated as a default regulatory component) are in close alignment with previous findings with respect to how best to compensate for the overly conservative performance of the AERMOD modeling system under low wind conditions.

In November, 2015, an article was published in the Journal of the Air and Waste Management Association presenting a rigorous evaluation of the North Dakota and Gibson Generating databases and the performance of the u* and LOWWIND option in the AERMOD model[8]. This evaluation is based on the same analysis presented at the 11th Modeling Conference (Paine, 2015), which demonstrated considerable improvement in AERMOD version 14134 performance with respect to tall-stack type sources, without introduction of underprediction bias. This publication is of particular importance, as it represents, to the best of Ohio EPA's knowledge, the first peer-review of the LOWWIND options as

[5] Brode, R (2015). Proposed Updates to AERMOD Modeling System. Presented at EPA's 11th Modeling Conference. Raleigh, NC, August, 2015.
[6] U.S. EPA Air Quality Modeling Group, Office of Air Quality Planning and Standards (2014). Webinar: AERMOD Modeling System Update. August 12, 2014.
[7] Paine, R (2015). AERMOD Low Wind Speed Evaluation with Tall-Stack Databases. Presented at EPA's 11th Modeling Conference. Raleigh, NC, August, 2015.
[8] Paine, R; Samain, O; Kaplan, M; Knipping, E; Kumar, N (2015*). Evaluation of low wind modeling approaches for two tall-stack databases.* Journal of the Air & Waste Management Association, 65:11, 1341-1353.

incorporated in recent versions of the AERMOD modeling system, as well as the second peer-reviewed analysis of the beta u* adjustment. Ohio EPA contends that the publication and peer review of the LOWWIND options would lend significant validity to the incorporation of this option into the AERMOD modeling system, as proposed by U.S. EPA. Further, such peer review should lessen the level of demonstration needed to justify the use of this option in modeling applications. Given the very recent nature of this publication, Ohio EPA is including this document as Appendix A of this submittal. Via correspondence with the first author of this publication, Ohio EPA obtained a white paper detailing an update to the above referenced study based on the most recent update to AERMOD (version 15181) and the LOWWIND3 option. Ohio EPA is including this document as Appendix B of this submittal.

Ohio EPA Model Performance Evaluations

In the course of SO_2 designations modeling, Ohio EPA has conducted, to date, two model vs. monitor performance evaluations in the Gavin/Kyger Creek source area and the J.M Stuart/Killen source area. The purpose of these analyses was to evaluate the performance of the default regulatory model options against those results obtained from model runs using the u* adjustment and LOWWIND3 options against monitored data, years 2012-2014. These options are herein referred to as ADJ_U* and LOWWIND3. These evaluations focused on the performance of the model against monitor data at various percentiles of maximum daily values, including the 99^{th} percentile, representing the form of the 2010 1-hour SO_2 standard. Ohio EPA selected percentiles for the evaluation over hour-by-hour comparisons for several reasons. Firstly, absent a more extensive on site meteorological data collection network in each source area, hour-by-hour comparisons would not accurately represent the exact meteorological conditions of the study area. Secondly, Ohio EPA conducted these evaluations at a single monitoring location in each source area, as other monitors were simply not available for comparison. Lastly, the majority of evaluations comparing hour-by-hour model vs. monitor performance did not have to account for background impacts from other sources. Background SO_2 values were necessarily and conservatively accounted for in Ohio EPA's modeling for the purposes of designation, but a source of accurate hour-by-hour background concentrations was not available in either source area. Therefore, Ohio EPA contends that while an hour-by-hour evaluation would be optimal, such an evaluation is not possible, nor would the results of such an analysis be representative for these source areas. Therefore, percentiles of maximum daily values were chosen by Ohio EPA as the metric for comparison of model output to monitor data. In all evaluations, Ohio EPA utilized the most up-to-date version of AERMOD, version 15181.

General James M. Gavin / Kyger Creek Model Performance Evaluation

Ohio EPA conducted model performance analyses using 2012-2014 actual emissions from the General James M. Gavin Plant and the Kyger Creek Station, modeling the impact of these facilities at the location of monitor 39-195-0003. This analysis was originally submitted as Appendix C of Ohio's recommended designation for the General James M. Gavin source area, submitted on September 16, 2015. Ohio EPA is presenting here only the significant results of the analysis at this monitor. This monitor is located 13 km to the Northeast of the General James M. Gavin plant in Pomeroy, Ohio, and was sited to monitor the combined impact of emissions from the General James M. Gavin and Kyger Creek Station facilities. Upon conducting initial modeling using current default regulatory options, Ohio EPA found that AERMOD significantly overestimated SO_2 concentrations at monitor 39-195-0003. The modeled three-year design value was 41 ppb, compared to an actual monitored design value of 30 ppb, without consideration of background concentration (10 ppb) in the modeled design value. Ohio EPA identified that a majority (57%) of available meteorological surface data hours from the 2012 to 2014 period modeled for this location fall under stable conditions. Stable hours were computed for each year of the three years, as well as the entire three-year period.

From the modeling results from the two formulations over the three year modeling period, hourly SO_2 values from a receptor placed at the Pomeroy monitor location were isolated for analysis. From these values, daily maximum values were computed for each day over the three year period and subsequently, the 99^{th} percentile daily maximum value for each of the three years was identified. The mean of these three 99^{th} percentile values is used for the computed Design Value from each modeling formulation, less an acceptable background value. Figure 1 shows the results of this analysis.

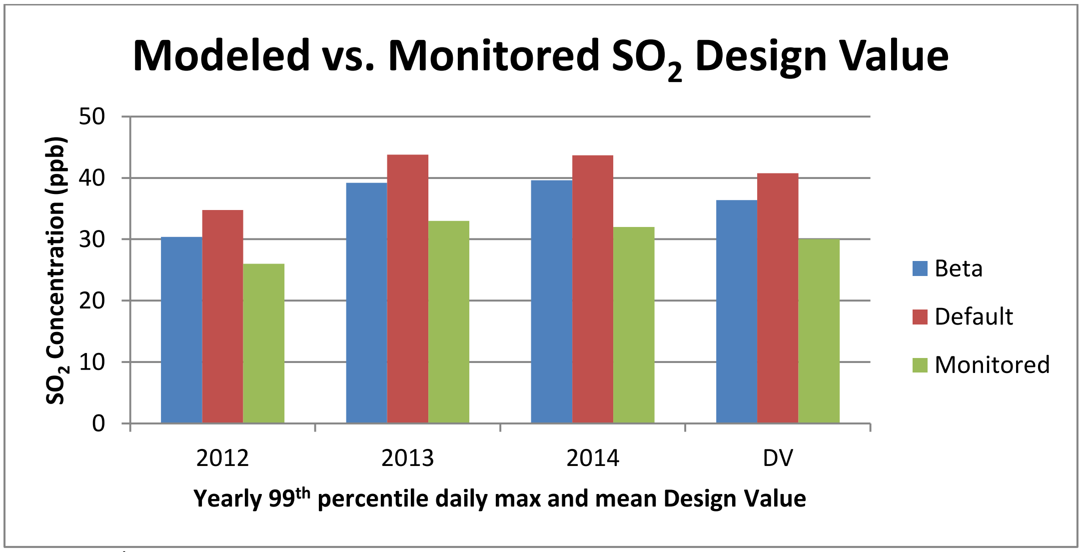

Figure 1: Annual 99^{th} percentile daily max and mean design value for the three year period of SO_2 concentration at monitor 39-195-0003 with modeled design values, with and without beta options, no background.

As shown in Figure 1, both modeling formulations overestimate the monitored SO_2 values at the Pomeroy monitor, even without adding a background SO_2 value to the model results with respect to monitored concentrations. The monitor design value is 30 ppb, and the design value computed from modeling with beta options is 36 ppb. The design value from Default options is 41 ppb. For each yearly 99^{th} percentile daily max value, and in turn the three-year design value, the modeled results with the beta options enabled show closer agreement to the monitor value, representing a substantial improvement in model performance using these beta options.

Utilizing the daily maximum values for the three year period as described in the previous analysis, the 99^{th}, 90^{th}, 75^{th}, 50^{th}, 25^{th} and 10^{th} percentile daily maximum values for each year were identified for the different model formulations for comparison against monitored values. These results are shown in Figures 2, 3, and 4 for years 2012, 2013, and 2014, respectively. As with the Design Value comparison, background has not been added to the model results.

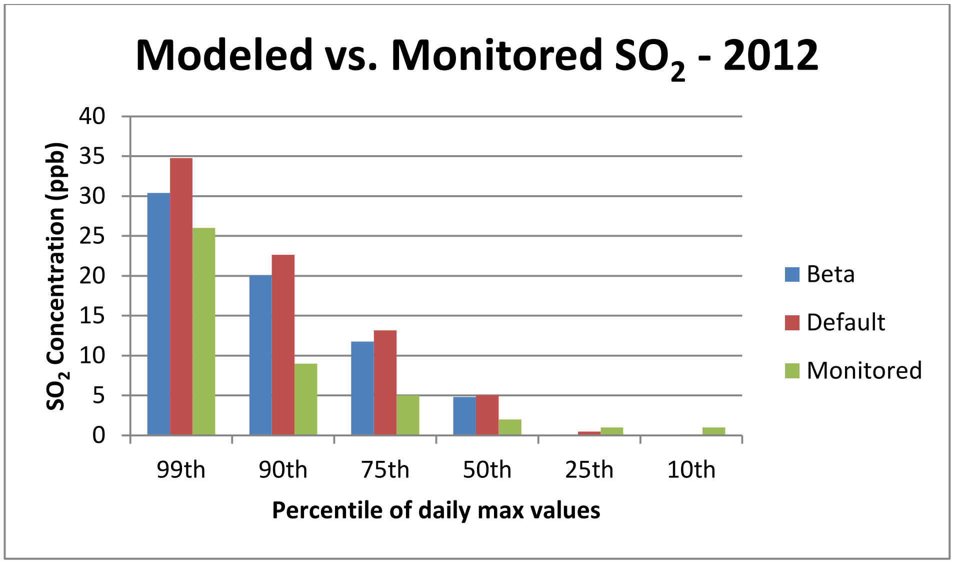

Figure 2: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2012 at the location of the Pomeroy monitor.

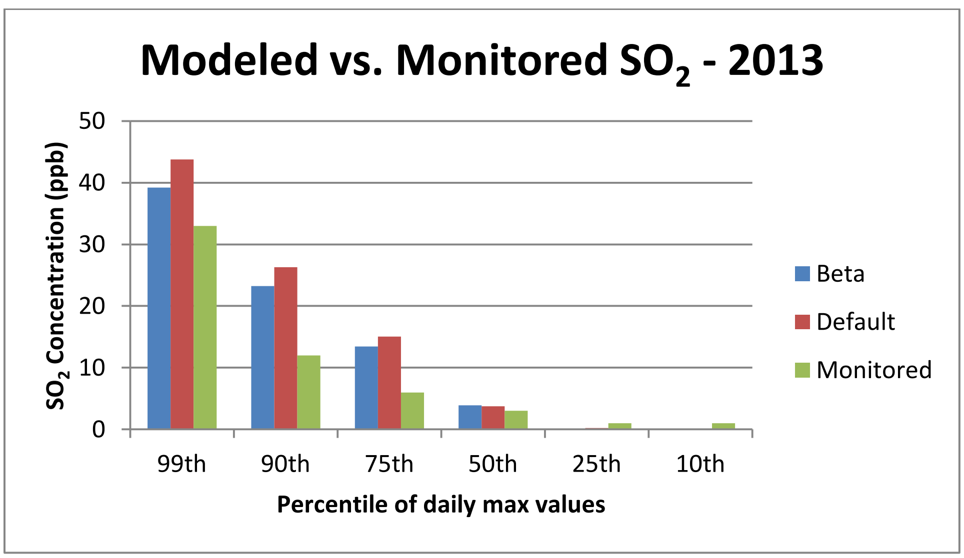

Figure 3: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2013 at the location of the Pomeroy monitor.

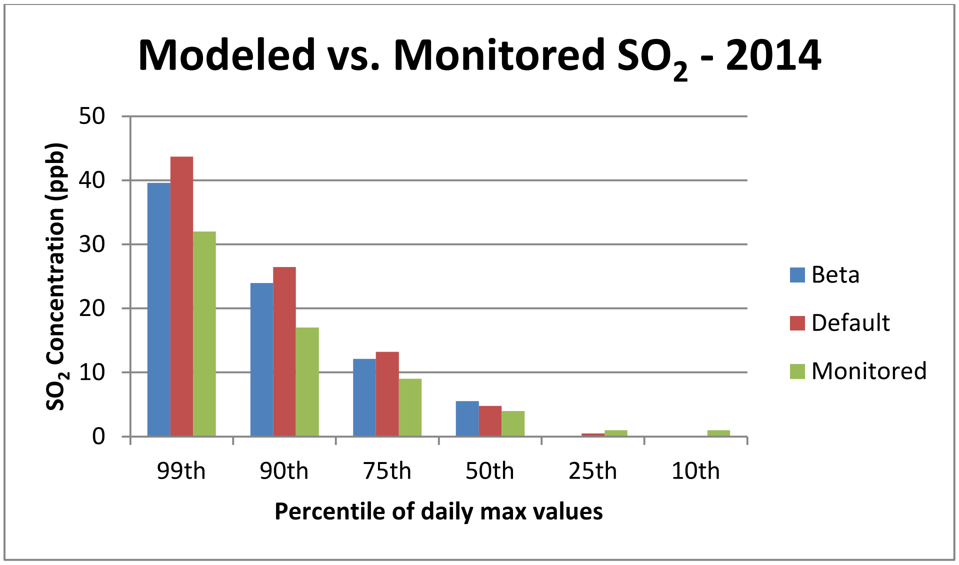

Figure 4: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2014 at the location of the Pomeroy monitor.

