INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT
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October 18, 2017

Mr. Robert A. Kaplan
Regional Administrator
U.S. Environmental Protection Agency
Region 5
77 West Jackson Boulevard
Chicago, IL 60604-3950

Re: Indiana's Response to U.S. EPA's 120-Day Letter Concerning Intended Round 3 Area Designations for the 2010 1-Hour Primary Sulfur Dioxide (SO_2) National Ambient Air Quality Standard (NAAQS)

Dear Mr. Kaplan:

This letter is in response to United States Environmental Protection Agency's (U.S. EPA's) 120-day letter on August 22, 2017, concerning the 2010 1-hour primary sulfur dioxide (SO_2) national ambient air quality standard (NAAQS) and the designation of areas in Indiana under Round 3.

Implementation of the 2010 primary 1-hour SO_2 standard began in 2013 when U.S. EPA established nonattainment areas based on 2010-2012 monitoring data. U.S. EPA entered into a consent decree with the Sierra Club and Natural Resources Defense Council (NRDC) in 2015, which established a timeline for designations in all remaining areas of the country in three additional rounds.

Under the court order, U.S. EPA was required to address areas around certain large SO_2 sources and areas with new monitored violations in Round 2 by July 2, 2016. U.S. EPA must designate remaining areas where modeling will be used to characterize air quality in Round 3 by December 31, 2017, and all remaining areas where states have elected to install and operate new air monitors in Round 4 by December 31, 2020.

U.S. EPA's Data Requirements Rule (DRR), which was finalized in 2015, directs U.S. EPA and states to characterize air quality around sources that emit 2,000 tons per year (TPY) or more of SO_2 according to timelines that coincide with Round 3 and 4 designations. The DRR provides U.S. EPA and states discretion in identifying SO_2 sources that have emissions below 2,000 tons per year but may be contributing to a violation of the SO_2 NAAQS.

Indiana has worked closely with U.S. EPA to ensure the appropriate and timely designation of areas under the first two rounds[1] and has provided data and information to help inform U.S. EPA's designations under Rounds 3 and 4[2]. Indiana acknowledges U.S. EPA's agreement with its recommendations of attainment for many of the areas being addressed in Round 3. The purpose of this letter is to provide additional data and information concerning U.S. EPA's proposed revisions to Indiana's recommendations of unclassifiable for Huntington County and attainment for an affected portion of Warrick County as well as to provide clarification regarding U.S. EPA's analysis for Floyd County.

<u>Huntington County</u>

U.S. EPA has applied the DRR to U.S. Mineral Products (USM) dba Isolatek. USM is a mineral wool manufacturer located in Huntington Township in Huntington County. Indiana did not include USM on its list of sources that are subject to the DRR because USM's reported actual SO_2 emissions in 2014 were 164 tons. Indiana believes that U.S. EPA has arbitrarily applied DRR requirements to USM for the following reasons:

- There are numerous sources across the United States, and within Indiana, whose SO_2 emissions are in a range similar to, or greater than, the USM SO_2 emissions but are not identified as DRR sources.

  In Indiana alone, there were 30 sources with reported actual SO_2 emissions greater than USM's actual reported emissions for 2014 and less than the 2,000 ton threshold that were not already accounted for in earlier rounds of designations.

  Specific to USM, in its Technical Support Document, U.S. EPA discusses, at great length, the annual SO_2 emissions for USM. SO_2 emissions were estimated to be either 164 TPY (as reported for 2014), 191 TPY, 444 TPY, or 1,393 TPY depending on the underlying assumption used in the calculations[3].

  Clearly, even the most conservative estimate of SO_2 emissions does not approach the 2,000 TPY threshold that U.S. EPA set for determining sources subject to the DRR; a threshold set by U.S. EPA that "prioritizes the resources that will be devoted to characterizing air quality near SO_2 sources nationally" (80 FR 51061); a threshold that is already on "the lower end of the range of thresholds" of sources that have the potential to contribute to violations of the NAAQS (80 FR 51061), and a threshold that "strikes a reasonable balance between the need to characterize air quality near sources that have a higher likelihood of contributing to a NAAQS violation and the

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[1] U.S. EPA issued designations in its initial round on July 25, 2013. U.S. EPA issued designations in Round 2 on June 30, 2016.
[2] Indiana submitted a list of 11 DRR sources on January 7, 2016. U.S. EPA added six sources to the list on March 26, 2016, including five sources that were already being addressed in Round 2 designations and U.S. Minerals (dba Isolatek) in Huntington County. Indiana submitted elected approaches for air quality characterization for all identified DRR sources on June 30, 2016; submitted updates on September 26, 2016; and submitted Round 3 designation recommendations on January 13, 2017, for areas near DRR sources and all other remaining areas in Indiana except a portion of Porter county where new monitors have been installed for the area's designation in Round 4.
[3] U.S. EPA's technical support document for Indiana (https://www.epa.gov/sulfur-dioxide-designations/so2-designations-round-3-state-recommendations-and-epa-responses) contains a discussion of the agency's emissions calculations.

analytical burden on air agencies" (80 FR 51061). U.S. EPA did not characterize the 2,000 TPY threshold as an arbitrary number, but rather as an indicator of sources warranting prioritization of state and federal resources.

U.S. EPA has more traditional means of collecting emissions related data to verify emissions, yet none of those were explored for USM or similar sources prior to identifying USM as an affected source.

- U.S. EPA has excluded sources that have similar, and potentially greater ambient impacts than USM. For example,

  - A manufacturer of mineral wool located in a rural Indiana county that has operational characteristics similar to USM. This source operates with additional controls but reported comparatively higher actual SO_2 emissions of 534 tons in 2014 (vs 164 tons for USM). Initial air dispersion modeling conducted in 2011 and 2012 using versions of AERMOD and AERMET that were current at that time, and 2008-2011 emissions data showed an air quality impact from the facility well above how U.S. EPA modeling has characterized impacts associated with USM.

  - A small power plant for an Indiana university reported 1,740 tons of SO_2 emissions in 2014, more than 10 times USM's reported emissions. As with the mineral wool manufacturer, initial air dispersion modeling was conducted in 2011 and 2012 that indicated an air quality impact from the source could be well above the standard. In addition, the plant is located in a community of more than 80,000 persons. Conversely, USM is located in an area with less than 20,000 persons, less than ¼ of the population in the vicinity of power plant.

- Indiana believes U.S. EPA's modeling does not provide sufficient data to make a nonattainment designation. More importantly, the modeling conducted by U.S. EPA does not comply with guidance specific to characterizing sources under the DRR.

  Indiana observed several differences between the U.S. EPA's modeling analysis and Indiana's modeling analysis for affected DRR sources. For example,

  - U.S. EPA used an older version of AERMOD (14134) instead of the most current version (v16216r). This is inconsistent with DRR Modeling Guidance which states that the most current version of AERMOD is required[4].

  - U.S. EPA used an older version of AERMET (14134) instead of the most current version (v16216). This is inconsistent with DRR Modeling Guidance which states that the most current version of AERMET is required.

[4] U.S. EPA Modeling Guidance, "SO_2 NAAQS Designations Modeling Technical Assistance Document (TAD), dated August 2016" (https://www.epa.gov/sites/production/files/2016-06/documents/so2modelingtad.pdf) and U.S. EPA memo (Clarification on the AERMOD Modeling System Version for Use in SO_2 Implementation Efforts and Other Regulatory Actions), dated March 8, 2017" (https://www3.epa.gov/ttn/scram/guidance/clarification/SO2_DRR_Designation_Modeling_Clarificaiton_Memo-03082017.pdf)

- U.S. EPA used five years (2008 – 2012) of meteorological data as well as non-concurrent emissions data. This is inconsistent with DRR Modeling Guidance which states that three years of meteorological data concurrent with emissions data should be used in order to agree with the three-year average form of the SO_2 NAAQS. Under the DRR, modeling should have been conducted using meteorological data from 2013 - 2015 or 2014 - 2016.

- U.S. EPA's modeling analysis did not use readily-available adjusted hourly-seasonal SO_2 background for all DRR sources.

- U.S. EPA's modeling analysis did not utilize an adjusted surface friction velocity (ADJ_U*). This became a regulatory option after U.S. EPA's analysis was conducted.

- U.S. EPA's modeling analysis included source characteristics of the blow chambers/screenhouses, including release heights and vertical/horizontal dimensions of each blow chamber/screenhouse, which are inconsistent with actual source characteristics.

- U.S. EPA's modeling did not characterize the three most recent years of operation. The intent of the DRR as it relates to modeling is to characterize what the three most recent years of monitoring data would represent if a network was present during that time. This is important given the variability of operations, meteorology, etc.

Indiana firmly believes that U.S. EPA's modeling does not provide sufficient data on which to base a designation. Furthermore, had Indiana submitted modeling comparable to the analysis on which U.S. EPA is relying to determine the status of USM, it is highly likely that U.S. EPA would have found the modeling inadequate for the purpose of rulemaking under the DRR because the modeling was not performed in accordance with DRR Modeling Guidance.

Indiana does not question whether the DRR provides states or U.S. EPA the authority to identify sources with actual emissions below the 2,000 ton threshold as requiring further air quality characterization. U.S. EPA's 2,000 ton threshold is an important indicator of the need for prioritized air quality characterization under the DRR. Arbitrarily and inconsistently including a source such as USM with reported emissions less than one tenth of the DRR's 2,000 ton threshold while excluding sources with similar, or greater, emissions and a potential for elevated air quality impacts represents a misapplication of the intent of the DRR to prioritize sources and resources. For these reasons, Indiana believes a designation of unclassifiable is appropriate for Huntington Township.

<u>Warrick County</u>

U.S. EPA and Indiana have identified an aluminum manufacturing facility and an adjacent power plant operated by the Aluminum Manufacturing Company of America (ALCOA) in Anderson Township, Warrick County, Indiana, as DRR sources. Indiana informed U.S. EPA on June 30, 2016 that air quality in the area of these sources would be characterized using air dispersion modeling. Indiana submitted monitoring data to support a recommendation of attainment on January 13, 2017, followed by a modeling protocol on June 23, 2017 prepared by ALCOA to describe procedures for the area's further characterization.

U.S. EPA indicated in its 120-day letter that the monitoring data submitted by Indiana was insufficient for use in an attainment designation and that staff was working to complete a review of the modeling protocol that adequately characterizes all SO_2 emission sources for the Alcoa Power Plant and the Alcoa Warrick Operations facility.

Indiana has since received and reviewed a final modeling analysis from ALCOA that demonstrates the area surrounding ALCOA as attaining the SO_2 NAAQS. Discussion with modeling staff from U.S. EPA – Region 5 and the Office of Air Quality Planning and Standards resulted in acceptance of Alcoa's modeling approach. This approach, described in more detail in the enclosed technical support document, is more representative of air quality characterization required by DRR guidance than the modeling results referenced by U.S. EPA in its initial designation recommendation. As such, Indiana believes a designation of attainment is appropriate for Anderson, Boon and Ohio Townships.

Indiana is enclosing the modeling analysis and an updated technical support document for U.S. EPA's consideration prior to the area's final designation by December 31, 2017.

<u>Floyd County</u>

U.S. EPA indicated, in its Technical Support Document, Indiana did not follow the SO_2 nonattainment planning guidance for 30-day average limitations for Louisville Gas and Electric – Mill Creek Generating Station located in Kentucky, for the Floyd County (Gallagher) DRR modeling. This guidance recommends a comparably stringent, upward adjusted 1-hour emission limit be applied to the modeling in place of the permitted 30-day averaging emission limit. In the case of Mill Creek, the Louisville Metro Air Pollution Control District air permitting staff provided the permitted 30-day average emission rate (0.17 lb of SO_2/MMBtu) as well as the conversion to a 1-hour emission rate (0.24 lb of SO_2/MMBtu). The 1-hour emission rate for Mill Creek was modeled by Indiana for its air quality characterization of the surrounding area. Therefore, Indiana believes the characterization of the Mill Creek facility is consistent with the SO_2 nonattainment planning guidance and is representative of relevant emissions in the Floyd County area.

This submittal consists of one (1) hard copy of the required documentation. An electronic version of the submittal in PDF format that is identical to the hard copy has been sent to Doug Aburano, Chief of U.S. EPA Region 5's Attainment Planning and Maintenance Section and Chris Panos of U.S. EPA Region 5.

Thank you for this opportunity to submit information and a new modeling analyses and update to Indiana's technical support document for preliminary recommendations for Round 3 designations under the 2010 primary 1-hour SO_2 NAAQS. If you have any questions or need additional information, please contact Keith Baugues, Assistant Commissioner, Office of Air Quality, at (317) 232-8222 or kbaugues@idem.IN.gov.

Sincerely,

Bruno Pigott
Commissioner

BP/kb/sd/bc/md/gf/as
Enclosures

1. ALCOA Warrick Power Plant and Warrick Operations Modeling Data and Update to the Technical Support Document for Indiana's Preliminary Recommendations Concerning Round 3 Designations for the 2010 Primary 1-Hour Sulfur Dioxide (SO_2) National Ambient Air Quality Standard (NAAQS)

cc: Chris Panos, U.S. EPA Region 5 (no enclosures)
John Summerhays, U.S. EPA Region 5 (no enclosures)
Doug Aburano, U.S. EPA Region 5 (no enclosures)
Keith Baugues, IDEM-OAQ (no enclosures)
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Brian Callahan, IDEM-OAQ (w/ enclosures)
Mark Derf, IDEM-OAQ (w/ enclosures)
Gale Ferris, IDEM-OAQ (w/ enclosures)
Amy Smith, IDEM-OAQ (w/ enclosures)
File Copy

Enclosure 1

ALCOA Warrick Power Plant and Warrick Operations Modeling Data

and

Update to the Air Quality Modeling Technical Support Document

for

Indiana's Preliminary Recommendations Concerning Round 3 Designations for the 2010 Primary 1-Hour Sulfur Dioxide (SO_2) National Ambient Air Quality Standard (NAAQS)

October 2017

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1.0 - ALCOA Warrick Operations LLC (18-173-00007) and Warrick Power Plant (18-173-00002)

1.1 Background

On September 12, 2017, the United States Environmental Protection Agency (U.S. EPA), the Indiana Department of Environmental Management (IDEM), and the Aluminum Manufacturing Company of America (ALCOA) Warrick Operations, LLC/ALCOA Warrick Power Plant (WPP) discussed four modeling cases based on their relationship to a field monitoring study conducted between July 11, 2015 and February 19, 2016 at four SO_2 monitoring sites surrounding the ALCOA facility (see Attachment F for additional information regarding the field study and certified SO_2 monitoring data). Based on the modeling analysis conducted by AECOM (ALCOA's environmental consultant), Case 4 shows the best prediction correlation of SO_2 concentrations to the field study monitors. The other three study cases all showed over prediction tendencies when compared to the field study monitors surrounding ALCOA's property. The modeling field study approach provided a useful tool to determine the best modeling approach for the DRR assessment. The Case 4 analysis is discussed below for the DRR modeling assessment.

1.2 Source Descriptions

ALCOA is an aluminum manufacturing facility located in the town of Newburgh in Warrick County, IN. WPP generates 742-megawatts (MW) of energy necessary to operate the aluminum smelters at ALCOA. ALCOA manufactures flat-rolled aluminum for food and beverage containers, lithographic printing plates, and industrial product applications.

ALCOA's primary aluminum reduction operations include five pot lines. The pot line operations manufacture metallic aluminum by the electrolytic reduction of aluminum center-worked prebake cells. Direct electrical current, passing between anodes and the cathode, electrolytically reduces the alumina to aluminum and oxygen. Molten aluminum is deposited and accumulates over time at the cathode beneath a layer of molten cryolite bath. Periodically the molten aluminum is siphoned from beneath the cryolite bath and processed to achieve specific metal properties or is retained as pure aluminum. The product aluminum is solidified into intermediate or final products.

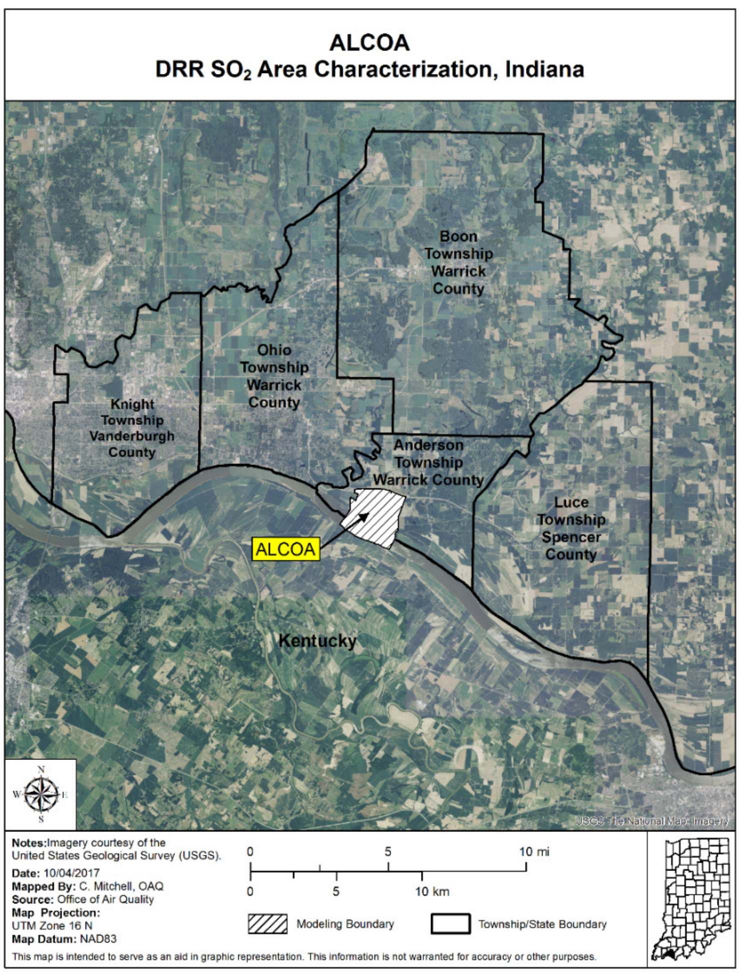
WPP sits approximately 400 meters south of the ALCOA smelters, along the Ohio River. The site consists of four coal-burning power-generation units, along with corresponding coal yards. Units 1 and 2 were constructed in 1956. Unit 3 was built in 1962. Unit 4 was added in 1970. Units 1, 2 and 3 exhaust to a common stack while Unit 4 exhausts to a separate stack. The facility provides electricity, steam, hot water and potable water to ALCOA's aluminum smelting and fabricating operation.

ALCOA was classified as a Data Requirements Rule (DRR) source based on their actual 2014 SO_2 emissions of 3,500 tons exceeding the DRR threshold of 2,000 tons of SO_2. WPP was also classified as a DRR source based on their actual 2014 SO_2 emissions of 4,993 tons exceeding the DRR threshold of 2,000 tons of SO_2. Both facilities are being examined under the DRR.

1.3 Characterization of Modeled Area

ALCOA/WPP is located at 4400 W SR 66 Newburgh, in Warrick County, Indiana approximately 20 kilometers east-southeast of Evansville on the banks of the Ohio River. A map of the area used for DRR modeling is shown below in Figure 1.1. Vectren's F.B. Culley Generating Station (Culley) is located directly east and adjacent to WPP.

Figure 1.1 - Map of ALCOA and Surrounding Area



1.4 Background Concentrations

The nearest 1-hour SO_2 monitored concentrations were taken from the Evansville – Buena Vista monitor. The 99^{th} percentile values from 2013 through 2015 and the 3-year design value listed in parts per billion (ppb) are found below in Table 1.1.

Table 1.1 - 99^{th} Percentile 1-hour SO_2 Values and the 3-year Design Value (ppb) Monitoring Site

Year	2013	2014	2015	2013-2015
Evansville – Buena Vista	18.6	32.3	18.1	23

1.5 Modeling Methodology

The ALCOA/WPP DRR modeling methodology resembles modeling used to evaluate New Source Review (NSR) and Prevention of Significant Deterioration (PSD) sources. However, Indiana has relied on U.S. EPA's SO_2 National Ambient Air Quality Standards (NAAQS) Designations Modeling Technical Assistance Document (TAD) in order to conduct an appropriate air dispersion modeling analysis for ALCOA to support 1-hour SO_2 designation recommendations. AECOM performed the modeling analysis for ALCOA which IDEM has reviewed for completeness.

1.5.1 Model Selection

In accordance with Appendix A of Appendix W to Title 40, Part 51 of the Code of Federal Regulations (40 CFR Part 51), the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) version 16216r was used in the modeling analysis. BPIPPRIME was used to account for any building downwash concerns.

1.5.2 Model Options

All regulatory default options within AERMOD were used to determine the air quality characteristics surrounding ALCOA. The area is considered primarily rural, based on the Auer's Classification Land Use methodology, as shown in Figure 1.2 below. Therefore, a rural classification was used, as provided for in the Guideline on Air Quality Models, Section 7.2.3 (EPA, 2005b) for all modeled emission points except ALCOA's aluminum smelters, which were modeled as urban as explained below.

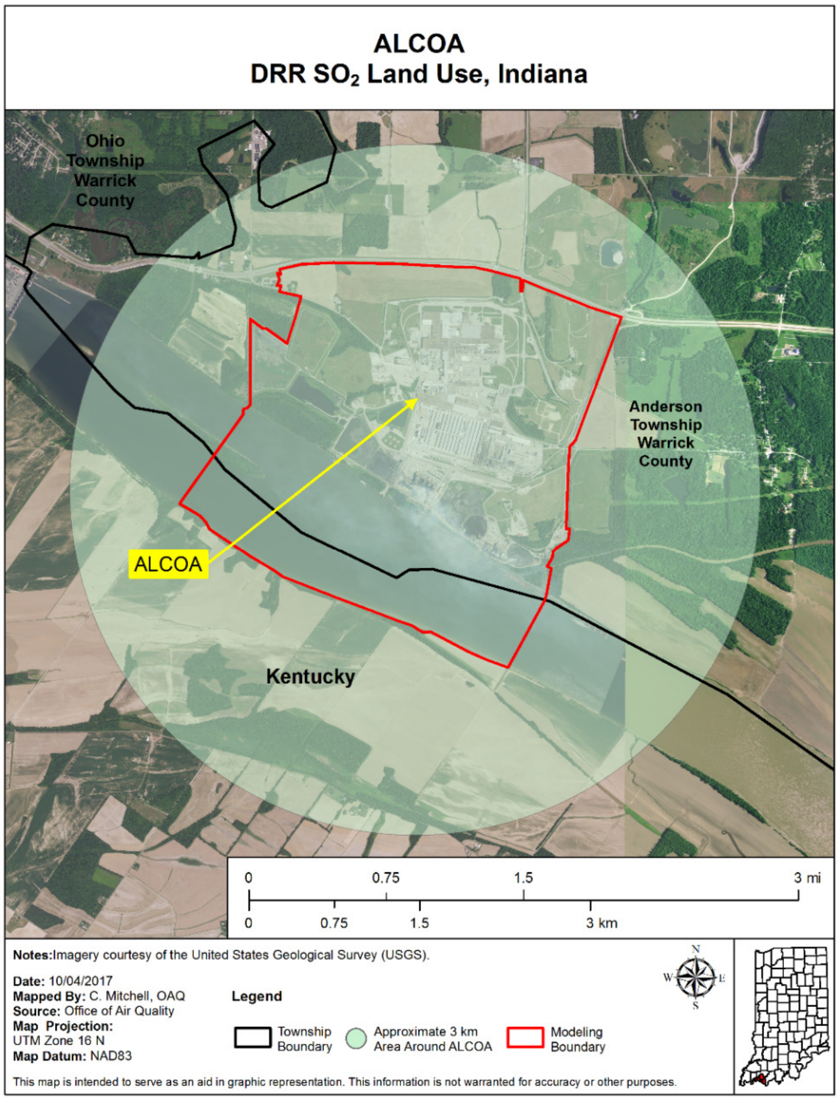
The choice of rural or urban for dispersion conditions usually depends upon the land use characteristics within 3 kilometers of the facilities (Appendix W to 40 CFR Part 51). Factors that affect the rural/urban choice, and thus the dispersion from the emission sources, include the extent of vegetated surface area, large bodies of water, types of industry and commerce, and building types and heights within the area. An Auer analysis of the area surrounding the ALCOA smelter operations, WPP, and Culley was conducted using satellite data of the area. The Auer land-use approach classifies an area according to 12 land-use types. In this scheme, areas of industrial, commercial, and compact residential land-use are designated urban. According to U.S. EPA modeling guidelines, if more than 50 percent of an area within a three-kilometer radius of a facility is classified as rural, then rural dispersion coefficients are to be used in the modeling. The Auer analysis indicates that the land use around the ALCOA, WPP and Culley facilities is rural. As a result, the WPP and Culley sources were be modeled using rural dispersion characteristics. The power plant stacks are 400 meters from the smelters and are in close proximity to the influences of the Ohio River to allow for the rural dispersion. However, due to the large industrial complex heat releases from the smelters, the ALCOA smelter sources were be modeled as urban, as explained further.

Emission sources such as the ALCOA aluminum smelter are associated with large fugitive heat releases that result in a localized urban-like dispersion environment. AERMOD typically estimates urban heat island effects using an urban or rural classification based on population density or land use. However, until updates to Appendix W were promulgated in 2017, AERMOD had not considered the urban effects that are created by large industrial complexes located in rural areas. The "highly industrialized area" effect can be addressed by a technique that accounts for the excess heat from an industrial complex and derives an effective population density related to the excess heat generated by the highly industrialized area as input to AERMOD.

In the case of the ALCOA smelters, there is approximately 450-MW daily electrical usage at all times for the smelting processes. This was calculated by looking at each potline energy usage in the smelting process which has a daily average usage of 90 MW for each of the five lines, which equates to approximately 450 MW. An example of typical electricity usage from the smelters is listed in Attachment A, showing the daily electricity usage at each of the five smelters over the course of a typical month (January 2016). In addition, the hot rolling mills in the area to the north of the smelting operations also emit fugitive heat from the process. The area involved in the ALCOA Warrick Operations smelting process is on the order of two square kilometers (2×10^6 m^2). The heat losses associated with the use of electricity in the aluminum smelting process can be on the order of 40-50%. Taking the lower end of the electrical usage and conservatively assuming that half of the heat loss is lost to the atmosphere while the remaining heat loss is absorbed by the buildings, the resulting atmospheric heat loss rate equates to approximately 100 MW. The heat loss from the smelting process to the atmosphere that is used to determine the effective urban-rural temperature difference is 50 W/m^2, which converts to an effective urban population density of two million. This equation is based on urban heat island research conducted by Oke (1973, 1982) and is shown in Attachment B, Appendix B "Urban Characterization of Industrial Source Complexes for AERMOD Modeling."

Consistent with the explanation provided above, the modeling approach for the ALCOA aluminum smelter sources is to characterize the facility as emitting into an urban boundary layer for AERMOD modeling with an effective population of two million.

Figure 1.2 - ALCOA 3-kilometer Radius to Determine Auer Classification Land Use



1.5.3 AERMAP

The AERMOD terrain preprocessor mapping program, AERMAP, was used to determine all the terrain elevation heights for each receptor, building, and source locations using the Universal Transverse Mercator (UTM) coordinate system. The most recent AERMAP version 11103 assigned the elevations from the National Elevation Dataset (NED) using the North American Datum (NAD) 1983 as recommended in Appendix W to 40 CFR Part 51 and later revised in the "AERMOD Implementation Guide, August 3, 2015."

1.6 Meteorological Data

1.6.1 AERMET

As stated in Appendix W to 40 CFR Part 51, section 8.3.1.2 and the SO_2 NAAQS Designations Modeling TAD, Indiana used 2013-2015 National Weather Service (NWS) surface and upper air meteorological data processed with the latest version of the AERMOD meteorological data preprocessor program AERMET (version 16216). Table 1.2 below lists surface and upper air meteorological stations used to conduct modeling.

The surface friction velocity parameter "ADJ_U*" option was also used, which is a regulatory default option under the 2017 Revisions to Appendix W final rule, effective May 22, 2017. Due to time constraints with the deadline for the DRR reporting, meteorological processing was performed by AECOM and provided to IDEM for approval.

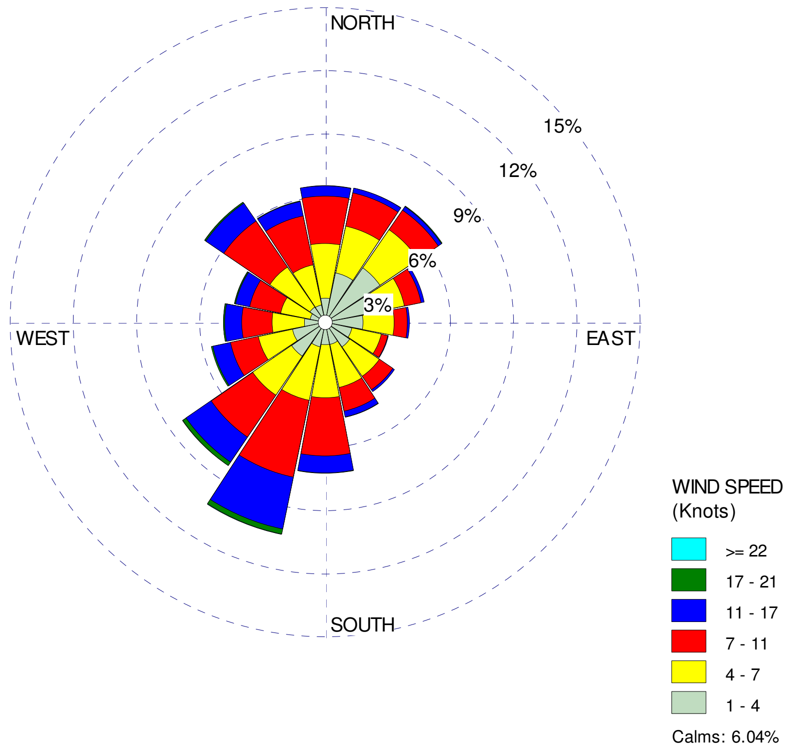
Table 1.2 - National Weather Service Meteorological Stations

Facility	Surface Meteorology	Upper Air Meteorology
ALCOA	Evansville, IN NWS	Lincoln, IL NWS

1.6.2 Wind Rose

The Evansville NWS surface meteorological data and the Lincoln, Illinois upper air meteorological data taken from 2013 - 2015 was be used to determine the meteorological conditions for the area surrounding ALCOA/WPP. The Evansville NWS wind rose for the 3-year modeled period 2013 - 2015 is shown as Figure 1.3 below. The Evansville NWS wind rose depicts the predominant wind direction as from the southwest for the 3-year modeled period 2013-2015.

Figure 1.3 - Evansville 3-year Cumulative Wind Rose (2013 – 2015)



1.6.3 AERMINUTE/AERSURFACE

The 1-minute wind speeds and wind directions, taken from the Automated Surface Observing System (ASOS) NWS meteorological stations, were processed with the U.S. EPA 1-minute data processor program AERMINUTE version 15272.

The U.S. EPA program AERSURFACE version 13016 was used to determine the surface characteristics; albedo, Bowen ratio, and surface roughness for two Evansville, Indiana NWS meteorological tower locations. The tower location was moved on March 19, 2014; therefore surface characteristics were determined for each location and processed at each location accordingly during the 3-year period. Surface characteristics were determined at the NWS location for each of 12 wind direction sectors with a recommended default radius of one kilometer.

The albedo and the Bowen ratio surface characteristics were adjusted during the three winter months of January, February, and December in accordance with the U.S. EPA Region V document, “Regional Meteorological Data Processing Protocol,” dated May 6, 2011. Additionally, a dry or wet Bowen ratio value was used during months when soil moisture conditions were abnormally dry or wet; otherwise the Bowen ratio value for average soil moisture conditions was used. The surface roughness value for snow cover was used if more than half of the month had days with at least one inch of snow on the ground. Otherwise, the no snow cover surface roughness value was used.

1.7 Receptor Grid and Modeling Domain

The receptor grid and modeling domain was based on guidance provided in the memorandum “Updated Guidance for Area Designations for the 2010 Primary Sulfur Dioxide National Ambient Air Quality Standards,” dated March 20, 2015 and the SO_2 NAAQS Designations Modeling TAD. A multi-nested rectangular receptor grid was used with appropriate spacing of receptors based on the distance from the modeled emission points to detect significant concentration gradients. The modeling domain extended out to include all sources and the appropriate distances to model maximum 1-hour SO_2 impacts to determine attainment designations for the area. A total of 12,217 receptors were used in the analysis as shown below in Figure 1.4. The following multi-nested rectangular receptor grid was used.