As Figures 2-4 show, both modeling formulations consistently overestimated SO_2 concentrations for all daily maximum values at or above the 50th percentile of daily maximum values, even without an added background concentration. Below the 50th percentile, both model formulations underestimated the monitored values without background, but as the monitored values at the 25th and 10th percentiles are in the 1 ppb range, this underestimation is negligible. With background concentration included, both model formulations overestimate the monitored values at all percentiles.

Ohio EPA's model performance evaluation of the General James M. Gavin source area demonstrates that AERMOD performance with respect to monitored values – both when considering elevated SO_2 concentrations which are used for design value calculation, and across a range of daily maximum concentration thresholds – improves with the ADJ_U* and LOWWIND3 options enabled. Additionally, both modeling scenarios consistently overestimate SO_2 concentrations as compared to monitor values in both analyses performed, which indicates that the use of the beta options will still provide conservative estimates of SO_2 concentrations. Ohio EPA concludes that enabling the ADJ_U* and LOWWIND3 options was the most appropriate modeling formulation for modeling in this source area, and that results are consistent with those evaluations detailed in the Previous Evaluations of Model Performance section of this document.

J.M. Stuart / Killen Source Area Model Performance Evaluation

Ohio EPA conducted model performance analyses using 2012-2014 actual emissions from the DP&L Stuart and Killen Stations, modeling the impact of these facilities at the location of monitor 39-001-0001. This monitor is located approximately 20 km North, North-East of the Stuart Station and 12.5 km West, North-West of the Killen Station in Adams County, Ohio. This analysis will be submitted as an Appendix to Ohio's recommended designation for the Stuart/Killen source area under the Data Requirements Rule. Ohio EPA is presenting here only the significant results of the analysis at this monitor.

Initial modeling of the Stuart and Killen facilities using current default regulatory options overestimated SO_2 concentrations at monitor 39-001-0001. The calculated three-year design value was 33.47 ppb, including the background concentration of 10 ppb, compared to an actual monitored design value of 26 ppb. Ohio EPA identified that a majority (57%) of representative meteorological surface data hours from the 2012 to 2014 period modeled for this location fall under stable conditions. Stable hours were calculated for each year of the three years, as well as the entire three-year period. Considering the prevalence of stable hours over the modeled time period, as well as the documented ability of the beta (ADJ_U* and LOWWIND3) options to improve model performance, Ohio EPA conducted further model performance evaluation to determine if inclusion of these beta options could correct the observed over-prediction of SO_2 concentrations in this scenario.

From the modeling results from the two formulations over the three year modeling period, hourly SO_2 values from a receptor placed at the West Union Adams County Hospital SO2 ambient air quality monitor location (39-001-0001) were isolated for analysis. From these values, the 99th percentile daily maximum value for each of the three years was identified. The mean of these three 99th percentile values was used for the Design Value from each modeling formulation, inclusive of a representative background value of 10ppb. Figure 5 shows the results of this analysis.

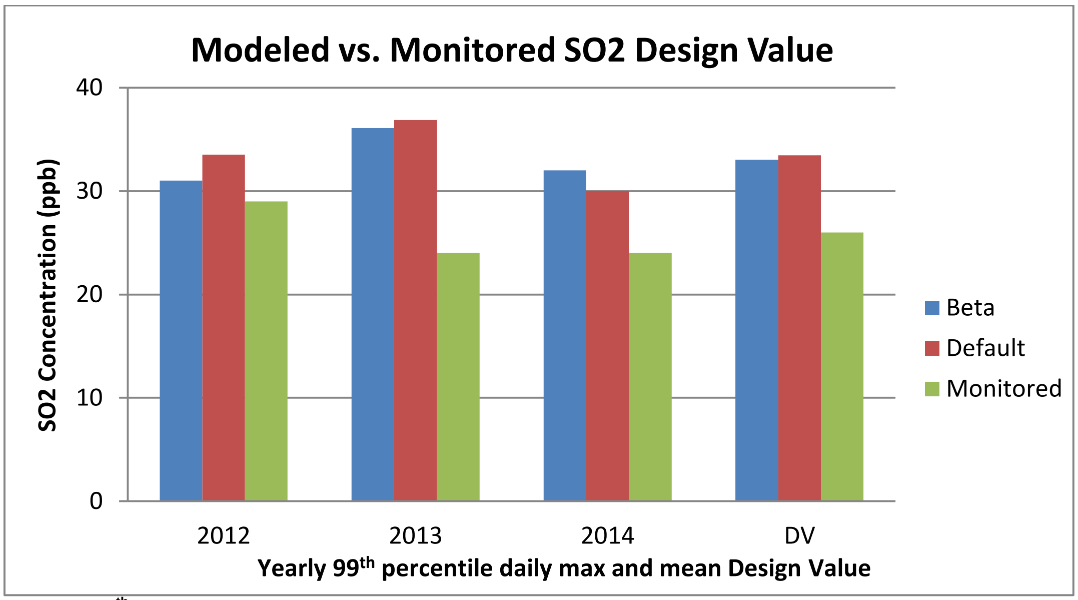

Figure 5: Annual 99th percentile daily max and mean design value for the three year period of SO_2 concentration at monitor 39-001-0001 with modeled design values, with and without beta options. A background concentration of 10ppb is included.

As shown in Figure 1, both modeling formulations overestimate the monitored SO_2 values at ambient air quality monitor 39-001-0001 with respect to monitored concentrations. The monitor design value is 26 ppb, and the design value computed from modeling with beta options is 33.04 ppb. The design value from Default options is 33.47 ppb. For each yearly 99th percentile daily max value, and in turn the three-year design value, the modeled results with the beta options enabled show closer agreement to the monitor value, representing an improvement in model performance using these beta options.

Utilizing the daily maximum values for the three year period as described in the previous analysis, the 99th, 90th, 75th, 50th, 25th and 10th percentile daily maximum values for each year were identified for the different model formulations for comparison against monitored values. These results are shown in Figures 6, 7, and 8 for years 2012, 2013, and 2014, respectively, and are inclusive a 10 ppb background.

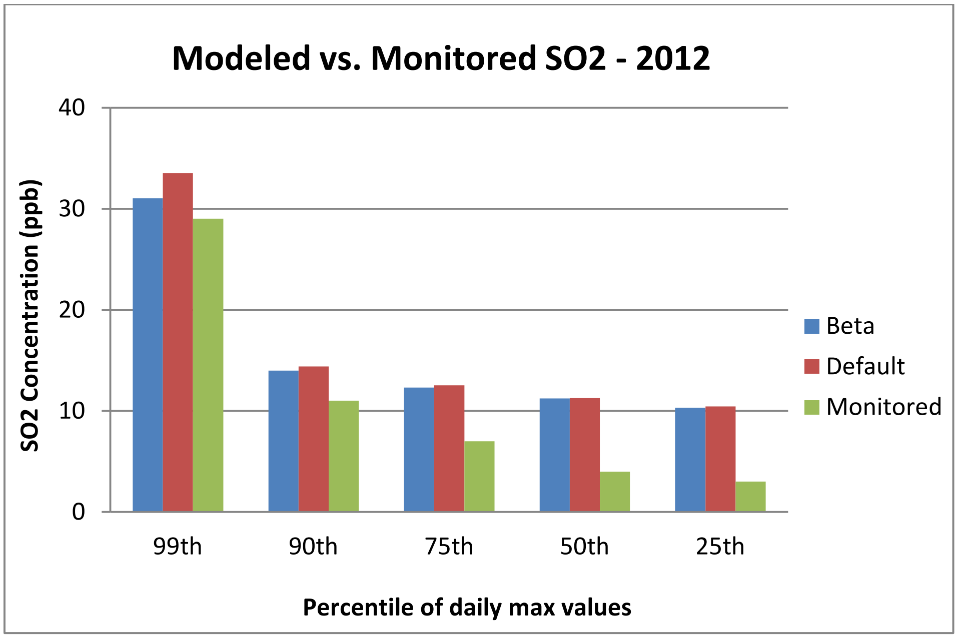

Figure 6: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2012 at the location ambient air quality monitor 39-001-0001.

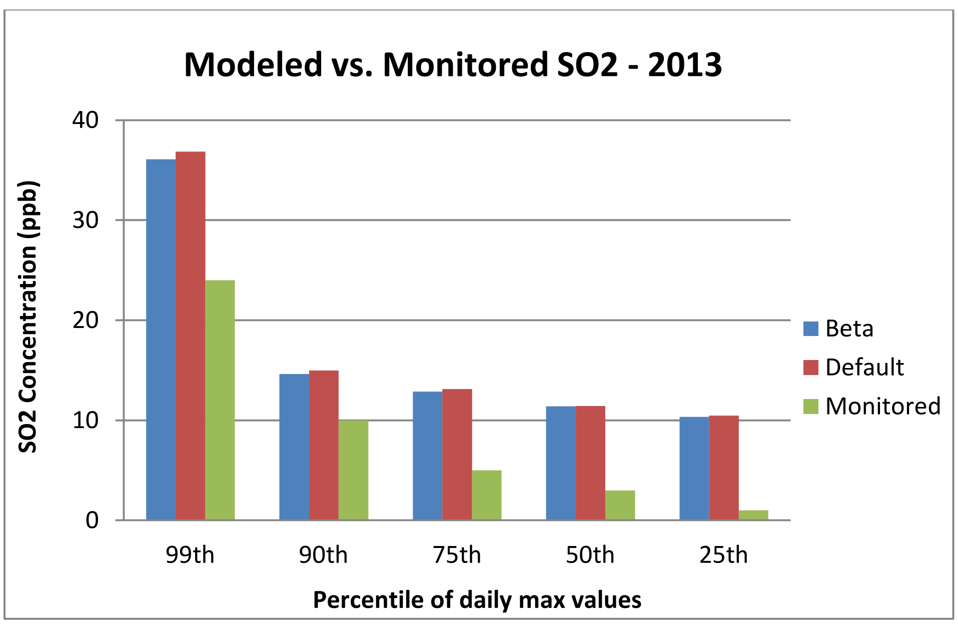

Figure 7: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2013 at the location of ambient air quality monitor 39-001-0001.

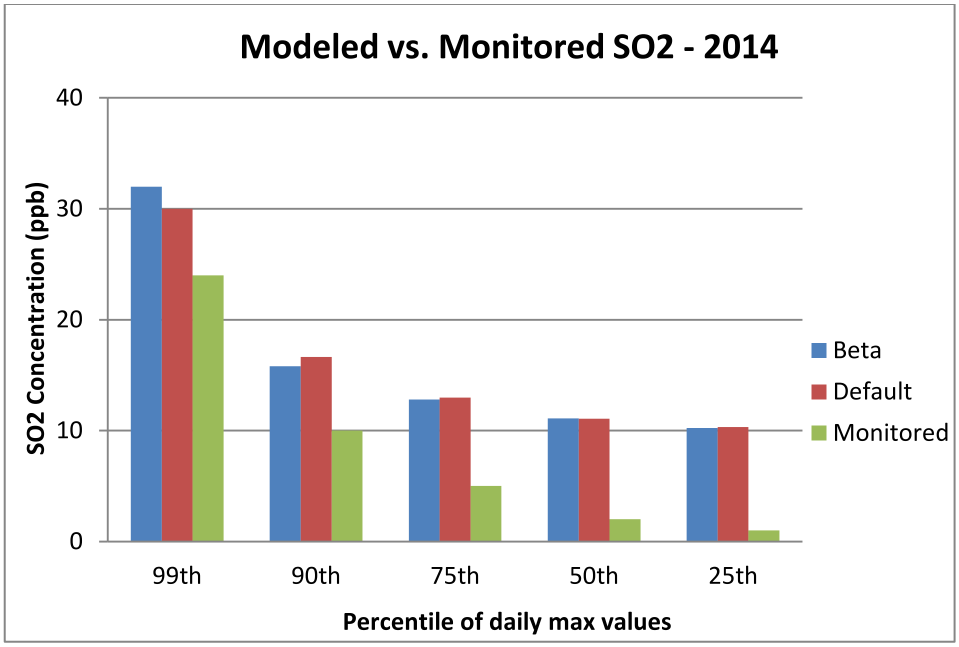

Figure 8: Comparison of SO_2 concentrations between the two model formulations and monitored values over a range of daily maximum thresholds for 2014 at the location of ambient air quality monitor 39-001-0001.

Ohio EPA's model performance evaluation demonstrates that AERMOD performance with respect to monitored values in the DP&L Stuart and Killen source area – both when considering elevated SO_2 concentrations which are used for design value calculation, and across a range of daily maximum concentration thresholds – improves with the ADJ_U* and LOWWIND3 options enabled. Additionally, both modeling scenarios, with a conservative 10 ppb background concentration, overestimate SO_2 concentrations as compared to monitor values in both analyses performed, which indicates that the use of the beta options will still provide conservative estimates of SO_2 concentrations. These analyses demonstrate a clear improvement in model performance for this source area by enabling the ADJ_U* and LOWWIND3 options, consistent with previously cited model performance evaluations. Ohio EPA concludes, therefore, that enabling the ADJ_U* and LOWWIND3 options is the appropriate modeling formulation for modeling in this source area. Although improvements in model performance were relatively minor in this source area, this evaluation serves to demonstrate that degradation in model performance does not occur, and that conservative results are still obtained with the beta options enabled.

Ohio EPA anticipates performing further evaluations of model performance as modeling for the Data Requirements Rule proceeds. Ohio EPA's analyses, to this point, are consistent with previously cited evaluations of these beta options in that these options improve the accuracy of the model outputs with respect to available monitor data, do not lead to underprediction, and still provide a measure of conservatism in model results.

Sources

Of those sources necessitating modeling under the Data Requirements Rule or named specifically in the March 2, 2015 Consent Decree, the large majority are considered tall stack sources, with stacks 500 feet or taller. This is consistent with the tall stacks database analyzed in Paine 2015 and Paine et al. 2015. In addition to those sources named in the Consent Decree or necessitating modeling under the Data Requirements Rule, two additional sources necessitated modeling due to proximity to other sources. The stack parameters for all sources Ohio EPA has modeled or potentially will model to fulfill the requirements of the Data Requirements Rule are given in Table 1.

	Source ID	Source Description	Easting (X)	Northing (Y)	Base Elevation	Stack Height	Temperature	Exit Velocity	Stack Diameter
			(m)	(m)	(m)	(m)	(K)	(m/s)	(m)
General James M. Gavin	UNIT1	Unit 1 main boiler	403277.18	4310126.46	172.80	252.98	328.15	14.86	12.8
	UNIT2	Unit 2 main boiler	403345.18	4310254.46	172.80	252.98	328.15	14.86	12.8
Kyger Creek Station*	CS12	Units 1 and 2	402257.17	4308093.45	178.60	252.98	326.2	15.26	7.53
	CS35	Units 3, 4, and 5	402248.17	4308099.45	178.60	252.98	326.2	15.23	9.2
Stuart Station	UNIT1_W	Wet stack Unit1 flue	265541.20	4279843.60	161.74	243.84	325.93	17.40	7.9
	UNIT2_W	Wet stack Unit 2 flue	265537.40	4279835.30	161.80	243.84	325.93	17.40	7.9
	UNIT3_W	Wet stack Unit 3 flue	265529.20	4279839.40	161.80	243.84	325.93	17.40	7.9
	UNIT4_W	Wet Stack Unit 4 flue	265533.40	4279847.80	161.82	243.84	325.93	17.40	7.9
	UNIT1_B	Coal utility boiler 1 bypass	265661.70	4279842.10	161.54	243.84	416.48	38.71	5.8
	UNIT2_B	Coal utility boiler 2 bypass	265594.10	4279875.00	161.68	243.84	416.48	38.71	5.8
	UNIT3_B	Coal utility boiler 3 bypass	265528.60	4279913.40	161.58	243.84	416.48	38.71	5.8
	UNIT4_B	Coal utility boiler 4 bypass	265455.00	4279952.30	161.63	243.84	416.48	38.71	5.8
	COMB2	Combination of two wet stacks	265535.30	4279841.70	161.78	243.84	325.21	17.40	11.2
	COMB3	Combination of three wet stacks	265535.30	4279841.70	161.78	243.84	325.21	17.40	13.8
	COMB4	Combination of four wet stacks	265535.30	4279841.70	161.78	243.84	325.21	17.40	15.9
Killen Station	UNIT2_K	Coal-fired boiler Unit 2	284256.20	4285315.80	162.23	274.32	325.21	5.98	8.8
Bay Shore	B002	Coal-fired Utility Boiler for Electric Generation	297139.00	4618513.00	177.12	143.87	340.37	12.37	7.0
	B003	Coal-fired Utility Boiler for Electric Generation	297139.00	4618513.00	177.12	143.87	340.37	12.37	7.0
	B004	Coal-fired Utility Boiler for Electric Generation	297139.00	4618513.00	177.12	143.87	340.37	12.37	7.0
	B005	Oil-fired Combustion Turbine	297194.00	4618115.00	177.35	7.89	504.26	12.11	3.1
	B006	Circulating fluidized bed (CFB) boiler	297049.00	4618409.00	177.08	91.44	423.71	24.66	3.7
	P001	Limestone dryer	296979.00	4618227.00	177.73	33.53	301.48	1.02	1.0
BP Husky*	BPB001	Hydrogen Plant Reformer Furnace	295952.19	4616914.65	177.79	56.39	594.26	5.87	2.6
	BPB005	Reformer 2 Regeneration Gas Heater	296011.69	4617041.15	178.02	21.34	699.82	2.30	1.1
	BPB006	Reformer 2 Furnace	296011.69	4617007.15	178.09	45.72	549.82	6.39	2.7
	BPB008	Isocracker 2 Feed Heater	295996.29	4616923.35	178.24	45.72	649.82	8.62	1.4
	BPB009	Isocracker 2 Stabilizer Reboiler	296076.59	4616946.35	178.31	45.72	477.59	7.72	1.8
	BPB013	Reformer 1 Regen Heater	295724.99	4616868.05	177.77	11.46	699.82	1.86	0.8
	BPB015	Reformer 1 Preheater	295708.09	4616900.55	177.70	36.58	522.04	11.16	3.6
	BPB017	Coker 2 Furnace	295749.99	4617072.25	176.78	41.15	713.71	9.79	1.3
	BPB018	FCC Preheater	295717.39	4616976.55	177.19	35.05	774.82	3.20	1.9
	BPB019	Crude/Vac 2 Furnace	295829.59	4617076.55	177.39	44.20	510.93	4.83	2.6
	BPB029	ADHT Heater	295858.49	4616856.75	177.39	30.48	505.37	2.80	1.1
	BPB030	West BGOT Heater	295959.79	4616872.15	177.87	43.28	533.15	1.13	1.2
	BPB032	Coker 3 Furnace	295609.99	4617074.85	176.82	53.34	588.71	4.07	3.0
	BPB033	East BGOT Heater	295996.25	4616889.36	178.24	30.48	544.26	1.29	1.5
	BPB034	East Alstom Boiler	295649.09	4617000.45	177.09	30.79	427.59	8.69	1.9
	BPB035	West Alstom Boiler	295636.09	4616991.75	177.09	30.79	449.82	8.69	1.9
	BPB036	Reformer 3 Heater	296036.47	4617182.16	178.00	65.53	402.59	5.11	3.8
	BPB053	Tank heaters (T115 & T116)	296773.03	4616954.44	178.20	14.63	533.15	1.15	0.9
	BPB903	asphalt tank heater (T175, T176)	296777.46	4616954.44	178.24	14.63	533.15	1.15	0.9
	BPP007	FCCU/CO Boiler	295663.59	4616987.35	177.09	75.29	505.37	21.91	3.4
	BPP009	SRU 1	295438.59	4617024.46	177.64	69.49	1033.15	26.39	1.1
	BPP037	SRU #2 & #3	295471.09	4617061.16	177.35	53.34	1172.04	14.23	1.5
	BPP003	East Hydrocarbon Flare	296067.97	4617030.16	178.31	105.31	1273.15	19.99	0.8
	BPP004	West Hydrocarbon Flare	295717.13	4617026.82	176.78	104.73	1273.15	19.99	2.3
	BPP049	East Acid Gas Flare	296068.38	4617029.93	178.31	54.56	1273.15	19.99	0.5
	BPP050	TRP SRU Acid Gas Flare	295441.13	4617067.69	177.61	54.56	1273.15	19.99	0.5
	BPP051	SRU#1 Acid Gas Flare	295405.27	4617024.28	177.70	54.56	1273.15	19.99	0.5
W.H. Sammis	B007	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B008	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B009	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B010	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B011	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B012	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
	B013	Coal fired boiler	531123.00	4486526.00	210.39	259.08	391.76	11.94	29.3
Miami Fort	6	Maimi Fort Unit 6	689915.80	4331624.00	149.31	179.83	398.71	16.27	5.2
	N7	Miami Fort Unit 7	689801.80	4331830.00	149.15	243.84	328.15	22.81	7.2
	N8	Miami Fort Unit 8	690125.40	4331565.00	149.84	243.84	327.04	21.73	7.2
Conesville	UNIT4	Boiler 4	424970.00	4448730.00	226.50	243.23	327.30	14.90	10.0
	CS056	Boilers 7 and 8	425207.00	4448783.00	225.90	243.84	327.80	24.80	7.9
Avon Lake	10	Unit 7	412080.90	4595403.70	179.73	159.72	466.48	27.65	3.2
	12	Unit 9	411877.20	4595233.20	182.98	182.88	427.59	15.57	7.3

Table 1: Potential sources for 1-hour SO_2 designations modeling.

Those stacks/units listed in Table 1 represent those units for which Ohio EPA believes that the ADJ_U* and LOWWIND3 options are likely applicable, based on previously cited evaluations and Ohio EPA's own conclusions of improved model vs. monitor performance when these options are enabled. This list is not intended to represent all sources that may necessitate modeling under the Data Requirements Rule, nor is this list indicative of whether or not a source is considering or pursuing a modeling or monitoring option.

Terrain

Prior analyses have shown that the ADJ_U* and LOWWIND options improve model performance without introducing underprediction bias. Recent evaluations have shown significant improvement with respect to tall-stack sources, particularly those located in elevated terrain (Paine, et al. 2015, Paine 2015). Of those facilities listed in Table 1, only the BP Husky facility is not primarily composed of tall-stack sources. The BP Husky facility is located very close to the Bay Shore facility, which is a tall-stack type source. Ohio EPA understands that, even for low-level releases and shorter stacks, prior evaluations indicate improved model performance when the ADJ_U* and LOWWIND options are utilized (Brode 2015).

A large majority of those facilities in Table 1 are located in areas of elevated terrain. The nature of the terrain surrounding these sources is well-illustrated using topographic maps, each of which is included as an appendix to this document for clarity. Additionally, Ohio EPA is submitting digital versions of each map, which enable the elevation data to be viewed in greater detail. All topographic maps included with this submittal were obtained from the U.S. Geological Survey National Map Viewer.

General James M. Gavin and Kyger Creek Source Area

The General James M. Gavin and Kyger Creek facilities are located in the Ohio River valley in Gallia County, Ohio. The topographic map for this area is given in Appendix C of this submittal. The outline of the facilities is shown on the leftmost side of the map. The base elevation for these facilities is between approximately 500 and 600 ft. The data shown in Appendix C indicates that the terrain of this area is dominated by hills rising to approximately 800 ft. This would indicate that this source area is similar to those evaluated in Paine et al. 2015. Ohio EPA's own model vs monitor performance analysis for this area shows improved model accuracy when the ADJ_U* and LOWWIND3 options are utilized.

J.M. Stuart and Killen Source Area

The J.M Stuart and Killen facilities are located in the Ohio River valley in Adams County, Ohio. The topographic maps for the Stuart and Killen facilities are given in Appendices D and E of this submittal, respectively. The outline of each facility is shown in black in each of the maps. The base elevation for these facilities is approximately 525 ft. The data shown in Appendices D and E indicates that the terrain of this area is dominated by hilly terrain between 800 and 900 feet in height. This would indicate that this source area is similar to those evaluated in Paine et al. 2015. Ohio EPA's own model vs monitor performance analysis for this area shows improved model accuracy when the ADJ_U* and LOWWIND3 options are utilized.

W.H. Sammis Source Area

The W.H. Sammis facility is located in the Ohio River valley in Jefferson County, Ohio. The topographic map of this area is given in Appendix F of this submittal. The base elevation for this facility is approximately 690 ft. The data shown in Appendix F indicates that the terrain of this area is dominated by hilly terrain, with multiple hills and ridges being 1,200 feet or greater in elevation. This would indicate that this source area is similar to those evaluated in Paine et al. 2015, with respect to tall stacks in elevated terrain.

Conesville Source Area

The Conesville facility is located in Coshocton County, Ohio. The topographic maps of the area surrounding this facility are given in Appendices G and H of this submittal. The base elevation for this facility is approximately 740 feet. The data shown in Appendices G and H indicates that the terrain of this area is dominated by hilly terrain, with multiple hills and ridges being 1,100 feet or greater in elevation. This would indicate that this source area is similar to those evaluated in Paine et al. 2015, with respect to tall stacks in elevated terrain.

Miami Fort Source Area

The Miami Fort facility is located in the Ohio River and Great Miami River valleys in Hamilton County, Ohio. The topographic map of the area surrounding this facility is given in Appendix I of this submittal. The base elevation for this facility is approximately 490 feet. The data shown in Appendix I indicates that the terrain of this area is dominated by hilly terrain, with multiple hills and ridges being 800 feet or greater in elevation. This would indicate that this source area is similar to those evaluated in Paine et al. 2015, with respect to tall stacks in elevated terrain.

Bay Shore and BP Husky Source Area

The Bay Shore and BP Husky facilities are located along the shore of Lake Erie in Lucas County, Ohio. The topographic map of the area surrounding this facility is given in Appendix J of this submittal. The data shown in Appendix J indicate that the Bay Shore and BP Husky facilities are located in relatively flat terrain.

Avon Lake Source Area

The Avon Lake facility is located along the shore of Lake Erie in Lorain County, Ohio. The topographic map of the area surrounding this facility is presented in Appendix K of this submittal. The data shown in Appendix K indicate that the Avon Lake facility is located in relatively flat terrain.

Analysis of the terrain surrounding the 10 facilities listed in Table 1 indicates that the General James M. Gavin, Kyger Creek, J.M Stuart, Killen Station, W.H. Sammis, Miami Fort, and Conesville facilities are located in hilly, elevated terrain primarily associated with the Ohio River valley. These facilities are also composed primarily of tall-stack type emission sources. Previous analysis and evaluations of tall-stack sources located in elevated terrain have demonstrated considerable improvement in AERMOD performance with respect to model vs. monitor comparisons. The remaining facilities, Avon Lake, Bay Shore, and BP Husky are located in the flat terrain associated with the shoreline of Lake Erie and northern Ohio. Both the Bay Shore and Avon Lake facility are tall-stack type sources, for which previous evaluation has shown improved performance regardless of terrain type (Paine et al. 2015, Paine 2015). Ohio EPA is assessing the applicability of the ADJ_U* and LOWWIND3 options with respect to the BP Husky facility, given the substantial number of shorter stacks at this facility. While Ohio EPA understands that some studies have shown that model accuracy with low-level releases is improved (Brode 2015), it has been demonstrated in some circumstances that further overprediction can be introduced when the ADJ_U* and LOWWIND3 options are utilized with low level releases.

Meteorology

Representative meteorological data for all facilities listed in Table 1 was processed by Ohio EPA using the most up-to-date version of the AERMET module, version 15181, for years 2012, 2013, and 2014. AERMINUTE version 14337 was used to derive an hourly winds input file based on ASOS 1-minute surface observations. Ohio EPA collected and analyzed the wind speed data for each year from the six representative meteorological stations to determine the number of non-zero wind speeds less than 2 meters/second and 1 meter/second. These results are given in Table 2.