The receptor grid has 50 meter spacing along the boundary of the secured areas of the joint Alcoa WPP and Vectren - Culley property with receptor spacing as follows:

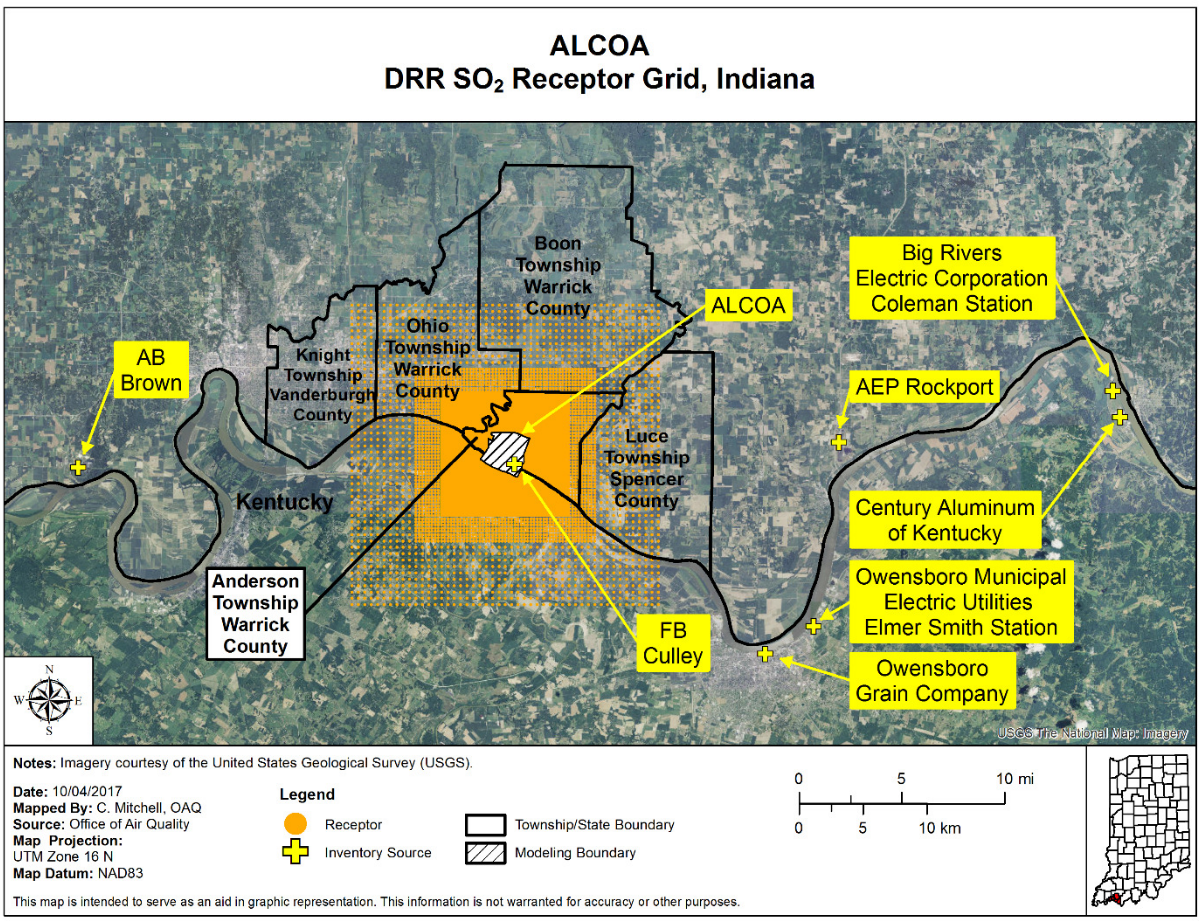
- Every 100 meters out to a distance of 3 kilometers,
- Every 250 meters between 3 and 5 kilometers,
- Every 500 meters between 5 and 10 kilometers.

The secured areas of both ALCOA and Culley were excluded from receptor placement; they are not “ambient air” as defined by the “Modeling Receptor Location Brief for ALCOA”, found in Attachment C of this document. The ALCOA smelter and the adjacent WPP are considered as one facility in their operating permit. In addition, the ALCOA and Vectren facilities have substantial interconnected and joint operations and joint ownership as follows:

- Federal Energy Regulatory Commission (FERC) documentation describes the interrelationship between ALCOA and Vectren, as noted below.
- Vectren owns a portion of the WPP Unit 4.
- Vectren also owns a portion of the 138-kilovolt (kV) substation in the Warrick Power Plant.
- ALCOA and Vectren jointly own foundations, towers, conductors and insulators, as well as switching and protective equipment added to the Culley station.

- ALCOA and Vectren jointly own and operate the "Tie Line 3 facility," a 2.2 mile, 138-kV line on these properties.
- ALCOA and Vectren jointly own other facilities in that area, including a 138 kV bus located at the WPP to service the WPP operation.
- Tie Line 3 runs from a jointly-owned generating unit (WPP Unit 4) to the 138 kV ring bus, and then to the Culley substation.
- Additional distribution lines connect the Culley Substation to the WPP, are jointly owned, and are used to meet the energy needs of ALCOA's smelting and rolling mill operations.
- ALCOA personnel periodically test all metering equipment associated with these interconnected facilities.
- In actual practice, ALCOA and Vectren personnel routinely work on equipment at both facilities.

Figure 1.4 - Alcoa Receptor Grid and Inventory Sources



Further discussion of what is considered ALCOA plant property to reflect the modeling receptor placement is provided in Attachment C.

1.8 Stack Heights

The use of actual stack heights rather than relying on Good Engineering Practice (GEP) stack heights when modeling actual emissions was utilized in the analysis per the SO_2 NAAQS Designations Modeling TAD.

1.9 Merged Stacks

ALCOA conducted a model-monitor comparison to determine appropriate source characterization for dispersion modeling. Details of this model-monitor evaluation can be found in Attachment B, Appendix A, Section 3. ALCOA focused on the emissions from the smelting operations where clusters of adjacent dry scrubber stacks associated with the potlines and ring furnace stacks at the smelters were merged within AERMOD. Merging of the stacks was warranted in the modeling analysis due to the tremendous heat release that results in a combined plume rise due to a convection effect. Specifically, six merged stacks represented the emissions from the 36 individual stacks at each Potline Areas 5 and 6, four merged stacks represented the combined emissions from the 36 individual stacks associated with Potline Area 2, and six individual stacks were merged into one stack for the ring furnace's western reactor area for modeling purposes. The merging process retained the common stack height for stacks in each cluster, but summed the stack exit areas for an equivalent stack diameter where the default option of stack-tip downwash was used. The emissions from Potline Areas 3 and 4 were modeled from the current 199-ft gas treatment center (GTC) stack. Likewise, the emissions from the ring furnace's eastern reactor were modeled with the current stack (not merged). The merging of stacks is further detailed in Attachment D, Section 5.1.

1.10 Temporally Varying Seasonal 1-Hour SO_2 Background

Temporally varying seasonal SO_2 background concentrations were developed in accordance with the recommended U.S. EPA guidance for establishment of such background concentrations in Section 8.2 of 40 CFR Part 51, Appendix W and considered appropriate and representative of the area. The monitoring data was reviewed and adjusted in order to avoid double counting of impacts from larger sources that are accounted through the dispersion modeling. The latest three years of SO_2 air quality monitoring data (2014-2016) was used.

The 99th percentile SO_2 concentrations by season (winter, spring, summer and fall) for each hour of the day were calculated to determine the temporally varying seasonal SO_2 background, which were directly input into the model and were part of the final modeled results.

Temporally varying seasonal 1-hour SO_2 background concentrations were taken from the Evansville – Buena Vista Road monitor for 2014-2016. The hourly seasonal SO_2 values used for representative background concentrations for the area surrounding ALCOA are listed below in Table 1.3.

Table 1.3 - 99th Percentiles for Temporally Varying Seasonal SO_2 Background Values (ppb)

	Hr 1	**Hr 2**	**Hr 3**	**Hr 4**	**Hr 5**	**Hr 6**	**Hr 7**	**Hr 8**
Winter	5.0	4.2	3.6	5.6	4.5	4.5	4.4	5.2
Spring	3.6	5.0	3.4	3.5	3.3	6.7	5.8	5.4
Summer	2.5	1.8	1.7	1.7	1.7	2.3	2.4	4.4
Fall	3.5	3.4	3.0	3.5	4.2	4.2	4.7	4.6

	Hr 9	**Hr 10**	**Hr 11**	**Hr 12**	**Hr 13**	**Hr 14**	**Hr 15**	**Hr 16**
Winter	8.9	10.0	9.0	9.8	11.2	11.9	12.1	12.7
Spring	8.2	10.2	11.9	9.0	8.9	9.8	9.3	8.8
Summer	8.7	8.4	6.4	6.1	6.1	6.7	5.1	4.5
Fall	5.5	7.7	9.8	8.2	9.3	8.6	8.7	6.1

	Hr 17	**Hr 18**	**Hr 19**	**Hr 20**	**Hr 21**	**Hr 22**	**Hr 23**	**Hr 24**
Winter	11.2	10.4	8.3	9.6	6.9	8.0	6.0	11.2
Spring	10.5	9.2	6.8	6.6	4.8	2.4	4.9	10.5
Summer	5.4	5.8	6.0	4.6	3.3	1.9	2.7	5.4
Fall	6.2	5.7	4.3	5.7	4.2	3.3	3.7	6.2

1.11 SO_2 Emissions Included in the Modeling Analysis

1.11.1 DRR Sources: ALCOA and WPP Emissions

Actual monthly-averaged emissions and monthly-measured exhaust parameters were used in the modeling for the smelting operations and were provided by ALCOA. These detailed emissions and exhaust parameters are included in the provided modeling files.

Actual hourly emissions and exhaust parameters were used in the modeling for the WPP and were provided by ALCOA, taken from the associated continuous emission monitoring (CEM) data. These detailed emissions and exhaust parameters are included in the provided modeling files.

1.11.2 Inventoried SO_2 Sources Included in the Modeling

SO_2 sources from the surrounding area were evaluated to determine if their SO_2 emissions had a potential impact on the air quality surrounding ALCOA, beyond what is captured through background monitoring data. The latest available actual emissions were input for some of the inventory sources.

Table 1.4 – ALCOA DRR Modeling Inventories

Source	Source ID	Location	SO_2 Emissions (tons per year)
FB Culley Power Plant	173-00001	Warrick County	Hourly CEM data
A.B. Brown	129-00010	Posey County	9,452.9 [a]
AEP Rockport	147-00020	Spencer County	Hourly CEM data
Owensboro Municipal Utilities	059-00027	Daviess County, KY	Hourly CEM data
Big Rivers Electric	091-00003	Hancock County, KY	8,145.9
Century Aluminum	091-00004	Hancock County, KY	2,052.7
Owensboro Grain	059-00039	Daviess County, KY	437.5

[a] Emission equivalent of A.B. Brown SO_2 emission limits in response to Round 2 designation requirements

1.12 Modeling Results

The 99th percentile of the 1-hour daily maximum modeled concentrations represents the fourth high of the 1-hour daily maximum SO_2 modeled concentrations and were averaged across three years to compare resulting concentrations to the 1-hour SO_2 NAAQS of 75 ppb (196.2 micrograms per cubic meter ($\mu g/m^3$)). Modeled concentrations include representative temporally varying seasonal 1-hour SO_2 background values to determine the overall impact for air quality characterization. The resulting concentrations were compared to the 1-hour SO_2 standard to indicate whether a modeled violation of the SO_2 NAAQS occurred. ALCOA's modeling report, detailing their modeling approaches and results, approved by U.S. EPA based on review and approval of modeling protocols submitted in June and September of 2017, can be found in Attachment D. U.S. EPA correspondence to provide comments on the ALCOA modeling approach for the 1-hour SO_2 designation modeling as it applies to the DRR can be found in Attachment E, while U.S. EPA – Region 5 approval of the ALCOA modeling protocol and Case 4 approach was confirmed in a telephone conversation with Mr. Mark Derf, Section Chief of the Office of Air Quality's Technical Support and Modeling Section, on September 14, 2017. IDEM's review of the ALCOA modeling methodologies and modeled results can be found below.

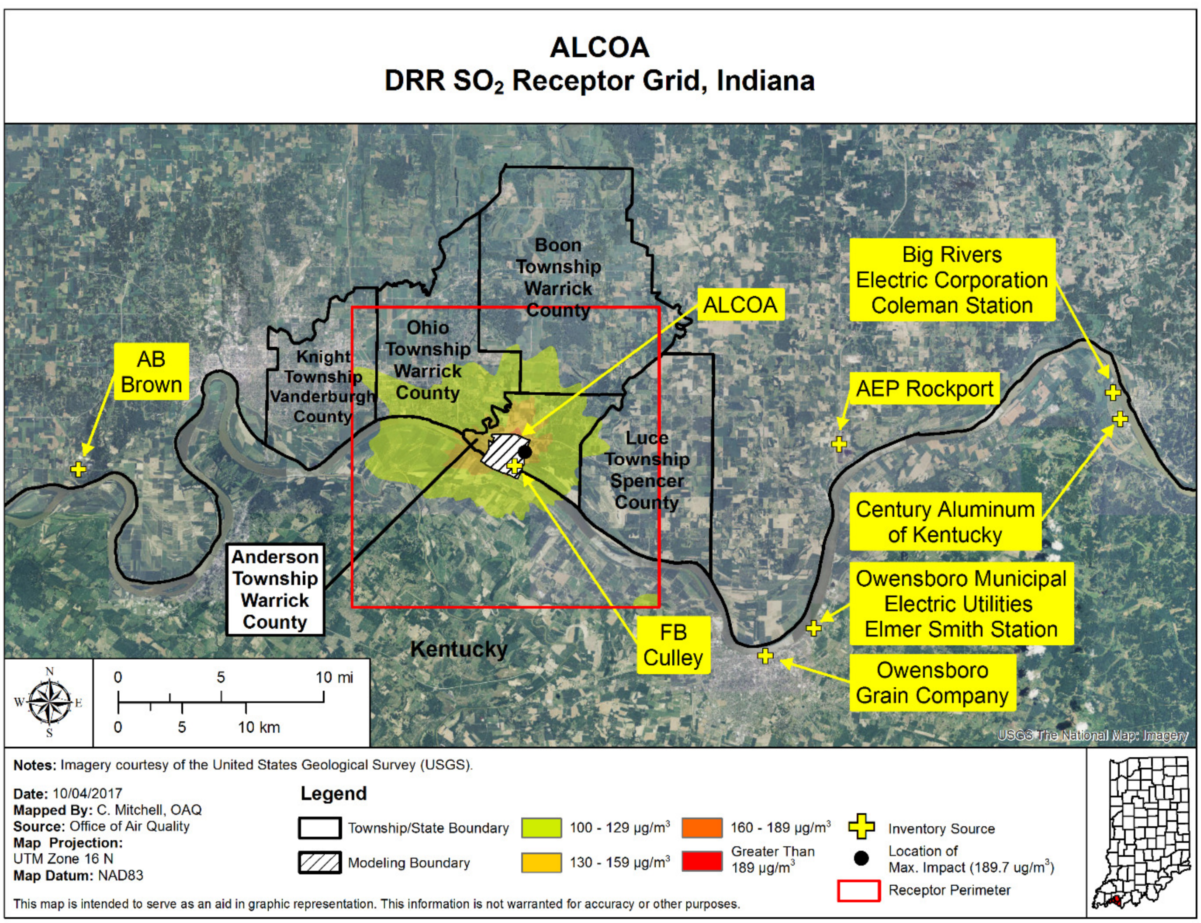
Table 1.5 shows the maximum predicted 99th percentile daily 1-hour SO_2 concentration. The overall maximum concentration was 189.68 $\mu g/m^3$, occurring at UTM coordinates 472146.09 East, 4196980.52 North.

Table 1.5 - ALCOA Modeling Results

Emission Scenarios	Total Modeled Concentration Including Seasonal Hourly Background (µg/m^3)	1-Hour SO_2 NAAQS (µg/m^3)	Facility Models Attainment
WPP	93.4	196.2	Yes
ALCOA	189.7	196.2	Yes

The concentration isopleths showing the maximum predicted 99th percentile daily 1-hour SO_2 concentration gradients can be found in Figure 1.5. All modeled concentrations fell below the 1-hour SO_2 NAAQS and were determined to attain the standard and the area surrounding ALCOA will be attainment.

Figure 1.5 - ALCOA Modeling Results



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Attachment A

ALCOA Warrick Operations
Electricity Usage for Five Aluminum Smelters

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ALCOA Warrick Operations Electricity Usage for Five Aluminum Smelters for January 2016

Alcoa Production Data and MW consumption for January 2016										
Date	**LINE 2**		**LINE 3**		**LINE 4**		**LINE 5**		**LINE 6**	
January-16	**MW**	**Al Production (tons)**	**MW**	**Al Production (tons)**	**MW**	**Al Production (tons)**	**MW**	**Al Production (tons)**	**MW**	**Al Production (tons)**
1	90	139	90	151	87	168	88	141	87	152
2	91	153	90	145	87	150	89	133	87	141
3	90	150	90	144	87	157	89	169	88	124
4	90	159	90	146	86	159	87	150	87	176
5	91	166	90	141	87	148	88	152	88	151
6	89	155	90	183	87	156	88	162	87	126
7	90	153	88	155	87	138	88	160	87	172
8	90	158	90	112	86	171	88	156	87	154
9	89	157	90	170	85	152	85	140	87	145
10	87	152	87	159	88	145	88	145	87	158
11	91	153	90	164	88	176	89	149	87	137
12	91	161	91	168	86	129	88	157	87	176
13	89	152	88	143	87	155	89	140	88	160
14	89	159	90	160	88	154	88	156	88	149
15	89	145	90	149	86	148	88	162	87	152
16	89	146	89	150	87	141	88	169	87	138
17	89	155	89	144	87	143	88	147	87	164
18	90	132	89	157	87	143	88	139	87	155
19	90	152	89	154	85	166	88	146	87	129
20	89	150	90	149	86	139	88	151	88	180
21	89	156	89	160	83	153	88	159	87	152
22	89	157	88	154	85	124	89	149	88	165
23	89	139	89	150	85	126	88	154	88	159
24	89	140	89	132	85	175	88	160	88	132
25	89	162	89	156	85	152	88	146	88	169
26	89	155	89	159	85	141	87	154	87	149
27	88	151	89	148	84	134	87	152	87	156
28	89	151	85	163	84	131	87	141	87	142
29	89	168	88	147	85	144	87	154	87	166
30	88	150	87	159	84	157	87	146	87	155
31	89	173	88	147	85	143	87	142	87	157
AVE	89.4	153.3	89.1	152.2	86.0	149.0	87.9	151.0	87.3	152.9

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Attachment B

ALCOA Revised Modeling Protocol
for the 1-hour SO_2 Data Requirements Rule

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Revised Modeling Protocol for the 1-hour SO_2 Data Requirements Rule

Alcoa Warrick Operations, Warrick Power Plant, and Culley Generating Station

Alcoa Warrick LLC
Newburgh, Indiana

Project Number: 60537431.1

September 2017

Quality information

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1. Introduction

1.1 Background

The United States Environmental Protection Agency (EPA) promulgated a 1-hour National Ambient Air Quality Standard (NAAQS) for SO_2 in 2010. The 1-hour SO_2 NAAQS is set to 75 ppb and the form of the standard is the average of the 99th percentile of the daily maximum 1-hour average concentrations realized in each of three consecutive calendar years (the "design value," or DV).

The EPA is implementing the 2010 1-hour SO_2 NAAQS in an approach that involves either a dispersion modeling or monitoring approach to characterize local SO_2 concentrations near isolated emission sources. EPA's Data Requirements Rule (DRR) was finalized on August 21, 2015 and two sources in Indiana that are subject to the DRR provisions are the Alcoa Warrick aluminum smelter and the adjacent Alcoa Warrick Power Plant, since both of these facilities have had annual SO_2 emissions in excess of 2,000 tons in recent operating years. Indiana has elected, and Alcoa has agreed, that the appropriate approach to characterize SO_2 concentrations in the vicinity of its facilities in Warrick County is modeling.

This document represents an update to the initial modeling protocol issued in June 2017, based upon recent discussions with EPA Region 5 and the Indiana Department of Environmental Management (IDEM). Certain aspects of the modeling approach are guided, in part, by the results of an SO_2 monitoring field study conducted during portions of 2015 and 2016 in the vicinity of these sources, which has indicated that monitored SO_2 concentrations are below the NAAQS. The field monitoring data are used for certain aspects of characterizing the smelter sources, while not altering the guideline model, AERMOD, for this application. New modeling approaches recently promulgated in 2017 with Appendix W (EPA's modeling guideline) are used for this modeling application.

This document describes the proposed modeling procedures to be used for the characterization of the SO_2 concentrations in the vicinity of the Alcoa facilities. It also provides, in an appendix to the protocol, the results of an evaluation of the proposed modeling approach using the recently-collected field data at 4 monitors in the vicinity of the Alcoa sources to support certain aspects of the modeling approach.

1.2 Document Organization

Section 2 provides a discussion of the Warrick County sources, which are the Alcoa smelter, the Warrick Power Plant, as well as an adjacent source (the Culley Generating Station); these sources will be modeled with actual emissions for the period 2013-2015. Section 3 describes the selection of the dispersion modeling approach for the Alcoa smelter, which is different from all other sources included in the modeling. The background sources and regional background to be used in the study are discussed in Section 4. The details of the modeling procedures are discussed in Section 5.

Appendix A presents the design and a discussion of the SO_2 monitoring data taken in the vicinity of the Alcoa sources in 2015 and 2016 as well as the results of an evaluation of certain candidate modeling approaches. Appendix B further describes the characterization of the effective urban population for the Warrick Operations modeling. A peer-reviewed published journal article describing source characterization of the highly industrialized area heat island effect (and other source characterization techniques) is presented in Appendix C. A discussion of why the use of a partial year is sufficient to provide support for the proposed modeling approach is provided in Appendix D. Documentation relating to an agreement between the owner and operator, Vectren, of the Culley station (previously Southern Indiana Gas & Electric Company) and Alcoa regarding air impacts from the smelter is provided in Appendix E.

2. Description of Warrick County SO_2 Emission Sources

2.1 Alcoa Smelter – Warrick Operations

Alcoa Warrick Operations is located in Warrick County Indiana, approximately 20 kilometers east-southeast of Evansville (and the Evansville airport) on the banks of the Ohio River. The area surrounding Alcoa Warrick Operations can be considered rural with mostly flat or gently sloping terrain. The major SO_2 sources at the smelter facility, besides a small fraction of SO_2 emissions which vents through the 10 potroom building roof vents, include:

Potline #2	Exhausted through a bank of 36 individual 14.94-m (height) stacks (“P02”)
Potlines #3 & #4	Exhausted through the 60.66-m high GTC stack (“P01”)
Potline #5	Exhausted through a bank of 36 individual 14.94-m high stacks (“P03”)
Potline #6	Exhausted through a bank of 36 individual 14.94-m high stacks (“P04”)
Ring Furnace	Exhausted through a bank of 7 individual 22.25-m high stacks (“P05”)

Figure 2-1 shows the locations of the major SO_2 sources associated with the Alcoa Warrick Operations, including the P2 monitoring site. This figure also outlines areas of processes that emit fugitive heat in the smelter complex.

Typical stack exhaust parameters for use in the model performance evaluation are provided in Tables 2-1 through 2-3 for the smelter sources. The smelter operation sources listed in Tables 2-1 through 2-3 have very steady operation, inherent in the nature of the aluminum production. Table 2-1 lists the stacks and associated stack parameters for the individual point sources. Table 2-2 lists the merged stacks and associated parameters that will be modeled with the proposed modeling approach, discussed in Section 5. The actual exit velocities and exit temperatures that will be modeled for the potline stacks vary by month and season. The values listed in Tables 2-1 and 2-2 are based on typical monthly data. The effective stack diameters listed in Table 2-2 for the potline stacks P02, P03, and P04 are based on the merging of several individual stacks, and the merged stack diameter for the western ring furnace stacks P05 is also based on the merging of six individual stacks. Table 2-3 lists the exhaust parameters for the smelter buoyant line sources; i.e., the potroom buildings.

Actual monthly-averaged emissions and monthly-measured exhaust parameters will be used in the modeling and have been provided by Alcoa.

Table 2-1: Typical Exhaust Parameters for Alcoa Warrick Smelter SO_2 Point Sources, Not Accounting for Merging

Index	Stack Name	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (K)
P01	Potlines #3 & #4 GTC Pollution Controls (1 stack)	60.66	6.10	15.49	359.7
P02	Potline #2 A-398 (36 individual stacks)	14.94	0.63	14.79	355.2
P03	Potline #5 A-398 (36 individual stacks)	14.94	0.63	17.92	350.2
P04	Potline #6 A-398 (36 individual stacks)	14.94	0.63	15.65	350.8
P5W1	Ring Furnace A-446 Western Reactors' Stack 1	22.25	0.67	16.10	351.0
P5W2	Ring Furnace A-446 Western Reactors' Stack 2	22.25	0.67	16.10	351.0
P5W3	Ring Furnace A-446 Western Reactors' Stack 3	22.25	0.67	16.10	351.0
P5W4	Ring Furnace A-446 Western Reactors' Stack 4	22.25	0.67	16.10	351.0
P5W5	Ring Furnace A-446 Western Reactors' Stack 5	22.25	0.67	16.10	351.0
P5W6	Ring Furnace A-446 Western Reactors' Stack 6	22.25	0.67	16.10	351.0
P5E1	Ring Furnace A-446 Eastern Reactor Stack	22.25	1.17	16.10	351.0

Table 2-2: Typical Exhaust Parameters for Alcoa Warrick Smelter SO_2 Point Sources, Accounting for Merging

Index	Stack Name	Stack Height (m)	Effective Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (K)
P01	Potlines #3 & #4 GTC Pollution Controls	60.66	6.10	15.49	359.7
P02	Potline #2 A-398 (4 stacks)	14.94	1.89	14.79	355.2
P03	Potline #5 and #6 A-398 (6 stacks)	14.94	1.54	17.92	350.2
P04	Potline #5 and #6 A-398 (6 stacks)	14.94	1.54	15.65	350.8
P05W	Ring Furnace A-446 Western Reactors (6 stacks)	22.25	1.64	16.10	351.0
P5E1	Ring Furnace A-446 Eastern Reactor	22.25	1.17	16.10	351.0

Table 2-3: Typical Exhaust Parameters for Alcoa Warrick Smelter Buoyant Line Sources

Index	Source Name	Release Height (m)	Avg Building Length (m)	Avg Building Width (m)	Avg Line Source Width (m)	Avg Building Separation (m)
L01	Potline #2, Room 103	14.02	305.00	18.30	1.52	21.60
L02	Potline #2, Room 104	14.02	305.00	18.30	1.52	21.60
L03	Potline #3, Room 105	14.02	305.00	18.30	1.52	21.60
L04	Potline #3, Room 106	14.02	305.00	18.30	1.52	21.60
L05	Potline #4, Room 107	14.02	305.00	18.30	1.52	21.60
L06	Potline #4, Room 108	14.02	305.00	18.30	1.52	21.60
L07	Potline #5, Room 109	14.02	305.00	18.30	1.52	21.60
L08	Potline #5, Room 110	14.02	305.00	18.30	1.52	21.60
L09	Potline #6, Room 111	14.02	305.00	18.30	1.52	21.60
L10	Potline #6, Room 112	14.02	305.00	18.30	1.52	21.60

2.2 Warrick Power Plant

Alcoa's Warrick Power Plant (WPP) is a 742-megawatt (MW) coal-fired power plant that provides the power necessary to operate the aluminum smelter. WPP's four active coal-fired boilers will be included in the modeling as nearby background sources. Units 1-3 exhaust through individual flues housed in a common stack while Unit 4 exhausts through a separate stack. All units have wet scrubber controls for SO_2.

Typical stack exhaust parameters for use in the model performance evaluation are provided in Table 2-4. Actual hourly emissions and exhaust parameters will be used in the modeling and will be provided by Alcoa.

Figure 2-1 shows the locations of the WPP sources in relation to the Alcoa smelter sources.

Table 2-4: Typical Exhaust Parameters for Warrick Power Plant SO_2 Point Sources

Index	Stack Name	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/sec)	Exit Temperature (K)
WPP_1-3	WPP Units 1-3	115.82	7.12 (Merged)	16.48	329.00
WPP_4	WPP Unit 4	115.82	6.10	15.80	329.00

2.3 Culley Power Plant

The F. B. Culley Generating Station (Culley), a 369-megawatt (MW) power plant, which is located about 1 km east-southeast of the Warrick Power Plant, is also being modeled as a nearby background source due to its proximity to Alcoa. This plant is owned and operated by Vectren Corporation (formerly Southern Indiana Gas and Electric Company). There are two units: Unit 2 (103.7 MW) and Unit 3 (265.2 MW);

however, Unit 2 has been permanently retired. Therefore, only Unit 3's emissions will be modeled in this analysis.

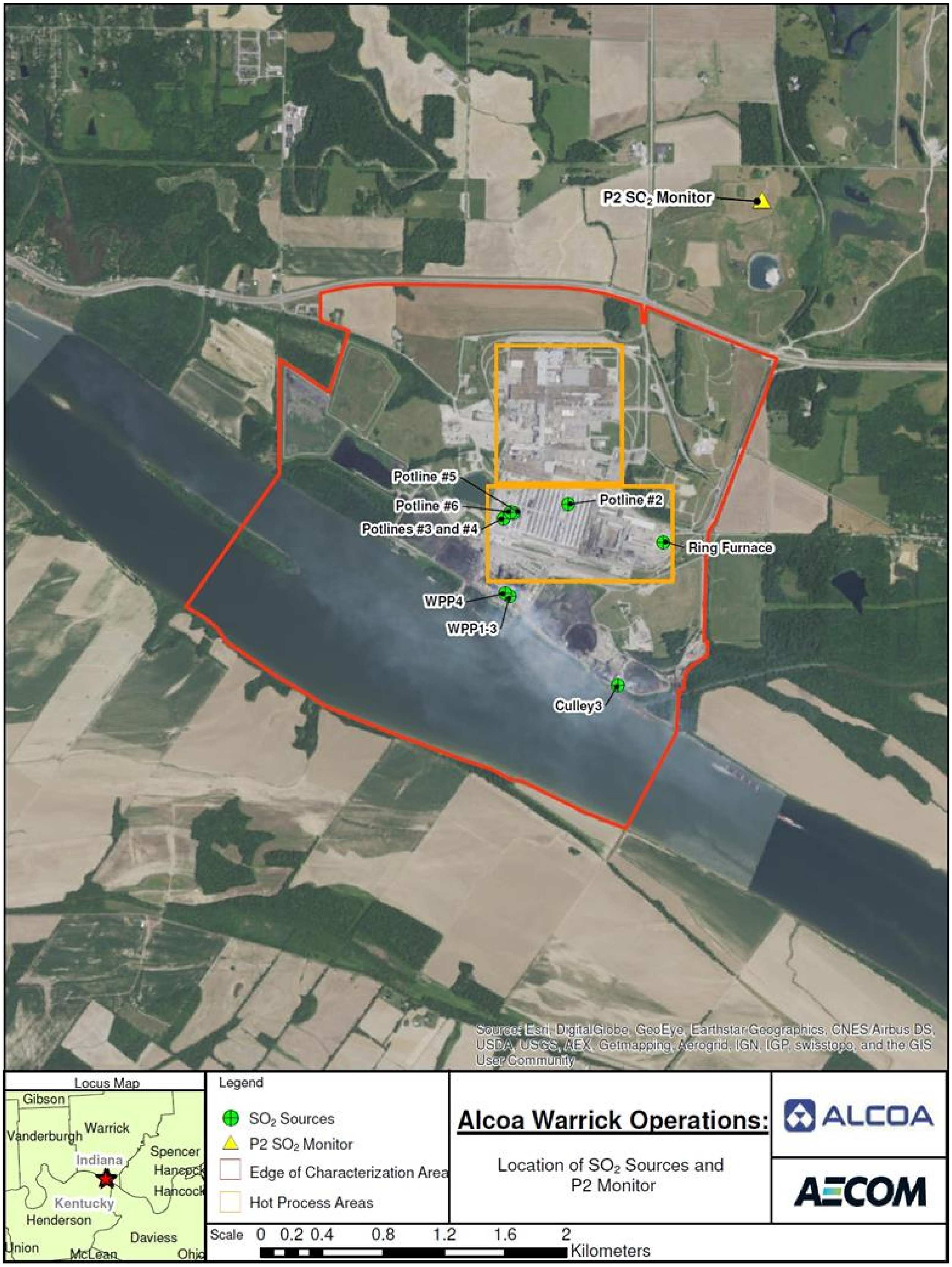
Typical stack exhaust parameters for use in the model performance evaluation are provided in Table 2-5 for Culley Unit 3. Actual hourly emissions and exhaust parameters will be used in the modeling and have been provided by Vectren.

Figure 2-1 shows the locations of the Culley Unit 3 stack in relation to Alcoa.

Table 2-5: Typical Exhaust Parameters for Culley Power Plant SO_2 Point Sources

Index	Stack Name	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/sec)	Exit Temperature (K)
Culley 3	Culley Unit 3	137.12	6.10	13.04	326.00

Figure 2-1: Alcoa SO_2 Sources, Hot Smelter Process Areas, and Surrounding Areas



3. Dispersion Modeling Approach

3.1 Use of AERMOD in Rural Mode for Non-Smelter Sources

The choice of rural or urban for dispersion conditions at the Alcoa smelter operations, WPP, and Culley usually depends upon the land use characteristics within 3 kilometers of the facilities (Appendix W to 40 CFR Part 51)[1]. Factors that affect the rural/urban choice, and thus the dispersion, include the extent of vegetated surface area, the water surface area, types of industry and commerce, and building types and heights within this area.

An Auer analysis of the area surrounding the Alcoa smelter operations, WPP, and Culley was conducted using satellite data as shown in Figure 3-1. The Auer land-use approach classifies an area according to 12 land-use types. In this scheme, areas of industrial, commercial, and compact residential land-use are designated urban. According to EPA modeling guidelines, if more than 50 percent of an area within a three-kilometer radius of a facility is classified as rural, then rural dispersion coefficients are to be used in the modeling.

The Auer analysis indicates that the land use around the facilities is rural. As a result, the WPP and Culley sources will be modeled using rural dispersion characteristics. However, due to the large industrial complex heat releases, the Alcoa smelter sources will be modeled as urban, as explained further in the next subsection. Due to the influence of the Ohio River, the WPP and Culley sources are modeled as rural.

3.2 Use of AERMOD in Urban Mode for Alcoa Smelter

Emission sources such as the Alcoa Warrick aluminum smelter are associated with large fugitive heat releases that result in a local urban-like dispersion environment. AERMOD typically estimates urban heat island effects using an urban/rural classification based on population or land use, but until updates to Appendix W proposed in July 2015 (80 FR 45340, July 29, 2015) that were promulgated in 2017, AERMOD has not considered the urban effects that are created by large industrial complexes located in rural areas. The “highly industrialized area” effect can be addressed by a technique that accounts for the excess heat from an industrial complex and derives an effective population related to the excess heat generated by the highly industrialized area as input to AERMOD. A discussion of this approach is provided in Appendix B, which has previously been provided to EPA by the American Iron & Steel Institute (AISI). A peer-reviewed published journal article describing source characterization of the highly industrialized area heat island effect (and three other source characterization techniques) is provided in Appendix C.