	Number of Non-Zero Low Wind Hours Per Year at Representative Met Data Sites					
	2012		2013		2014	
	<2 m/s	<1 m/s	<2 m/s	< 1 m/s	<2 m/s	<1 m/s
KHTS	3630	738 (8.4%)	3425	712 (8.1%)	2717	215 (2.5%)
KTDZ	1698	318 (3.6%)	851	58 (0.6%)	1218	160 (1.8%)
KCVG	1638	296 (3.4%)	1385	241 (2.8%)	1408	283 (3.2%)
KCMH	2212	413 (4.7%)	1739	333 (3.8%)	1902	366 (4.2%)
Cardinal Onsite	5164	2243 (25.5%)	4691	1811 (20.7%)	4704	1885 (21.5%)
KCLE	1226	172 (2.0%)	791	63 (0.7%)	965	82 (0.9%)

Table 2: Wind speed data, 2012-2014, at representative meteorological stations in Ohio.

The results of the analysis presented in Table 2 indicate that, with the exception of the onsite meteorological data collected at Cardinal monitor 39-081-0019, the meteorological data representative of those facilities listed in Table 1 contain relatively few wind speeds less than 1 meter/second. However, Ohio EPA's experience has shown that the 1-hour SO_2 design value, based on the 99th percentile of maximum daily values, is often highly dependent on a relatively small number of elevated ground level impacts. Thus, even the small proportion of low wind speed hours in each meteorological data set could result in over predictions at the level of the design value. Further, given the relatively low percentages of low wind conditions in the majority of the data sets, it is not likely that a bias towards underprediction would be introduced via the use of the ADJ_U* and LOWWIND3 options. That is, a majority of the hours in each data set would not be impacted by the use of these model options, and the relatively small proportion of hours likely to generate overprediction at the design value level would be corrected. This is consistent with Ohio EPA's own model performance evaluation of these options as well as with previously cited studies and evaluations of these options.

Summary

The purpose of modeling for the Data Requirements rule is to provide an accurate representation of ambient air quality, where each receptor in the modeling domain is treated as a surrogate to an ambient air quality monitor. It is therefore imperative that the most accurate modeling approach be utilized. Based on a substantial and growing body of research, the peer review of both low wind correction options, and Ohio EPA's own modeling results, it is apparent that the most accurate modeling approach for the 1-hour SO_2 Data Requirements Rule is the use of AERMOD with the ADJ_U* and LOWWIND3 options enabled when appropriate.

State of Ohio 2010 Revised Sulfur Dioxide National Ambient Air Quality Standard: Response to U.S. EPA 120-day Letter:

APPENDIX B

STATISTICAL ANALYSIS OF MODEL PERFORMANCE AT THE CARDINAL AND SAMMIS POWER PLANTS

As part of an ongoing effort on the part of Ohio EPA to analyze the appropriateness of the LOWWIND3 and ADJ_U* beta options of the AERMOD modeling system, in particular for modeling performed to inform designations under the 2010 1-hour SO_2 standard, two locations with large electric generating units (EGUs) were selected based on the availability of nearby representative monitors at which model performance under various formulations of AERMOD could be conducted. These facilities, the Cardinal and Sammis power plants, also have provided to Ohio EPA highly refined hourly emissions data files for use as input into the AERMOD model. This document will present:

1. The general modeling approach taken for each source area
2. Descriptions of the statistical measures of model performance selected by Ohio EPA
3. A brief description of each source area
4. Facility-specific model performance analyses
5. Select bibliography

Modeling Approach

Per U.S. EPA's Modeling TAD,

> "Since the purpose here pertains to designations, this guidance supports analyses of existing air quality rather than analyses of emissions limits necessary to provide for attainment. Consequently, the guidance in this TAD differs in selected respects from the guidance published in Appendix W. These differences include:
>
> - Placement of receptors only in areas where it is feasible to place a monitor vs. all ambient air locations (NSR, PSD, and SIP)
> - Use of the most recent 3 years of actual emissions (designations) vs. maximum allowable emissions (NSR, PSD, and SIP)
> - Use of 3 years of meteorological data (designations) vs. one to five years (NSR, PSD, and SIP)
> - Use of actual stack height for designations using actual emissions vs. Good Engineering Practice (GEP) stack height for other regulatory applications (NSR, PSD, and SIP)"

Ohio EPA incorporated the differences listed above and followed Appendix W guidance where applicable to modeling for designation purposes. The averaging period for the 2010 SO_2 NAAQS is the 99th percentile of maximum monitored daily values, averaged over three years. Per the Modeling TAD, three years of National Weather Service data is sufficient to allow the modeling to simulate a monitor. Thus, the modeled form of the standard is expressed as the 99th percentile of maximum daily values averaged over three years (herein referred to as "design value") for the purposes of designation. As such, Ohio EPA followed these same guidelines in these modeling exercises for the purposes of the statistical analyses presented here. Ohio EPA relied on additional output files, primarily the MAXDAILY file, to generate suitable data for these analyses.

The recommended dispersion model for modeling for SO_2 designations is the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) modeling system. There are two input data processors that are regulatory components of the AERMOD modeling system: AERMET, a meteorological data preprocessor that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, and AERMAP, a terrain data preprocessor that incorporates complex terrain using United States Geological Survey (USGS) Digital Elevation Data. Additionally, Ohio EPA utilized the AERMINUTE module to incorporate 1-minute ASOS meteorological data into the hourly surface input file. Ohio EPA utilized the most up-to-date versions of AERMOD and the associated preprocessors available at the time of the attainment modeling analyses. These are as follows: AERMOD version 15181, AERMET version 15181, AERMINUTE version 14337, and AERMAP version 11103.

Ohio EPA conducted these model performance evaluations at receptors placed only in the location of ambient air quality monitors in each source area. Monitoring data was collected from the U.S. EPA Air Quality System Database, and Unit 3 monitoring data, which is not reported to the AQS, was provided to Ohio EPA by American Electric Power (AEP).

Meteorological Data

In order to generate meteorological input data for use with AERMOD, AERMET, along with AERMINUTE and AERSURFACE preprocessing for the modeling domain was conducted to generate the surface (.sfc) and profile (.pfl). Ohio EPA used the AERMINUTE pre-processing module. This module accepts as input 1-minute ASOS meteorological surface observations, calculates an hourly average for each hour in the modeled time period, and substitutes any missing values from the co-located ISHD surface data. Use of AERMINUTE reduces the number of calm hours present in the input files, and these enhanced hourly files are therefore considered more representative of local meteorological conditions.

For the Sammis source area, meteorological data from 2012-2014 from the Pittsburgh, PA upper air and surface station (Station # 94823) located at the Greater Pittsburgh International Airport were used. For the Cardinal source area, Ohio EPA utilized 2013 on-site meteorological data collected at surface station 39-081-0019, which is part of the Cardinal meteorological station network. These meteorological data were previously used in Ohio's Attainment demonstration for the Steubenville OH-WV nonattainment area, which was submitted to U.S. EPA on October 13, 2015. AERSURFACE was run using twelve sectors and monthly surface characteristics, centered on the location of the meteorological station for both source areas. Monthly Bowen ratios were determined at each surface station by comparing monthly precipitation values against the most recent 30-year precipitation values. For the Pittsburgh surface station, these data were gathered from National Oceanic and Atmospheric Association: National Climatic Data Center Local Climatological Data Publications[1]. For the Cardinal surface station, precipitation data from the station were compared to 30-year normal collected from the Prism Climate Group, Oregon State University database[2]. Note that a 30-year precipitation record at the Cardinal station is not available as the meteorological stations did not begin operating until 2011.

Background

Various background concentrations were used in this analysis, based in part on past evaluations conducted at monitors in the Cardinal network, which suggests that an appropriate, monitor specific background can be derived by evaluating the monitor data between the 50th and 90th percentiles, with the exception of monitor 39-081-0018. Past analyses conducted at this monitor by both Ohio EPA and American Electric Power indicate that this monitor is impacted relatively strongly by other sources in the area. To maintain conservatism and consistency, Ohio EPA selected the 90th percentile hourly monitored value at each monitor, and applied these values at the monitoring locations in the Cardinal network. For monitor 39-081-0018, the 90th percentile value of 10 ppb recorded at the monitor in 2013, plus an additional 13.15 ppb obtained from Ohio's October 13, 2015 attainment demonstration base case modeling for all other sources in the region. A fixed background of 19 ppb, which Ohio EPA considers highly conservative, was applied at the Sammis source area monitors. This background was derived from data recoded at the West Virginia monitor 54-029-0007, which is approximately 9 kilometers south-southeast of Sammis. Being south of Sammis and outside of the predominant winds of the area, this monitor is largely outside of the area of influence of Sammis emissions, and representative of the region. 19 ppb was calculated as the 95th percentile of daily maximum SO_2 values averaged across three years 2012 to 2014.

Statistical Evaluation of Model Performance:

Ohio EPA selected several well-established statistical measures which have been used frequently to assess model performance[3,4]. A brief description of each metric is provided below.

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[1] http://www.ncdc.noaa.gov/IPS/lcd/lcd.html

[2] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created June 2014.

[3] Environmental Protection Agency. (2007). *Guidance on the use of models and other analyses for demonstrating attainment of air quality goals for ozone, $PM_{2.5}$, and regional haze* (EPA Publication No. 454-B-07-002). Research Triangle Park, NC: U.S. Environmental Protection Agency.

[4] Boyan, J. & Russell, A. G. (2006) PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models. *Atmospheric Environment*, 20, 4946-4959.

Normalized mean bias

$$NMB = \frac{\sum_{i=1}^{N}(Model_i - Obs_i)}{\sum_{i=1}^{N} Obs_i} \times 100\%$$

Bias indicates systematic distortion in one direction as percent deviation in predicted values from observed values. Normalized mean bias (NMB) is constructed by normalizing absolute mean bias by observation mean, which avoids over-inflating the observed range of values. The metric has a range of -100% to +∞ and is asymmetric, tending to weight over-predictions more than under-predictions. A model with low bias would return a NMB approaching zero.

Normalized mean error

$$NME = \frac{\sum_{i=1}^{N}|Model_i - Obs_i|}{\sum_{i=1}^{N} Obs_i} \times 100\%$$

Coupled with NMB, normalized mean error (NME) is a measure of precision that normalizes mean absolute error relative to observations. The metric has a range of zero to +∞.

Mean fractional bias

$$FBIAS = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(Model_i - Obs_i)}{\left(\frac{Model_i + Obs_i}{2}\right)}\right) \times 100\%$$

Mean fractional bias (FBIAS) has an added advantage to the similar mean normalized bias in its symmetry, equally weighting positive and negative bias estimates. Each prediction-observation set is normalized by the average of the model and observation prior to calculating the mean. The metric has a range of -200% to 200% with FBIAS approaching zero indicating low bias.

Mean fractional error

$$FERROR = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|Model_i - Obs_i|}{\left(\frac{Model_i + Obs_i}{2}\right)}\right) \times 100\%$$

Similar to FBIAS, mean fractional error (FERROR) bounds maximum error, preventing a few data points from dominating the metric. The metric has a range of zero to 200%.

Normalized mean square error

$$NMSE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{(Model_i - Obs_i)^2}{\overline{Model} \times \overline{Obs}}\right)$$

$$\overline{Model} = \frac{1}{N}\sum_{i=1}^{N} Model_i$$

$$\overline{Obs} = \frac{1}{N}\sum_{i=1}^{N} Obs_i$$

Normalized mean square error (NMSE) is a measure of scatter and reflects both random and systematic error. Normalization by the product of prediction and observation means prevents bias towards over- or under-predicting models.

In addition to the above statistical metrics, Ohio EPA also determined mean bias and error for each data set, which measure the average bias and error of model predictions expressed in units of concentration (ppb). The focus of these analyses was the highest 20% of modeled and monitored maximum daily values.

It has come to Ohio EPA's attention that some evaluations of model performance concerning the various low-wind corrections proposed by U.S. EPA have relied on the "robust high concentration" (RHC) as a measure of model performance. This approach was recommended by U.S. EPA in a document dating from 1992, well before the promulgation of the probabilistic 1-hour NO_2 and SO_2 standards[5]. Upon further analysis and research on the use of the RHC methodology, Ohio EPA has determined that while this approach is perfectly acceptable when applied to short-term deterministic standards, the method is inappropriate for the probabilistic 1-hour standards. Therefore, Ohio EPA has rejected the RHC approach, and utilized straightforward and robust statistical measures, focused on the maximum daily values, which reflect the form of the standard.

Source Area Description:

The Cardinal Plant is located in the Ohio River Valley immediately south of Brilliant, Ohio. The plant elevation is approximately 670 feet above mean sea level with the surrounding ridges that make up the valley walls typically extending 450 to 600 feet above the plant grade. In 2008, as part of the process to modify the Cardinal Plant Unit 3 Flue Gas Desulfurization (FGD) Permit to Install (PTI) to allow the discharge of the FGD effluent gas from a duct routed into the cooling tower, a specialized air quality modeling study was undertaken. This study used an innovative technique to evaluate the emission discharge from the cooling tower discharge that was judged to be qualitatively correct. The reason for this qualitative judgment was the lack of objective

[5] Environmental Protection Agency, 1992. Protocol for Determining the Best Performing Model. Publication No. EPA–454/ R–92–025. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93–226082)

data to use to perform a model evaluation. As a result, it was agreed as part of the permit modification that an ambient air monitoring network would be installed in the area around Cardinal Plant and operated for roughly one year prior to the conversion of the Unit 3 discharge from the existing stack to the new FGD discharge located in the stack and then for roughly two years following the conversion to determine if the modeling was reasonably accurate.

Staff from Ohio EPA, American Electric Power Service Corporation (AEPSC), and Shell Engineering worked together to develop an ambient monitoring network that would allow a thorough testing of CALPUFF, the model that was used in the PTI modification modeling exercise, along with AERMOD and potentially other models to determine if the methodology used in the Cardinal Plant Unit 3 permit modification modeling was reproducing ambient conditions with acceptable accuracy. This effort resulted in a monitoring network that included three meteorological sites and four ambient monitors, with two of the meteorological sites co-located with ambient monitors. Figure 1 shows the locations of the monitoring sites surrounding the Cardinal Plant. As these monitors were sited specifically to monitor "hot-spots", or areas where maximum impacts were modeled, and given the availability of on-site meteorological data, the Cardinal monitoring network is an ideal location to perform an analysis of model performance. Note that, due to the unusual emission characteristics of Unit 3, which require detailed analyses to characterize properties, only a single year, 2013, was used in the analysis of model performance at the Cardinal monitoring network. Ohio EPA anticipates expanding this analysis in the future as additional years of characterized emission parameters become available.

Figure 1: Cardinal power plant and monitoring network.

Table 1 lists the monitor number, 2013 99th percentile monitored concentration (4th highest maximum daily monitored value), and distance from Unit 3 for the four monitors comprising the Cardinal monitoring network.

Monitor ID	2013 99th Percentile (ppb)	Distance from Unit 3 (km)
Unit 3	24	0.4*
54-009-6000	21	0.7
39-081-0020	33	2.6
39-081-0018	52	4.2

Table 1: 4th-high maximum daily values and distance from Cardinal Unit 3 egress point. *Unit 3 monitor is located inside the fence line of the Cardinal facility and is not considered ambient air for regulatory purposes.

The Sammis Power Plant is located approximately 30 kilometers to the north of the Cardinal Plant, and similarly located in the Ohio River valley. The terrain is very similar to that described above for the Cardinal Source area, and the plant itself has a base elevation of 690 feet above sea level. Unlike the Cardinal Plant, there is no facility specific monitoring network. There are, however, several monitors in close proximity to the facility that are not impacted to a strong degree by other sources in the area. Ohio EPA selected two of these monitor locations for the analysis presented here. Figure 2 shows the location of the Sammis Plant and the two monitors chosen for this analysis.

Figure 2: W.H. Sammis power plant and AQS monitor locations.

Table 2 lists the monitor number, 2012-2014 99th percentile monitored concentration (4th highest maximum daily monitored value), the 2012-2014 design value, and distance from the Sammis Plant for the two monitors selected for this analysis.

Monitor ID	2012 99th Percentile (ppb)	2013 99th Percentile (ppb)	2014 99th Percentile (ppb)	2012-2014 Design Value (ppb)	Distance from Sammis (km)
54-029-0005	24	29	34	29	4.7
42-007-0002	42	21	29	31	11.4

Table 2: 4th-high maximum daily values, 2012-2014 design values, and distance from Sammis power plant.

Model Performance Evaluation for Cardinal Monitoring Network:

As an initial evaluation of model performance, Ohio EPA plotted modeled vs. monitor concentrations for the top 20% of maximum daily values, year 2013, for each monitor in the Cardinal network. Note that the data are not paired in time. These data are shown in Figures 3-6, below. For comparative purposes, Ohio EPA has included in each figure

2:1, 1:1, and 1:2 lines, as well as an indication of the 99th percentile maximum daily value recorded at each monitor. The summary statistics at each monitor location are presented and discussed in turn.

Cardinal Unit 3 Monitor Analysis:

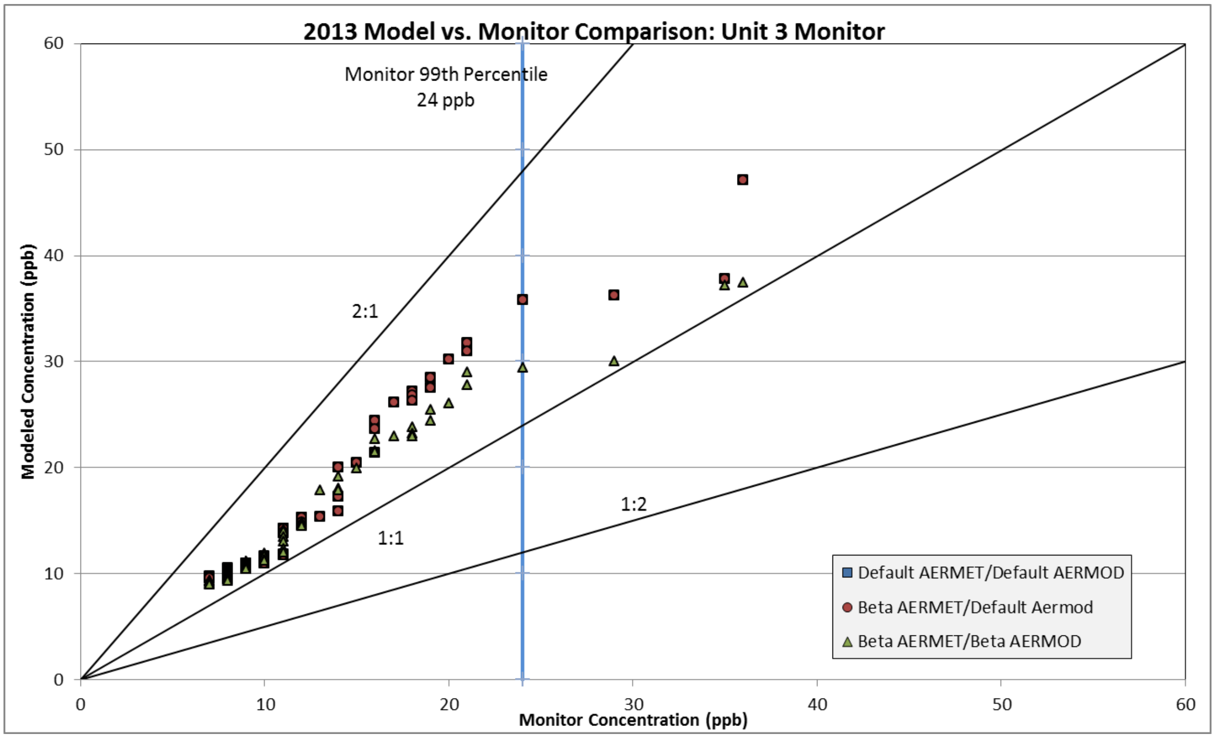

Figure 3: 2013 model vs. monitor results at Cardinal Unit 3 monitor.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2013: Unit 3	Mean Bias (ppb)	3.48	3.48	2.81
	Mean Error (ppb)	3.48	3.48	2.81
	Normalized Mean Bias(%, -100 to ∞)	29.82	29.81	24.05
	Normalized Mean Error(%, 0 to ∞)	29.82	29.81	24.05
	Mean Fractional Bias(%, -200 to +200)	23.54	23.54	20.84
	Mean Fractional Error(%, 0 to 200)	23.54	23.54	20.84
	Normalized Mean Square Error	0.12	0.12	0.06

Table 3: Model performance evaluation statistics, Unit 3 monitor.

The Unit 3 monitor of the Cardinal monitoring network is located approximately 400 meters for the egress point of the Cardinal Unit 3 boiler. This monitor is located inside the fenceline of the Cardinal facility, and is not considered ambient air for regulatory purposes. The results of the model performance evaluation at this monitor location are somewhat unexpected. It should be noted that the parameterization of the unique emissions characteristics of Cardinal Unit 3, which vents through the cooling tower, were based on model vs. monitor comparisons at this monitor, using the default version of AERMOD. Ohio EPA had initially hypothesized that if the LOWWIND3 option were to introduce under-predictive bias at any monitor in the network, it would be most apparent at this monitor location. The data presented in Figure 3 and Table 3, above, indicate that this is not the case. Indeed, examination of Figure 3 shows a clear improvement in the accuracy of the model when the LOWWIND3 option is enabled. This improvement is not as readily apparent when the statistics presented in Table 3 are examined, but these data do indeed show an improvement in model performance without the introduction of under-predictive bias.

Cardinal 54-009-6000 Analysis:

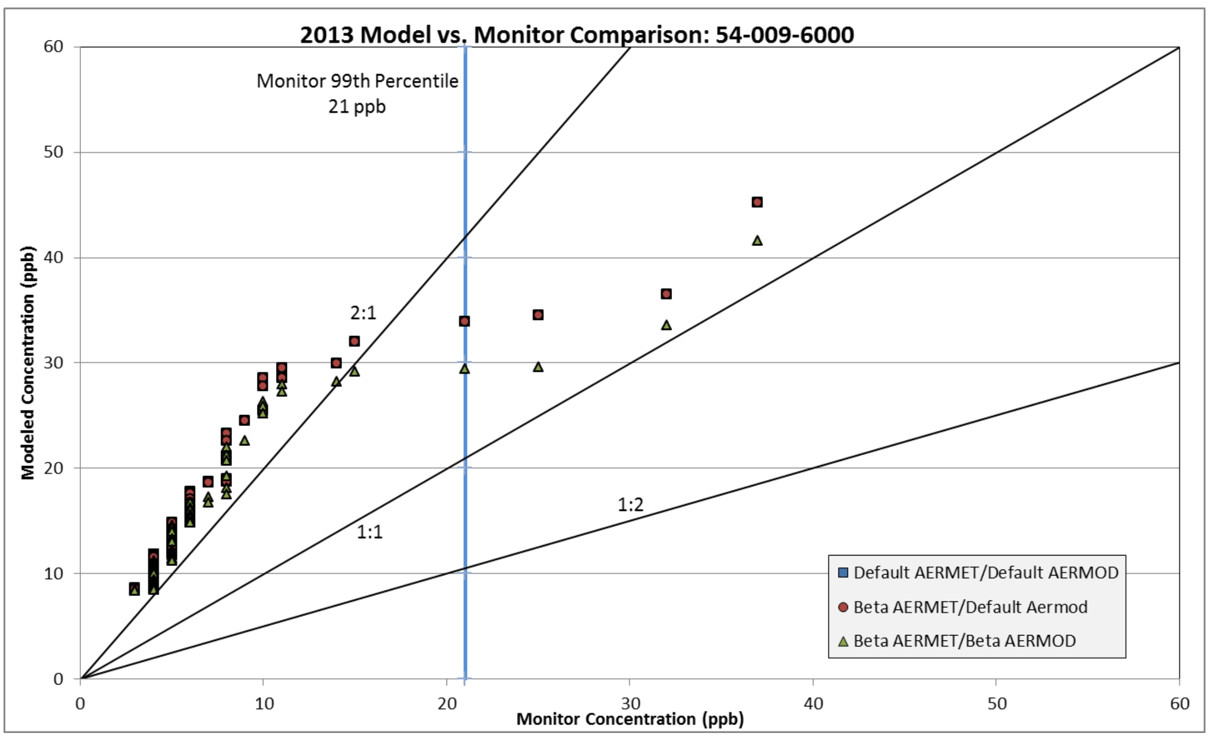

Figure 4: 2013 model vs. monitor results at monitor 54-009-6000.

2013: 54-009-6000	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	9.12	9.12	8.24
	Mean Error (ppb)	9.12	9.12	8.24
	Normalized Mean Bias(%, -100 to ∞)	139.39	139.39	125.89
	Normalized Mean Error(%, 0 to ∞)	139.39	139.39	125.89
	Mean Fractional Bias(%, -200 to +200)	85.11	85.11	80.96
	Mean Fractional Error(%, 0 to 200)	85.11	85.11	80.96
	Normalized Mean Square Error	0.96	0.96	0.78

Table 4: Model performance evaluation statistics, monitor 54-009-6000.

Figure 4 and Table 4 present the graphical and statistical analysis of model performance at monitor location 54-009-6000. This monitor is located near the valley floor approximately 700 meters directly to the east of Cardinal Unit 3. The data in Table 4 clearly indicate that the model, under all formulations, is highly over-predictive at this monitoring location. When these statistics are interpreted in light of the graphical comparison of model performance, it is clear that model performance degrades markedly below the 99th percentile maximum daily value and that these values are, in general, driving the statistics. Via verbal communication with technical experts from American Electric Power, and based on past observations of model performance at this monitor, these results are not unsurprising. At this particular monitoring location, concentrations are typically low, and rise only when the emissions plume from Unit 3 directly impact the monitor location. Given the complex terrain, and therefore complex meteorology of the Ohio River valley, those periods where the plume is not directly impacting this location are difficult to replicate completely. The less frequently occurring periods where the plume more directly impacts the monitor location inform the design value at this monitor, and seem to be more easily replicated by the AERMOD model. Therefore, a reasonable approach to evaluating the model performance at this monitor location is to consider results at the level of the design value and above. Examination of these data as shown in Figure 4 indicates that the model is slightly over-predictive under all formulations, and it is apparent that AERMOD with LOWWIND3 enabled and meteorology with the ADJ_U* option yield the best model performance at this monitor.