In the case of the Alcoa smelter, there is approximately a 450-MW electrical usage needed to power the 5 aluminum reduction lines. In addition, hot rolling mills in the area to the north of the smelting operations also emit fugitive heat. The area involved in the Alcoa Warrick Operations process, shown in the orange rectangles in Figure 2-1, is on the order of 2 square kilometers (2 x 10^6 m^2).

The heat losses associated with the use of electricity in the aluminum smelting process can be on the order of 40-50%[2]. Taking the mid-point of that range and conservatively assuming that half of this is lost to the atmosphere (the rest to the buildings), we get an atmospheric heat loss rate of about 100 MW. The heat loss to the atmosphere, when applied to the 2 square km area, results in an effective urban-rural temperature difference of 50 W/m^2, which converts to an effective urban population of 2 million, based upon the formulation described in Appendix B.

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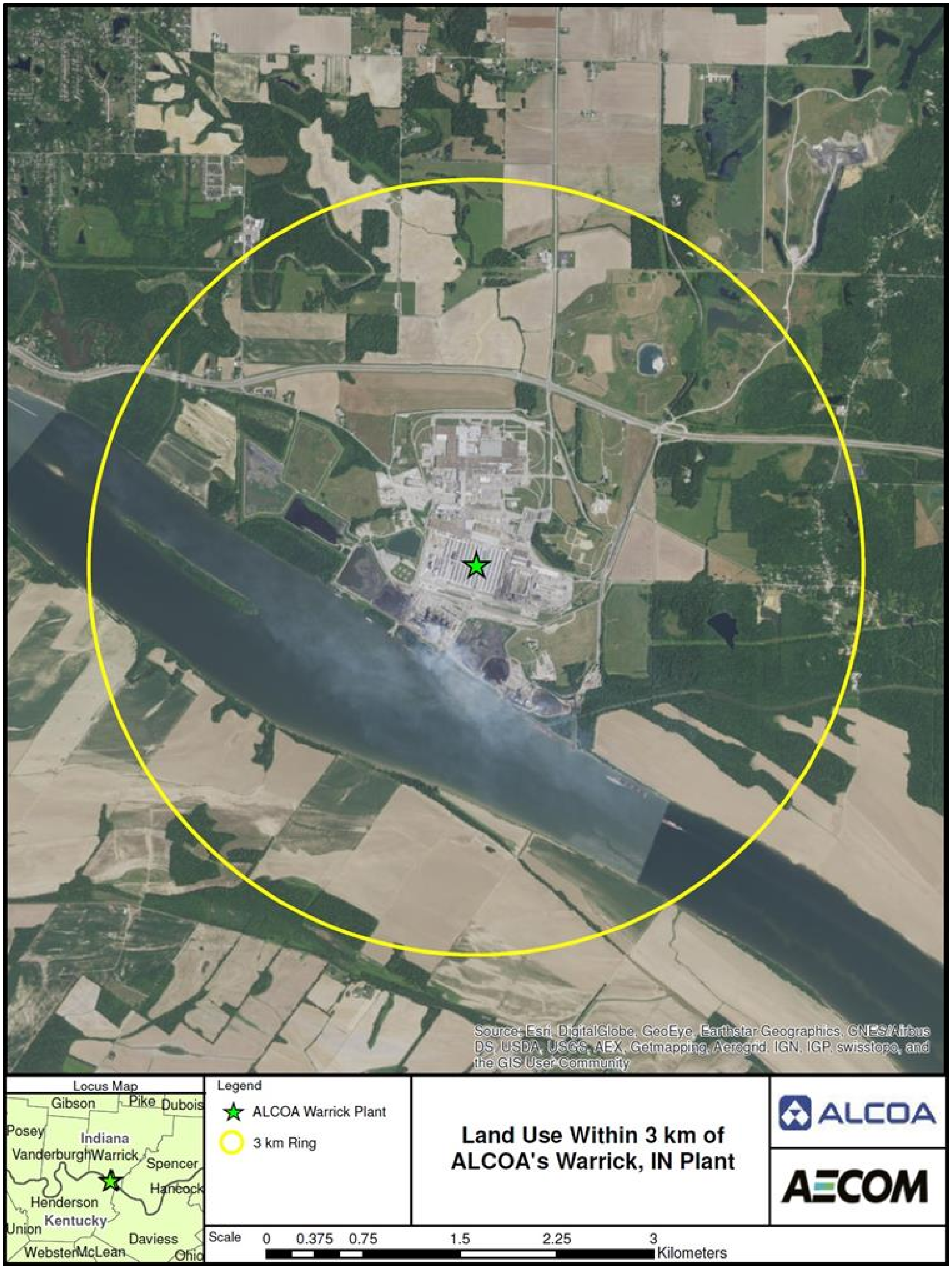
[1] EPA’s Guideline on Air Quality Models, available at http://www.epa.gov/ttn/scram/guidance/guide/appw_05.pdf.
[2] See, for example discussions at http://peter-entner.com/E/Theory/EBal/EBal.aspx and http://www.tms.org/pubs/journals/JOM/9905/Welch-9905.html.

Consistent with the calculations provided above, the modeling approach for the source characterization effects for Warrick Operations will assume that the aluminum smelter sources are emitting into an urban boundary layer for AERMOD modeling with an effective population of 2 million.

3.3 Building Downwash Treatment for Smelter Sources

The effects of the large heat releases from the smelter play a role in the merging of plumes from adjacent dry scrubber stacks and in a liftoff effect that resists building downwash effects. In the case of the aluminum smelter, the potline buildings are not enclosed, but instead have openings that promote inflow from the bottom so that the natural convection will improve the dispersion (and increase the lift) of the hot effluent from the potline roof vents. The associated fugitive heat losses may act to offset building downwash effects. However, downwash effects are conservatively retained in this modeling application, while the convective heating effects are accommodated with partial stack merging as described in Section 5.

Figure 3-1: Satellite Photo of the Area within 3 km of the Alcoa Operations, WPP, and Culley



4. Background Sources and Regional Background

4.1 Emission Sources Outside Warrick County

Besides the Warrick and Culley power plants, other SO_2 background sources provided by IDEM that are located within 50 kilometers from the Warrick operations will also be included in the modeling for this analysis. The sources that will be modeled are listed in Table 4-1. Figure 4-1 shows the locations of these background sources with respect to the Warrick operations.

Table 4-1: Background Sources to be Included in Modeling

Source	Source ID	Location
A.B. Brown	18-129-00010	Posey County, IN
AEP Rockport	18-147-00020	Spencer County, IN
Owensboro Municipal Utilities Elmer Smith Station	21-059-00027	Daviess County, KY
Big Rivers Electric Corporation Coleman Station	21-091-00003	Hancock County, KY
Century Aluminum of KY LLC	21-091-00004	Hancock County, KY
Owensboro Grain Company	21-059-00039	Daviess County, KY

4.2 Regional Background from Area Monitor

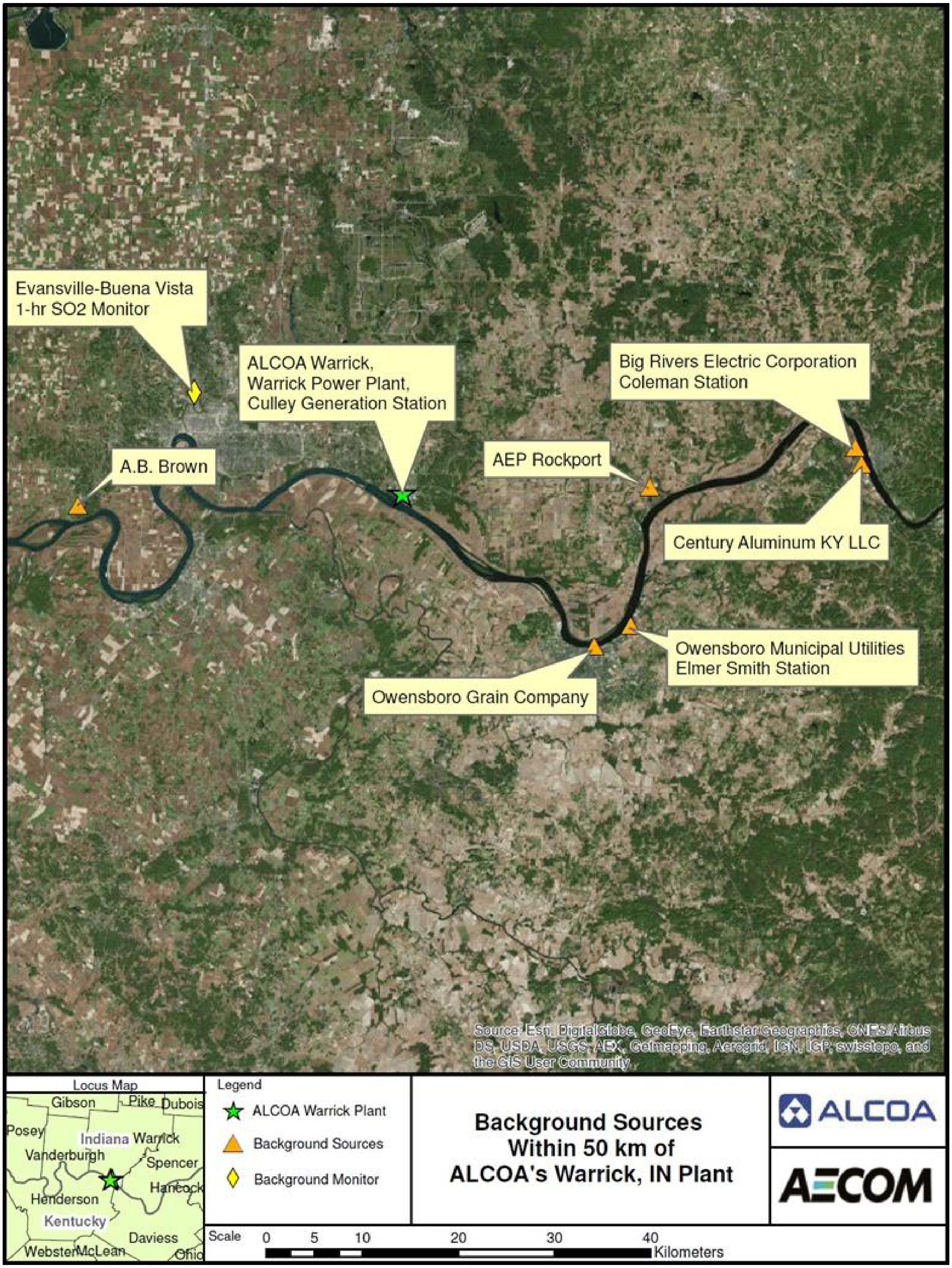
Hourly SO_2 ambient background data for the Evansville-Buena Vista monitor will be processed into season/hour-of-day format following methodology described in the EPA March 1, 2011 guidance[3] for use in this modeling analysis. The most recent three years of data will be used (2014-2016). Although the monitoring could double count the impacts of the modeled Alcoa or A.B. Brown sources (see the monitor location in Figure 4-1), the values as listed in Table 4-2 have not been adjusted for that effect. These values will be used in conjunction with the BACKGRND SEASHR keyword in the source card and added to the AERMOD-predicted concentrations for comparison with the 1-hour SO_2 NAAQS of 75 ppb, or 196.5 $\mu g/m^3$.

[3] https://www3.epa.gov/ttn/scram/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf

Table 4-2: Evansville-Buena Vista Monitored SO_2 Background Concentrations (µg/m^3)

Hour	WINTER	SPRING	SUMMER	FALL
0	13.10	9.34	6.46	9.26
1	11.00	13.10	4.72	9.00
2	9.52	9.00	4.37	7.77
3	14.58	9.08	4.54	9.08
4	11.88	8.65	4.37	10.92
5	11.70	17.55	6.11	10.92
6	11.44	15.20	6.38	12.31
7	13.54	14.06	11.53	12.05
8	23.41	21.48	22.71	14.32
9	26.11	26.72	21.92	20.09
10	23.58	31.18	16.86	25.59
11	25.76	23.49	15.98	21.40
12	29.43	23.32	16.07	24.45
13	31.27	25.76	17.55	22.44
14	31.70	24.28	13.45	22.71
15	33.27	23.14	11.88	15.89
16	29.43	27.51	14.15	16.24
17	27.16	24.10	15.20	14.93
18	21.75	17.82	15.72	11.18
19	25.06	17.20	12.05	14.93
20	18.17	12.66	8.56	10.92
21	20.87	6.20	4.89	8.73
22	15.63	12.75	6.99	9.69
23	18.25	11.53	5.59	9.69

Figure 4-1: Sources to be Included in the Modeling



5. Modeling Procedures

5.1 Proposed Modeling Approach

The proposed modeling approach will use AERMOD version 16216r with source characterization refinements as noted below, including the BLP model component for the potline roof emissions, and AERMOD's normal point-source treatment for the other (stack) sources. The modeling approach involves no changes to AERMOD; rather, the only unique issues involve how the Alcoa smelter sources are characterized for input to the modeling.

Although the power plant stack sources will be modeled in the same manner (using the EPA-approved ADJ_U* low wind option), the Warrick Operations smelter sources will be modeled as urban to account for source characterization effects such as those noted by the AISI presentation[4] made by Robert Paine at the 11th EPA Modeling Conference, a technique further described in the published journal article provided in Appendix C. Specifically, the modeling approach will differ from a default modeling approach that does not consider the site-specific issues in the following areas:

- Clusters of the adjacent dry scrubber stacks and ring furnace stacks at the smelter will be merged due to the tremendous heat release (see Figure 5-1) that basically results in a combined plume rise. Specifically, six stacks each will represent the emissions from the long and narrow rectangular Potline Areas 5 and 6 (see Figure 5-2), four stacks will represent the combined emissions from nearly square Potline Area 2 (see Figure 5-2), and six stacks will be merged for the ring furnace's western reactor area (see Figure 5-3), as noted in Table 2-2. The merging process will retain the common stack height for stacks in each cluster, but will sum the stack top areas for an equivalent diameter stack where the default option of stack-tip downwash will be used. The emissions from Potline Areas 3 and 4 will continue to be modeled with the current 199-ft stack. Likewise, the emissions from the ring furnace's eastern reactor will continue to be modeled with the current stack (not merged).
- Urban dispersion characterization will be used for the smelter sources, as discussed in Section 3.2. The power plant sources will be assigned a rural characterization.
- For the smelter sources, building downwash will be included in the modeling in spite of the tremendous fugitive heat releases within the smelter area that would tend to make the emissions buoyant.
- The aluminum smelter rooftop vent sources will be modeled with the BLP approach installed in AERMOD version 16216r. The five sets of twin potline roof vents are listed in Table 2-3 and represent the buoyant line sources.

For the stack merging, the nearly square shape of the Potline 2 stacks (see Figure 5-2) was amenable to a set of 4 stacks distributed evenly through the set of 6 x 6 stacks, with each merged stack representing a 3x3 array of individual stacks. The use of the same approach for the more elongated areas for Potlines 5 and 6 (also shown in Figure 5-2) led to model under-predictions[5] in the evaluation described in Appendix A, so a more conservative approach that better fit the shape of the stack area was to merge only 6 stacks in a group. The discussion in Appendix A shows that merging of fewer stacks (such as 3 in each line) led to AERMOD over-predictions.

5.2 Meteorological Processing

Three years (2013-2015) of the most recent hourly surface meteorological data from Evansville, IN airport will be processed with AERMET, the meteorological preprocessor for AERMOD, which is consistent with guidance stated in 9.3.1.2 of 40 CFR Part 51, Appendix W (EPA modeling guidelines). Concurrent hourly

[4] http://www.epa.gov/ttn/scram/11thmodconf/presentations/2-2_AISI_NAAQS_Issues.pdf.
[5] The tests that resulted in under-predictions are not included in Appendix A; modeling approaches that resulted in under-predictions were not considered for the final model evaluation tests.

upper air data from Lincoln, IL will also be processed. AERMET will also use 1-minute wind speeds and directions taken from the Evansvillle, IN airport surface station as processed by the most recent version of AERMINUTE (15272). The "ADJ_U*" option will also be used, which is considered a default option under the 2017 Appendix W final rule that became effective on May 22, 2017. Processing of the meteorological data will be performed by AECOM.

The meteorological data required for input to AERMOD has been created with the latest version of AERMET (16216). AERMET creates two output files for input to AERMOD:

- SURFACE: a file with boundary layer parameters such as sensible heat flux, surface friction velocity, convective velocity scale, vertical potential temperature gradient in the 500-meter layer above the planetary boundary layer, and convective and mechanical mixing heights. Also provided are values of Monin-Obukhov length, surface roughness, albedo, Bowen ratio, wind speed, wind direction, temperature, and heights at which measurements were taken.
- PROFILE: a file containing multi-level meteorological data with wind speed, wind direction, temperature, sigma-theta (σ_θ) and sigma-w (σ_w) when such data are available. AERMET requires specification of site characteristics including surface roughness (z_o), albedo (r), and Bowen ratio (B_o). These parameters will be developed according to the guidance provided by EPA in the AERMOD Implementation Guide (AIG)[6].

AERMET requires specification of site characteristics including surface roughness (z_o), albedo (r), and Bowen ratio (B_o). These parameters were developed according to the guidance provided by EPA in the recently revised AERMOD Implementation Guide[7] (AIG).

The AIG provides the following recommendations for determining the site characteristics:

1. The determination of the surface roughness length should be based on an inverse distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.
2. The determination of the Bowen ratio should be based on a simple un-weighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10-km by 10-km region centered on the measurement site.
3. The determination of the albedo should be based on a simple un-weighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as defined for Bowen ratio, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

The AIG recommends that the surface characteristics be determined based on digitized land cover data. Surface characteristics will be determined by AECOM for AERMET processing.

5.3 Good Engineering Practice Stack Height Analysis

A Good Engineering Practice (GEP) stack height analysis will be performed to determine the potential for building-induced aerodynamic downwash for all stacks subject to downwash effects. The analysis procedures described in EPA's Guidelines for Determination of Good Engineering Practice Stack Height (EPA 1985)[8], Stack Height Regulations (40 CRF 51), and current Model Clearinghouse guidance[9] will be used. For the BLP-type analysis, we will use the building dimensions used historically for the Alcoa BLP-only modeling (see Table 2-3).

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[6] EPA 2015. AERMOD Implementation Guide (AIG). Office of Air Quality Planning and Standards, Research Triangle Park, NC. August.https://www3.epa.gov/ttn/scram/models/aermod/aermod_implementation_guide.pdf

[7] https://www3.epa.gov/ttn/scram/7thconf/aermod/aermod_implmtn_guide_3August2015.pdf.

[8] Available at http://www.epa.gov/scram001/guidance/guide/gep.pdf.

[9] http://www.epa.gov/scram001/guidance_clearinghouse.htm

The EPA's Building Profile Input Program (BPIP-Version 04274) version that is appropriate for use with PRIME algorithms in AERMOD will be used to incorporate downwash effects in the model. The building dimensions of each structure will be input in the BPIP-PRIME program to determine direction-specific building data. BPIP-PRIME addresses the entire structure of the wake, from the cavity immediately downwind of the building, to the far wake.

5.4 Receptors

For SO_2 DRR modeling, receptors will be excluded from the nearby Ohio River (only in the area near the Alcoa and Vectren's Culley facilities for simplicity) as well as within the secured areas of the Alcoa and Culley plants themselves. The secured areas on Alcoa property to be excluded from receptor placement have recently been reviewed by Alcoa, and they now include certain areas along the Ohio River bank that were included in previous modeling, but could have been excluded. These areas are posted and/or patrolled by plant personnel, and any unauthorized person who accesses the site will be noticed and removed. An area on Culley property east of a service road will be included in the modeling although it could be excluded based upon posting and patrolling; this area is not close to peak predicted areas.

The secured areas of both Alcoa and Culley will be excluded from receptor placement; they are not "ambient air". The Alcoa smelter and the adjacent Warrick Power Plant are considered as one facility in their operating permit. In addition, the Alcoa and Vectren facilities have substantial interconnected and joint operations as follows:

- Vectren owns a portion of the Warrick Power Plant ("Alcoa Power") Unit 4.
- FERC documentation[10] describes the interrelationship between Alcoa and Vectren, as further noted below.
- Alcoa and Vectren jointly own and operate the "Tie Line 3 facility", a 2.2 mile,138-kV line on these properties.
- Alcoa Power and Vectren jointly own other facilities in that area, including a 138 kV bus located at the Warrick plant to service the Warrick plant's operation.
- Tie Line 3 runs from a jointly-owned generating unit (Warrick Unit 4) to the 138 kV ring bus, and then to the Culley substation.
- Additional distribution lines connect the Culley Substation to the Warrick plant and are used to meet the energy needs of Alcoa's smelting and rolling mill operations.
- A legal agreement dating back to the initiation of operations at the smelter provide for an emissions easement, which in effect provides Alcoa a property right, due to emissions from Alcoa onto Culley property (now Vectren, but formerly Southern Indiana Electric & Gas Company, or SIGECO). They are provided in Appendix E, along with a map showing the area involved in the easement.

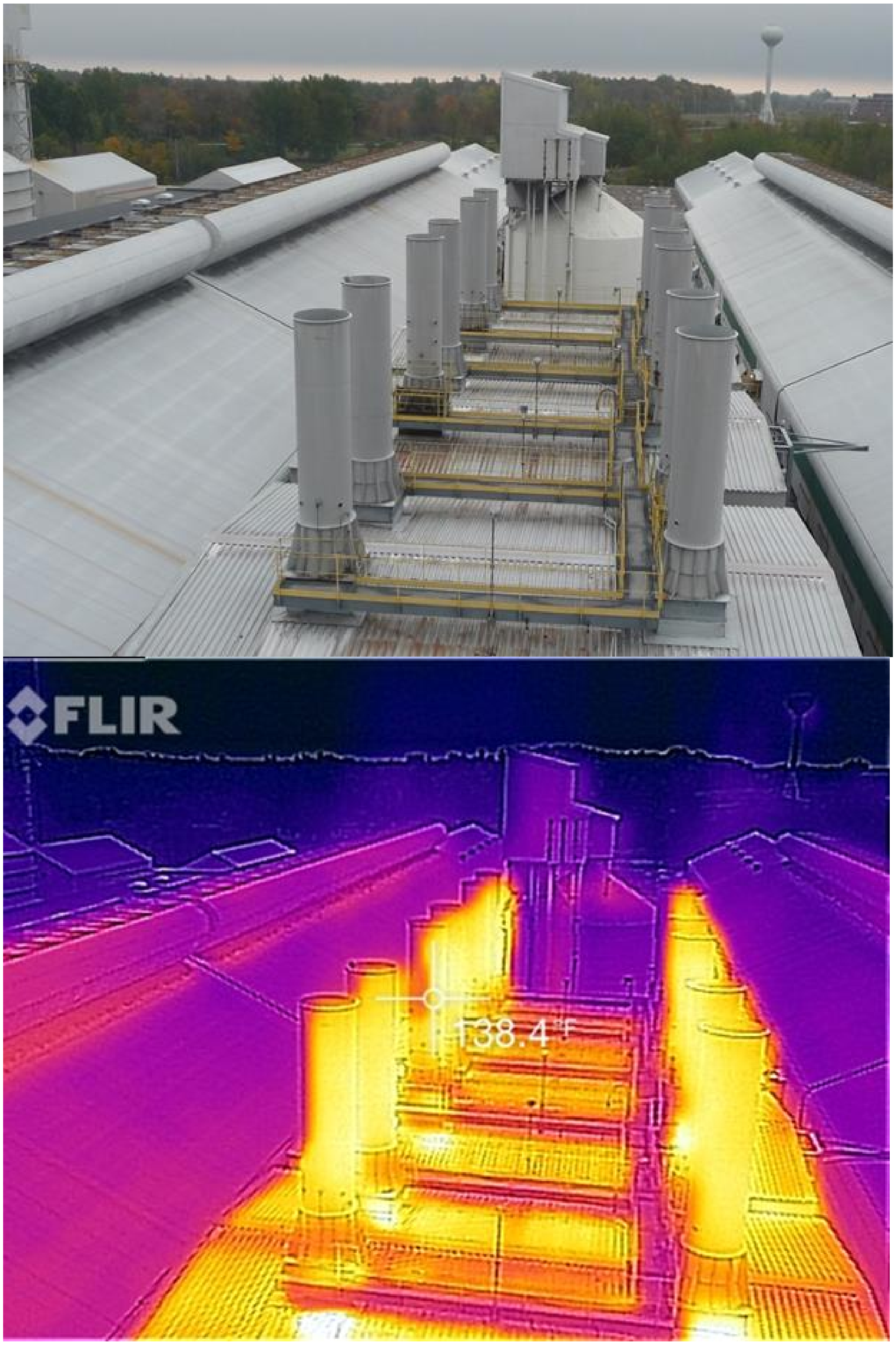
The receptor grid will have 50-m spacing along the boundary of the secured areas of the joint Alcoa and Vectren property with receptor spacing as follows:

- Every 100 meters out to a distance of 3 kilometers,
- Every 250 meters between 3 and 5 kilometers,
- Every 500 meters between 5 and 10 kilometers.

The receptor grid is illustrated in Figures 5-4 and 5-5. It is not expected that peak model predictions will extend beyond 10 kilometers from the Alcoa sources. The model-ready receptor file will use the most recent version of AERMAP version 11103.[11]

[10] https://www.ferc.gov/CalendarFiles/20131206161329-OA13-6-000.pdf.

Figure 5-1: Visible and Infrared Imagery of Potline Area at an Aluminum Smelter



[11] Indiana's Air Quality Modeling Protocol – Data Requirements Rule for the 2010 Primary 1-Hour Sulfur Dioxide Addressing the National Ambient air Quality Standard (NAAQS), June 2016.

Figure 5-2: Depiction of Stack Merging for Potlines 2, 5, and 6

Figure 5-3: Depiction of Stack Merging for the Aluminum Smelter Stacks

Figure 5-4: Receptor Grid to be used for Modeling (Zoom-Out View)

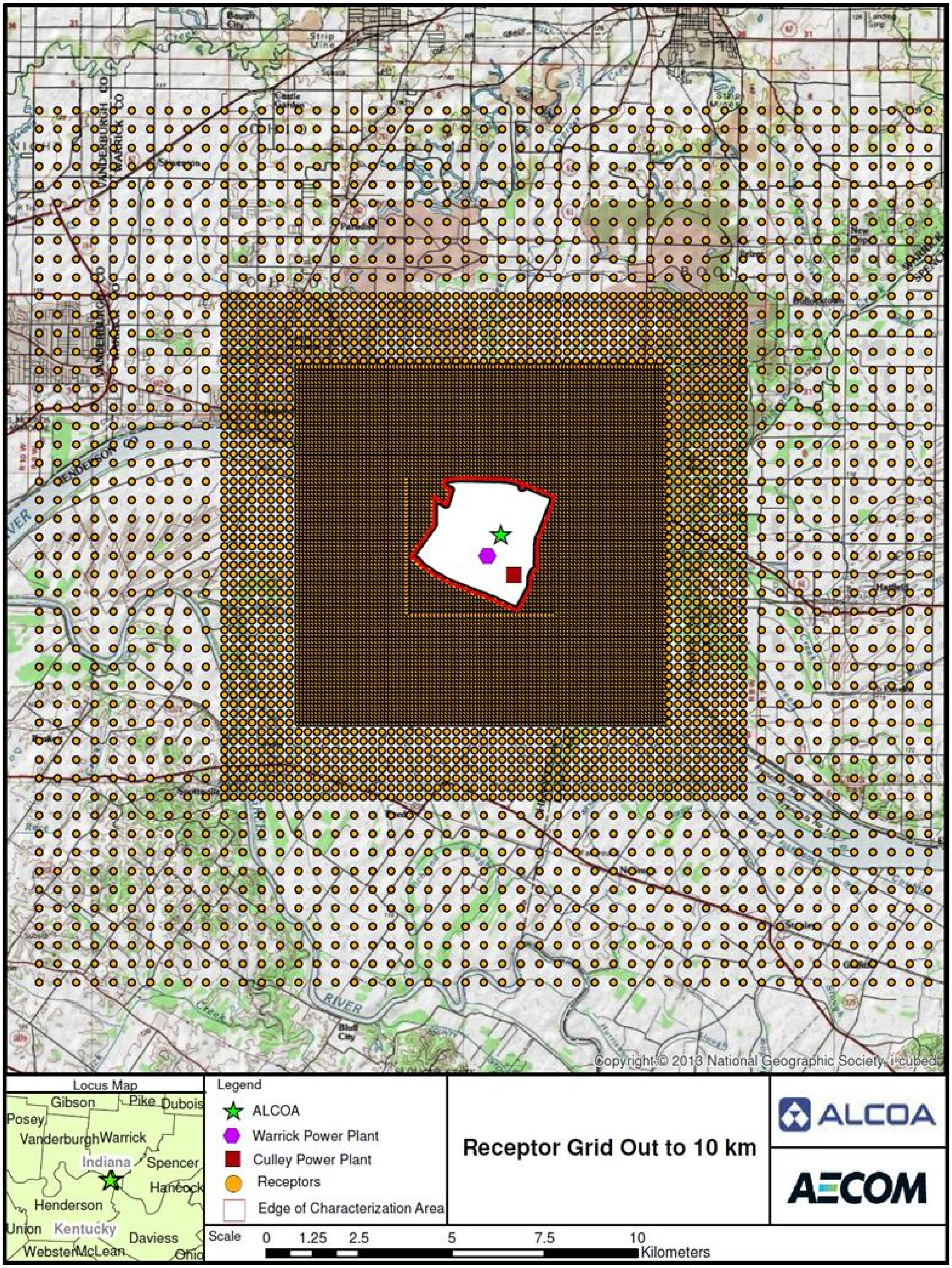
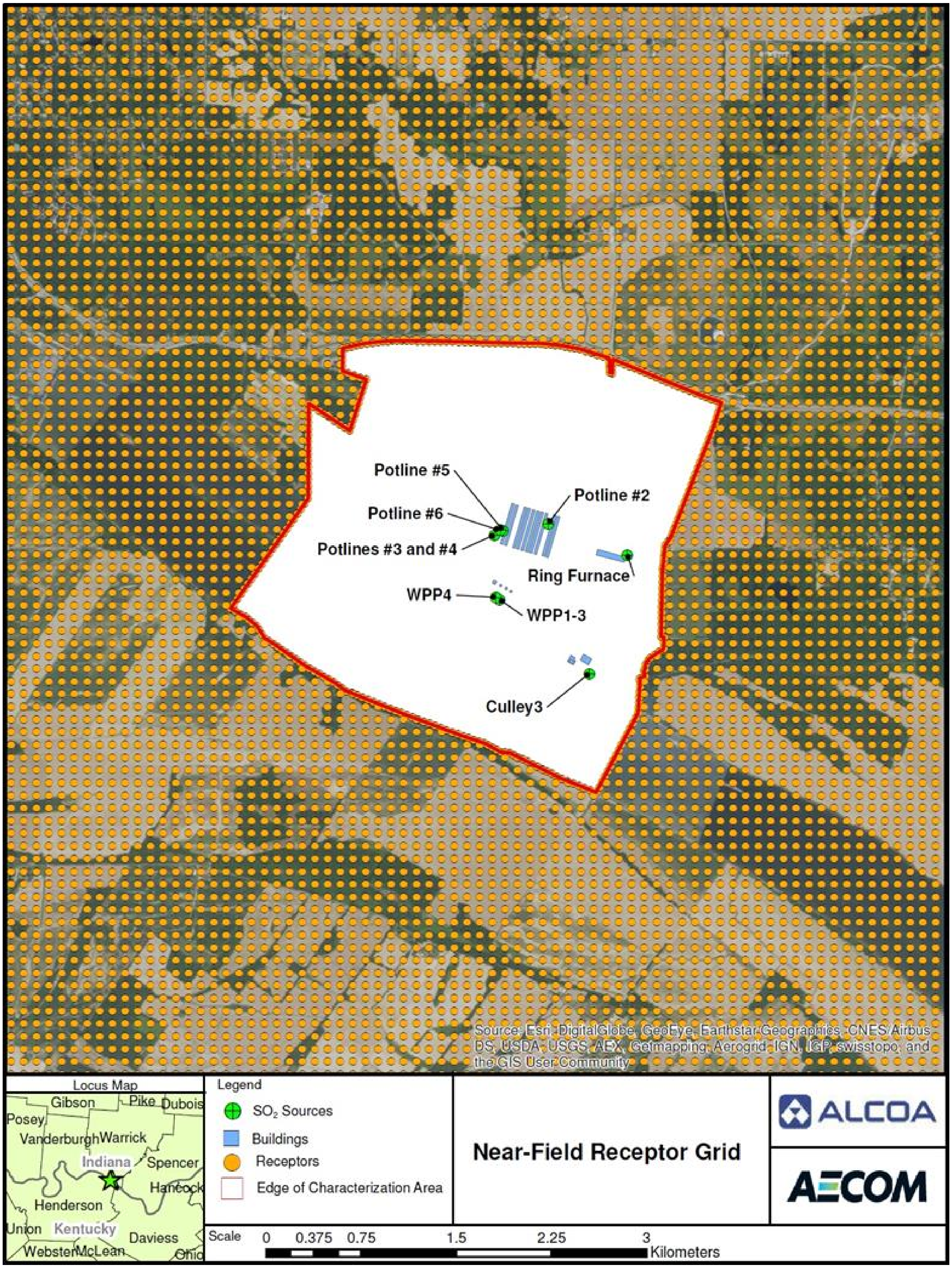


Figure 5-5: Receptor Grid to be used for Modeling (Zoom-In View)



6. Results of SO_2 Characterization Study

A report will be provided that summarizes the modeling results including tables and figures that indicate the level and locations of peak modeled impacts. A modeling archive will be provided electronically to IDEM.

Areas with peak design concentrations (99^{th} percentile peak daily 1-hour maximum concentrations) will be reviewed and additional receptors will be modeled in these areas if the receptors spacing is more than 100 meters. The modeling results of this SO_2 characterization will be used to determine if the current levels of SO_2 in the area of the Alcoa sources comply with the NAAQS as part of the DRR demonstration for the Alcoa sources.