Cardinal 39-081-0020 Analysis:

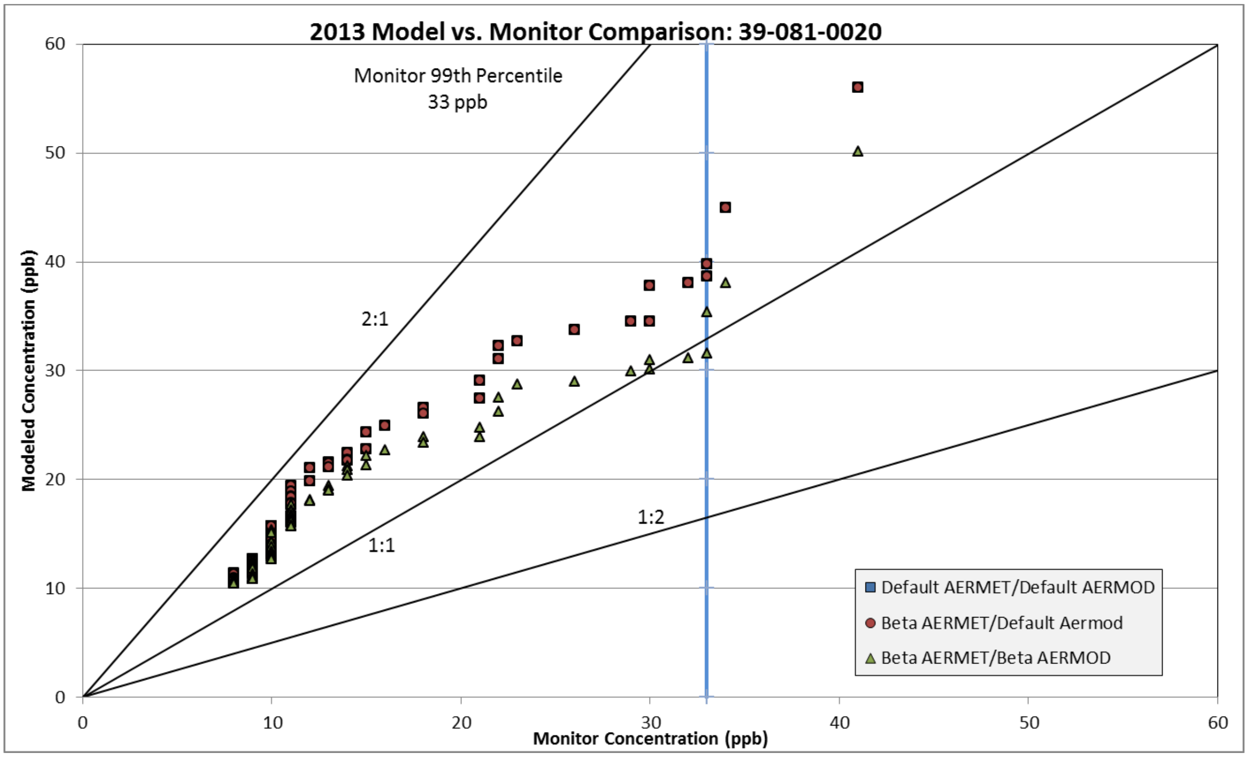

Figure 5: 2013 model vs. monitor results at monitor 39-081-0020.

2013: 39-081-0020	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	5.57	5.57	3.84
	Mean Error (ppb)	5.57	5.57	3.91
	Normalized Mean Bias(%, -100 to ∞)	41.18	41.18	28.40
	Normalized Mean Error(%, 0 to ∞)	41.18	41.18	28.87
	Mean Fractional Bias(%, -200 to +200)	34.98	34.98	27.54
	Mean Fractional Error(%, 0 to 200)	34.98	34.98	27.74
	Normalized Mean Square Error	0.14	0.14	0.07

Table 5: Model performance evaluation statistics, monitor 39-081-0020.

Figure 5 and Table 5 present the graphical and statistical analysis of model performance at monitor location 29-081-0020. This monitor is located near the valley floor approximately 2.6 kilometers directly to the northeast of Cardinal Unit 3 and at a similar elevation to that of monitor 54-009-6000. Examination of Figure 5 indicates excellent model performance at this monitor location under all model formulations. At the design value, the default AERMOD formulation over-predicts the monitored design value of 33 ppb by 4.4 ppb. The LOWWIND3 formulation slightly underpredicts the monitored design value by 1.4 ppb. Across the range of values, it appears that the LOWWIND3 option improves the accuracy of the model overall. This observation is borne out in the statistics calculated at this monitor location. In particular, Ohio EPA notes the marked improvement in the normalized mean bias and error.

Cardinal 39-081-0018 Analysis:

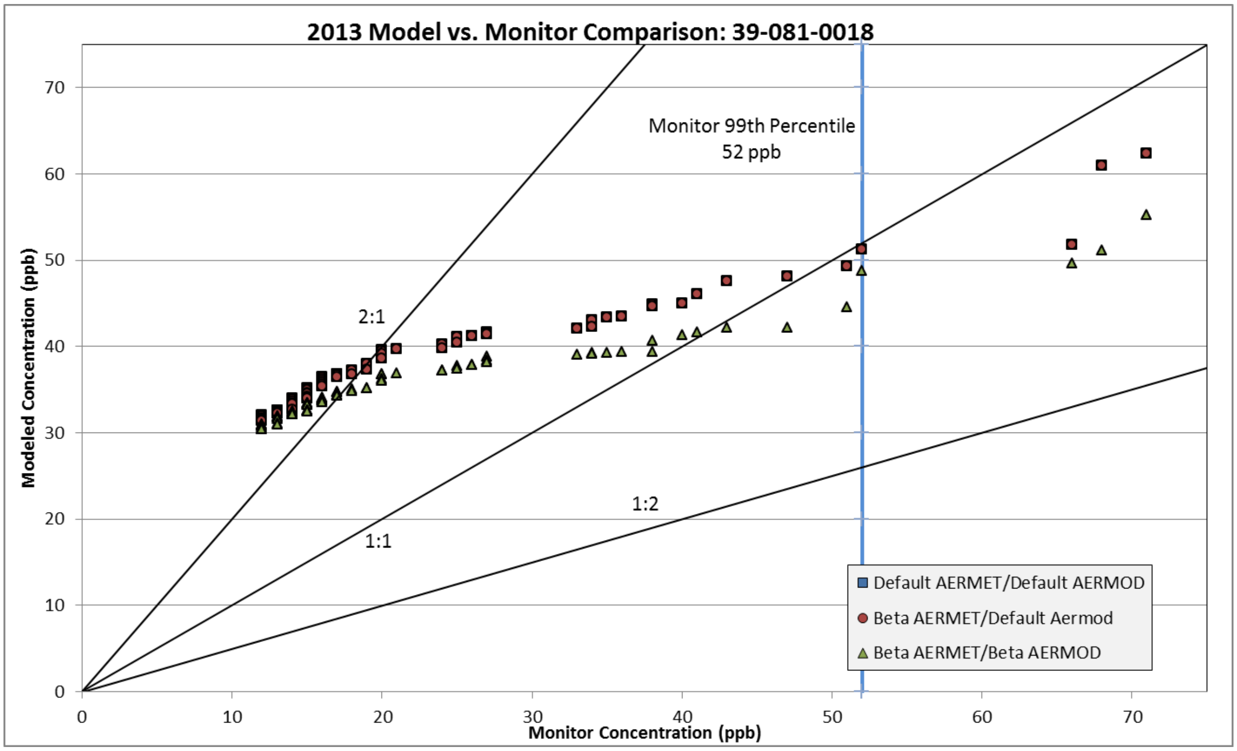

Figure 6: 2013 model vs. monitor results at monitor 39-081-0018.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2013: 39-081-0018	Mean Bias (ppb)	15.33	15.33	12.94
	Mean Error (ppb)	15.98	15.98	14.29
	Normalized Mean Bias(%, -100 to ∞)	68.66	68.66	57.99
	Normalized Mean Error(%, 0 to ∞)	71.60	71.60	64.02
	Mean Fractional Bias(%, -200 to +200)	58.99	58.99	53.34
	Mean Fractional Error(%, 0 to 200)	60.09	60.09	55.81
	Normalized Mean Square Error	0.34	0.34	0.28

Table 6: Model performance evaluation statistics, monitor 39-081-0018.

Monitor 39-081-0018 is located approximately 4.2 kilometers to the northeast of Cardinal Unit 3. This monitor is situated well above the valley floor at an elevation of approximately 310 meters above sea level. Prior studies conducted at this monitor, as well as Ohio's attainment demonstration for the Steubenville, OH-WV nonattainment area indicate that emissions from other facilities, in addition to the Cardinal Plant, impact this monitor. These impacts from other facilities can be quite large at times. Although Ohio EPA attempted to some degree to mitigate this by including a fixed background informed by previous modeling, the modeling results at this monitor are somewhat difficult to interpret. Further investigation into either a variable background profile or the inclusion of additional sources may be necessary to obtain more meaningful statistics at this location. However, it can be seen in Figure 6 that all model formulations under-predict to some degree the highest of the maximum daily values recorded at this monitor, and over-predict to varying degrees for concentrations of approximately 40 ppb and less. The statistics presented in Table 6 demonstrate that some degree of improved model performance is observed when the LOWWIND3 option is utilized. This is consistent with the model performance at the other monitors in the Cardinal network, but until a more refined treatment of background or additional sources can be included, Ohio EPA maintains a lesser degree of confidence in these data.

Model Performance Evaluation in Sammis Source Area:

As with the Cardinal monitoring network, Ohio EPA plotted modeled vs. monitor concentrations for the top 20% of maximum daily values, years 2012-2014, for each of the two monitors chosen for this evaluation. Additionally, Ohio EPA also plotted the 3-year average modeled and monitored values (form of the standard). Note that the data are not paired in time. For comparative purposes, Ohio EPA has again included in each figure 2:1, 1:1, and 1:2 lines, as well as an indication of the 99^{th} percentile maximum daily value recorded at each monitor. The summary statistics at each monitor location are presented and discussed in turn. Figures 7-10 and Tables 7-10 below present these data as described above for monitor 54-029-0005. Figures 11-14 and Tables 11-14 present these data for monitor 42-007-0002.

Monitor 54-029-0005 Analysis:

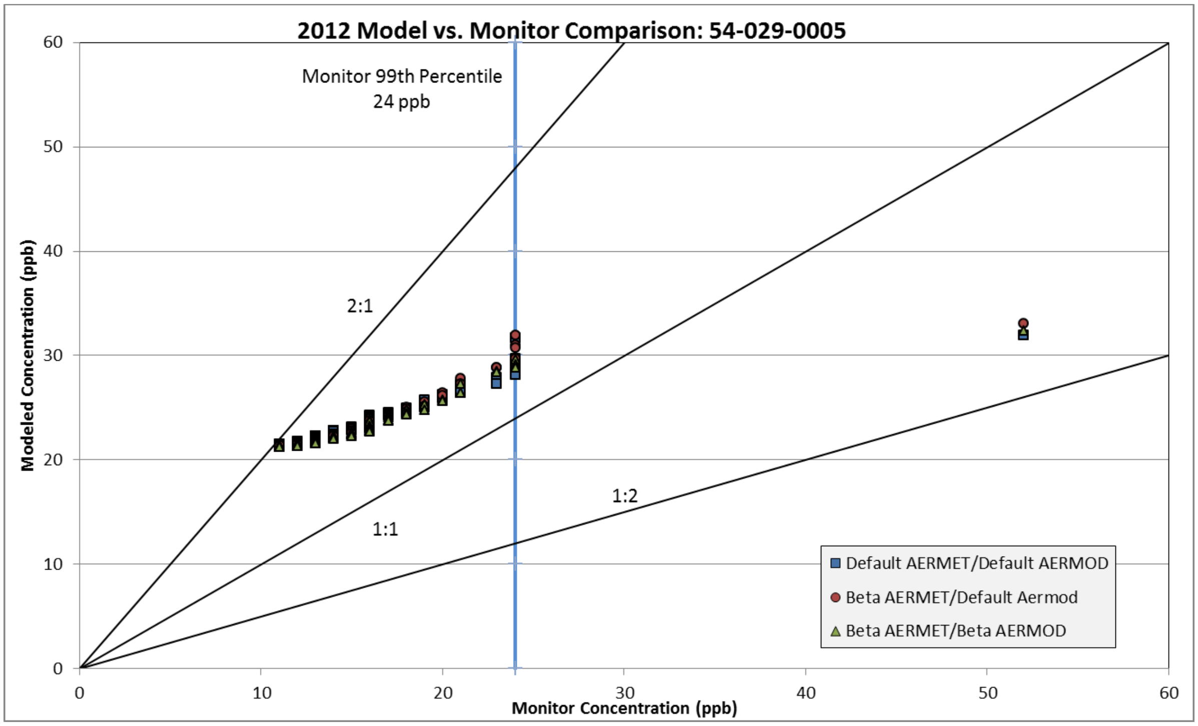

Figure 7: 2012 model vs. monitor results at monitor 54-029-0005.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2012: 54-029-0005	Mean Bias (ppb)	8.11	8.17	7.81
	Mean Error (ppb)	8.11	8.17	7.81
	Normalized Mean Bias(%, -100 to ∞)	54.06	54.43	52.07
	Normalized Mean Error(%, 0 to ∞)	54.06	54.43	52.07
	Mean Fractional Bias(%, -200 to +200)	43.81	43.95	42.58
	Mean Fractional Error(%, 0 to 200)	43.81	43.95	42.58
	Normalized Mean Square Error	0.20	0.20	0.19

Table 7: 2012 model performance evaluation statistics, monitor 54-029-0005.

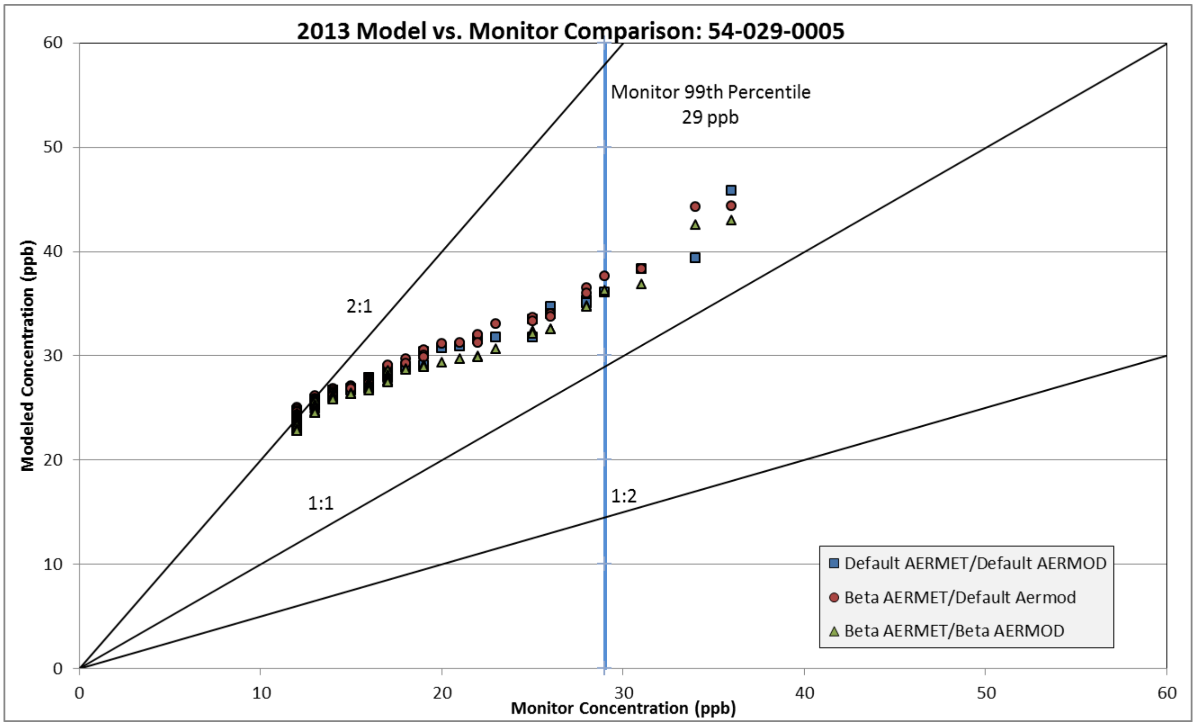

Figure 8: 2013 model vs. monitor results at monitor 54-029-0005.

2013: 54-029-0005	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	11.00	11.17	10.52
	Mean Error (ppb)	11.00	11.17	10.52
	Normalized Mean Bias(%, -100 to ∞)	67.43	68.53	64.49
	Normalized Mean Error(%, 0 to ∞)	67.43	68.53	64.49
	Mean Fractional Bias(%, -200 to +200)	52.58	53.05	50.95
	Mean Fractional Error(%, 0 to 200)	52.58	53.05	50.95
	Normalized Mean Square Error	0.28	0.29	0.26

Table 8: 2013 model performance evaluation statistics, monitor 54-029-0005.

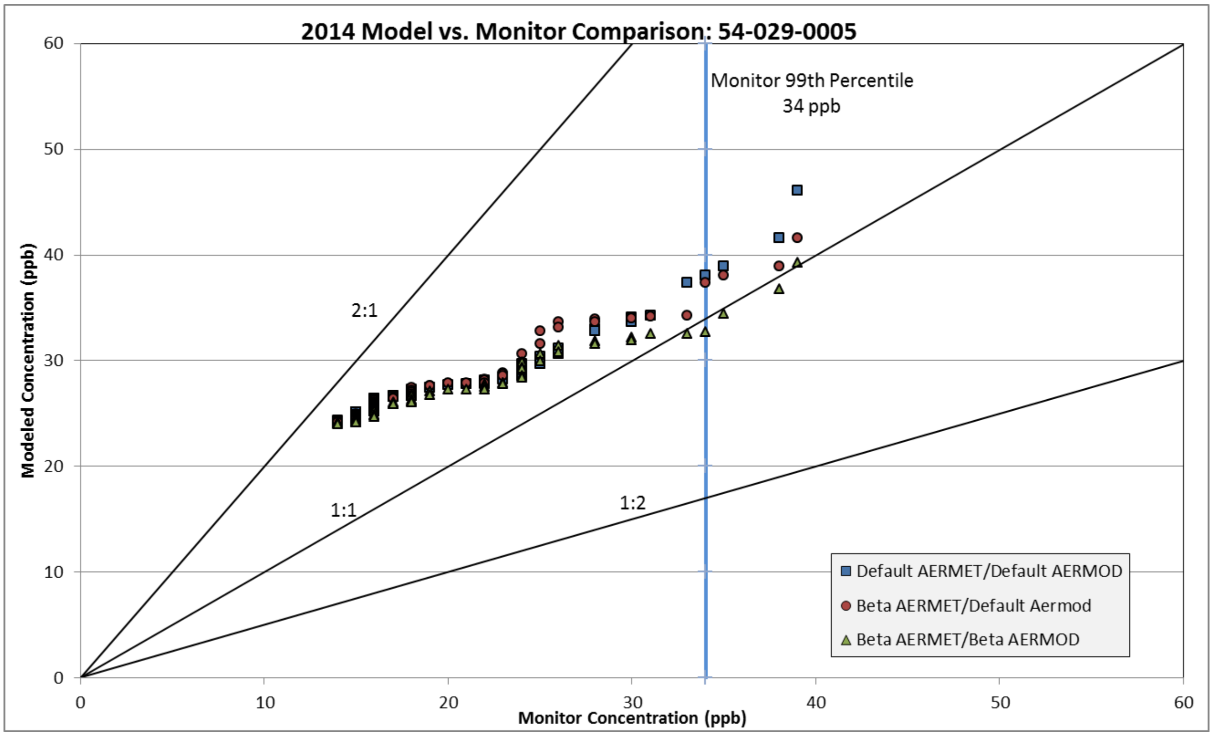

Figure 9: 2014 model vs. monitor results at monitor 54-029-0005.

2014: 54-029-0005	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	7.86	7.91	7.15
	Mean Error (ppb)	7.86	7.91	7.24
	Normalized Mean Bias(%, -100 to ∞)	40.16	40.38	36.48
	Normalized Mean Error(%, 0 to ∞)	40.16	40.38	36.98
	Mean Fractional Bias(%, -200 to +200)	35.57	35.73	33.34
	Mean Fractional Error(%, 0 to 200)	35.57	35.73	33.53
	Normalized Mean Square Error	0.13	0.13	0.11

Table 9: 2014 model performance evaluation statistics, monitor 54-029-0005.

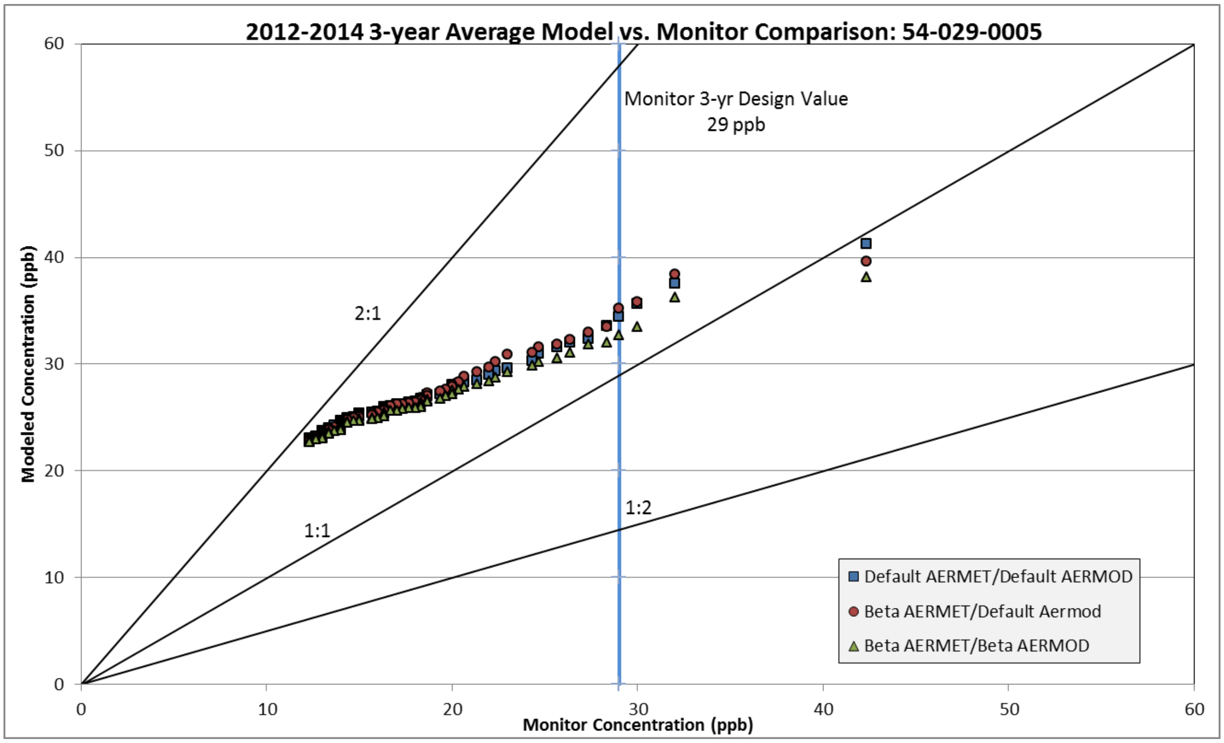

Figure 10: 2012-2014 model vs. monitor results at monitor 54-029-0005.

2012-2014 3-year Average: 54-029-0005	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	8.99	9.08	8.49
	Mean Error (ppb)	8.99	9.08	8.49
	Normalized Mean Bias(%, -100 to ∞)	52.99	53.55	50.06
	Normalized Mean Error(%, 0 to ∞)	52.99	53.55	50.06
	Mean Fractional Bias(%, -200 to +200)	43.73	44.00	41.98
	Mean Fractional Error(%, 0 to 200)	43.73	44.00	41.98
	Normalized Mean Square Error	0.19	0.20	0.18

Table 10: 2012-2014 model performance evaluation statistics, monitor 54-029-0005.

Monitor 54-029-0005 is located approximately 4.7 kilometers to the east of the Sammis plant. This monitor is situated well above the valley floor at an elevation of approximately 350 meters above sea level. The Sammis plant itself has a base elevation of approximately 210 meters above sea level. The data shown in Figures 7-10 would seem to indicate that the model is performing well, although slightly over-predictive. What is most remarkable about these data is the lack of clear separation between the default and beta model formulations. The statistics in Tables 7-10 indicate that although the model formulation utilizing LOWWIND3 exhibits the least amount of bias and error, the degree of separation amongst the formulations is not nearly as dramatic as those observed at the Cardinal monitoring network. A full discussion of this result is presented at the end of the *Monitor 42-007-0002 Analysis* section of this document, below.

Monitor 42-007-0002 Analysis:

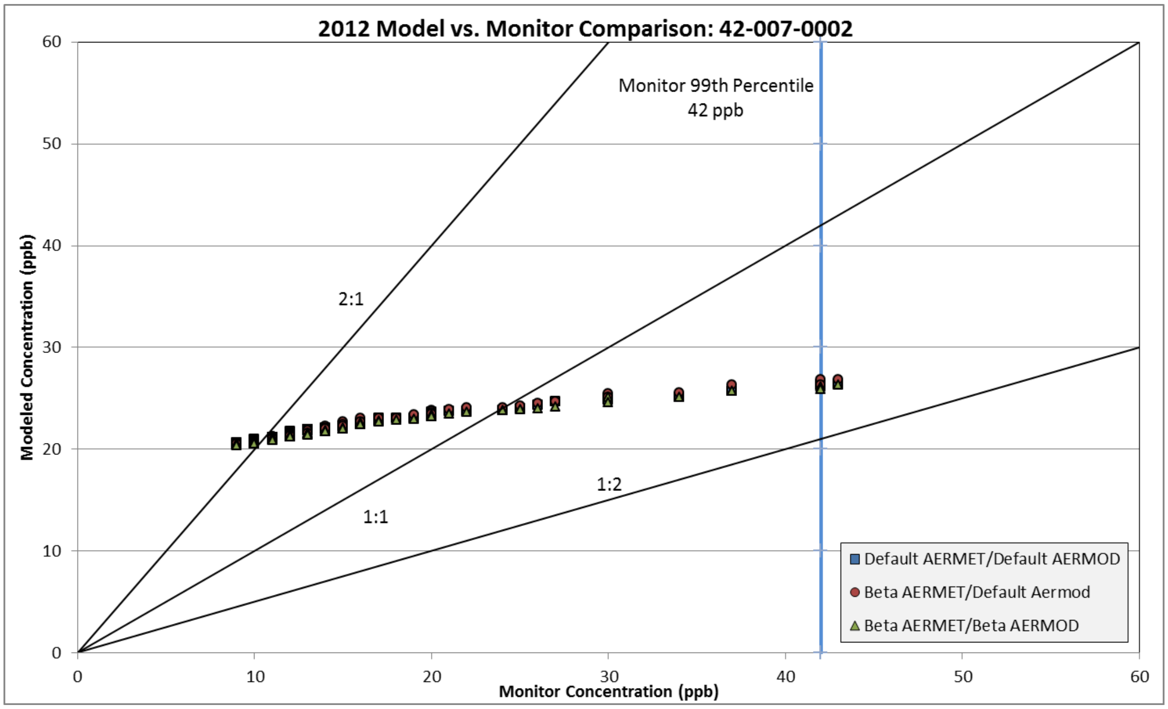

Figure 11: 2012 model vs. monitor results at monitor 42-007-0002.

2012: 42-007-0002	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	6.19	6.28	6.03
	Mean Error (ppb)	8.50	8.50	8.39
	Normalized Mean Bias(%, -100 to ∞)	39.47	40.04	38.44
	Normalized Mean Error(%, 0 to ∞)	54.23	54.22	53.51
	Mean Fractional Bias(%, -200 to +200)	41.08	41.44	40.40
	Mean Fractional Error(%, 0 to 200)	48.37	48.39	47.88
	Normalized Mean Square Error	0.25	0.25	0.24

Table 11: 2012 model performance evaluation statistics, monitor 42-007-0002.