Appendix A Site-Specific Field Study Near Alcoa Warrick Operations and Model Evaluation Study: 2015-2016

AECOM

Site-Specific Field Study Near Alcoa Warrick Operations and Model Evaluation Study: 2015-2016

Date
September 2017

Prepared by
Laura Warren, Adrienne Kieldsing, and
Robert Paine

1 Introduction

1.1 Introduction and Overview

Alcoa Warrick Operations is located in Warrick County Indiana, approximately 20 kilometers east-southeast of Evansville on the bank of the Ohio River. The area surrounding Alcoa Warrick Operations can be considered rural with mostly flat or gently sloping terrain. The major SO_2 sources at or near the smelter facility are 10 potlines, a ring furnace, and the Warrick Power Plant (WPP). A small fraction of SO_2 emissions also vents through the potroom building roof vents.

EPA has indicated that a site-specific characterization of the sources for the Warrick Operations aluminum smelter needs to be supported by a site-specific field study. Accordingly, Alcoa, IDEM, and EPA agreed in 2015 upon a 4-monitor network that was described in a model evaluation protocol submitted[1] to the agencies in 2015. The monitoring network was designed to measure peak short-term SO_2 impacts from the Alcoa smelter and the adjacent coal-fired power plants (WPP and nearby Culley Generating Station). That monitoring network went into operation on July 11, 2015. Although there was intent to operate the network for a full year, Alcoa announced plans to shut down the smelter for economic reasons during the first quarter of 2016. Accordingly, just before the emissions from the smelter were reduced and then totally eliminated with a plant shutdown by late March 2016, Alcoa ended the monitoring program as of February 19, 2016.

This document describes the use of the July 2015 – February 2016 SO_2 monitoring data resulting from the field study for a model evaluation of modeling using several modeling options with AERMOD that basically adjust how the smelter and Warrick Power Plant sources are characterized. Section 1.2 describes the design of the monitoring network. Section 2 describes SO_2-emitting sources at Warrick Operations, neighboring F. B. Culley Generating Station operated by Vectren, and discusses the modeling approaches used for comparison with monitored SO_2 concentrations. Section 3 provides the results of the model-to-monitor comparisons. Section 4 discusses the model evaluation study conclusions.

1.2 Ambient and Meteorological Monitoring Network Design

During the period of 2010-2014, there were two site-specific field studies for the Alcoa Warrick Operations SO_2 concentration pattern, and this information was communicated to IDEM and EPA through presentations and reports in several meetings and conference calls. Based upon special field studies that occurred in December 2010 and also during winter 2014, it was apparent that peak observed SO_2 concentrations occur at or near the plant fence line to the north and east of the plant. Accordingly, Alcoa, IDEM, and EPA agreed upon a 4-monitor network which was designed to measure peak short-term SO_2 impacts from the Alcoa smelter and the adjacent coal-fired power plants (WPP and Culley Generating Station).

In order to develop a model evaluation database suitable for testing a site-specific modeling approach, Alcoa expanded its SO_2 monitoring network beyond the historical site about 1 km north-northeast of the smelter (the P2 site). The additional sites (denoted as S1, S2, and S3) were sited to capture peak concentrations expected near the smelter, as determined from previous modeling analyses and short-term field studies. A map showing the plant fence line, the existing P2 monitoring site, and the locations of the new monitoring sites (S1, S2, and S3) is depicted in **Figure 1-1**. Geographical coordinates for these monitors are provided in **Table 1-1**.

[1] AECOM, 2015. Alcoa Warrick Operations: Site-Specific SO_2 Model Evaluation Protocol. AECOM Document No. 60323156.100, September 2015.

The additional three sites that augmented the P2 site were placed near the plant fence line in the downwind direction for prevailing winds, so as to capture source lineup conditions. This monitoring network went into operation on July 11, 2015. Monitoring data from the network was submitted to IDEM on a quarterly basis.

The default and site-specific models to be evaluated with this field database are based upon the AERMOD model. Due to the flat terrain and the stack release height of about 15 meters for the smelter SO_2 sources of key interest, a standard 10-meter meteorological tower located near the P2 site was used in the study design to provide site-specific meteorological data suitable for the model evaluation. The meteorological tower measured wind direction and wind speed at the 10-meter level, as well as ambient temperature and sigma theta turbulence.

The monitoring equipment was operated and maintained according to the provisions of 40 CFR 58, Appendix A and the IDEM Quality Assurance Manual. Further details regarding the instrumentation used in the study as well as site photos are provided in the 2015 model evaluation study protocol.

Figure 1-1: Map of Alcoa Warrick monitors

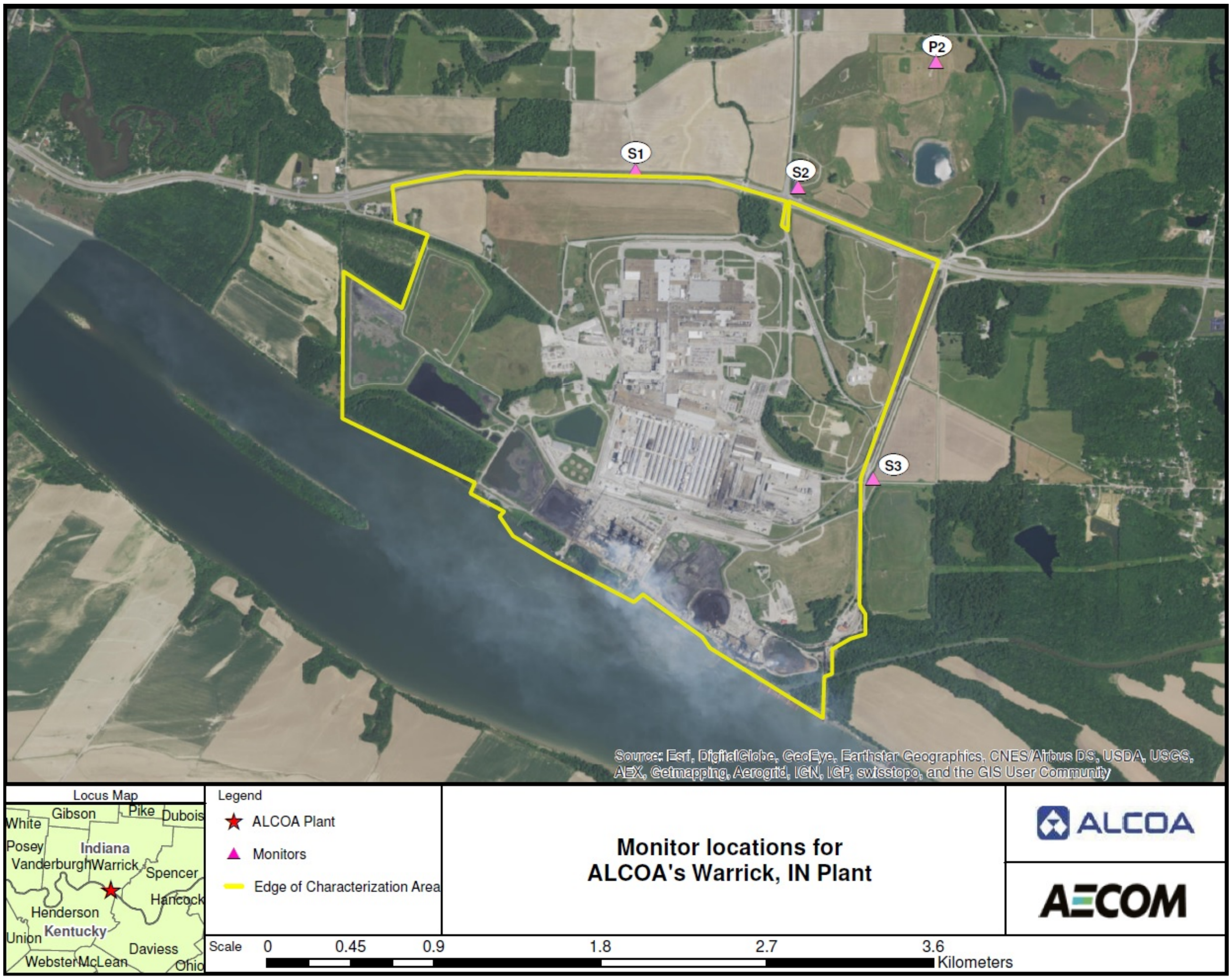


Table 1-1: Alcoa Warrick monitor locations

Monitor	UTM East (m)	UTM North (m)
P2	472393.59	4198940.07
S1	470801.31	4198431.47
S2	471679.77	4198339.62
S3	472085.98	4196764.55

2 Modeling Approaches for Evaluation

On July 29, 2015, EPA proposed[2] updates to their preferred short-range dispersion model, AERMOD, introducing version 15181. These updates were promulgated in a rule[3] published on January 17, 2017, which became effective on May 22, 2017. Features of the latest AERMOD model version 16216r (including the AERMET pre-processor version 16216) relevant to this modeling application are as follows:

- Bug fixes found in AERMET and AERMOD versions 14134 and 15181 have been made in the new version.
- The Buoyant Line and Point source model (BLP) has been installed into AERMOD. This is helpful for modeling the buoyant line roof-vent sources from the potline operations at Warrick Operations. All other sources will be modeled as standard vertical stacks.
- Low wind model improvements are now able to be used, specifically the ADJ_U* option in AERMET.

For the model evaluation process using various applications of AERMOD version 16216r, the following issues were considered in the model evaluation design:

- The modeling will include actual emissions from the Alcoa Warrick Operations, the WPP, and the Culley Generating Station. The Warrick Operations emissions are very steady, and will be specified on a monthly-averaged basis. The power plant emissions are available on an hourly-averaged basis from Continuous Emission Monitors. There are no other major SO_2 sources within 20 km to be considered in the analysis, although several are just outside that distance. Not including these SO_2 sources outside of 20 km will reduce the model predictions and slightly bias the modeling results toward under-prediction.
- All stacks will be modeled with actual stack heights with default building downwash effects applied, using the Building Profile Input Program (BPIP-PRIME) processor.
- The meteorological processing option called ADJ_U* will be used for some of the cases tests.
- For the "Case 1" (default) modeling approach, the dry scrubber stacks at the smelter will be modeled as individual stacks subject to building downwash, and not merged due to the fact that they are spaced more than one diameter apart.
- Also for the "Case 1" modeling approach, rural dispersion will be used for all sources modeled due to the land use within 3 km of the smelter and the power plant sources indicating a rural characterization.
- Additional modeling cases involve urban dispersion for the smelter sources using an effective population of 2 million, as discussed in the main protocol document.
- EPA has suggested using urban dispersion for the Warrick Power Plant (WPP) sources as well, but the justification for this assumption is needed because of the proximity of the WPP to the Ohio River for the important S and SW flows. Therefore, we have conducted evaluation testing for WPP modeled as both urban and rural as a sensitivity test for the best performing model option (Case 4, as it turns out).
- The merging of stacks at the smelter in the modeling accounts for convective buoyancy associated with the fugitive heat releases for equipment other than the stacks.

For this model-to-monitor comparison study, each modeling case is briefly described in **Table 2-1** with additional details described in the following sections. Modeled receptors coincide with the monitor locations. Meteorological data comes from the P2 site-specific meteorological tower data for wind direction and wind speed at the 10-meter level, as well as ambient temperature. Because ADJ_U* is being used for Cases 2 - 4, sigma-theta measurements will not be included in the meteorological data processing, consistent with EPA Guideline for Air Quality Models (Appendix W). Other meteorological input data required for use by AERMOD is supplied in the form of cloud cover data from the nearby Evansville, IN airport (also used to substitute any missing P2 wind or ambient temperature data during the field study period) and upper air data from Lincoln, IL (as specified by the IDEM guidance).

[2] 80 FR 45340.
[3] 82 FR 5182.

The regional SO_2 background to be used for this evaluation was taken from the Alcoa monitors for the actual period of the study. To avoid double-counting the modeled source impacts, we conducted an analysis of the cumulative frequency of the monitored concentrations at the four monitors (see **Figure 2-1**) as well as for all four monitors combined (see **Figure 2-2**). A concentration level of 20 µg/m^3, where the curves are definitely trending upward (but with the percentile below 99%), is a reasonable estimate for the background. This value is well below some of the higher hourly/seasonal values from the Buena Vista monitor. The use of a constant background value improves the ability to interpret the sensitivity evaluation runs. For conservatism, no other background sources were included in the modeling, which tends to bias the modeling toward under-predicting in the evaluation.

Table 2-1: Modeling case descriptions

Case No.	Dispersion Environment for Culley Power Plant Source	Dispersion Environment for WPP Power Plant Sources	Dispersion Environment for Smelter Sources	Meteorology	Select Smelter Source Stacks Merged?
1	Rural	Rural	Rural	Default	No
2	Rural	Urban	Urban	ADJ_U*	No
3	Rural	Urban	Urban	ADJ_U*	Yes
4	Rural	Rural & Urban Tested	Urban	ADJ_U*	Yes, additional merging than Case 3

Figure 2-1: Cumulative frequency of observed 1-hr SO_2 concentrations at each monitor

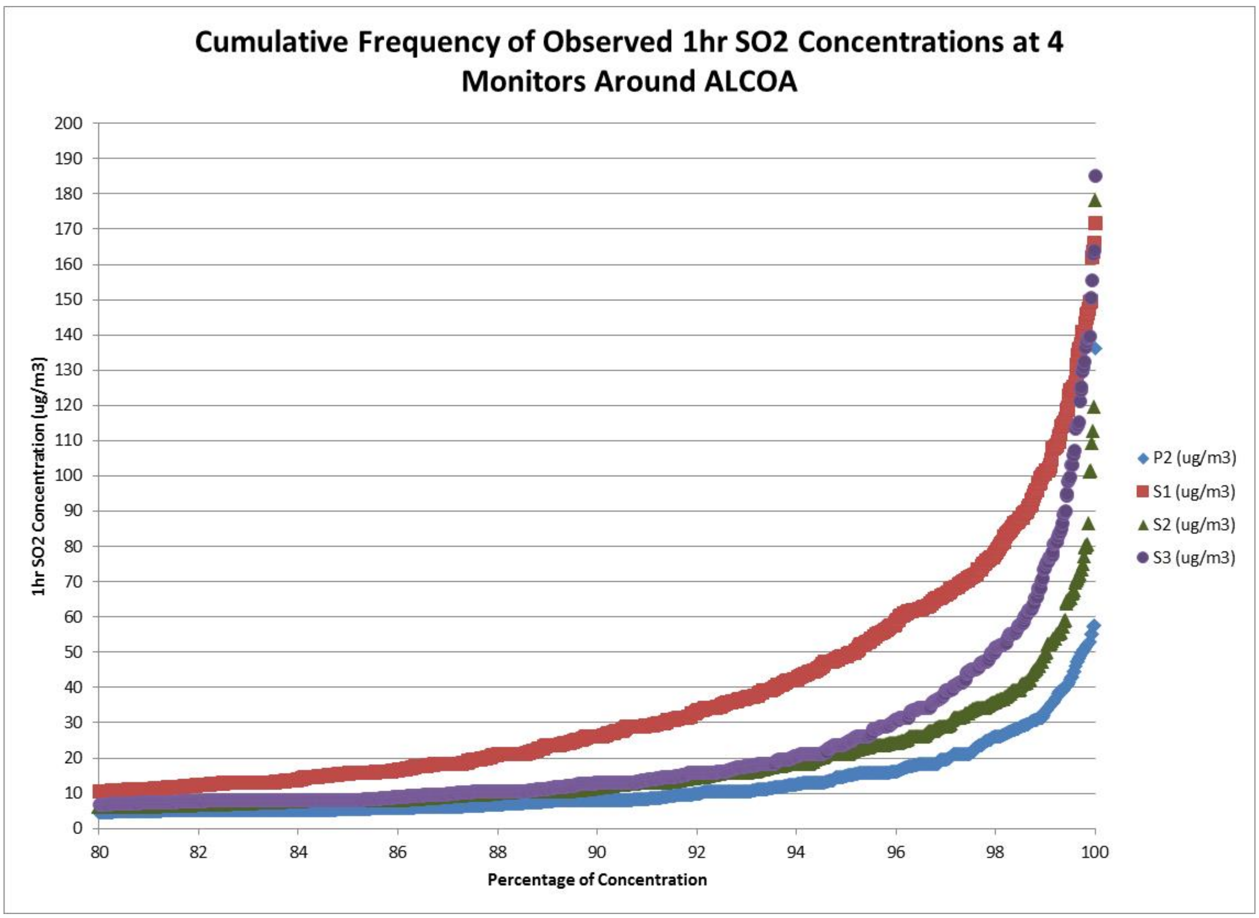
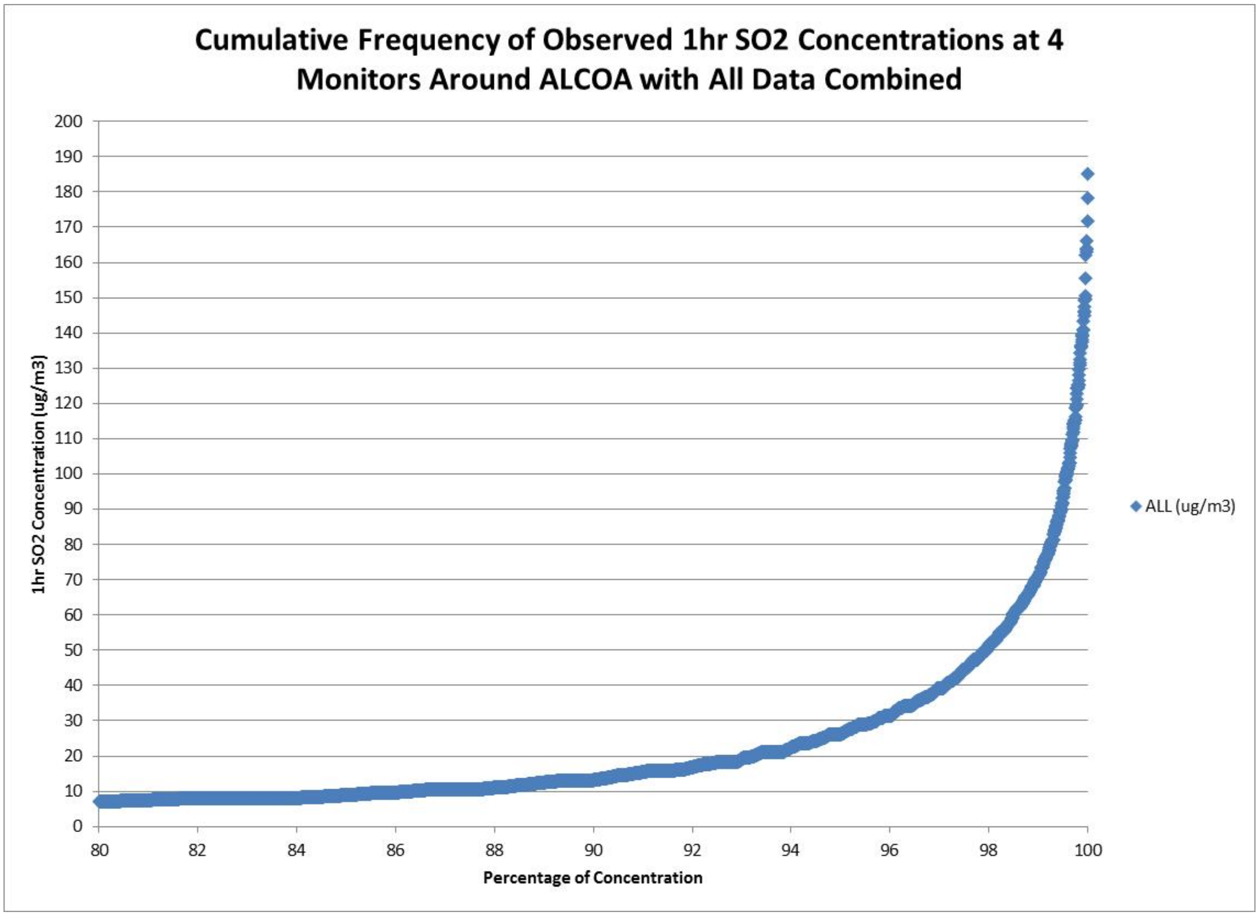


Figure 2-2: Cumulative frequency of observed 1-hr SO_2 concentrations for all monitors combined



2.1 Default Modeling Approaches (Cases 1 and 2)

One of the default model approaches using AERMOD, referenced as “Case 1”, uses default model options and source characterization procedures described in the EPA Guideline for Air Quality Models (Appendix W). The Case 1 modeling approach uses the following model configuration for comparison with monitored concentrations:

- Building downwash is included (this option is included for all cases);
- Rural dispersion is used;
- The individual dry scrubber stacks are modeled without any merging.

The stack parameters used in the modeling are shown in **Table 2-2**.

An additional modeling approach (“Case 2”) was tested with a change from Case 1 involving urban dispersion for the smelter sources (i.e. P01, P02, P03, P04, and P05) with an effective population of 2 million as input. Although the area around the facility would be categorized as rural based on land use and population methodologies described in Appendix W, Warrick Operations is located in a “highly industrialized area” that causes an urban heat island-like effect. The change to Appendix W proposed in July 2015 (80 FR 45340, July 29, 2015) that was promulgated in 2017 now allows for consideration for these effects created by large industrial complexes located in rural areas. The “highly industrialized area” effect can be addressed by a technique that accounts for the excess heat from an industrial complex and derives an effective population equivalent to the scale of the highly industrialized area as input to AERMOD. For Warrick Operations, the effective population identified by quantifying the heat release is 2 million. The determination of this population input is discussed further in the modeling protocol (Section 3.2). For Case 2, Warrick Power Plant (WPP) was modeled as urban. WPP was modeled as both urban and rural in a sensitivity study for one of the other cases (Case 4) as described below.

Also, in Case 2, the ADJ_U* AERMET option was used. This option was also used in Cases 3 and 4 as well.

Table 2-2: Source characterization for testing Cases 1 and 2

Source ID	Description	Base Elevation (m)	Release Height (m)	Stack Diameter (m)
P01	Potlines #3 & #4 GTC Pollution Controls (1 stack)	119	60.66	6.10
P02_01 - P02_36	Potline #2 A-398 (36 individual dry scrubber stacks)	119	14.94	0.63
P03_01 - P03_36	Potline #5 A-398 (36 individual dry scrubber stacks)	119	14.94	0.63
P04_01 - P04_36	Potline #6 A-398 (36 individual dry scrubber stacks)	119	14.94	0.63
P5W1 - P5W6	Ring Furnace A-446 (6 western reactor stacks modeled as separate stacks)	119	22.25	0.67
P5E1	Ring Furnace A-446 (1 eastern reactor stack)	119	22.25	1.17
L01-L10	Potline #2 – 6 Roof Vents	119	14.02	n/a [A]
WPP_1-3	WPP Units 1-3	119	115.82	7.12 [B]
WPP_4	WPP Unit 4	119	115.82	6.10
CULLEY3	Culley Unit 3	113	137.12	6.10

[A] *L01 – L10 are buoyant line sources as described in the model protocol and thus do not have a stack diameter.*
[B] *Equivalent stack diameter due to merged flues.*

2.2 Modeling Approach Using Partial Merging of Smelter Stacks

Two other cases were included in the model evaluation tests. These cases (Case 3 and Case 4) were similar to Case 2, except that partial merging of the closely-spaced smelter stacks was done to reflect the convective effects of the large fugitive heat releases. Case 3 assumes that each row of 3 stacks for potline groups 2, 5, and 6 are merged, for a total of 12 merged stacks for each group of 36 stacks. Case 4 assumes additional merging depending upon the layout of each group of 36 stacks. For potline groups 5 and 6 with 12 rows of 3 stacks each, two rows of 3 stacks each are merged, for a total of 6 stacks in each group. For potline group 2, with a tighter arrangement featuring essentially 6 rows of 6 stacks, the merging results in 3 rows of 3 stacks merged, for a total of 4 stacks. **Figure 5-2** in the main protocol document shows the locations of the Case 4 stacks as modeled. Case 4 was also run with WPP modeled as both urban and rural.

The stack parameters used in the modeling for Case 3 are shown in **Table 2-3**, and for Case 4 in **Table 2-4**. To model merged stacks, equivalent stack diameters were determined based on the combined area of the individual stacks.

Table 2-3: Smelter source characterization for the Case 3 approach

Source ID	Description	Base Elevation (m)	Release Height (m)	Stack Diameter (m)
P01	Potlines #3 & #4 GTC Pollution Controls (1 stack)	119	60.66	6.10
P02_02 - P02_35	Potline #2 A-398 (12 stacks each merged with 3 individual dry scrubber stacks)	119	14.94	1.09 [B]
P03_02 - P03_35	Potline #5 A-398 (12 stacks each merged with 3 individual dry scrubber stacks)	119	14.94	1.09 [B]
P04_02 - P04_35	Potline #6 A-398 (12 stacks each merged with 3 individual dry scrubber stacks)	119	14.94	1.09 [B]
P05W	Ring Furnace A-446 (1 stack merged with 6 individual western reactor stacks)	119	22.25	1.64 [B]
P5E1	Ring Furnace A-446 (1 eastern reactor stack)	119	22.25	1.17
L01-L10	Potline #2 – 6 Roof Vents	119	14.02	n/a [A]
WPP_1-3	WPP Units 1-3	119	115.82	7.12 [B]
WPP_4	WPP Unit 4	119	115.82	6.10
CULLEY3	Culley Unit 3	113	137.12	6.10

[A] *L01 – L10 are buoyant line sources as described in the model protocol and thus do not have a stack diameter.*
[B] *Equivalent stack diameter due to merged flues.*

Table 2-4: Model source characterization for the Case 4 approach

Source ID	Description	Base Elevation (m)	Release Height (m)	Stack Diameter (m)
P01	Potlines #3 & #4 GTC Pollution Controls (1 stack)	119	60.66	6.10
P02m01 - P02m06	Potline #2 A-398 (4 stacks each merged with 9 individual dry scrubber stacks)	119	14.94	1.89 [B]
P03m01 - P03m06	Potline #5 A-398 (6 stacks each merged with 6 individual dry scrubber stacks)	119	14.94	1.54 [B]
P04m01 - P04m06	Potline #6 A-398 (6 stacks each merged with 6 individual dry scrubber stacks)	119	14.94	1.54 [B]
P05W	Ring Furnace A-446 (1 stack merged with 6 individual western reactor stacks)	119	22.25	1.64 [B]
P5E1	Ring Furnace A-446 (1 eastern reactor stack)	119	22.25	1.17
L01-L10	Potline #2 – 6 Roof Vents	119	14.02	n/a [A]
WPP_1-3	WPP Units 1-3	119	115.82	7.12 [B]
WPP_4	WPP Unit 4	119	115.82	6.10
CULLEY3	Culley Unit 3	113	137.12	6.10

[A] *L01 – L10 are buoyant line sources as described in the model protocol and thus do not have a stack diameter.*
[B] *Equivalent stack diameter due to merged flues.*

3 Results of the Model-to-Monitor Evaluation Study

As discussed above, four modeling cases were selected for a model-to-monitor evaluation for Warrick Operations. AERMET/AERMOD version 16216/16216r was run for each of these cases.

The model input configuration (domain, meteorological data, etc.) used in this comparison study includes:

- Modeling using data from the period of 7/11/2015 – 2/19/2016 using actual emissions and site-specific meteorological data;
  - Site-specific data from the P2 meteorological station and Lincoln, IL upper air station; the wind rose from July 11, 2015-February 19, 2016 is shown in **Figure 3-1**.
- A receptor grid consisting of the four SO_2 monitor locations. Although additional receptors are sometimes used in model evaluations to account for "near misses" in the modeling, that was not done for this analysis. The results are such that the modeled concentrations could be underestimated in the evaluation.

Model-predicted impacts presented in the following sections include regional constant background concentration of 20 µg/m^3 determined from the site-specific monitored concentrations during the 8-month field study.

3.1 Monitored Concentrations

During the 4-monitor field study, not a single instance of a 1-hour SO_2 NAAQS exceedance occurred at any monitor from July 11, 2015 to February 19, 2016. **Figure 3-2** provides a time series of the monitored concentrations (provided in units of micrograms per cubic meter, µg/m^3). The black dashed line notes the level of the 1-hour SO_2 NAAQS at 196.5 µg/m^3. The 99th percentile monitored concentrations (in this case, the 3rd highest concentration) are important because modeling uses the 99th percentile to determine the relevant model results in relation to the 1-hour SO_2 NAAQS. **Figure 3-3** provides the 99th percentile monitored concentrations by monitor.

3.2 Results of the 99th Percentile Concentration Comparisons

The results of the 1-hour 99th percentile model and monitor SO_2 concentrations are summarized in **Table 3-1** for all cases. For the AERMOD Case 1, the modeled-to-monitored ratios were far greater than 1.0. Results for Case 2 were still exhibiting considerable over-prediction, while the results for Case 3 and especially Case 4 were closer to being unbiased. With WPP modeled as rural, the overall modeling results show a higher prediction tendency overall versus WPP modeled as urban.

Due to the overall best performance for Case 4, additional modeling was conducted using both rural and urban dispersion for WPP. For Case 4, the predicted-to-observed ratios are greater than 1.0 for all monitors except for S1. At the S1 monitor, we note that one of the top 3 daily 1-hour maximum concentrations appears to have been caused by a high emission condition involving Culley (November 24, 2015, hour 9) while the highest few predicted cases did not feature high Culley emissions. To provide for a comparison focused upon Alcoa emissions, we provide 99th percentile results with and without this "Culley case" that influenced the comparison in **Table 3-2**. When the Culley-influenced observed case is set aside, the predicted-to-observed ratio is about 0.97 for both the rural and urban WPP modeling approaches for the S1 monitor, and the predicted results for WPP modeled as rural are higher than those for WPP modeled as urban.

Ambient SO_2 monitored observations have the potential to vary from an unbiased calibration state by up to 10% and still be considered to be acceptable within the uncertainty of the measurements. This is related to the tolerance in the EPA procedures (EPA, 2013)[4] associated with quality control checks and span checks of ambient measurements. Therefore, even ignoring uncertainties in model input parameters and other contributions that can also lead to modeling uncertainties, just the uncertainty in measurements indicates that modeled-to-monitored ratios between 0.9 and 1.1 are within the instrumentation tolerance and can be considered "unbiased".

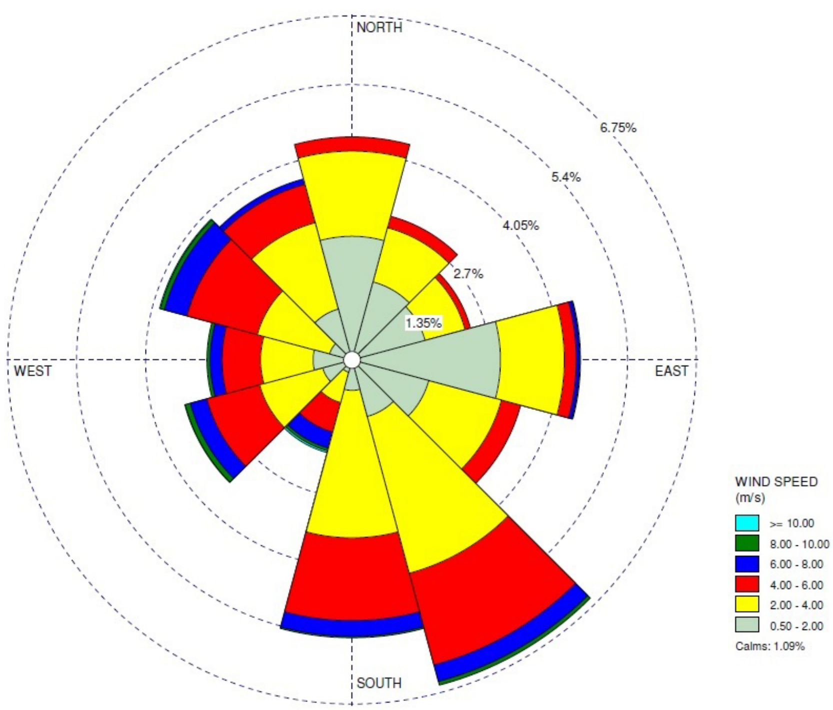
[4] U.S. Environmental Protection Agency, 2013. *Quality Assurance Handbook for Air Pollution Measurement System, Volume II, Ambient Air Quality Monitoring Program*. https://www3.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf

3.3 Results of Quantile-Quantile Plots

Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time, can be assessed with quantile-quantile (Q-Q) plots[5] (Chambers et al.17). Q-Q plots are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time at a given monitoring location. The sorted list of predicted concentrations is then plotted by rank against the observed concentrations, also sorted by rank. These concentration pairs are no longer paired in time, but they are paired by location. The Q-Q analysis is useful for answering the question, "Over a period of time, does the distribution of the model predictions match those of observations?" Scatterplots, which use data paired in time, provide a stricter test, answering the question: "At a given time and place, does the magnitude of the model prediction match the observation?" It is the experience of model developers[6],[7] that wind direction uncertainties can and do cause disappointing scatterplot results from what are otherwise well-performing dispersion models. Therefore, the Q-Q plot instead of the scatterplot is a more pragmatic procedure for demonstrating model performance of applied models. Venkatram et al.[8] make a cogent argument for the use of Q-Q plots for evaluating regulatory models.

Figures 3-4, 3-5, 3-6, and 3-7 display quantile-quantile (Q-Q) plots representing the ranked model to monitor concentrations at each of the four Warrick Operations monitor sites for Cases 1-4, respectively. While **Figure 3-7** shows the Case 4 results for WPP modeled as urban, **Figure 3-8** provides results with WPP modeled as rural. It is evident that the trend in performance from Case 1 to Case 4 shows improvement from case to case. The results in **Figure 3-8** show similar behavior for the S1 monitor, but the highest point for the S2 and P2 monitors show improvement from under-prediction tendencies when WPP is modeled as rural rather than urban. In addition, for the run with WPP modeled as rural, only the "Culley case" point is below the 0.9 predicted-to-observed line. In general, the modeling results with WPP modeled as rural are more conservative vs. those with WPP modeled as urban.

Figure 3-1: Wind rose from P2 meteorological site (July 11, 2015-February 19, 2016)



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[5] Chambers, J. M., Cleveland, W. S., Kleiner, B., and Tukey, P. A., 1983. Chapter 3: Comparing Data Distributions. Graphical Methods for Data Analysis. (Bell Laboratories). Wadsworth International Group and Duxbury Press.

[6] Weil J.C, Sykes and Venkatram A., 1992. Evaluating air-quality models: Review and outlook. *J. Appl. Met.*, 31, p 1121-1144.

[7] Liu, M. K., and G. E. Moore, 1984. Diagnostic validation of plume models at a plains site. EPRI Report No. EA-3077, Research Project 1616-9, Electric Power Research Institute, Palo Alto, CA.

[8] Venkatram, A., R. W. Brode, A. J. Cimorelli, J. T. Lee, R. J. Paine, S. G. Perry, W. D. Peters, J. C. Weil, and R. B. Wilson, 2001. A complex terrain dispersion model for regulatory applications. Atmos.Environ., 35, 4211-4221.

Figure 3-2: Monitored SO_2 concentrations during the 4-monitor field study

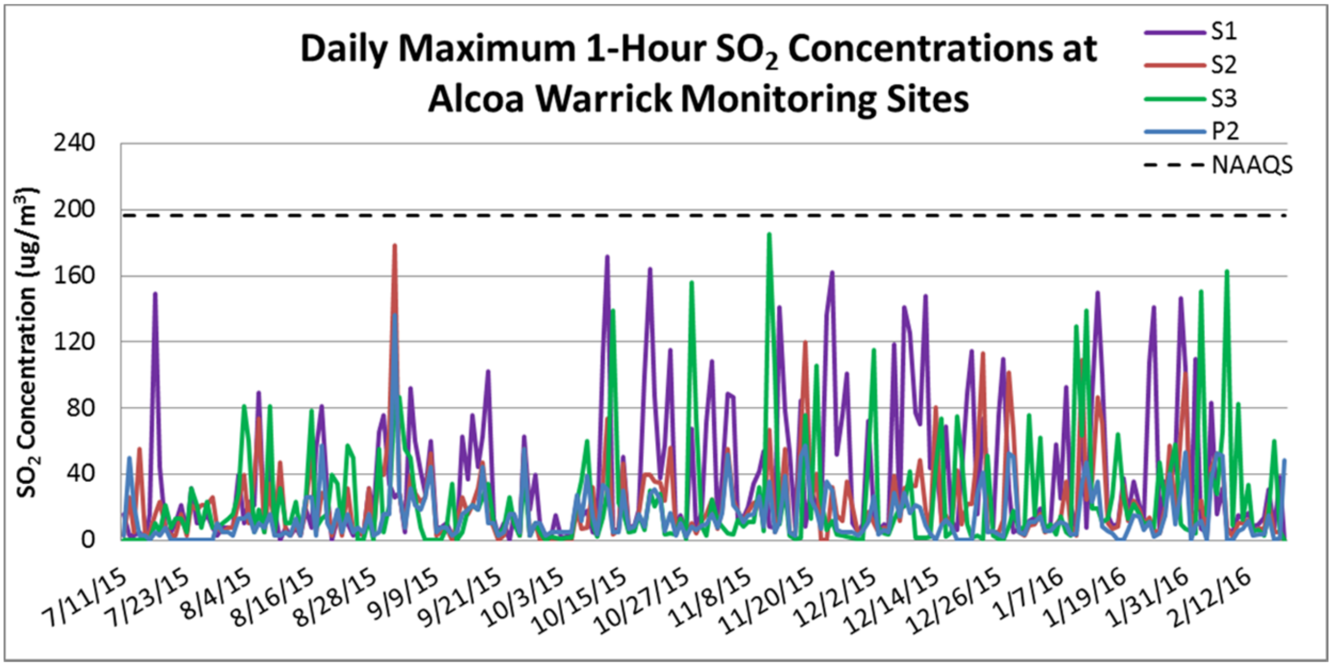


Figure 3-3: Monitored 99th percentile SO_2 concentrations during the 4-monitor field study

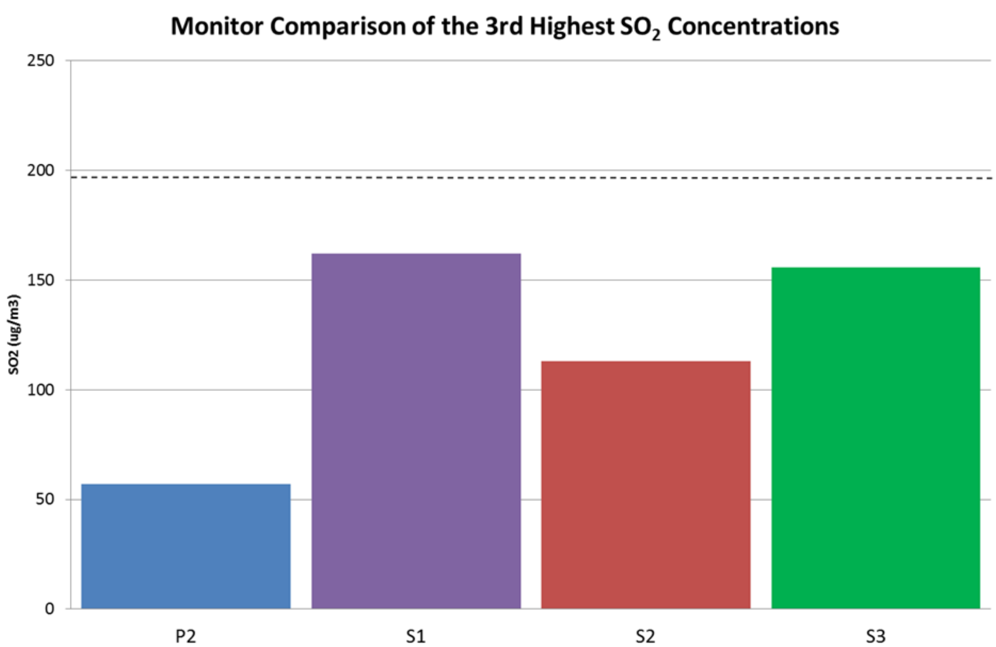


Table 3-1: Model-predicted 99th percentile daily peak 1-hour SO_2 concentrations as compared to the monitors – all 4 cases

Scenario	Monitor	Observed	Predicted*	Ratio
Case 1: AERMOD Default Rural. No Stack Merging	P2	57.1	537.9	9.42
	S1	161.9	941.1	5.81
	S2	112.9	1057.3	9.36
	S3	155.6	1954.9	12.56
			Geometric Mean	8.96
Case 2: AERMOD U* Urban. No Stack Merging	P2	57.1	299.0	5.24
	S1	161.9	398.1	2.46
	S2	112.9	414.1	3.67
	S3	155.6	595.3	3.83
			Geometric Mean	3.67
Case 3: AERMOD U* Urban. Potlines 2, 5, and 6 stacks: 12 merged stacks each. Ring furnace western reactor stacks merged into 1 stack.	P2	57.1	195.4	3.42
	S1	161.9	207.0	1.28
	S2	112.9	192.2	1.70
	S3	155.6	272.3	1.75
			Geometric Mean	1.90
Case 4: AERMOD U* Urban. Potline 2 stacks: 4 merged stacks. Potlines 5 and 6 stacks: 6 merged stacks each. Ring furnace western reactor stacks merged into 1 stack. WPP modeled with **urban** dispersion. "Culley case" included in the observations.	P2	57.1	118.1	2.07
	S1	161.9	144.4	0.89
	S2	112.9	133.7	1.18
	S3	155.6	166.0	1.07
			Geometric Mean	1.24
Case 4: AERMOD U* Urban. Potline 2 stacks: 4 merged stacks. Potlines 5 and 6 stacks: 6 merged stacks each. Ring furnace western reactor stacks merged into 1 stack. WPP modeled with **rural** dispersion. "Culley case" included in the observations.	P2	57.1	129.9	2.27
	S1	161.9	144.5	0.89
	S2	112.9	153.2	1.36
	S3	155.6	166.0	1.07
			Geometric Mean	1.31

* Includes regional background added to model predicted SO_2 concentrations.

Table 3-2: Model-predicted 99th percentile daily peak 1-hour SO_2 concentrations as compared to the monitors – Case 4 results with Culley case removed

Scenario	Monitor	Observed	Predicted*	Ratio
Case 4:	P2	57.1	118.1	2.07
WPP modeled with **urban** dispersion.	S1	149.6	144.4	0.97
"Culley case" not included in the	S2	112.9	133.7	1.18
observations.	S3	155.6	166.0	1.07
			Geometric Mean	1.26
Case 4:	P2	57.1	129.9	2.27
WPP modeled with **rural** dispersion.	S1	149.6	144.5	0.97
"Culley case" not included in the	S2	112.9	153.2	1.36
observations.	S3	155.6	166.0	1.07
			Geometric Mean	1.34

* Includes regional background added to model predicted SO_2 concentrations.

Figure 3-4: Quantile-quantile charts of daily maximum 1-hour SO_2 concentrations for Case 1

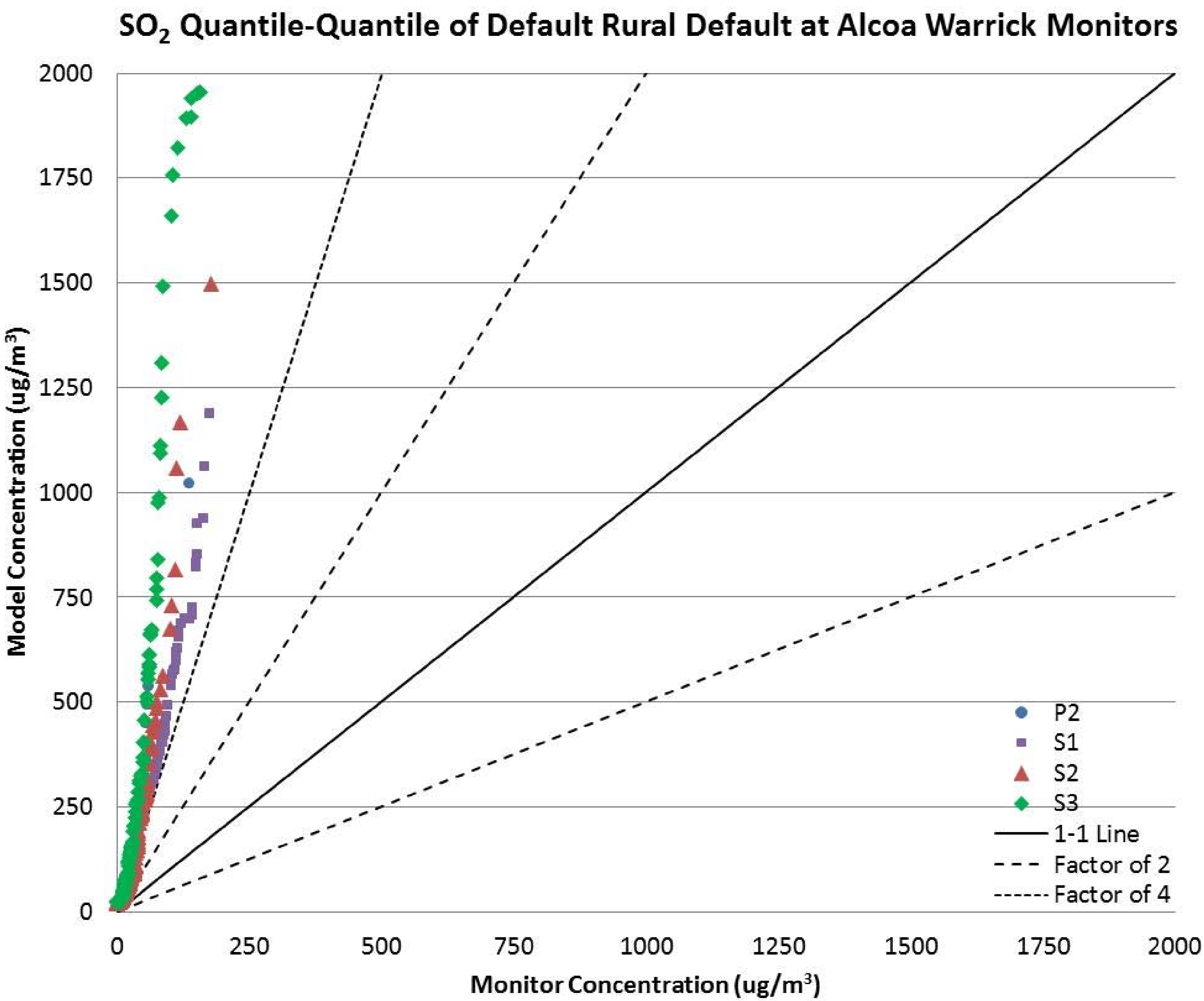


Table 3-~~35~~: Quantile-quantile charts of daily maximum 1-hour SO_2 concentrations for Case 2

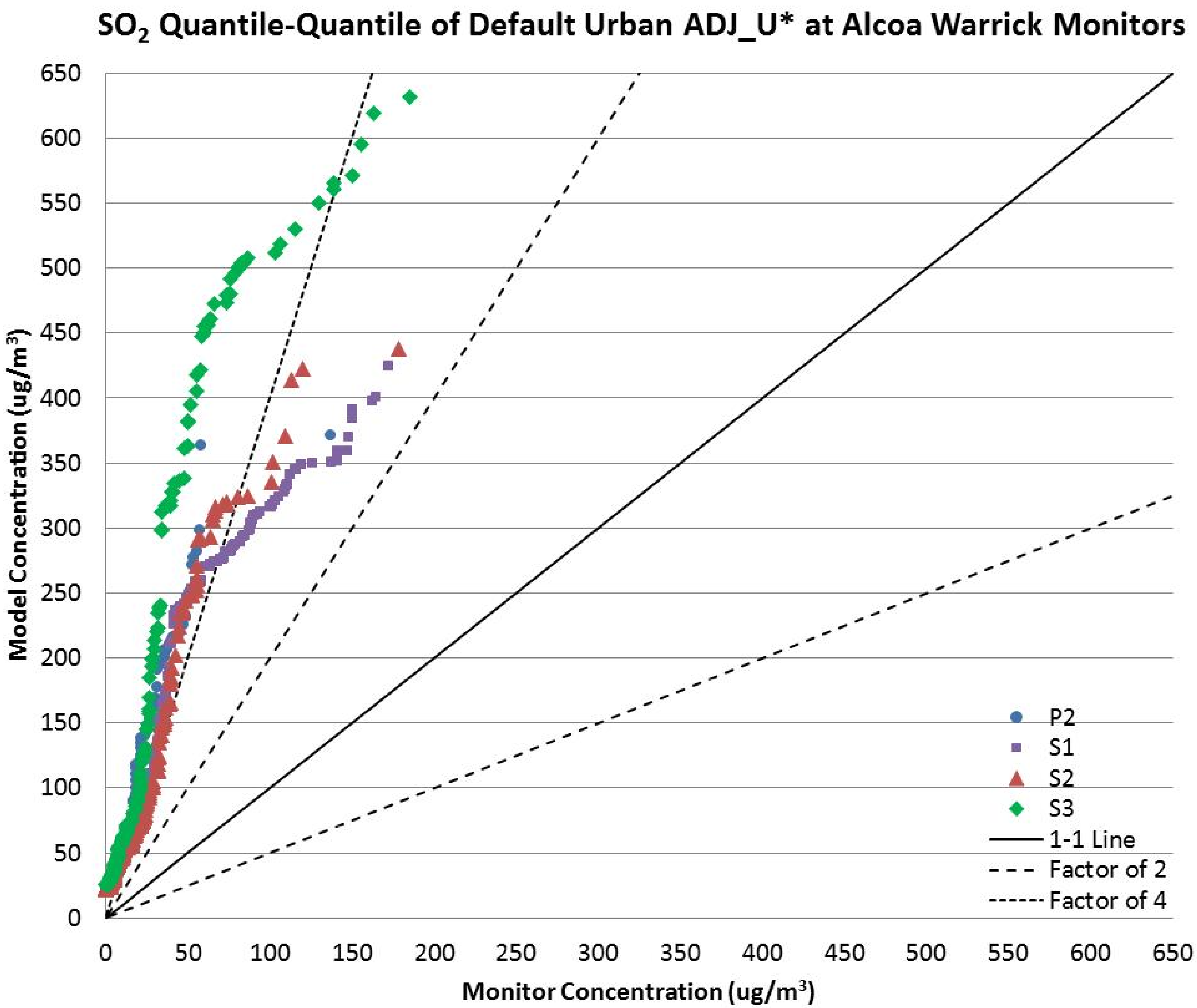


Table 3-46: Quantile-quantile charts of daily maximum 1-hour SO_2 concentrations for Case 3

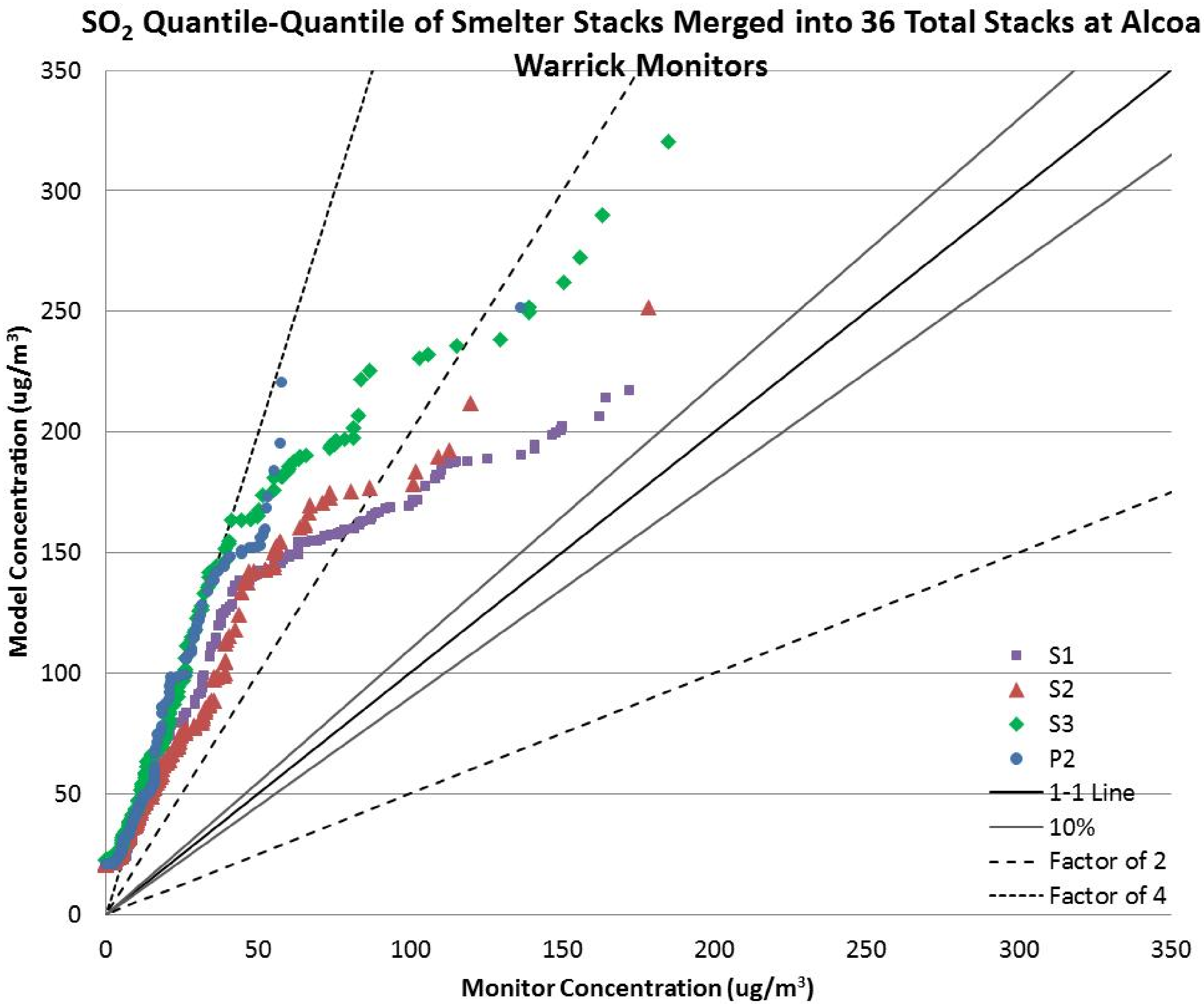


Table 3-5~~7~~: Quantile-quantile charts of daily maximum 1-hour SO_2 concentrations for Case 4 with WPP modeled as an urban source

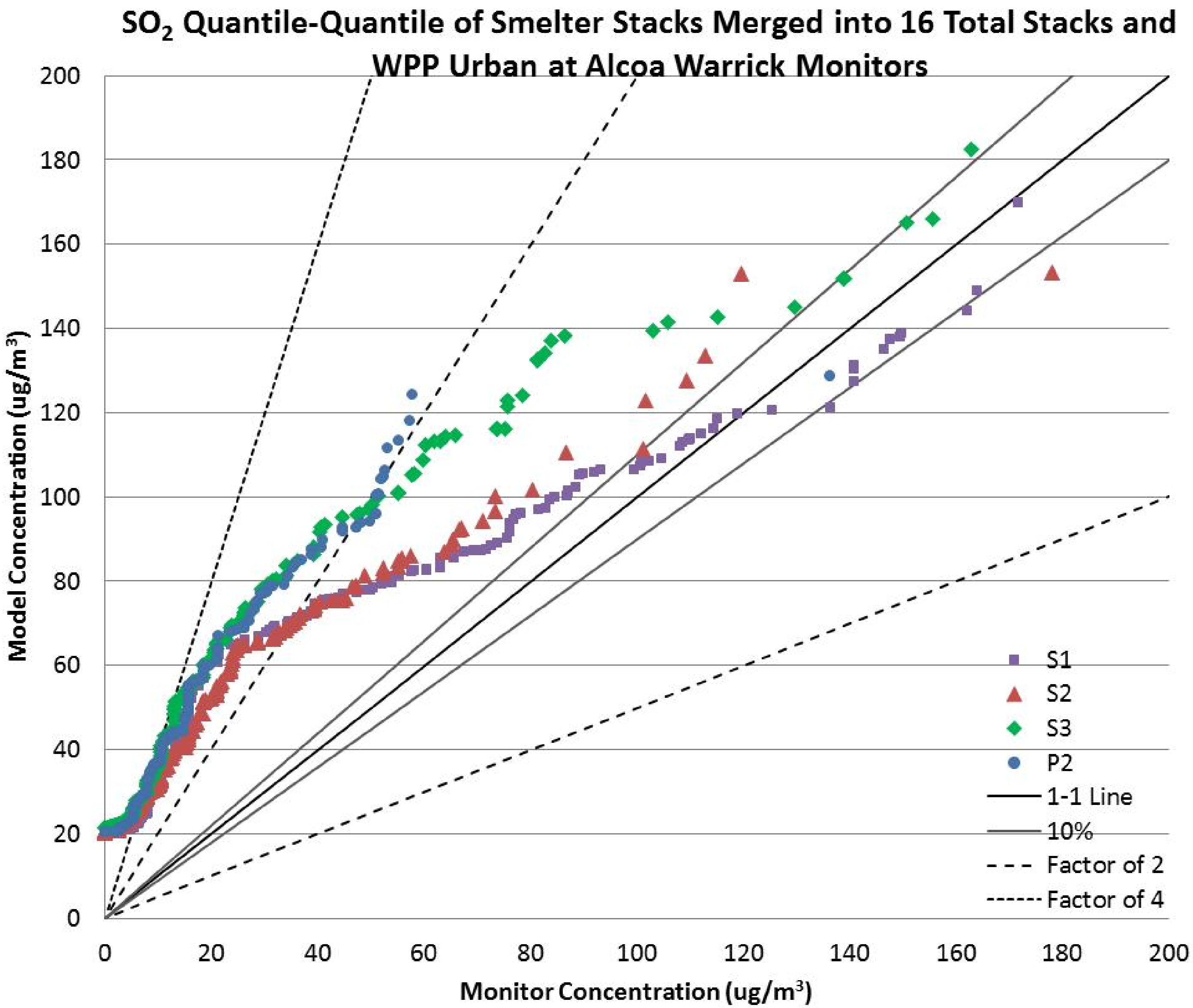
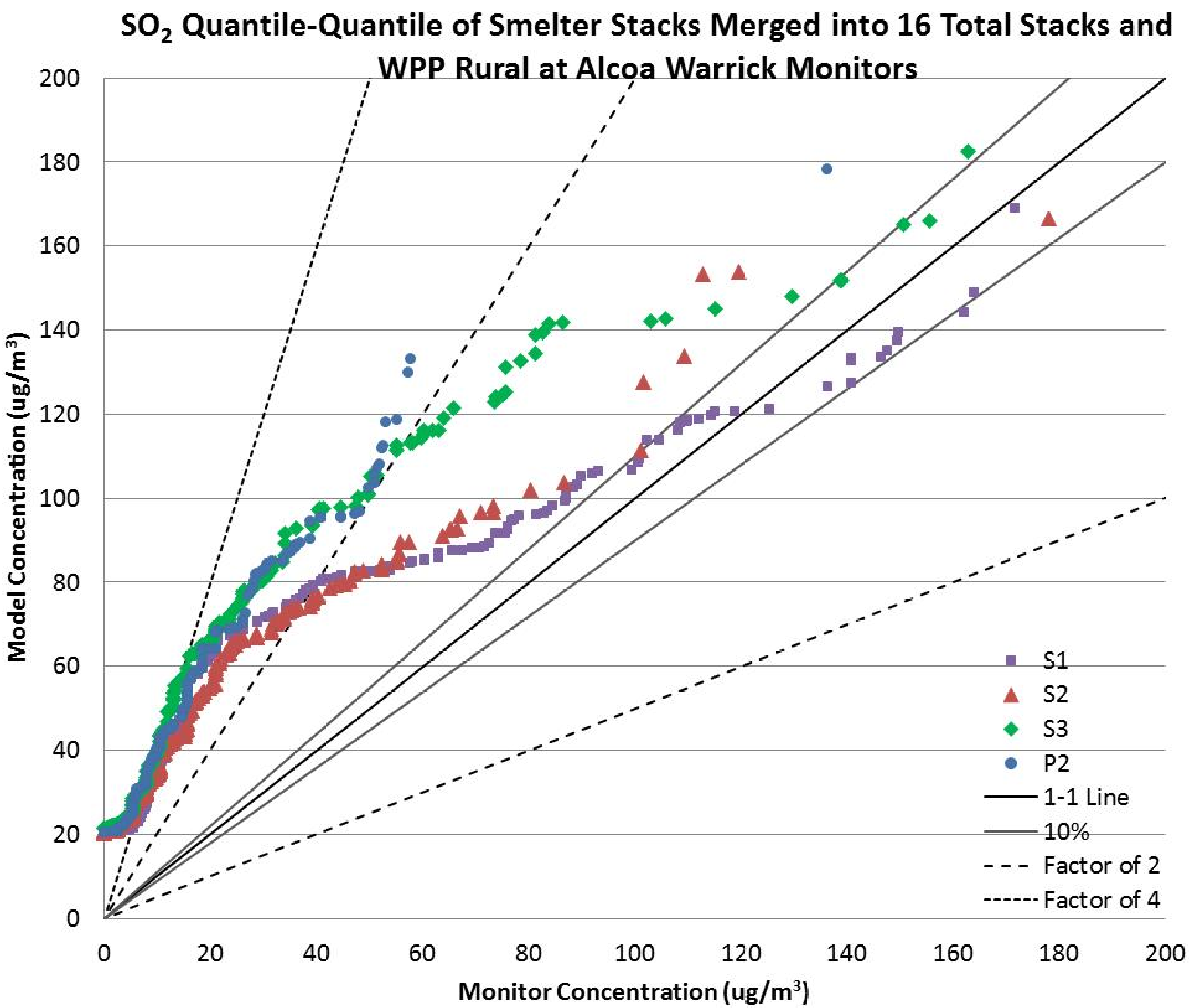


Table 3-68: Quantile-quantile charts of daily maximum 1-hour SO_2 concentrations for Case 4 with WPP modeled as a rural source



4 Evaluation Comparison Conclusions

An evaluation of several methods to characterize the Alcoa Warrick Operations sources has been conducted using an 8-month, multi-monitor field study database for Alcoa Warrick Operations. Modeled impacts are based on AERMET/AERMOD (v16216/16216r) with regulatory default options used in all modeling scenarios including the use of the new ADJ_U* default AERMET option for many of the cases tested. The differences among the cases tested involve the characterization of the smelter and WPP as urban vs. rural, as well as some merging of the closely-spaced scrubber stacks for three of the potline areas as well as the bake furnace area.

The model evaluation results indicate that the model over-prediction without consideration of a Highly Industrialized Area (HIA) urban heat island effect and partial merging of smelter source stacks is substantially reduced if these effects are considered. The results from this model evaluation study illustrate how a more accurate characterization of the smelter sources results in better model performance for Alcoa Warrick Operations. The fact that Case 4 results with WPP modeled as either rural or urban shows unbiased or an over-prediction tendency at all of the monitors lends support to the use of Case 4 for the SO_2 DRR modeling demonstration. The choice of whether to model WPP as urban or rural appears to have a small effect upon the model evaluation results, although the predictions are higher with the rural treatment and there was an improvement for the highest prediction at two monitors (S2 and P2) when WPP was modeled as rural. Due to the influence of the Ohio River to reduce the urban effect on WPP for winds between south and west, which are associated with peak modeled and monitored concentrations, modeling WPP as rural for the Case 4 application is recommended for the SO_2 Data Requirements Rule modeling analysis.

Appendix B Urban Characterization of Industrial Source Complexes for AERMOD Modeling

Introduction

The United States Environmental Protection Agency (EPA) maintains recommendations for dispersion modeling approaches for emission sources at Appendix W, 40 CFR (Code of Federal Regulations) Part 51, available at http://www.epa.gov/ttn/scram/guidance/guide/appw_05.pdf. Supplemental AERMOD implementation guidance is available at http://www.epa.gov/ttn/scram/7thconf/aermod/aermod_implmtn_guide_19March2009.pdf.

The topic of this "white paper" is the determination as to whether a specific emission source should be characterized as being in a rural or urban area, and if urban, then the assignment of an "effective urban population". The choice of urban vs. rural influences how the dispersion is treated, especially at night, for which an urban area is characterized by a near-neutral boundary layer with a specified height that is a function of urban-rural temperature difference (or population as a robust input metric). The current guidance addresses traditional urban areas that are characterized by large populations or urban-like surface characteristics. However, for industrial areas with large heat releases that result in large temperature excesses, the traditional classification approaches are often not appropriate. The population near such areas is often much reduced because of zoning issues, and the area beyond the immediate industrial park may be rural in nature, resulting in a misleading characterization for this type of source.

AERMOD's Model Formulation for Urban Dispersion

In urban areas, AERMOD accounts for the dispersive nature of the "convective-like" boundary layer that forms during nighttime conditions by enhancing the turbulence over that which is expected in the adjacent rural, stable boundary layer. The enhanced turbulence is the result of the urban heat flux and associated mixed layer, which are estimated from the urban-rural temperature difference as suggested by Oke (1978; 1982)[1,2].

Although urban surface characteristics (roughness, albedo, etc.) influence the boundary layer parameters at all times, the effects of the urban sublayer on the structure of the boundary layer is largest at night and relatively absent during the day (Oke,1998)[3]. An urban "convective-like" boundary layer forms during nighttime hours when stable rural air flows onto a warmer urban surface. Following sunset, the urban surface cools at a slower rate than the rural surface because buildings in the urban area trap the outgoing thermal radiation and the urban subsurface has a larger thermal capacity. AERMOD accounts for this by enhancing the turbulence above that found in the rural stable boundary layer (i.e., a convective-like urban contribution to the total turbulence in the urban stable boundary layer). The convective contribution is a function of the convective velocity scale, which in turn, depends on the surface heat flux and the urban mixed layer height. The upward heat flux is a function of the urban-rural temperature difference, where the urban temperature is taken at the core of the urban area.

The urban-rural temperature difference depends on a large number of factors that cannot easily be included in applied models such as AERMOD. For simplicity, the data presented in Oke (1973; 1982)[4,2]

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[1] Oke, T. R., 1978. Boundary Layer Climates. John Wiley and Sons, New York, New York, 372 pp.

[2] Oke, T. R., 1982. The energetic basis of the urban heat island. Quart.J.Roy.Meteor.Soc., 108: 1-24.

[3] Oke, T. R., 1998. An algorithmic scheme to estimate hourly heat island magnitude. Preprints, 2nd Urban Environment Symposium, American Meteorological Society, Boston, MA, 80-83.

[4] Oke, T. R., 1973. City size and the urban heat island. Atm.Env., 7: 769-779.

is used to construct an empirical model. Oke presents observed urban-rural temperature differences for a number of Canadian cities with populations varying from about 1000 up to 2,000,000. These data represent the maximum urban effect for each city since they were collected during ideal conditions of clear skies, low winds, and low humidities. An empirical fit to the data yields the following relationship:

$$\Delta T_{u\text{-}r} = \Delta T_{max} [0.1 \ln (P/P_o) + 1.0] \quad (1)$$

where ΔT_{max} = 12°C, Po = 2,000,000 (the city population associated with the maximum temperature difference in Oke's data), and P is the population of the urban area being modeled. Since the ambient nighttime temperature of an urban area is higher than its surrounding rural area, an upward surface heat flux must exist in the urban area. It is assumed that this upward surface heat flux, Hu, is related to the urban-rural temperature difference through the following relationship

$$Hu = \alpha \rho c_p \Delta T_{u\text{-}r} u_*, \quad (2)$$

where, as noted in the AERMOD formulation document[5], α is an empirical constant (0.03), ρ is the density of air (about 1.2 kg/m^3), c_p is the specific heat at constant pressure (1 watt-sec/g-deg K), and, as noted above, u_* is on the order of 0.1 m/s. This equation can be solved for ΔTu-r:

$$\Delta T_{u\text{-}r} \sim Hu/4, \quad (3)$$

where Hu is the anthropogenic ("excess") heat release in units of watts per square meter in the "urban core" (an industrial area at least a few hundred meters on a side[6]).