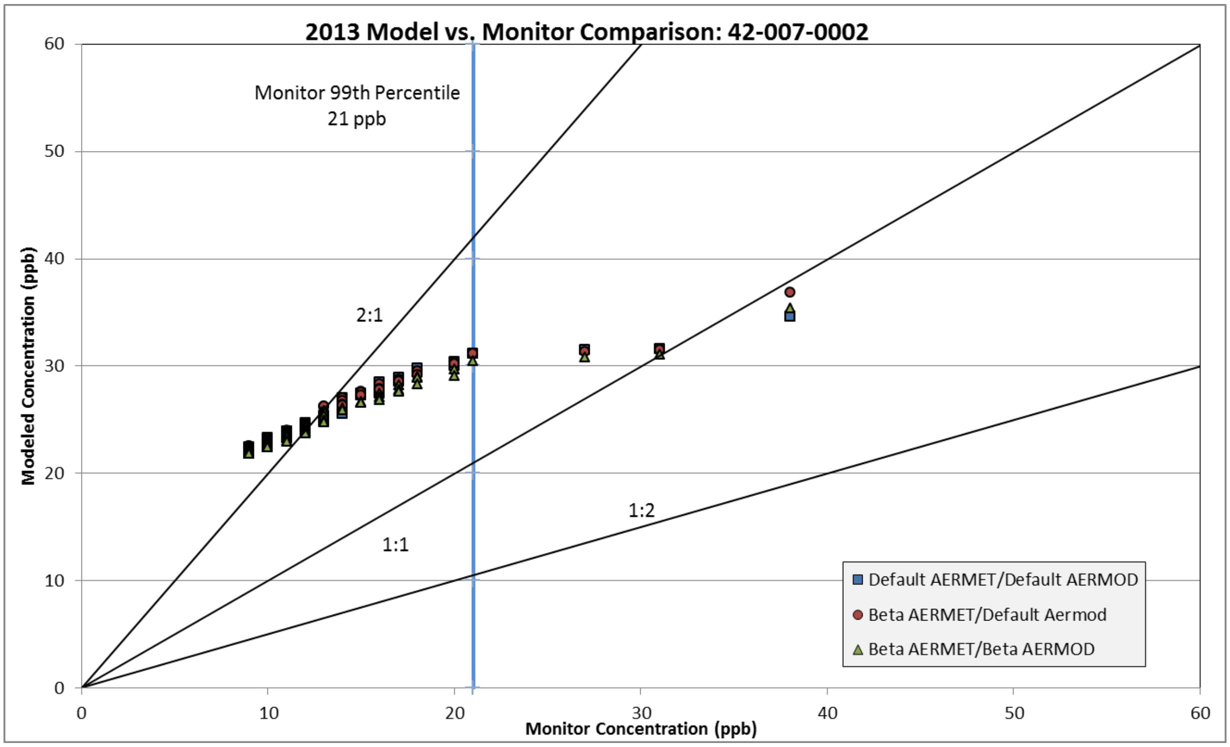

Figure 12: 2013 model vs. monitor results at monitor 42-007-0002.

	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
2013: 42-007-0002	Mean Bias (ppb)	12.02	12.13	11.73
	Mean Error (ppb)	12.02	12.13	11.73
	Normalized Mean Bias(%, -100 to ∞)	96.34	97.27	94.08
	Normalized Mean Error(%, 0 to ∞)	96.34	97.27	94.08
	Mean Fractional Bias(%, -200 to +200)	66.95	67.37	65.98
	Mean Fractional Error(%, 0 to 200)	66.95	67.37	65.98
	Normalized Mean Square Error	0.49	0.50	0.47

Table 12: 2013 model performance evaluation statistics, monitor 42-007-0002.

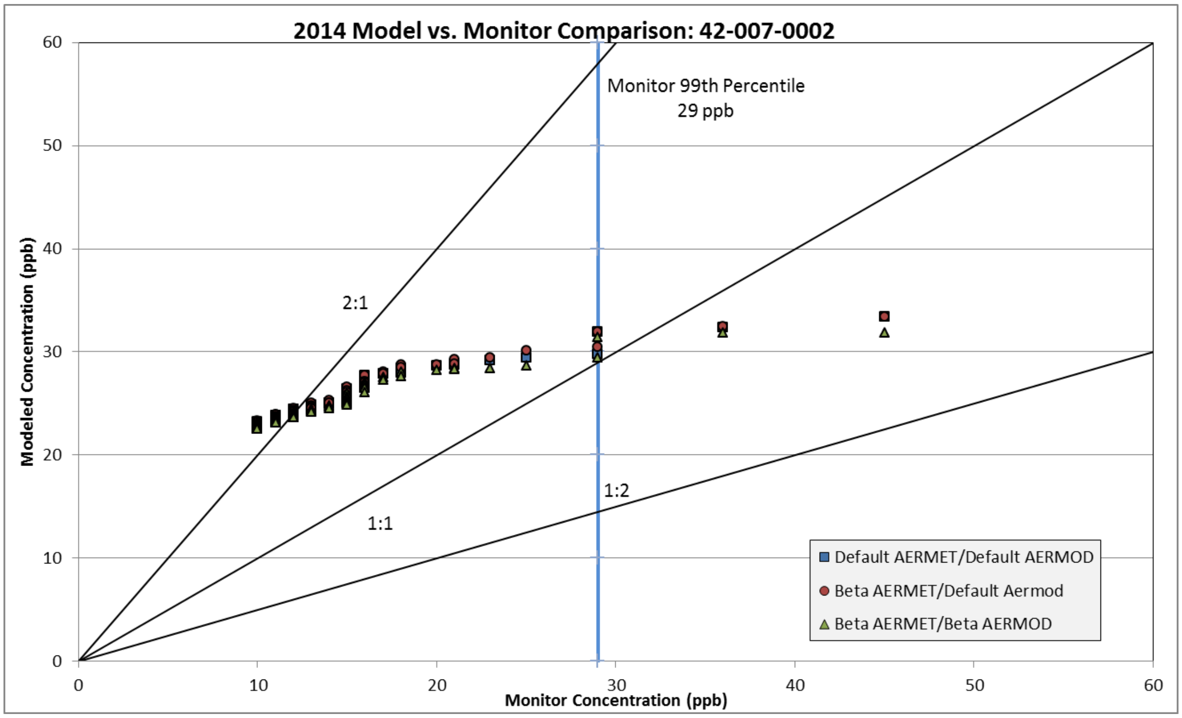

Figure 13: 2014 model vs. monitor results at monitor 42-007-0002

2014: 42-007-0002	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	10.89	11.01	10.62
	Mean Error (ppb)	10.99	11.11	10.74
	Normalized Mean Bias(%, -100 to ∞)	78.67	79.49	76.69
	Normalized Mean Error(%, 0 to ∞)	79.39	80.20	77.52
	Mean Fractional Bias(%, -200 to +200)	59.03	59.43	58.05
	Mean Fractional Error(%, 0 to 200)	59.32	59.72	58.39
	Normalized Mean Square Error	0.38	0.38	0.36

Table 13: 2014 model performance evaluation statistics, monitor 42-007-0002

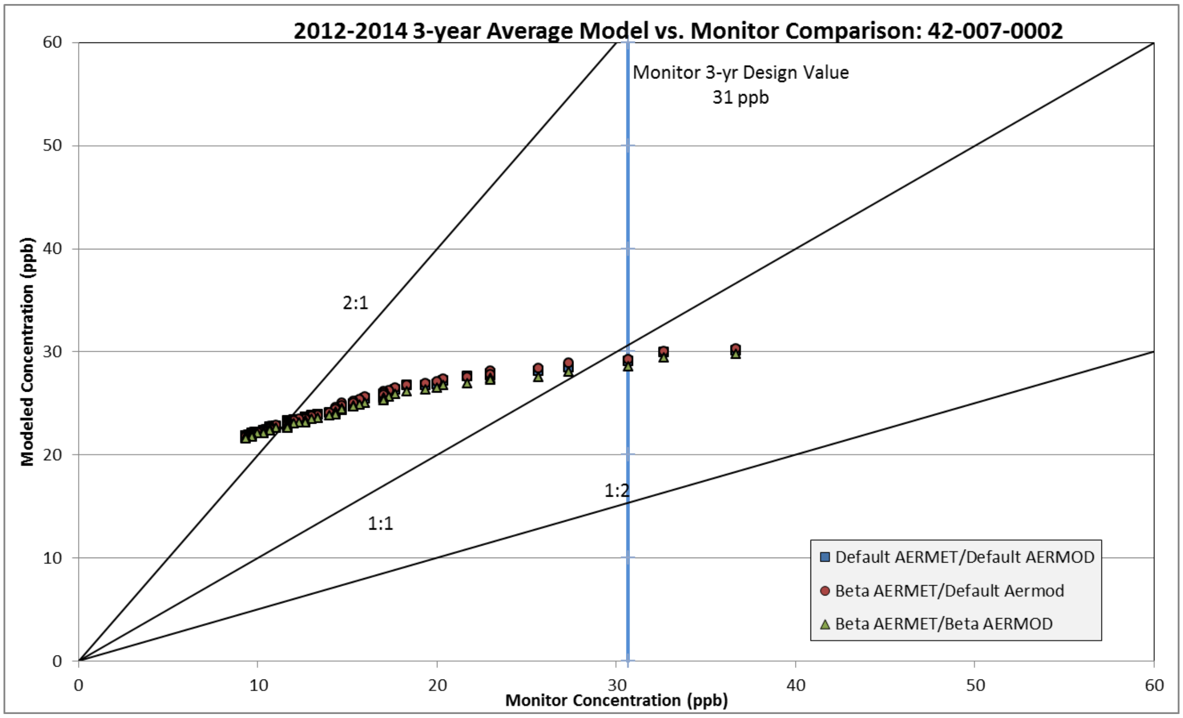

Figure 14: 2012-2014 model vs. monitor results at monitor 42-007-0002

2012-2014 3-year Average: 42-007-0002	Statistic	Default AERMOD Default AERMET	Default AERMOD Beta AERMET	Beta AERMOD Beta AERMET
	Mean Bias (ppb)	9.70	9.81	9.46
	Mean Error (ppb)	10.00	10.09	9.80
	Normalized Mean Bias(%, -100 to ∞)	69.28	70.04	67.60
	Normalized Mean Error(%, 0 to ∞)	71.43	72.10	70.00
	Mean Fractional Bias(%, -200 to +200)	55.46	55.85	54.57
	Mean Fractional Error(%, 0 to 200)	56.39	56.74	55.62
	Normalized Mean Square Error	0.33	0.33	0.32

Table 14: 2012-2014 model performance evaluation statistics, monitor 42-007-0002

Monitor 42-007-0002 is located approximately 11.4 kilometers to the east-northeast of the Sammis plant. This monitor is situated well above the valley floor at an elevation of approximately 410 meters above sea level. The Sammis plant itself has a base elevation of approximately 210 meters above sea level. The data shown in Figures 11-14 would seem to indicate that the model is performing moderately well, but the statistics in Tables 11-14 indicate that there is significantly more bias and error at this monitor location than that determined at monitor 54-029-0005. As with monitor 54-029-0005, the most remarkable quality of these data is the lack of clear separation between the default and beta model formulations. The statistics in Tables 11-14 indicate that although the model formulation utilizing LOWWIND3 exhibits the least amount of bias and error, the degree of separation amongst the formulations is not nearly as dramatic as those observed at the Cardinal monitoring network. This suggests that the LOWWIND3 option does not degrade model performance in instances when low winds are not observed to a large degree in the meteorological data.

To assess this, Ohio EPA determined the number of hours exhibiting winds speeds less than 1 meter/second. This analysis was conducted for years 2012-2014 for the Pittsburgh meteorological data utilized in the analysis of monitors in the Sammis source area and for 2013 for the Cardinal monitoring network. These data are shown in Table 15.

	2012	2013	2014
Sammis: # of Hours with WS<1	738	712	215
Cardinal: # of Hours with WS<1	--	1811	--

Table 15: Number of hours with wind speeds below 1 m/s

Table 15 clearly shows that the meteorological data utilized in for the model performance evaluation exhibits far fewer hours with wind speeds below 1 meter/second than the data utilized for the analysis in the Cardinal monitoring network. This may explain to some degree the similar performance of the model under all formulations in the Sammis source area, and the clear improvement observed at the Cardinal monitoring network when the LOWWIND3 option is utilized. Although it is acknowledged that there may be other factors controlling the model performance, it is clear that when a substantial portion of hours in the meteorological data are less than 1 meter/second, model performance is improved utilizing the LOWWIND3 option, and when there is not a substantial proportion of low winds, model performance is not degraded by the use of this option.

Conclusions:

Ohio EPA has conducted an-depth evaluation of model performance in two SO_2 source areas to determine the utility of the LOWWIND3 and ADJ_U* options of the AERMOD modeling system, and to assess the impact these options have on model performance with respect to bias and error at the maximum daily value level, consistent with the form of the standard. Both facilities analyzed are considered tall-stack sources and are located in complex terrain. The analyses conducted here indicate that the LOWWIND3 and ADJ_U* option improve model performance in the presence of low wind conditions, and have little effect on model performance when such conditions are not present. This is consistent with other studies included in the Select Bibliography below and those previously cited in Ohio's December 2015 request to utilize these options. These improvements include more accurate estimates of the 99th percentile maximum daily values, and thus design values used for the 2010 1-hour SO_2 NAAQS. Further, these options do not introduce under-predictive bias, an observation consistent with previous studies cited by Ohio EPA and in other analyses conducted by Ohio EPA with respect to these options. Ohio EPA therefore contends that model performance is enhanced and improved when these options are utilized, and has demonstrated this in three source areas (Cardinal, Sammis, and Gavin) against seven different ambient air quality monitors. When Ohio EPA's work is considered in light of the ever-expanding body of research on these options, the vast majority of which express the same conclusion, it is clear that these options should be readily available to utilize in modeling efforts to meet the requirements of the Data Requirements Rule. Given the stringency of the standard and the stated purpose of modeling under the Data Requirements Rule, whereby each receptor is treated as a proxy for an ambient air quality monitor, the most accurate and un-biased model formulation should be utilized. It is Ohio EPA's opinion, formed in part from our own analyses as well as other highly respected members of the modeling community, that the most accurate formulation available is the AERMOD model with the LOWWIND3 option enabled and utilizing meteorological data processed with the ADJ_U* option.

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