For Eqn. 2, AERMOD's developers (AERMIC) chose α to ensure that the upward heat flux is consistent with maximum measured values of the order of 0.1 ms-1ºC. Because ΔTu-r has a maximum value on the order of 10ºC, and u* is on the order of 0.1 ms-1, α should have a maximum value on the order of 0.1. Although AERMIC assumed that α has a maximum (city center) value of about 0.1, AERMOD uses an effective value of α that is averaged over the entire urban area. Assuming a linear variation of α from 0 at the edge of the urban area to about 0.1 at the center of the urban area results in an area average equal to one-third of that at the center (since the volume of cone is one-third of that of a right circular cylinder of the same height). Therefore, AERMIC tested an area-averaged value of α equal to 0.03 against the Indianapolis data. This choice for α is consistent with measured values of the upward heat flux in Canadian cities reported by Oke (1973; 1982)[4,2]. The results of the developmental testing indicated that this choice for α resulted in an adequate fit between observations and AERMOD-predicted concentrations.

The mixing height in the nighttime urban boundary layer, Ziu, is based on empirical evidence presented in Oke (1973; 1982)[4,2] that, in turn, suggests the following relationships:

$$Ziu \sim R^{1/2} \text{ and } R \sim P^{1/2} \quad (4)$$

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[5] Available at http://www.epa.gov/ttn/scram/7thconf/aermod/aermod_mfd.pdf.

[6] In a series of personal communications, Dr. Steve Hanna indicated that the minimum size of an industrial area needed to take on "urban" characteristics has been the subject of much discussion over the years. He indicated that an "expert elicitation" would likely result in a minimum size estimate of a few hundred meters. The anthropogenic heat release per unit area of major cities such as Indianapolis (extensively studied by EPRI in the 1980s) would be on the order of 50 $watts/m^2$.

where R is a measure of the city size and P is the population of the city. The first relationship is based on the observed growth of the internal convective boundary layer next to shorelines (Venkatram 1978). The second relationship implicitly assumes that population densities do not vary substantially from city to city.

The equations listed above lead to the following equation for the nocturnal urban boundary layer height due to convective effects alone:

$$Ziuc = Ziuo\ (P/Po)^{1/4}, \qquad (5)$$

where Ziuo is the boundary layer height corresponding to Po. Based on lidar measurements taken in Indianapolis (1991), and estimates of Ziu found by Bornstein (1968) in a study conducted in New York city, Ziuo is set to 400 m in AERMOD.

AERMIC Discussion Notes for the Urban Option

The information provided below is excerpted from notes from the AERMIC meeting of July 17-18, 2001, during which the urban option in AERMOD was discussed when AERMOD was being developed.

At that time, there were some implementation issues with AERMOD that remained (and still remain 13 years later!), specifically the issue of an industrial source that has a large anthropogenic heat flux. In such a case, while this condition would in reality result in urban-like dispersion, the land use or population tests mentioned in Appendix W, as noted above, result in a rural assignment for input to AERMOD. Therefore, a procedure should be developed to model this source as urban in AERMOD.

The suggested approach in the AERMIC discussion was to allow the AERMOD user to specify a nontraditional type of urban source that is subject to urban dispersion due to industrial anthropogenic heat release rather than due to the presence of a traditional city. The user would specify the anthropogenic heat flux due to the source, or an urban-rural delta-T, if available; this would be used to determine a surrogate population value for input to AERMOD. The effective population could be calculated through the use of Eqn. 1 (listed above) if $\Delta T_{u\text{-}r}$ is specified, of Eqns. 1-3 if instead the anthropogenic heat flux is specified.

Example Applications

Example 1: $\Delta T_{u\text{-}r}$ is specified

In this case, suppose that the use of thermal infrared satellite[7] data provides a $\Delta T_{u\text{-}r}$ value of $10^{o}C$. The procedures for conducting this estimate are described in a companion white paper, and are also discussed in the open literature (e.g., Fung et al., 2009[8] and Nichol, 2005[9]. This value would be averaged over some specified area, possibly the area represented by the active industrial source

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[7] A companion 'white paper" that discusses the derivation of the effective "industrial complex heat island" temperature excess is entitled, "Quantifying Urban-Rural Temperature Differences for Industrial Complexes Using Thermal Satellite Data".

[8] Fung, W. Y., K. S. Lam, J. Nichol, and M. S. Wong, 2009. Derivation of Nighttime Urban Air Temperatures Using a Satellite Thermal Image. J. Appl. Clim. and Met. 48: 863-872.

[9] Nichol, J., 2005. Remote Sensing of Urban Heat Islands by Day and Night. Photogrammetric Engineering & Remote Sensing. 71: 613-621.

complex, but at least an area with side lengths of several hundred meters. From Eqn. 1, the surrogate population, P, is expressed as:

$$P = Po \exp [10(\Delta T_{u\text{-}r} / \Delta T_{max} - 1.0)], \qquad (6)$$

where

$\Delta T_{u\text{-}r}$ is specified by the user,

$\Delta T_{max} = 12^{o}C$, and

Po = 2,000,000.

In this case, with $\Delta T_{u\text{-}r}$ = 10 deg C, P ~ 400,000.

Example 2: anthropogenic heat flux is specified

In this case, suppose that estimates of the excess heat generated yield a value averaging 40 watts per square meter of anthropogenic heat generation in an industrial area several hundred meters on a side. This value lies within the 10-100 w/m^2 range stated by Hanna et al. (2001)[10] for urban areas. In this case, the application of Eqn. 3 with typical values stated above for α, ρ, c_p, and u* results in a value of ΔTu-r of 10 deg K. Then, using Eqn. 6, the effective population is about 400,000.

Evaluation with cases for which both the ΔTu-r and the excess heat flux estimates are available is recommended for further verification of the formulations noted in this document.

[10] Hanna, S. E. Marciotto, and R. Britter. "Urban Energy Fluxes in Built-Up Downtown Areas and Variations across the Urban Area, for Use in Dispersion Models." J. App. Met. and Clim., 50 : 1341-1353.

Appendix C Atmospheric Environmental Peer- Reviewed Journal Article About Source Characterization Techniques

Atmospheric Environment 129 (2016) 55–67

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Source characterization refinements for routine modeling applications

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HIGHLIGHTS

- Dispersion modeling source characterizations for unique facilities are described.
- Highly industrialized areas causing a heat island effect can be modeled as urban.
- Stacks with waste heat countering downwash can apply weighting to these effects.
- Extra rise for moist plumes is realistically estimated for use in "dry" models.
- Stacks in a row with merged plumes can be better represented to improve modeling.

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Source characterization

ABSTRACT

Steady-state dispersion models recommended by various environmental agencies worldwide have generally been evaluated with traditional stack release databases, including tracer studies. The sources associated with these field data are generally those with isolated stacks or release points under relatively ideal conditions. Many modeling applications, however, involve sources that act to modify the local dispersion environment as well as the conditions associated with plume buoyancy and final plume rise. The source characterizations affecting plume rise that are introduced and discussed in this paper include: 1) sources with large fugitive heat releases that result in a local urbanized effect, 2) stacks on or near individual buildings with large fugitive heat releases that tend to result in buoyant "liftoff" effects counteracting aerodynamic downwash effects, 3) stacks with considerable moisture content, which leads to additional heat of condensation during plume rise – an effect that is not considered by most dispersion models, and 4) stacks in a line that result in at least partial plume merging and buoyancy enhancement under certain conditions. One or more of these effects are appropriate for a given modeling application. We present examples of specific applications for one or more of these procedures in the paper.

This paper describes methods to introduce the four source characterization approaches to more accurately simulate plume rise to a variety of dispersion models. The authors have focused upon applying these methods to the AERMOD modeling system, which is the United States Environmental Protection Agency's preferred model in addition to being used internationally, but the techniques are applicable to dispersion models worldwide. While the methods could be installed directly into specific models such as AERMOD, the advantage of implementing them outside the model is to allow them to be applicable to numerous models immediately and also to allow them to remain applicable when the dispersion models themselves are updated. Available evaluation experiences with these techniques, which are discussed in the paper, indicate improved model performance in a variety of application settings.

1. Introduction

The AERMOD dispersion model (Cimorelli et al., 2005), recommended by United States Environmental Protection Agency (USEPA) for general short-range modeling applications out to a distance of 50 km, is widely used in air quality permit and compliance applications on an international scale (EPA Victoria, 2015). This model has been tested and evaluated against a number of traditional stack release databases (USEPA, 2003). However, aside from traditional building downwash situations, model evaluations for AERMOD and models used in other countries generally

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Abbreviations

ADMS	Atmospheric Dispersion Modelling System, an air quality dispersion model used for industrial emissions developed by Cambridge Environmental Research Consultants
AERMOD	A short range, steady-state air quality dispersion modeling system developed by the American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC)
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer, an instrument aboard the polar orbiting satellite called Terra
CALPUFF	A non-steady state air quality dispersion modeling system used for long range transport maintained and distributed by Exponent
HIA	Highly Industrialized Areas
OML	Short range air quality dispersion model that incorporates low wind effects related to aerodynamic downwash
PRIME	Plume Rise Model Enhancements, a building downwash algorithm used in the AERMOD model
SCICHEM	SCIPUFF air quality dispersion modeling system that includes chemistry
SCIPUFF	Second-order Closure Integrated Puff, an air quality dispersion modeling system maintained and distributed by Sage Management
SO_2	Sulfur Dioxide
TAPM	The Air Pollution Model, a photochemical grid modeling system
USEPA	U.S. Environmental Protection Agency

do not include scenarios in which the emission source itself substantially alters the dispersion environment. Because model performance can be an even greater challenge for some nontraditional emission sources, accurate representation of the source and its surrounding environment that influence plume rise is important.

To address this general issue, we have implemented and tested four different source characterization procedures with AERMOD, which could also be implemented in other models. All of these approaches affect buoyant plume rise, and in the case of the urban approach for highly industrialized areas, also affects plume dispersion. These approaches are different than other dispersion modeling refinements that might affect chemical transformation of released pollutants (such as NOx) because they generally do not change meteorological processing or dispersion (except for the urban approach). These effects are also independent of (and do not duplicate or replace) the low wind AERMOD enhancements described by USEPA (2012). While AERMOD itself could be modified to incorporate these changes, applying the source characterizations outside the model is beneficial because the procedures can be applicable to other dispersion models and would be more readily available for implementation. Any model changes to AERMOD would likely take several years for formal incorporation into the USEPA regulatory version. Therefore, as designed, each of the advanced plume rise techniques can be performed now using processors outside of AERMOD. In countries where other models are recommended, the methods described in this paper can be considered for those models as well. Other models for which these approaches could be used include, among others, CALPUFF (Scire et al., 2000), The Air Pollution Model (TAPM) (Hurley, 2008), Atmospheric Dispersion Modelling System (ADMS) (CERC, 2015), SCIPUFF (Sykes et al., 1999), and OML (Olesen et al., 2007).

The first source characterization method addresses sources with large "fugitive" heat releases that result in a local urban-like dispersion environment. As used in this paper, "fugitive" refers to sources of heat that are not specifically considered as input to the dispersion model. While the stack exhaust temperature and velocity are considered for plume rise calculations, the heat releases of unrelated processes in large industrial complexes are generally ignored, although they affect the dispersion environment, as noted below. AERMOD estimates urban heat island effects using an urban/rural classification based on population or land use (USEPA, 2004a), but it does not consider the effects created by large industrial complexes located in remote, rural areas. The "highly industrialized area" (HIA) effect can be addressed by a technique that accounts for the heat from an industrial complex and derives an effective urban population equivalent to the scale of the HIA as input to AERMOD, which would model the source as urban.

A second source characterization issue unaccounted for within AERMOD is similarly related to fugitive heat releases on or near individual buildings that affect plume rise from nearby stacks. These unaccounted-for heat releases generally occur on a horizontal scale well below a kilometer and affect stack plume rise in the vicinity of individual buildings. While the areal extent of the fugitive heat releases may be too small to qualify as an urban-like HIA, they can exhibit a tendency to cause buoyant effects that counteract localized aerodynamic downwash effects that would otherwise result in plumes being caught in downdrafts behind buildings. Building aerodynamic effects are handled within AERMOD by the Plume Rise Model Enhancements (PRIME) (Schulman et al., 2000) model, which was developed with limited evaluation in low winds or with buildings associated with fugitive heat releases. To account for downwash effects for cases with fugitive heat releases from buildings, a procedure called "LIFTOFF" is described, along with a model-to-monitor field study evaluation demonstrating improved prediction of receptor impacts.

Thirdly, stacks with substantially moist plumes can lead to latent heat release of condensation after the plume exits the stack, providing additional plume rise relative to a "dry" plume scenario. Although some of the initial added buoyancy is later lost due to partial evaporation, a net gain in plume rise occurs. AERMOD (and many other steady-state plume models) have plume rise formulations that are based on the assumption of a dry plume, in that the chimney plume is considered to be far from being saturated and carries essentially no moisture. A procedure to incorporate the moist plume effect by adjusting the input exit temperature data can be performed prior to an AERMOD model analysis using a pre-processor called "AERMOIST." This pre-processor makes use of a European validated plume rise model called "IBJpluris" that already incorporates moist plume effects and has been found to accurately predict the final rise of a moist plume (Janicke and Janicke, 2001; Janicke Consulting, 2015). The adjustments to plume rise using IBJpluris with and without moist plume effects can be transferred to AERMOD (or other models, as appropriate) by adjusting the input stack temperature of each affected source on an hourly basis, as a function of ambient temperature and relative humidity.

Finally, multiple stacks in a line can result in plume merging and buoyancy enhancement under certain conditions. The tendency of adjacent stack plumes to at least partially merge is a function of several factors which include the separation between the stacks, the angle of the wind relative to the stack alignment, and the plume rise for individual stack plumes (associated with individual stack buoyancy flux and meteorological variables such as stack-top wind speed). A procedure called "AERLIFT" has been created as a processor that works in conjunction with AERMOD for assessing and incorporating plume merging from aligned emission sources. It uses an hourly emissions file from an initial AERMOD run to refine the exhaust characteristics of the merging plumes on an hourly basis, and then AERMOD is run a second time with this new input of effective hourly exhaust parameters for each affected source.

In the sections below, we discuss the formulation and implementation of each of these source characterization effects. Note that these effects are generally independent from each other and can be run in combination, if appropriate. For example, in the case of a large industrial facility such as a steel mill, the characterization for a modeling application could include the urban characterization, liftoff effects of the plumes near buildings, moist plume effects (e.g., quench towers), and partial merging of plumes from stacks in a line.

2. Highly industrialized area heat islands

The urban heat island effect is a well-known phenomenon as it relates to urban and suburban areas that experience higher temperatures when compared to their rural surroundings. The key issue for plume dispersion in an urban area is that the urban heat island prevents the boundary layer from becoming stable at night, and results in weakly convective mixing at night within a deeper layer than that which exists in rural areas.

Urban surface characteristics such as albedo and surface roughness continuously affect boundary layer parameters (USEPA, 2004a). However, the boundary layer structure is most influenced by these urban surface characteristics at night (Oke, 1998). At night, an urban boundary layer is created when stable rural air reaches a warmer urban surface. Because buildings and urban surfaces trap heat more efficiently than rural areas, urban areas are slower to cool at night than the rural environments.

AERMOD currently accounts for urban environments by adjusting the urban area's surface heat flux and boundary layer height based on the urban-rural temperature difference of the urban core's temperature to the neighboring rural area's temperature (USEPA, 2004a). To calculate the urban-rural temperature difference, $\Delta T_{u\text{-}r}$, population information is used in the following equation:

$$\Delta T_{u-r} = \Delta T_{max}[0.1 \ln(P/P_o) + 1.0] \quad (1)$$

where $\Delta T_{max} = 12$ K, $P_o = 2{,}000{,}000$, the population related to the maximum temperature difference in Oke (1973, 1978, 1982), and P is the population of the urban area being modeled (USEPA, 2004a). AERMOD uses the population input value to simulate the height of the urban boundary layer.

The area of population considered for input into this AERMOD model formulation is defined using methods described in USEPA model guidance (USEPA, 2005). For locations considered to be isolated urban areas, published census data are used. Guidance further states that, "[f]or urban areas adjacent to or near other urban areas, or part of urban corridors, the user should attempt to identify that part of the urban area that will contribute to the urban heat island plume affecting the source(s)." (USEPA, 2015) For other situations, the user may determine the population within the area where the population density exceeds 750 people per square kilometer as described in the AERMOD Implementation Guide (USEPA, 2015).

To determine upward surface heat flux, H_u, resulting from the urban-rural temperature difference at night, the following relationship can be derived:

$$H_u = \alpha \rho c_p \Delta T_{u-r} u_* \quad (2)$$

where α is an empirical constant (0.03) described in the AERMOD model formulation document, ρ is the density of air (about 1.2 kg/m^3), c_p is the specific heat at constant pressure (1 W-s/g-K), and u_* is on the order of 0.1 m/s (USEPA, 2004a). This equation can be solved for $\Delta T_{u\text{-}r}$ (in units of K):

$$\Delta T_{u-r} \approx H_u/4 \quad (3)$$

where H_u is the anthropogenic heat release in units of watts per square meter in the "urban core."

A lesser known cause of urban heat island effects, and unaccounted for in AERMOD, but described by Hanna and Britter (2002) is an industrial complex that mimics a heat signature similar to cities. Fugitive heat releases at industrial facilities can be equivalent to the level of heat trapped by urban surfaces and buildings, and contribute to the effects seen in highly industrialized areas on a more compact scale, but more centered at the location of the emissions. These HIAs are not considered in the traditional urban classification approaches used for AERMOD, even though Irwin (1978) suggested this approach in an internal USEPA memo. The population near such areas is often much reduced because of zoning issues, and the area beyond the immediate industrial park may be rural in nature, resulting in a misleading characterization for this type of source. This mischaracterization was recognized in an independent study by Schewe and Colebrook (2013), who recognized the appropriateness of the urban approach for a large industrialized area.

2.1. Surrogate population for highly industrialized area characterization

Based upon Irwin's suggestions and with some adaptations to the AERMOD formulation, we are providing an approach here to specify a nontraditional type of urban source that is subject to urban dispersion due to industrial anthropogenic heat release rather than due to the presence of a traditional city. The user would specify the anthropogenic heat flux resulting from the source, or an urban-rural temperature difference, if available. This would be used to determine a surrogate "effective" population value for input to AERMOD. The effective population could be calculated through the use of eq (1) if $\Delta T_{u\text{-}r}$ is specified or eqs (1)–(3) if the anthropogenic heat flux is specified. A value of $\Delta T_{u\text{-}r}$ less than 3–4 K is likely insufficient to support an urban designation with a large effective population because, according to eqs (1)–(3), the resulting effective population would be too small (e.g., only 2,500 for a 4 K temperature difference). A more practical temperature difference threshold is about 8 K, which corresponds to an effective population of 70,000.

In eqs (2) and (3), it is important to note that the "urban core" of a HIA heat release (H_u) depicts an area with a horizontal extent of at least a few hundred meters on a side. In a follow-up to Hanna and Britter (2002), Dr. Hanna indicated that the minimum size of an industrial area needed to take on urban characteristics has been the subject of much discussion (Hanna et al., 2011; Hanna, 2014 – personal communication to authors). In his personal communication, Hanna referred to his 2011 reference (noted below) and indicated that an "expert elicitation" would likely result in a minimum size estimate of a few hundred meters. The anthropogenic heat release per unit area of major cities such as Indianapolis (extensively studied by the Electric Power Research Institute (EPRI) in the 1980s) would be on the order of 50 W/m^2. This value lies within the 10–100 W/m^2 range stated by Hanna et al. (2011) for urban areas.

2.2. Satellite analysis and model evaluation

A modeling study was undertaken using an evaluation database in Lake County in northwestern Indiana USA to test the performance of the AERMOD model for a HIA. Several AERMOD options were tested to determine the most representative scenario of 1-h average ground-level SO_2 modeled concentrations due to emissions from industrial complexes such as steel mills with respect to ambient monitoring stations in Gary and Hammond, Indiana (Fig. 1). The Gary monitor was located about 300 m from the nearest source, and generally within 2 km of the cluster of sources in close proximity to the monitor. The Hammond monitor was generally between 1 and 4 km away from nearby sources. Downwash effects, if present, would have affected the Gary monitor more than the Hammond monitor.

USEPA guidance for land use characterization indicated that this area should be modeled as rural, but the heat releases from the numerous iron and steel industry sources in this area create a dispersion environment that is effectively representative of an urban area with a large population.

For this model evaluation, the thermal imagery method was selected to determine the temperature difference between the populated areas and the industrial facilities. The procedures for conducting this estimate, discussed in more detail in open literature (e.g., Fung et al., 2009; Nichol, 2005; Voogt and Oke, 2003), are to obtain thermal infrared radiation (TIR) data for multiple time periods from polar-orbiting satellite instruments such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Landsat 8 (NASA, 2004; USGS, 2015). These data are then processed to account for surface emissivity, based on additional land use-related satellite data coinciding with the same time periods of interest, to derive a form of land surface temperature called brightness temperature. The satellite data used in these analyses must have relatively cloud-free skies so that the resulting temperature is representative of the ground rather than a cloud layer. The ASTER and Landsat 8 instruments have the ability to reliably detect land surface temperature perturbations as small as 1–2 K (Fung et al., 2009).

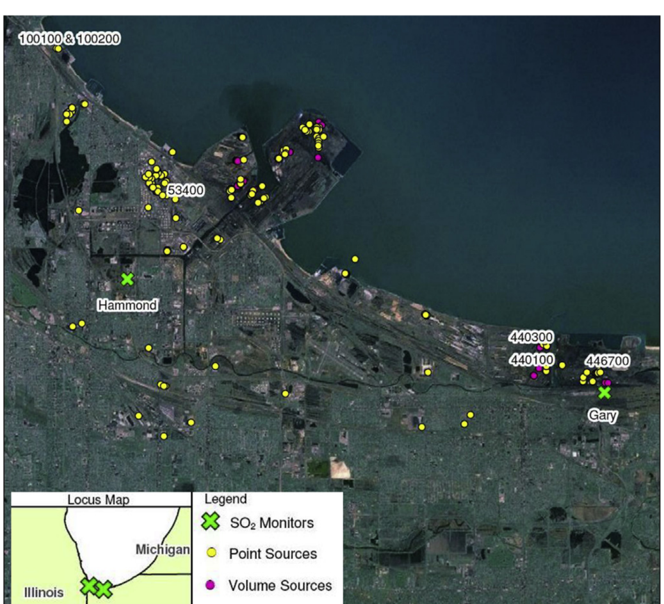

Fig. 1. Location of various emission sources in the Gary and Hammond, IN area in relation to the SO_2 ambient air monitors.

Whenever possible, multiple satellite images should be selected representing ΔT_{u-r} to examine diurnal trends as well as seasonal temperature variations of the HIA's surroundings. Ultimately, satellite data availability and the need for a nearly cloud-free image often limit a comparison of this nature. The ΔT_{u-r} uncertainty is reduced when the HIA emits heat at a constant rate such as steel, iron, or aluminum processing plants which generally operate 24 h per day, 7 days per week.

Brightness temperature in northwest Indiana was reviewed to estimate the temperature difference for the area of interest, derived from measurements by the ASTER instrument. On a summer day, maximum temperatures associated with industrial facilities were approximately 310–315 K which led to a temperature difference of about 11–12 K (Fig. 2). Although the satellite-measured temperature difference between the HIAs and the populated areas would often be greater at night, the temperature difference in this case was based upon a summer day due to satellite data availability. Note that this temperature difference measured by the satellite automatically accounts for the "urbanized" temperature excess of the HIA caused by the overall industrial heat releases not otherwise accounted for in the model. Using eq (1), this temperature difference was consistent with heavily populated areas with typical populations on the order of 1,000,000 instead of the region's U.S. Census Bureau population data of 10,000.

Three scenarios for the northwest Indiana application were run with building downwash and actual emissions for the year 2008 using AERMOD with default options: 1) rural land use, 2) urban land use with a small (actual) population of 10,000, and 3) urban land use with a large population of 1,000,000. Two model receptors were used to coincide with the SO_2 monitoring locations nearest to the facilities. In all three scenarios, the highest concentrations most frequently occurred during the night or early morning hours. The rural and small urban population modeling approaches led to AERMOD overpredictions of 1-h SO_2 as high as a factor of 10 at two monitors ranging from 1 to 10 km from the sources being modeled. The urban, large population scenario resulted in improved model performance by reducing the atmospheric stability at night, leading to higher plume rise and a deeper mixing layer for plume dispersion. The results still indicate that AERMOD overpredicted the 99th percentile daily maximum 1-h SO_2 ground-level concentration

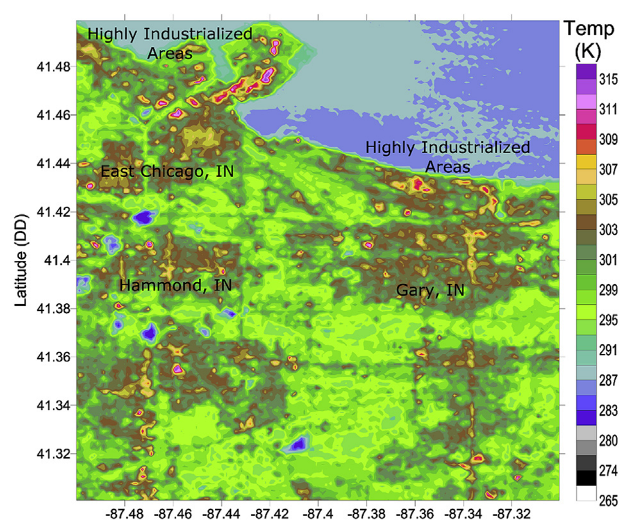

Fig. 2. Brightness temperature from ASTER band 14 on June 10, 2008 at 11 a.m. local time.

Table 1
AERMOD modeling results for rural and urban land use scenarios.

Monitor	Land use	Population	99th percentile of the daily maximum 1-h SO_2 ($\mu g/m^3$)
Hammond (96 $\mu g/m^3$)	Rural	NA	290.4
	Urban	10,000	935.5
	Urban	1,000,000	179.0
Gary (175 $\mu g/m^3$)	Rural	NA	1298.2
	Urban	10,000	1855.9
	Urban	1,000,000	392.2

Note: 1-h SO_2 99th percentile (4th highest) monitored values are listed in by monitor in parenthesis.

(which is the basis for the ambient standard in the United States) by a factor of about 2 at the Hammond and Gary monitors (Table 1). Additional refinements such as the use of liftoff effects as noted below might have further reduced this overprediction, but that analysis was not performed in this evaluation. In general, these results in comparison to the other scenarios indicate that improved model performance could be obtained by using an urban dispersion approach with an effective large population (e.g., on the order of 1,000,000).

Since actual rather than potential emissions were used in this evaluation, it is not likely that emission input uncertainty would cause the large overpredictions noted. It is possible that downwash effects are part of the overprediction problem, but such predictions are a function of the nocturnal temperature lapse rate, which is significantly different in urban vs. rural dispersion conditions in AERMOD. We strongly believe that the use of the urban characterization, as well as implementation of low wind speed improvements, are the enhancements leading to improved model performance. This northwest Indiana study involved the two monitors for which results have been reported. Additional case studies are needed to further verify these findings and approaches of which we present to encourage independent researchers to conduct such studies.

3. Plume liftoff in industrial complex environments with fugitive heat and low wind conditions

AERMOD estimates building downwash effects by applying its downwash model, PRIME, concentration estimates in the near-field where building wakes are predicted, while transitioning to the AERMOD estimates without building wake considerations in the far field (USEPA, 2004a). This transition is performed without consideration of low wind speed conditions, which can lead to poor model performance, particularly when building aerodynamic effects are estimated by the model under nearly calm conditions. Downwash conditions in near calm winds are likely to be subject to the effects of wind meander, leading to an intermittent downwash effect in any given direction. Such low wind effects have not been adequately evaluated.

In the current AERMOD implementation using default model options on a facility with short stacks close to the heights of nearby buildings, very high 1-h ground-level concentrations due to building downwash have been found by the authors to be predicted even with nearly calm winds in stable conditions. The top three predicted concentrations occurred with wind speeds less than 1.5 m/s. This is a condition for which persistent downwash effects might not be expected due to strongly buoyant plumes and weak building aerodynamic effects. For example, the CALPUFF model (Scire et al., 2000) does not consider building downwash to occur for wind speeds less than 0.5 m/s. In discussions among co-designers of the PRIME downwash algorithm in AERMOD, Dr. Lloyd Schulman and Mr. Robert Paine, Dr. Schulman confirmed that the PRIME downwash algorithm was never tested for such light wind, stable conditions, and there is no mechanism in the model for addressing the lack of or intermittent nature of the wake behind a building in very light wind conditions (Schulman, personal communication to the author, November 4, 2011). The model is assuming a plume is caught in a building wake, even in such light wind conditions, and then impacting ground-level receptors at the fenceline under very low dilution conditions. Note that when the PRIME algorithm was developed, modeling and evaluating downwash under very light winds was not a major concern when airport wind speeds in the United States were not reported below 3 knots (about 1.5 m/s). In recent years, the further use of sonic anemometers at airports and the processing of 1-min data have made the need to accommodate very low wind speeds a significant challenge. It is also noteworthy that for airport databases (including that for the northwest Indiana study), there are no turbulence measurements, and so the simulation of turbulence is affected by the boundary layer parameterization. This is one reason why the use of urban dispersion and possibly the low wind improvements to AERMOD will lead to better performance for the plume liftoff field study and its associate model evaluation presented in more detail in a subsequent section. To the extent that building downwash may be a factor, it should be noted that the depth of the enhanced turbulence region in PRIME may be overstated, as indicated by Petersen (2015).

In light winds with significant wind meander, building wake effects are unsteady, as noted by Robins (1994). However, AERMOD's basic meander treatment for low winds only applies to non-downwash dispersion, and was never implemented in the PRIME model within AERMOD. Therefore, the building downwash impacts due to PRIME predictions do not account for the intermittency of downwash effects that would tend to reduce hourly-averaged ground-level concentrations in one location. A downwash approach that accounts for low wind speeds and the inherent intermittency of steady wake effects under such conditions is already incorporated into regulatory models similar to AERMOD such as the Danish OML model (Olesen and Genikhovich, 2000) and the United Kingdom ADMS model (Robins et al., 2013).

In addition to the mistreatment of low wind conditions, a plume is able to gain buoyancy within an environment where the source's buildings provide fugitive heat on a smaller scale in comparison to a highly industrialized area. AERMOD and other steady-state plume models do not consider the additional buoyancy plume uplift due to these waste heat releases (in addition to stack releases of the pollutants of interest) in the area of an emission source, especially on or around the controlling building. An example of this is a cooler vent from taconite production furnaces; the vents do not release pollutants, but they duct very hot air to the building roof environment that will affect the aerodynamics around the building. For these cases with significant additional heat releases in the same vicinity, but not related to the pollutant stacks, plumes will resist downwash effects, especially in light wind cases. This resistance allows the plume to avoid downdrafts behind the building, which are nullified by "liftoff" conditions due to the excess heating (Hanna et al., 1998).

3.1. The LIFTOFF approach

The heat flux associated with thermal releases triggering plume liftoff can be estimated and used in an alternative approach with the use of a buoyancy flux term, F_b. Hanna et al. (1998) suggest a combined dimensionless buoyancy flux:

$$F^{**} = F_b / \left(W\,U^3 \right) \tag{4}$$

where F_b is the buoyancy flux, U is a reference wind speed, and W is the initial plume width. An approach that can be used as a post-processor to any dispersion model such as AERMOD, called "LIFTOFF", accounts for conditions with no downdraft effects using a weighting factor between one extreme (liftoff conditions, no downwash) and non-liftoff conditions (normal downwash) modeled in separate AERMOD runs. This weighting factor, γ, ranges from 0 to 1 on an hourly basis (Hanna et al., 1998):

$$\gamma = \exp\left(-6F^{**0.4} \right) \tag{5}$$

where with large buoyancy, the downwash weight approaches 0 and with minimal buoyancy, it approaches 1. To perform these calculations, an estimate of the heating is needed for the buoyancy flux term, F_b. To quantify the combined effects of the heat release, wind, and plume width, it is necessary to estimate these values. Once these values are obtained, the final calculation can be performed using the hourly weighting factor between modeled concentrations with and without downwash ($C_{Downwash}$ and $C_{No\ Downwash}$, respectively) to determine the final LIFTOFF concentrations, $C_{LIFTOFF}$:

$$C_{LIFTOFF} = \gamma\, C_{Downwash} + (1-\gamma)\, C_{No\ Downwash} \tag{6}$$

To account for low wind effects, LIFTOFF reads the 10-m reference wind speed information from the AERMET SURFACE file for each hour. In combination with the heat release and plume width information, LIFTOFF applies a weighting scheme as shown in eq (6), which is similar to the dependence on the wind intermittency for the approach used in the OML model (Olesen and Genikhovich, 2000). In general, during low wind events, it is expected that the no-downwash solution will be weighted more heavily than the downwash solution. The degree of weighting is also dependent upon the magnitude of the heat release and the initial plume width which is conservatively taken to be as large as the building width. Although the USEPA's Building Profile Input Program (USEPA, 2004b) is generally used to determine the building width, these input values can be manually edited in the event that this pre-processor overestimates the effective building width which can occur when the wind direction coincides with a long and narrow building.

For modeling applications without source-related fugitive heat releases, LIFTOFF should not be used because the calculated effect will be zero with no heat release rate. It is likely that the current PRIME model overpredicts in low winds due to its lack of considering wind meander and the related intermittent wake effects. However, with fugitive heat releases, there is a dependency of the liftoff potential on wind speed because a high wind speed would tend to dilute the effects of the heating. Therefore, the dependence of the LIFTOFF approach on all three components: heat release rate, wind speed, and initial source width is warranted. It is important, however, that any current evaluations of LIFTOFF with a substantially modified PRIME model would be useful to determine whether the weighting factor between the downwash and no downwash solutions should be adjusted.

For buoyancy effects due to source-related heat release scenarios, LIFTOFF calculates F^{**} and applies the resulting weighting factor between the downwash and no downwash model runs. These calculations are performed for each hour using the wind direction and require building width information which serves as a conservatively large estimate of the initial plume width. Additionally, an estimation of the heating is needed for the buoyancy flux term. External heating measurements can be obtained from an engineering evaluation or by estimating the temperature excess in satellite thermal imagery data using the same procedure described to estimate $\Delta T_{u\text{-}r}$ for a highly industrialized area. The temperature difference is used to solve for H_u in eq (3), where the buoyancy flux, F_b, is proportional to the heat release rate, H_u (USEPA, 1995; Briggs, 1969).

3.2. Model evaluation case study of the LIFTOFF approach

Model performance of the LIFTOFF procedure at an industrial facility featuring process areas with considerable fugitive heat releases was assessed using data from a three-month field study with four SO_2 monitors located on-site. These SO_2 monitors were oriented around the facility's three point sources in areas where the highest modeled impacts occurred based on AERMOD using default options and downwash without consideration of liftoff conditions. Monitors were approximately 400–1200 m away from the point sources (Fig. 3). The buildings affecting the point sources are shown in Fig. 4. The aspect ratio of the horizontal to vertical building dimensions was approximately 2.5:1.

Using the facility's continuous emission monitor data, several model scenarios were tested including AERMOD with default options and building downwash, AERMOD with default options and no building downwash, and the LIFTOFF technique. Although the facility was located in an isolated, rural area, it had a significant source-to-ambient temperature difference of approximately 8 K as measured by satellite imagery (Fig. 5). The area of fugitive heat was approximately 300 × 600 m, leading to a heat release of approximately 6 MW.

Modeled and monitored 1-h ground-level concentrations were

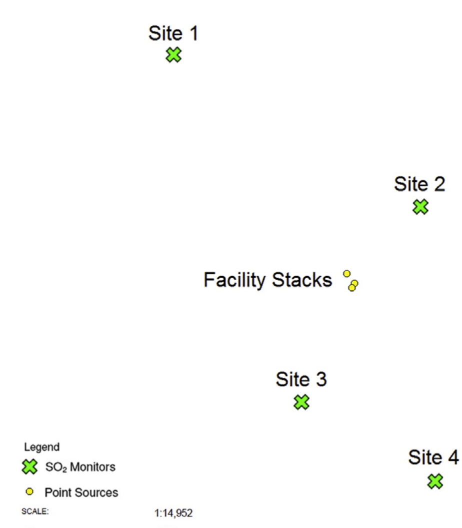

Fig. 3. At left, the industrial facility point source emissions in relation to SO_2 ambient air monitor locations.

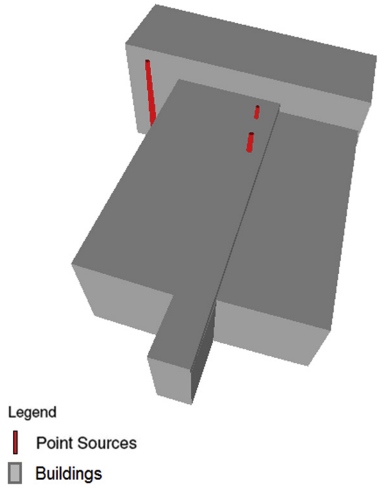

Fig. 4. At right, a 3D view, looking toward the northeast, of the industrial facility's building dimensions and point source locations.

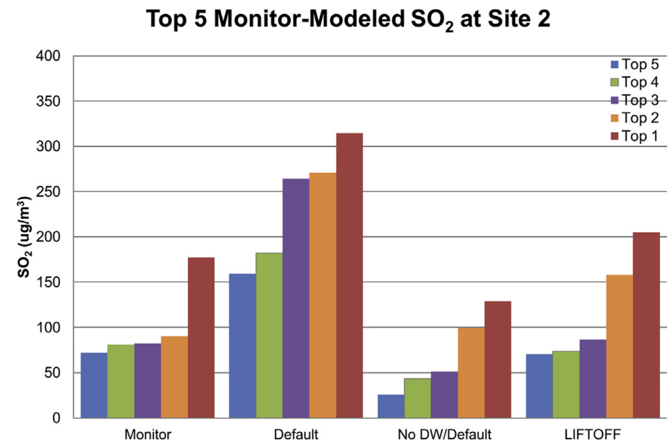

Fig. 6. Top 5 ranked daily maximum 1-h SO_2 at site 2. "Default" uses default options and downwash. "No DW" uses default options without downwash effects. "LIFTOFF" refers to the approach weighs the downwash and no downwash effects on an hourly basis.

ranked from highest to lowest and compared. In general, for the top five ranked concentrations, AERMOD with downwash indicated large overpredictions, while AERMOD without downwash exhibited a modest underprediction tendency. However, the LIFTOFF scenario (which is a weighted average of the downwash and no downwash cases computed from hourly wind and building dimension data) was relatively unbiased, and generally exhibited a modest overprediction tendency as shown by Fig. 6 for Site 2. Site 2 is the location that measured the highest SO_2 concentration during the field study. At all monitors, the top five ranked LIFTOFF concentrations were generally higher than the top five ranked observations, which is most evident in quantile-quantile comparisons of monitored to modeled concentrations as shown in Fig. 7 for each site. The LIFTOFF results have a modest overprediction and avoid the large overpredictions that are evident if no consideration is made for the fugitive heat release. More information on this model evaluation is provided in the corresponding supplemental material.

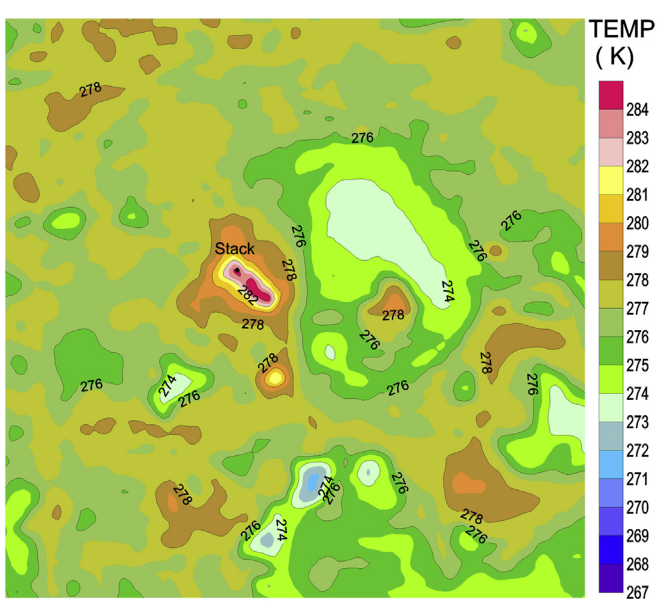

Fig. 5. Brightness temperature from Landsat 8 TIR band 11 April 21, 2013 10 p.m. local time.

4. Effects of a moist plume on plume rise calculations

The final plume rise formula in AERMOD and most other dispersion models is based on the assumption of a dry plume, where the stack plume is far from being saturated and carries essentially no liquid water load. However, in many cases for moist plumes, the effect on plume rise can be significant due to heat of condensation and should be accounted for, particularly for emission sources that operate flue gas desulphurization equipment, or scrubbers, designed to remove several pollutants from combustion plumes. The scrubbing process acts to partially or fully saturate exhaust gases while minimizing any liquid "drift" emerging from the scrubber to minimize chemically erosive processes. This process acts to cool the plume relative to the unscrubbed exhaust, resulting in a reduction of plume rise. However, the moist plume exits the stack and the heat of condensation released by the liquid water particles acts to make the plume gases warmer, giving the plume additional buoyancy. Some of this buoyancy is lost as the droplets evaporate on mixing, but a net gain in plume rise is realized from the heating/cooling process. The largest net rise is realized for the situation where the ambient air itself is near saturation.

A validated, moist plume rise model called "IBJpluris" has been found to accurately predict the final rise of a moist plume (Janicke and Janicke, 2001) and can be used to complement the dispersion modeling process when moisture content can be a significant factor. The IBJpluris model formulation includes a general solution for bent-over moist (initially saturated) chimney plumes (Janicke and Janicke, 2001). The model was reviewed by Presotto et al. (2005), which indicated that despite a number of entrainment formulas available, IBJpluris possessed the physical capability of representing the impacts of heat of condensation on symmetric chimney plume rise. The Presotto et al. (2005) paper also reported field evaluation results for the IBJpluris model involving aircraft measurements through moist plumes emitted by stacks and cooling towers. Therefore, IBJpluris was selected as the core model for developing and applying a simple adjustment method to the standard Briggs (1975) plume rise formula used by AERMOD to account for thermodynamic modification of plume rise.

4.1. The moist plume pre-processor

A method has been developed and incorporated into a pre-processor called "AERMOIST", whereby adjustments can be made

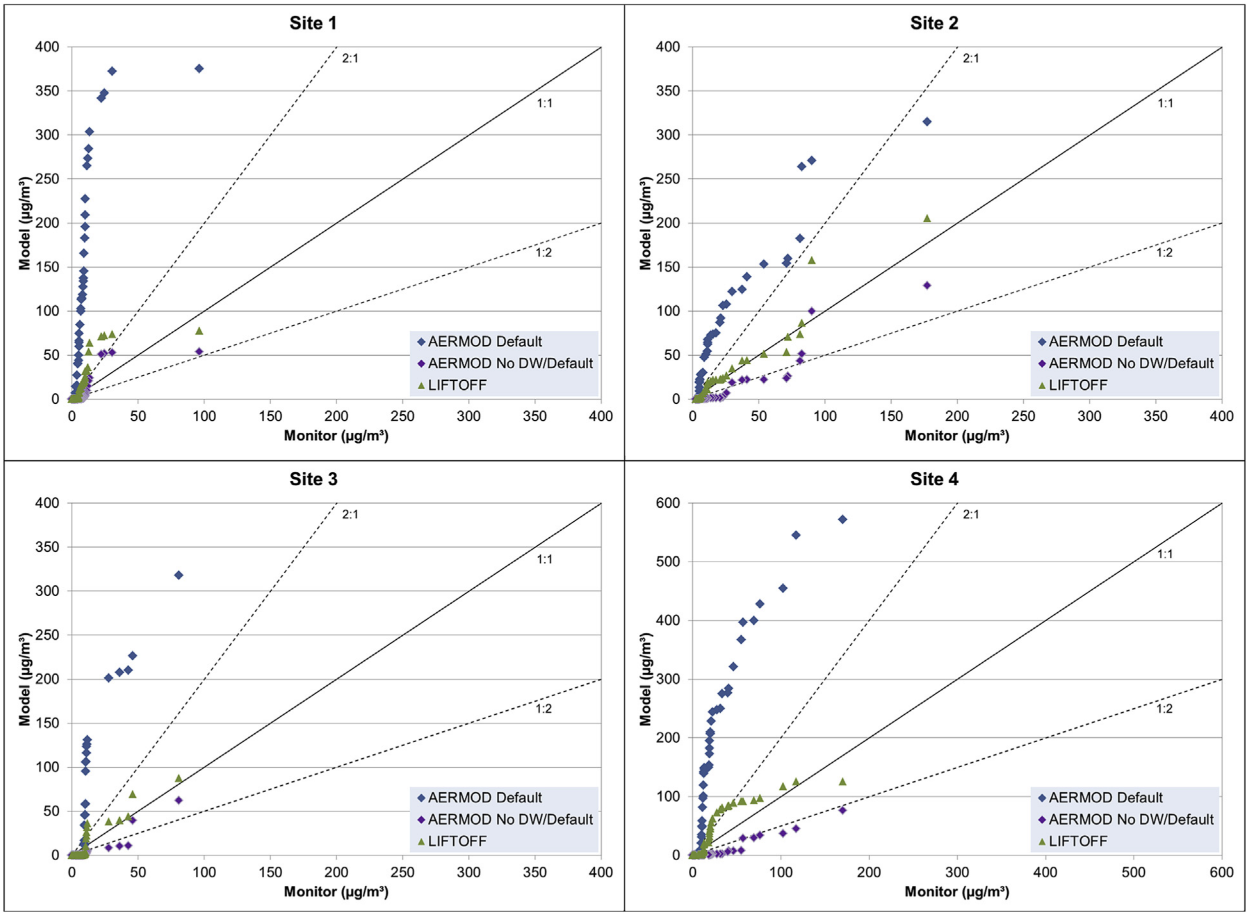

Fig. 7. Quantile-quantile comparisons between monitored and modeled daily maximum 1-h SO_2 concentrations at sites 1–4. "AERMOD Default" uses default options and downwash while "AERMOD No DW/Default" uses default options without downwash. "LIFTOFF" refers to the approach that weighs the downwash and no downwash effects on an hourly basis.

to better simulate the rise of a moist plume using a dry plume model like AERMOD. This is done by performing IBJpluris model runs for both the actual moist plume and a dry plume so that the adjustments for the difference can be made and transferred to hourly plume input data for models such as AERMOD. By assuming the ambient environment that the plume rises through is identical for both a dry and wet plume, a reasonable assumption is that the ratio of the wet to dry plume rise for IBJpluris can be used to adjust the dry dispersion model plume rise to a moist plume rise prediction:

$$[\Delta h_w(\text{model})]/[\Delta h_d(\text{model})] = [\Delta h_w(\text{IBJpluris})]/[\Delta h_d(\text{IBJpluris})] \quad (7)$$

where Δh is the change in final plume rise, and subscripts "w" and "d" correspond to moist and dry plumes, respectively. The approach assumes that this scaling ratio is independent from changes in wind speed and stability, although the variations in rise may be rather large. This assumption is reasonable since the rise is functionally related to the sum of exiting buoyancy and vertical momentum fluxes and the difference between dry and moist rise depends mainly on buoyancy, which is primarily temperature- and relative humidity-dependent.

The rising plume, by analogy, can be treated as if it were a rising moist thermal and cloud dynamic process. Concepts such as the buoyancy factor (Jacobson, 2005) can be applied since this same buoyancy factor appears in the Briggs (1975) dry plume rise. The major difference is that the cloud buoyancy depends on the virtual temperature, which depends on temperature, pressure, and relative humidity of both the plume and the environment. The buoyancy factor, F_b, for both plume and cloud water as normalized density can be expressed by the difference between plume temperature and ambient temperature, divided by the plume temperature, when virtual temperature is equal to dry bulb temperature. The approximate term appears in Briggs (1975) final plume rise formula for the dry buoyancy flux term. The final rise Δh_f is a power law function of F_b, where the power is '1/3' as derived by Briggs (1975). Following Jacobson (2005), the moist buoyancy can be expressed in terms of the virtual temperatures and water vapor partial pressures of the plume and the ambient environment as T_{va}, T_{vp}, and P_a, P_{wa}, P_{wp}, where P_{wp} is assumed to be saturated, P_s. The virtual temperature, T_v, can be expressed in terms of dry bulb temperature, T (Arya, 2001):

$$\begin{aligned} T_v &= T(1 + 0.608\, q_v) \\ &= T\{1 + 0.608[0.622\,(RH)\,P_s/(P_{da} + 0.622\,(RH)\,P_s)]\} \end{aligned} \quad (8)$$

where q_v is the mixing ratio in kg of moisture per kg of dry air, P_{da} is the dry atmosphere pressure, and RH is relative humidity as a fraction. For a plume exit temperature of 325 K, the virtual temperature of a saturated plume is 390 K. As the saturated plume temperature increases, so do the effects of virtual temperature, especially for higher stack temperature and relative humidity.

Using a relationship for estimating the saturation vapor pressure of water derived from the Clausius-Clapeyron equation (Arya, 2001), the relative humidity of a plume can be estimated from the moisture content (%) at the plume exit temperature:

$$P_s = 6.112 \exp\{6816[(1/273.15) - (1/T)] + 5.1309 \ln(273.15/T)\} \quad (9)$$

where all pressures are in hectopascals (millibars). The IBJpluris model has the ability to treat sub-saturated plumes as long as the plume emission temperature is held constant. Using eq (9) and the moisture content of the exiting plume, the relative humidity of the plume can be estimated. As the ambient air retains more moisture, the plume travels higher before reaching equilibrium with the ambient air.

4.1.1. Equivalent dry plume temperature approach

An effective approach for representing moisture in plumes is to adjust only the plume temperature rather than changing both plume and ambient temperatures, which would be required if virtual temperature were to be used directly. This revised plume temperature is generated by AERMOIST and can be referred to as an "equivalent dry plume temperature", and it is always greater than the original plume temperature and does not equal the virtual temperature. This hourly equivalent plume temperature is input to a dispersion model such as AERMOD in an hourly emissions input file so that the moist plume rise is more accurately modeled. The scaling relationship based on the right hand side of eq (7) forms the first part of the adjustment model. The plume height scaling parameter is given by the moist over the dry buoyancy flux:

$$\beta = \left(\Delta h_w^3 \big/ \Delta h_d^3\right) \quad (10)$$

where subscripts w and d refer to moist and dry buoyancy fluxes, respectively.

Two equations relating final rise to equivalent plume and ambient temperature are:

$$\Delta h_d^3 = \lambda F_{bdry} = \lambda\left[(T_p - T_a)/T_p\right] \quad (11)$$

$$\Delta h_w^3 = \lambda F_{bwet} = \lambda\left[(T_p^{eq} - T_a)/T_p^{eq}\right] \quad (12)$$

The exponent of 3 in eq (10) is due to the Briggs (1975) plume rise dependence on the buoyant flux, F_b, to the '1/3' power. As the vertical momentum flux becomes a larger fraction of the total flux, the effective exponent for the buoyant rise becomes smaller because the momentum plume rise is proportional to the momentum flux, F_m, to the 1.5 power. In AERMOIST, the exponent is treated as a user input to be conservative (<3) when the total plume rise may have appreciable momentum at release. A smaller buoyant rise exponent, such as 2.5, helps to insure that the model is conservative and the plume rise is not overstated.

From the equations stated above, the equivalent plume temperature, T_p^{eq}, can be solved for directly as:

$$T_p^{eq} = T_p\, T_a/\left[(1-\beta)T_p + \beta T_a\right] \quad (13)$$

The ratio, β, is a function of both humidity and temperature and is found by the dry and moist IBJpluris simulations. As β goes to 1, the equivalent plume temperature approaches the dry plume temperature, T_p.

To provide the hourly equivalent plume temperature to AERMOD, a simple interpolation bilinear model is constructed using a series of βs across a range of temperature and relative humidity. At the end points of each range, β is calculated using IBJpluris and applied in a Taylor first-order expansion to create a bilinear model for the wet to dry ratio of plume rise within each range, $\beta(T_a, RH_a)$. The model assumes that ambient air at stack exit will be in the range from 253 to 313 K. Ambient temperatures outside of this range are clipped. The ambient relative humidity is assumed to lie between 0% and 95%. Values above 95% are clipped because these lie in a range of extreme sensitivity to conditional instability.

In AERMOIST, the IBJpluris model is exercised in both dry and wet mode for each range and an array of temperatures and humidity over the range of possible values, $\beta(T_i, RH_j)$ ratios, is saved for each stack that is modeled and are used to estimate the model adjustment coefficients, $C_{i,j}$ and $D_{i,j}$. The continuous model for the moist to dry plume rise ratio becomes:

$$\beta(T_a, RH_a) = \beta(T_i, RH_j) + (T_a - T_i)\, C_{i,j} + (RH_a - RH_j)\, D_{i,j} \quad (14)$$

The $\beta(T_a, RH_a)$ are used to estimate the equivalent hourly plume temperatures for input to the dispersion model for each hour of emissions. By modifying only the plume temperature, multiple sources can be included in the model run, each with their own series of equivalent hourly plume temperatures. Dry plumes can also be modeled with standard, constant input data.

4.1.2. Moist plume rise testing

The IBJpluris model was exercised for a typical saturated, scrubbed power plant, with characteristics as listed in Table 2. The exiting plume moisture content for this test stack is 13.4%, and for a surface pressure of 1000 hPa, $P_s = 134$ hPa which, according to eq (8), translates into a saturated plume ($RH_p = 100\%$) for an observed stack temperature of 325 K. The source's plume characteristics suggest that such an observed temperature (dry bulb) is actually near 340 K in terms of the virtual temperature for the saturated plume.

The profile used by AERMOIST assumes neutral conditions with a height constant humidity and turbulence profile. For a given environmental humidity value, the plume was modeled with dry humidity (0%) and a moist humidity based on the actual moisture content of the plume. The resulting plume rises as a function of downwind distance are illustrated for the dry (0% RH_p) and the moist (100% RH_p) plume cases with a dry ambient humidity (0% RH_a), and for a saturated plume emitted into a nearly saturated environment in Fig. 8. The rise at 2000 m downwind is 189.8 m for the dry plume and dry environment, 209.3 m for a saturated plume in a dry ambient environment, and 219 m for the saturated plume rise in a 90% constant RH environment. At an ambient temperature of 293 K, the percent increase over the dry case is 10.3% and when a moist environment is considered, it is 15.4%.

AERMOIST systematically exercises IBJpluris for each of the temperatures and relative humidity ranges (bins). Assuming final rise estimates at 2000 m downwind for a select set of temperature and relative humidity ranges, it is apparent that the largest rise of the saturated plume occurs at 90% humidity environmental conditions for the cooler ambient temperatures. The dependency on ambient humidity of final rise at any ambient temperature is rather

Table 2
Moist plume characteristics used in the test case.

Stack height (m)	Exit diameter (m)	Exit temperature (K)	Exit velocity (m/s)
171.45	14.23	325.37	15.16

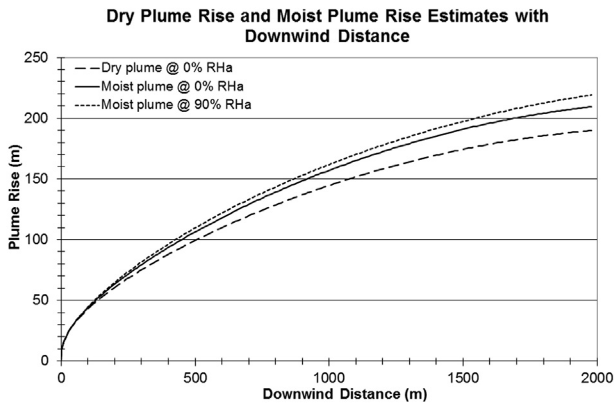

Fig. 8. Plume rise as a function of downwind distance for dry rise and an initially saturated plume by the test source for two constant relative humidity environmental conditions.

small for a dry plume, allowing for ambient RH to be ignored for dry plumes. However, moist plume rise will increase substantially as the ambient humidity approaches saturation with an increase of over 10% from dry, cool air to moist cool air. Using virtual temperature by itself does not explain this effect. As the ambient temperature increases and the buoyancy factor decreases, the change in plume rise with humidity is reduced. The resulting equivalent plume temperatures for use in dispersion modeling generated by AERMOIST, which actually runs the validated IBJpluris plume rise model, produce improved plume rise estimates for moist plumes. As evaluated by Presotto et al. (2005), the IBJpluris model predicts a more realistic plume rise for moist plumes than a model that represents a moist plume as a dry plume. Therefore, using the AERMOIST technique in conjunction with a dry plume model such as AERMOD will result in improved model performance by reduction its inherent model overprediction.

5. Plume merging of stacks in a line

When adjacent stacks are positioned in a line, the individual plumes have shown to have a tendency to merge causing a buoyancy enhancement under certain conditions. This plume merging tendency is influenced by the stacks' proximity, the wind direction relative to the stack configuration, and individual stack plume rises. Briggs (1984), refers to the results of wind tunnel studies for a row of identical stacks that indicate the usefulness of a merger parameter, S′, to determine the effect of the angle of the wind relative to the stack alignment:

$$S' = (\Delta s \sin\theta) \Big/ \left[L_b^{1/3} (\Delta s \cos\theta)^{2/3}\right] \quad (15)$$

where Δs is the average spacing between the aligned stacks, θ is the wind angle relative to the alignment angle of the adjacent, inline stacks, L_b is the buoyancy length scale where:

- $L_b = F_b/U^3$,
- F_b is the buoyancy flux where $F_b = g\, V_s^2 D_s^2/4\ [(T_p - T_a)/T_p]$,
- U is the wind speed at plume height,
- V_s is the stack gas exit velocity,
- T_p is the stack gas temperature,
- T_a is the ambient temperature, and
- D_s is the stack diameter.

By definition, S′ is undefined when the wind is exactly normal to the alignment angle, so in practice for that case, an angle not exceeding 89.99° is used in the approach described in the next section.

Wind tunnel studies using neutral conditions showed that S′ less than 2.3 results in buoyancy enhancement while values above 3.3 indicate no enhancement (Briggs, 1984). Intermediate values would indicate partial enhancement. For those wind angles that allow plume merging, a formulation for the buoyancy enhancement accounting for other factors noted above due to the merging of adjacent plumes can be taken from the Manins implementation (Manins et al., 1992) of the Briggs formulation:

$$E = (N + S)/(1 + S) \quad (16)$$

$$S = 6\left\{[(N-1)\,\Delta s]/\left(N^{1/3}\,\Delta h\right)\right\}^{3/2} \quad (17)$$

where E is the buoyancy enhancement factor, N is the number of stack in the row, S is a separation factor, and Δh is the plume rise for one stack. While the buoyancy flux would be enhanced, the momentum flux should be unchanged. The formula for the momentum flux in AERMOD and many other dispersion models is:

$$F_m = (T_a/T_p)\, V_s^2\, D_s^2/4 \quad (18)$$

Therefore, the buoyancy enhancement would increase T_p and V_s in a manner to provide the appropriate multiplier to F_b while retaining F_m by retaining the ratio of V_s^2/T_p.

Several investigators noted in Briggs (1984) have studied and reported buoyancy enhancement for only two stacks. Briggs noted that "all of the authors referenced in this section compared the predictions of their models, at least for N = 2, with the semi-empirical results of Briggs (1974) and concluded that, as different as these approaches seem, their predictions were very similar." Additionally, the plume rise enhancements plotted in neutral conditions by Anfossi (1985) indicated that even for stacks separated by 77 m, some enhancement was observed in conditions of substantial buoyancy.

Additional supporting evidence for plume merging from two stacks is available from more recent journal articles. These articles are consistent in reporting an angular dependence on the extent of the merging. Macdonald et al. (2002) indicated that there is a definite enhancement for flow parallel to the line of stacks. For larger angles, due to dual rotors from plumes (clockwise looking downwind on the right side and counterclockwise on the left side), there can sometimes be some plume rise suppression between two closely spaced stacks for wind angles approaching a perpendicular to the line of stacks. These authors also noted plume rise enhancement for power plant stacks separated by a distance of more than 1 km, providing support for no arbitrary distance cutoff for this algorithm. The Briggs algorithm will automatically reduce the plume rise enhancement as the distance between the stacks increases.

Furthermore, Overcamp and Ku (1988) conclude that "tests with azimuthal angles of 0° and 30° showed enhanced rise". Tests with azimuthal angles of 60° and 90° did not appear to exhibit enhanced rise (Overcamp and Ku, 1988), information that was incorporated into the Briggs formulation. Similar confirmation of plume merging effects from two identical, separated stacks is documented by Contini et al. (2006). The dependence of the enhanced buoyancy on the approach angle to the stacks is similar to findings by the other investigators.

5.1. The AERLIFT technique

The AERLIFT technique has been developed to account for potential merging of plumes from aligned emission sources and the resulting partial to full enhanced plume buoyancy. This intermediate processor, run outside of the AERMOD modeling system for this implementation, creates an enhanced hourly emissions file using information from an initial model run with information for effective stack exhaust characteristics of the partially merged plumes. The model is then run a second time using the adjusted source parameters.

To define the parameters necessary for calculating the buoyancy enhancement on an hourly basis, the initial dispersion model run for the stacks involved is set up to run with a 10-km ring of 360 receptors set 1° apart in flat terrain. Next, the AERLIFT processor takes the meteorology and the model output data (i.e., the hourly and source specific final plume rise and effective wind speed) to determine first whether plume merging occurs, and if so, by how much.

The maximum enhancement factor applied to the buoyancy flux is the number of stacks in the line. The AERLIFT processor applies the enhancement factor to the original stack velocity and temperature, and derives an altered set of parameters that increases the buoyancy flux by the appropriate factor while preserving the momentum flux. This is done to conservatively apply the enhancement to only the buoyancy component. During stable hours, AERLIFT uses the plume rise directly in eq (17). For added degree of conservativeness, during unstable hours for when the stack top is less than the mixing height, AERLIFT selects the minimum between the final plume rise and the mixing height, which is defined as the maximum of the mechanical and convective mixing heights, for use in eq (17).

Finally, a second dispersion model run is performed using the appropriate terrain options and modeling receptors for the emission source as well as the enhanced hourly emission file from AERLIFT.

5.2. Evaluation of AERLIFT

AERMOD has been tested with the AERLIFT approach with a model evaluation field study conducted by Eastman Chemical Company in Kingsport, Tennessee, USA (described by Paine et al., 2013; Szembek et al., 2013). This study featured a 1-year monitoring period with 4 monitors featuring a line of 5 coal-fired boiler stacks. The inclusion of the AERLIFT approach significantly reduced AERMOD overpredictions, as noted by Szembek et al. (2013). The need for this feature was particularly evident when plumes from a row of 5 stacks indicated overprediction for impacts at a monitor located in elevated terrain, in spite of other model improvements from the low wind options (adjusted u* and LOWWIND options in AERMOD). When this single feature was tested in isolation, it resulted in a higher plume rise and a better model evaluation result in both flat and elevated terrain. This improvement was due to the effect of AERLIFT on plume rise and the attendant effect on predicted concentrations.

6. Examples of source characterization applications

Examples of the use of both the highly industrialized area (urban) application and the LIFTOFF approach would be a large aluminum smelter or large steel mill. These sources typically feature extensive areas of excess heat releases and stacks in the midst of the heated building areas. The heat release can be quantified with either a satellite thermal imagery analysis or through engineering estimates of the heat loss.

An example of a facility with only the LIFTOFF effect would be a smaller heated industrial area such as a taconite ore processing facility. This type of facility might typically have the heat release area encompassing only a few hundred meters. If the facility's point sources have considerable plume moisture, then the AERMOIST approach may also be used.

Stack releases from processes involving flue gas desulfurization controls would be good candidates for the AERMOIST approach. Flue gas desulfurization controls treat the plume by injecting an alkaline reagent into the flue gas to remove SO_2 from the gas. This treatment results in higher plume moisture content than those without the treatment, thus making it viable for the AERMOIST approach.

For any of these applications, a situation with a row of stacks (even if only 2) would qualify for the AERLIFT approach, especially if they are within a few stack diameters of each other. As noted above, the stack separation distance affects the plume rise change due to stack merging.

At the time this paper was submitted in revised form, there were a few modeling applications in the United States for which these methods have been proposed and are either being applied based upon the past evaluations reported in this paper, or are going to be evaluated in the near future based upon new field data. In the case of the Eastman Chemical evaluation study (Paine et al., 2013; Szembek et al., 2013), the urban characterization as well as LIFTOFF have been used in the same application as approved USEPA techniques.

7. Summary

Steady-state plume models such as AERMOD have not been extensively tested or designed for scenarios where an emission source modifies the dispersion environment. Model performance for these conditions has become increasingly important in light of short-term pollutant standards, e.g., for 1-h SO_2 and 1-h NO_2 United States ambient standards. Four independent source characterization techniques described in this paper have been adapted and evaluated to better represent plume rise effects for nontraditional sources and their surrounding environment. These techniques are implemented as universally applicable to many dispersion models and are thus designed to be used as external processors that interact with the main dispersion model.

Two of these source characterization methods address fugitive heat releases at industrial complexes. The first occurs on a large scale resulting in a local urban-like dispersion environment called a “highly industrialized area”. To account for this excess heat, an effective population equivalent to the scale of the HIA can be calculated using an already existing relationship between population to urban-rural temperature difference and used as input to the dispersion model. We recommend that this approach is applied to areas with a scale of at least several hundred meters and an excess temperature between the HIA and the surrounding area of at least 8 K. The second, smaller scale excess heat release issue relates to building downwash effects, and can be addressed by using the LIFTOFF procedure and a weighting relationship using procedures developed by Hanna et al. (1998). Both the HIA's effective population and LIFTOFF technique can be applied in the same modeling application. Both have been evaluated and shown to provide modest overpredictions.

Stacks with moist plumes can lead to latent heat release of condensation after the plume exits the stack, providing additional plume rise relative to a dry plume case. This effect has been neglected in many dispersion models, but with the increasing use of flue gas desulfurization controls that inject considerable water vapor into the plume exhaust, accommodating this effect is very important. The AERMOIST procedure incorporates this moist plume effect by refining the hourly input exit temperature data based on a scaling ratio developed using a previously validated European model (the IBJpluris model) which incorporates moist plume effects. Stack sources for which this approach is particularly relevant is for processes involving wet and dry flue gas desulfurization controls.

Lastly, multiple stacks in a line can result in plume merging and buoyancy enhancement under certain conditions. The AERLIFT processor assesses and incorporates plume merging from aligned emission sources using an hourly emissions file from an initial model run. The exhaust characteristics of the merging plumes are refined by AERLIFT on an hourly basis, and then the dispersion model is run a second time with a new input of effective hourly exhaust parameters for each affected source.

These advanced plume rise procedures have been designed for use with dispersion models without the need to change the modeling system code, and are shown to improve model performance. They can be used individually, or in combination. By including these procedures outside of the modeling code as source characterization techniques, these procedures are available to a large suite of modeling approaches. In addition, their use as more accurately portraying the source plume behavior is inherently a refinement outside the model's treatment of plume transport and dispersion. Although we have provided available model performance results, we encourage much wider testing and evaluation of these approaches in a variety of settings.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.atmosenv.2016.01.003.

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Appendix D Justification for Use of a Three-Season Field Study Database for use in the Alcoa Warrick Site-Specific Evaluation

Justification for Use of a Three-Season Field Study Database for the Alcoa Warrick Site-Specific Evaluation

Date
September 2017

Prepared by
Laura L. Warren and
Robert Paine

Client
Alcoa Warrick LLC

1 Introduction and Overview

EPA indicated that the preferred AERMOD modeling approach for Warrick Operations should be supported by a site-specific field study. Accordingly, to address both the SO_2 NAAQS implementation (to characterize SO_2 concentrations near the facility, addressed in this protocol) and to potentially apply for a New Source Review permit application in the future, Alcoa, IDEM, and EPA agreed in 2015 upon a 4-monitor network that was described in a model evaluation protocol submitted[1] to the agencies in 2015. The monitoring network was designed to measure peak short-term SO_2 impacts from the Alcoa smelter and the adjacent coal-fired power plants (WPP and the adjacent Culley Generating Station). That monitoring network went into operation on July 11, 2015. Although there was intent to operate the network for a full year, Alcoa announced plans to shut down the smelter for economic reasons during the first quarter of 2016. Accordingly, just before the emissions from the smelter were reduced and then totally eliminated with a plant shutdown by late March 2016, Alcoa ended the monitoring program after February 19, 2016. Thus, the monitoring period addressed the seasons of summer, autumn, and winter, but not spring.

This appendix demonstrates that the three seasons of monitoring represents the worst-case portion of the year, and that the model evaluation results can be used to support acceptance of the site-specific modeling approach (Case 4 as described in Appendix A) for the Alcoa Warrick Operations. Section 2 describes the design of the monitoring network. Section 3 describes seasonal trends in the monitored concentrations (2014-2015) for the P2 monitor and modeled concentrations (using 2014-2015 P2 meteorological data) to justify the use of this period for the model evaluation. Conclusions are presented in Section 4.

[1] AECOM, 2015. Alcoa Warrick Operations: Site-Specific SO_2 Model Evaluation Protocol. AECOM Document No. 60323156.100, September 2015.

2 Ambient and Meteorological Monitoring Network Design and Observations

2.1 Network Design

During the period of 2010-2015, there were multiple site-specific field studies for the Alcoa Warrick Operations SO_2 concentration pattern, and this information was communicated to IDEM and EPA through presentations and reports in several meetings and conference calls. Based upon special field studies that occurred in December 2010 and also during early 2014, it was apparent that peak observed SO_2 concentrations occur at or near the plant fence line to the north and east of the plant. Accordingly, Alcoa, IDEM, and EPA agreed upon a 4-monitor network which was designed to measure peak short-term SO_2 impacts from the Alcoa smelter and the adjacent coal-fired power plants (WPP and Culley Generating Station).

In order to develop a model evaluation database suitable for testing a site-specific model, Alcoa expanded its SO_2 monitoring network beyond the historical site about 1 km north-northeast of the smelter (the P2 site). The additional sites (denoted as S1, S2, and S3) were sited to capture peak concentrations expected near the smelter, as determined from previous modeling analyses and short-term field studies. A map showing the plant fence line, the existing P2 monitoring site, and the locations of the additional monitoring sites (S1, S2, and S3) is depicted in **Figure 2-1**. Geographical coordinates for these monitors are provided in **Table 2-1**.

The additional three sites that augmented the P2 site were placed near the plant fence line in the downwind direction for prevailing winds, so as to capture source lineup conditions. This monitoring network went into operation on July 11, 2015. Monitoring data from the network was submitted to IDEM on a quarterly basis.

The default and site-specific models to be evaluated with this field database are based upon the AERMOD model and are described in Appendix A. Due to the flat terrain and the stack release height of about 15 meters for the smelter SO_2 sources of key interest, a standard 10-meter meteorological tower located near the P2 site was used in the study design to provide site-specific meteorological data suitable for the model evaluation. The meteorological tower measured wind direction and wind speed at the 10-meter level, as well as ambient temperature and sigma theta turbulence.

The monitoring equipment was operated and maintained according to the provisions of 40 CFR 58, Appendix A and the IDEM Quality Assurance Manual. Further details regarding the instrumentation used in the study as well as site photos are provided in the 2015 model evaluation study protocol submitted to IDEM in September 2015.

2.2 Monitored Concentrations

During the 4-monitor field study, not a single 1-hour SO_2 NAAQS exceedance at any monitor occurred from July 11, 2015 to February 19, 2016. **Figure 2-2** provides a time series of the monitored concentrations where concentrations are provided in units of micrograms per cubic meter (ug/m^3). The black dashed line notes the level of the 1-hour SO_2 NAAQS at 196.5 $\mu g/m^3$. The 99th percentile monitored concentrations (in this case, the 3rd highest concentration) are particularly important because modeling uses the 99th percentile to determine the relevant model results in relation to the 1-hour SO_2 NAAQS. **Figure 2-3** provides a bar graph of the 99th percentile monitored concentrations by monitor.

Figure 2-1: Map of Alcoa Warrick Monitors

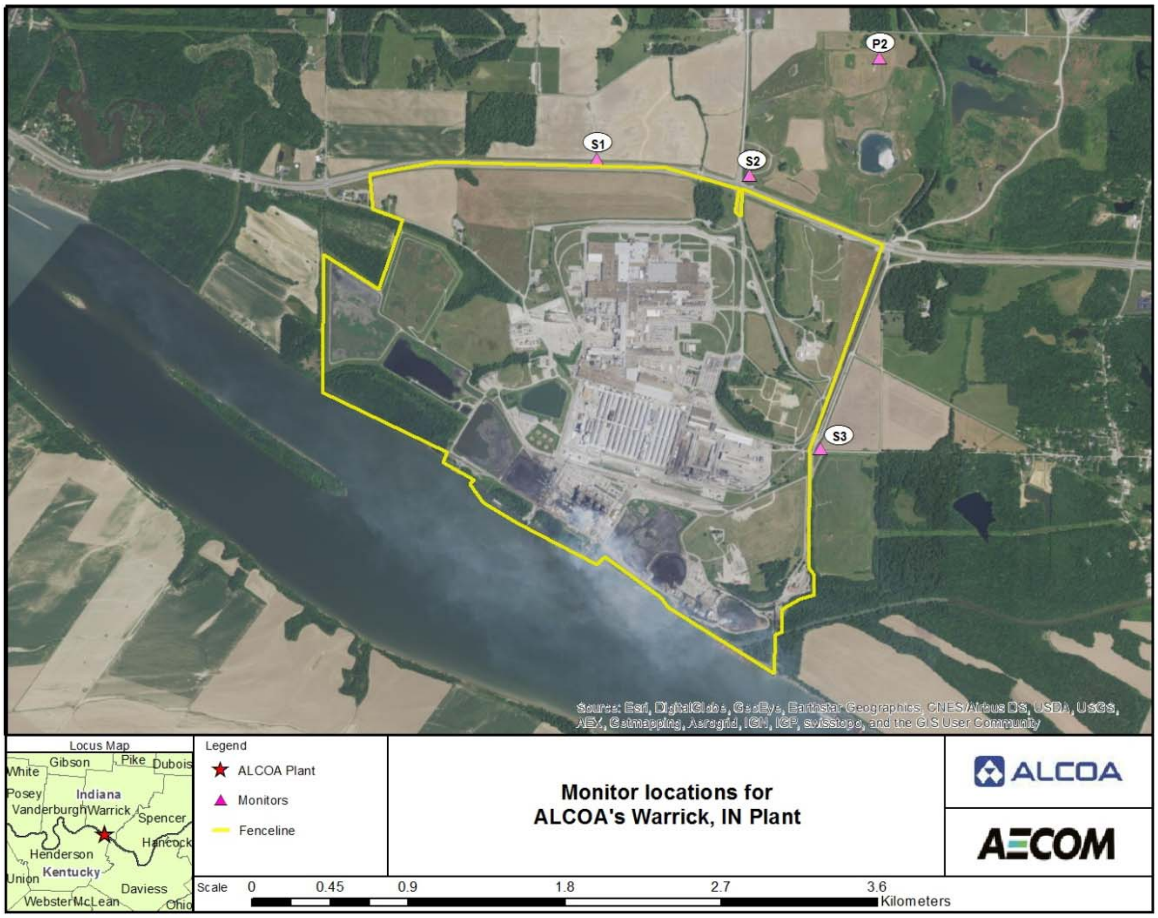


Table 2-1: Alcoa Warrick Monitor Locations

Monitor	UTM East (m)	UTM North (m)
P2	472393.59	4198940.07
S1	470801.31	4198431.47
S2	471679.77	4198339.62
S3	472085.98	4196764.55

Figure 2-2: Monitored SO_2 Concentrations during the 4-monitor Field Study

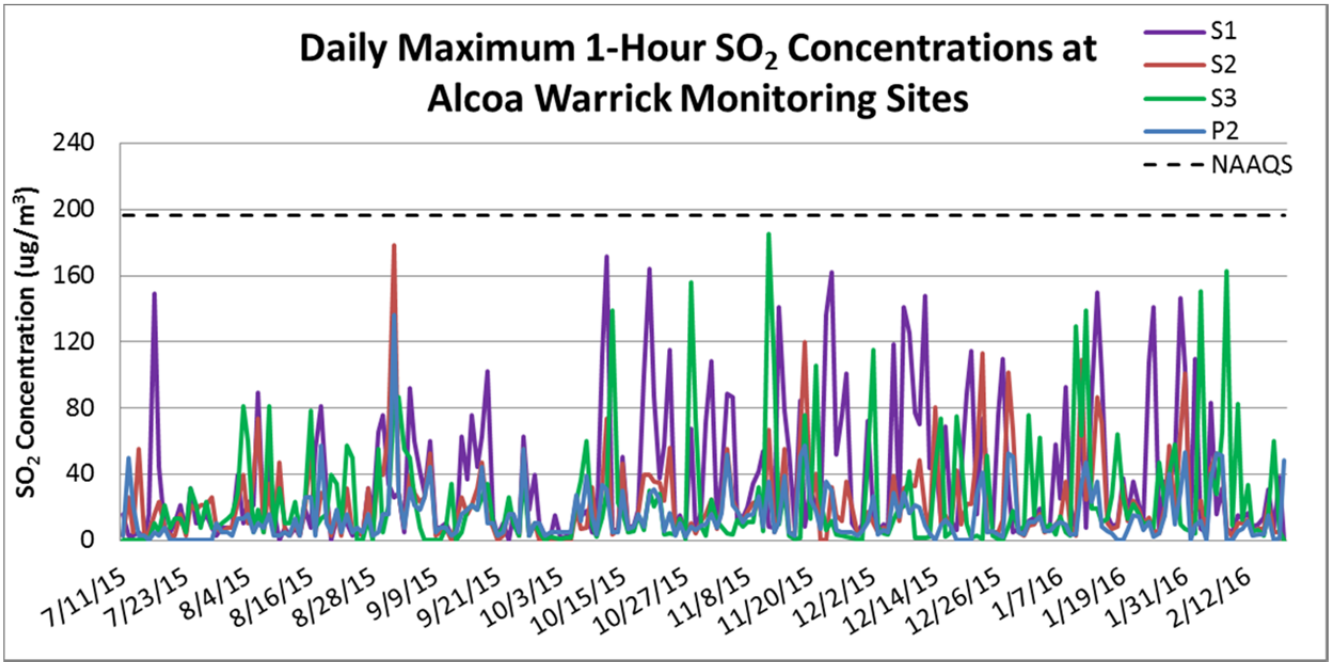
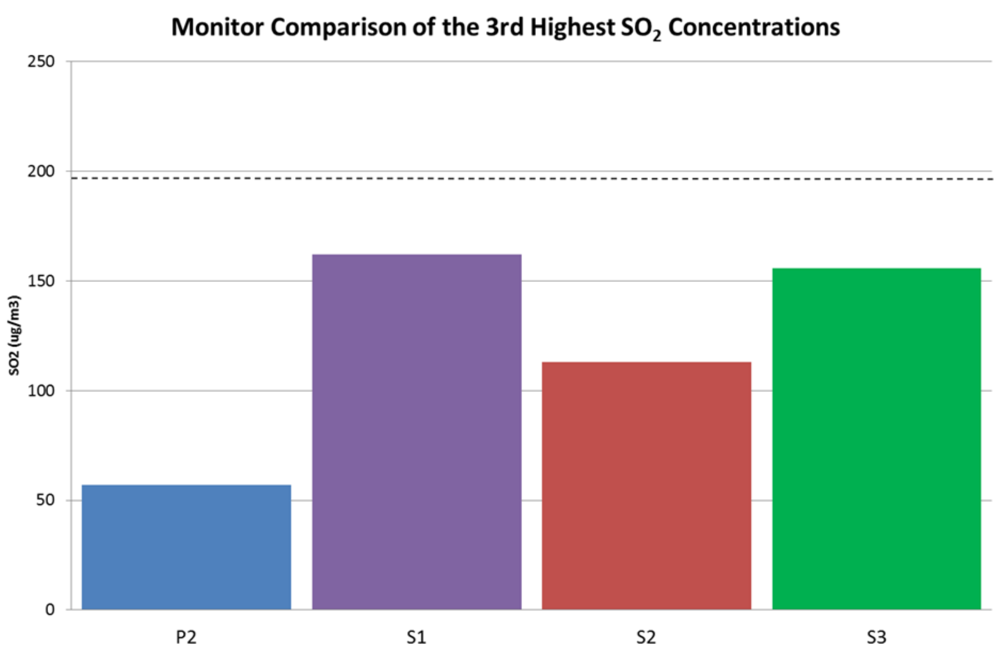


Figure 2-3: Monitored 99th Percentile SO_2 Concentrations during the 4-Monitor Field Study



3 Review of Monitoring Period vs. Full Year

In most cases, model-to-monitor evaluations are performed using at least one year of monitoring data. This field study ended earlier than expected as a result of the facility's shutdown, as previously discussed. As such, the three seasons of available monitoring data were investigated to determine whether the monitoring program covered the time of year when worst-case concentrations would be expected. Seasons are defined here as winter from January – March, spring as April – June, summer as July – September, and autumn as October – December.

3.1 Review of 2 Recent Years of P2 Monitoring Data

The P2 monitor is a long-term monitor that most recently had full year data for both 2014 and 2015. Therefore, these full years vs. the three-season model evaluation study period were reviewed to determine whether the controlling concentrations would change if the evaluation study monitoring had been extended for a full year. For both 2014 and 2015, we examined the seasons for the top 4 daily 1-hour maximum concentrations as well as the number of days with daily maximum concentrations above 50% of the NAAQS at P2.

For 2014, the top 4 daily maximum concentrations all occurred in the seasons covered by the site-specific monitoring and all of the daily maximum concentrations above 50% of the NAAQS occurred in these 3 seasons. For 2015, 3 of the top 4 daily maximum concentrations occurred in the seasons covered by the site-specific monitoring, and the top 4 days constitute all of the days above 50% of the NAAQS. From this analysis, it is apparent that the 3 seasons covered by the monitoring study addressed most of the peak concentrations seen at the P2 monitor in 2014 and 2015.

3.2 Modeling Analysis at the 4 Monitoring Sites for 2014-2015

We also conducted a modeling analysis using actual monthly smelter emissions and constant full-load emissions for the power plant sources in 2014 and 2015 to determine if the preferred site-specific modeling approach would predict peak daily 1-hour maximum concentrations during the period of the monitoring study vs. the spring season. The P2 meteorological data was used for this period. This 2014-2015 meteorological data was processed in the same manner described in Appendix A. Constant emissions for the power plants were used in lieu of actual hourly emissions because the smelter sources are the focus of this study. By using the 95^{th} percentile 2014-2015 emissions, exit temperature, and exit velocity for each plant, constant stack parameters were determined in order to represent full load conditions.

The top 5 peak daily 1-hour maximum concentrations as modeled with the preferred modeling approach (Case 4 as described in Appendix A) are listed at each monitor in **Table 3-1** for monitors P2, S1, S2, and S3, respectively. The results indicate that of these top 5 predicted values, occurrences in the spring were very limited:

- One for P2
- Two for S1
- None for S2
- None for S3.

The top 5 daily 1-hour maximum modeled concentrations indicate that the field study is adequate in its representation of the worst-case scenario concentrations. Out of 20 potential days (i.e., 5 days per monitor location), only 3 days occurred in the spring season and these days were either 3^{rd} or 4^{th} ranked for the applicable monitors.

Table 3-1: Top 5 SO_2 Modeled Concentrations with P2 Meteorology (2014-2015)

Monitor	Rank	Modeled SO_2 Concentration (µg/m^3)	Date
P2	1ST	173.0	1/16/2015
	2ND	169.3	7/26/2015
	3RD	160.7	2/17/2015
	4TH	157.6	5/22/2014
	5TH	145.4	7/9/2014
S1	1ST	359.9	2/14/2014
	2ND	238.2	8/23/2015
	3RD	236.7	6/5/2015
	4TH	227.9	5/26/2014
	5TH	222.1	8/18/2015
S2	1ST	232.2	1/16/2015
	2ND	199.3	8/11/2014
	3RD	196.5	1/3/2014
	4TH	196.2	7/26/2015
	5TH	175.9	7/25/2015
S3	1ST	203.9	1/16/2015
	2ND	203.2	7/27/2014
	3RD	191.9	8/20/2014
	4TH	190.7	11/12/2015
	5TH	188.2	9/2/2015

4 Conclusions

An analysis of the seasonal dependence of monitored concentrations at P2 (the monitor with 2 recent years of monitoring) indicates that the season not covered by the field study (spring) would not be expected to substantially alter the expected peak monitored concentrations.   A separate analysis of the seasonal dependence of modeled concentrations at all 4 monitors for 2014 and 2015 similarly indicates that spring would not be expected to add substantially to the peak modeled concentrations for these years. Accordingly, the evaluation results for the seasons covered by the evaluation study monitoring period are likely to similar to those obtained if monitoring had also covered the spring season.

Appendix E Documentation of Fume Easement for Culley Power Plant Property

November 3, 1961

Mr. G. R. Woehler
Vice President
Southern Indiana Gas & Electric Company
20-24 N. W. Fourth Street
Evansville 3, Indiana

Dear Mr. Woehler:

As requested in your letter of October 27, 1961, we are furnishing you the recording data on the Fumes Easement from SIGECO to ALCOA.

"Received for Record the 31st day of October, 1961 at 8:55 o'clock A.M. and recorded in Record 126 Page 311-15.

Kenneth Scott, RWC"

Very truly yours,

ALUMINUM COMPANY OF AMERICA

E. T. Thomas
Real Estate Agent

ETT/ap

nnooc: cc: Mr. J. R. Ibach - Warrick Works

S.F.151-4MM-4-60 Printed in USA

RECEIVED FOR RECORD THE 31st DAY OF OCTOBER, 1961 AT 8:55 O'CLOCK A.M. AND RECORDED IN RECORD 126 PAGE 311-15.

KENNETH SCOTT, RWC

KNOW ALL MEN BY THESE PRESENTS that SOUTHERN INDIANA GAS AND ELECTRIC COMPANY, an Indiana corporation, having an office and place of business in Evansville, Indiana (hereinafter referred to as "Southern Indiana"), for and in consideration of the sum of One Dollar ($1.00) and other good and valuable considerations to it in hand paid by ALUMINUM COMPANY OF AMERICA, a Pennsylvania corporation, having its principal office and place of business in Pittsburgh, Pennsylvania, and ALCOA GENERATING CORPORATION, an Indiana corporation, having an office and place of business in Warrick County, Indiana (hereinafter referred to collectively as "Alcoa"), the receipt of which is hereby acknowledged, has granted, bargained, sold and conveyed and does hereby grant, bargain, sell and convey unto Alcoa as a servitude running with and binding upon the following described premises, and every part thereof, to wit:

All that part of fractional Sections 16, 17 and 21, Township 7 South, Range 8 West of the Second Principal Meridian, Warrick County, Indiana described as follows:

Beginning at a point in said Section 17 which is located by commencing at the Northeast corner of Section 17, thence running South 1 degree, 9 minutes, 50 seconds West along the East line thereof a distance of 1053.07 feet, thence South 65 degrees, 30 minutes and 42 seconds West, a distance of 402.04 feet, thence North 88 degrees, 28 minutes and 18 seconds West a distance of 388.47 feet, thence North 74 degrees, 29 minutes and 18 seconds West a distance of 1326.97 feet, thence South 31 degrees, 30 minutes and 42 seconds West a distance of 1500.0 feet more or less to the aforementioned place of beginning; thence North 31 degrees, 30 minutes, 42 seconds East a distance of 1500.0 feet more or less, thence South 74 degrees, 29 minutes and 18 seconds East a distance of 1326.97 feet to a point in the Northeast quarter of Section 17, thence South 88 degrees, 28 minutes and 18 seconds East a distance of 388.47 feet, thence North 65 degrees, 30 minutes and 42 seconds East a distance of 1755.65 feet to a point in the Northwest Quarter of Section 16, thence South 1 degree, 9 minutes and 21 seconds West a distance of 1852.64 feet, thence South 26 degrees, 57 minutes and 25 seconds West a distance of 333.62 feet, thence South 88 degrees, 59 minutes and 35 seconds East a distance of 244.2 feet, thence North 1 degree, 9 minutes and 21 seconds East a distance of 2626.58 feet to the North line of the Northwest Quarter of Section 16, thence South 88 degrees, 9 minutes and 31 seconds East along the North line of said Quarter Section a distance of 1309.42 feet to the Northeast corner of the Northwest quarter of said Section 16, thence South zero degrees, 56 minutes and 9 seconds West along the East line of said Northwest quarter of Section 16 a distance of 2630.07 feet to the Southeast corner of said Northwest quarter of Section 16, which point is also the Northeast corner of the Southwest quarter of said Section 16, thence South 1 degree, 20 minutes and 44 seconds West along the East line of said Southwest quarter of Section 16, a distance of 2638.85 feet to the Southeast corner of said Southwest quarter of Section 16, which point is also the Northeast corner of the Northwest quarter of Section 21, thence South 1 degree, 20 minutes and 44 seconds West along the East line of said Northwest quarter of Section 21 a distance of 110 feet more or less to the low water mark of the Ohio River, thence in a Northwesterly direction along the low water mark of the Ohio River for a distance of 2252.0 feet more or less to a point on a line which is parallel to and 760 feet East of the West line, and the extension thereof, of the Southwest quarter of said Section 16, thence North 1 degree, 9 minutes and 50 seconds East, and parallel to said West line of the Southwest quarter of Section 16, a distance of 620.0 feet more or less to the center of Little Pigeon Creek, thence in a Southwesterly direction along the center line of said Creek a distance of 109.0 feet more or less to a point on a line which is parallel to and 660.0 feet East of said West line of the Southwest quarter of Section 16, thence South 1 degree, 9 minutes and 50 seconds West and parallel to said West line of the Southwest quarter of Section 16, a distance of 537.0 feet more or less to the low water mark of the Ohio River, thence in a Northwesterly direction along the low water mark of the Ohio River a distance of 3931.40 feet more or less to the place of beginning.

AND

All that part of the Northwest Quarter of the Northwest Quarter of Section 23, Township 6 South, Range 8 West, Warrick County, Indiana, described as follows:

Beginning at the Northwest corner of said quarter-quarter section; thence East along the North line of said quarter-quarter section 130 feet; thence South and parallel with the West line of said quarter-quarter section 125 feet; thence West and parallel with the North line of said quarter-quarter section 130 feet to a point on the West line of said quarter-quarter section; thence North along the West line of said quarter-quarter section 125 feet to the place of beginning, containing approximately .40 acre,

AND

All that part of the East one-half of the Southwest Quarter of Section 7, Township 5 South, Range 8 West, Warrick County, Indiana, described as follows:

Beginning at a point 227 feet East of the Southwest corner of said half-quarter section and running thence North 81 feet to an iron pipe; thence West 85 1/2 feet to the approximate center of the Boonville and Folsomville Road; thence in a Southwesterly direction along said road 110 feet to the South line of said Section 7; thence East 160 1/2 feet to the point of beginning, containing approximately .25 acre,

and for the benefit of and as appurtenant to the tract of land owned by Alcoa, hereinafter described, as the dominant tenement, the unrestricted irrevocable privilege to permit to be carried by air currents or otherwise over, across and upon the land above described, as the servient tenement, such dust, smoke, fumes, gases, chemicals, minerals and other effluents, or substances, known or unknown, anticipated or unanticipated, as may be released, liberated or discharged at or from the plants and facilities now or hereafter owned or operated by Alcoa, its successors or assigns, and incident to the smelting and fabrication of aluminum or the carrying on of other activities necessary or convenient thereto, which plants and facilities are located on the dominant tenement situated in Warrick County, Indiana, and described as follows:

> All of Section 8 and parts of Sections 9, 16 and 17 in Township 7 South, Range 8 West of the Second Principal Meridian, lying in Warrick County, Indiana, said land being particularly described as follows:
>
> Commencing at the Northwest corner of Section 8; thence Easterly along the North line of Section 8 to the Northeast corner thereof; thence in a Southeasterly direction to the intersection of the Westerly line of the Yankeetown Dock Corporation's railroad right of way as described in the instrument recorded in Deed Record 111, Pages 129 to 134 in the Office of the Recorder of Warrick County, Indiana, with the North line of the Southwest Quarter of Section 9; thence in a Southwesterly direction along the Westerly line of the Yankeetown Dock Corporation's railroad right of way to its intersection with the North line of the Northwest Quarter of Section 16; thence Westerly along the North line of Section 16 to a point which is 1,220.50 feet East of the Northwest corner of Section 16; thence South 1 degree, 11 minutes and 42 seconds West, a distance of 473.94 feet to a point; thence South 65 degrees, 30 minutes and 42 seconds West, a distance of 1,353.61 feet to the West line of Section 16; thence South 65 degrees, 30 minutes and 42 seconds West, a distance of 402.04 feet to a point in the Northeast Quarter of Section 17; thence North 88 degrees, 28 minutes and 18 seconds West, a distance of 388.47 feet to a point; thence North 74 degrees, 29 minutes and 18 seconds West, a distance of 1,326.97 feet; thence South 31 degrees, 30 minutes and 42 seconds West, a distance of 1,500 feet, more or less, to the Ohio River; thence downstream with the meanders of said River to the West line of Section 17; thence Northerly along the West line of Section 17, a distance of 589 feet to the Northwest corner of Section 17; thence Northerly along the West line of Section 8 to the place of beginning.

Southern Indiana, for itself, its assigns and successors in title to the premises constituting the servient tenement, does hereby covenant and agree that neither Southern Indiana, nor any subsidiary or affiliate of Southern Indiana, nor the assigns of Southern Indiana or any such subsidiary or affiliate, nor any successor in title to the said premises, nor anyone claiming by, through or under any of them, will, at any time file or prosecute any action at law or proceedings in equity against Alcoa seeking to enjoin the maintenance or operation of the said plants and facilities, or any plants and facilities for the same or similar purposes replacing or supplementing the plants and facilities now or hereafter constructed or maintained by Alcoa upon the said premises constituting the dominant tenement, or seeking in any manner to secure any redress whatsoever for any loss, damage or injury, including loss of life (subject, however, to the provisions hereinafter set forth), caused or claimed to have been caused in any manner by such dust, smoke, fumes, gases, chemicals, minerals or other effluents or substances, known or unknown, anticipated or unanticipated, whether such loss, damage or injury be to persons or to property, real or personal, including but not by way of limitation, personal discomfort, sickness, or loss of life, damage or injury to crops, shrubs, trees or other forms of vegetation on the land, to cattle, horses, or other livestock on the land, to the conduct of any business on the land, or to the value of said land as residential property, farm property, industrial or commercial property, or otherwise.

PROVIDED, HOWEVER, that it is understood that Southern Indiana has no right, title or interest in the property referred to as the dominant tenement; that Southern Indiana has not had and will not have any control over the design of the said Warrick Works, or as to whether or not any smoke, dust, fumes, gases, chemicals, minerals or other effluents or substances will be emitted therefrom, or as to the nature or effect thereof; and nothing herein contained shall be construed to constitute Southern Indiana as either active or passive participant in the emanations, if any, of such effluents, or their carriage over, upon or unto any property other than the servient estate, nor to impose any liability upon Southern Indiana with respect to any claims or damage to lands other than those described above as the servient tenement, or to confer any rights or benefits to or upon anyone hereunder, including Alcoa, other than as expressly hereinabove provided.

PROVIDED, FURTHER, that nothing contained herein shall be deemed to apply to, or to prevent, Southern Indiana from making any claim against Alcoa, or any subsidiary or successor of Alcoa or to exonerate Alcoa or any subsidiary or successor of Alcoa from liability for any such claim, or from instituting any action or prosecuting any remedy as against Alcoa or any subsidiary or successor of Alcoa, with respect to (1) any loss or damage to buildings, structures or machinery erected by or maintained by Southern Indiana or any subsidiary or affiliate of Southern Indiana on the servient tenement or (2) for interference with the conduct of the electric generating operations or other business of Southern Indiana or any subsidiary or affiliate of Southern Indiana now or hereafter conducted upon the servient tenement.

Alcoa hereby agrees that if any person shall bring an action against Southern Indiana, whether or not Alcoa is joined as a party thereto, for damages claimed to have resulted from the discharge by Alcoa of dust, smoke, fumes, gases, chemicals, minerals or other effluents or substances over, across and upon the servient tenement pursuant to the rights herein granted and Southern Indiana shall give Alcoa timely notice of such action, Alcoa shall defend, or, at its election, pay the cost, including attorneys' fees, of defending, such action and shall reimburse Southern Indiana for any damages which Southern Indiana is required to pay upon final determination thereof.

TO HAVE AND TO HOLD the described irrevocable privilege to Alcoa, its successors and assigns.

IN WITNESS WHEREOF, Southern Indiana has caused this instrument to be executed in its corporate name by its duly authorized officers this 24th day of October, 1961.

ATTEST:

SOUTHERN INDIANA GAS AND ELECTRIC COMPANY

/s/ S. G. Clifford
Asst. Secretary

By /s/ A. B. Brown
President

STATE OF INDIANA

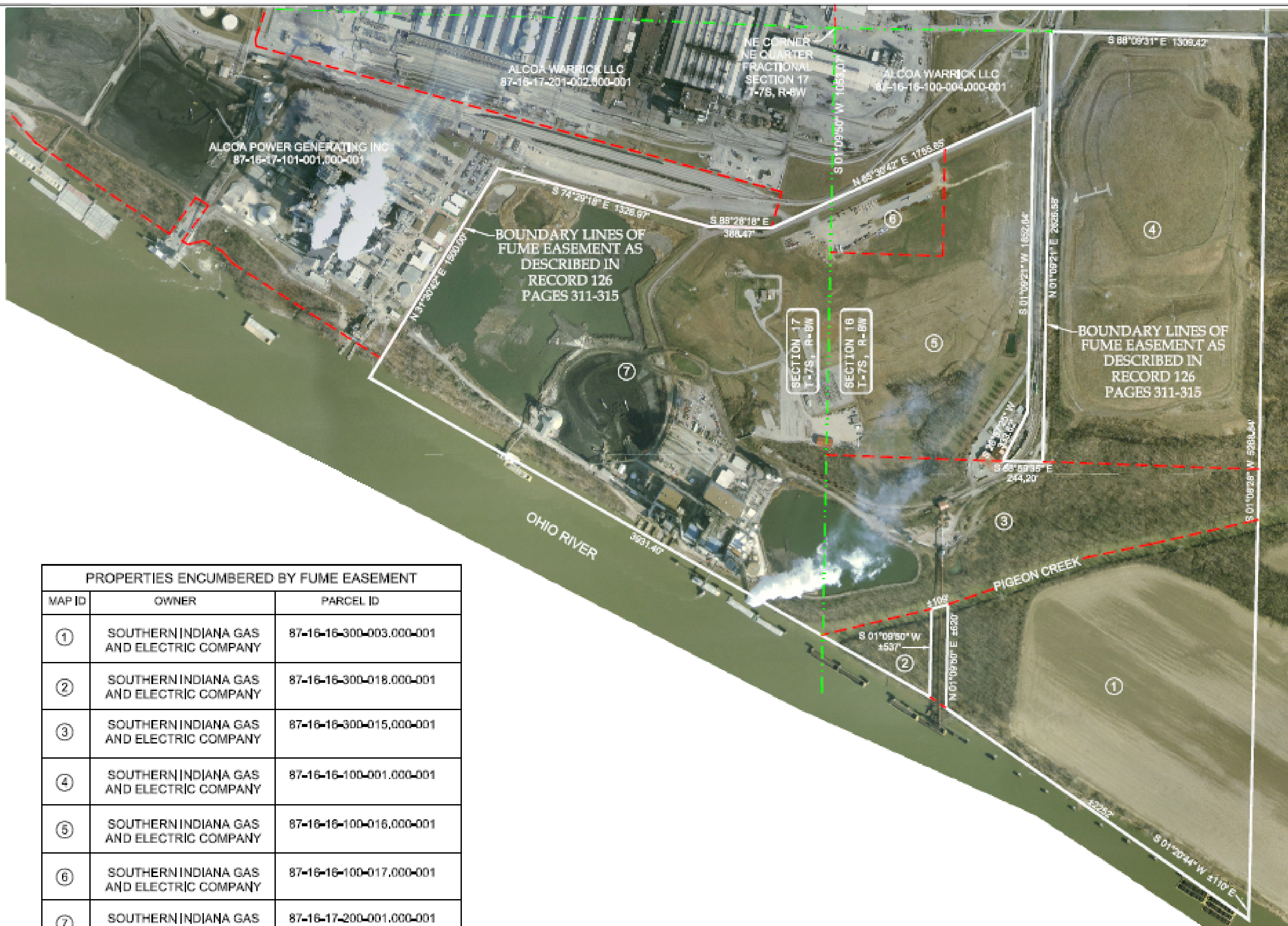
COUNTY OF ~~[illegible]~~ Vanderburgh

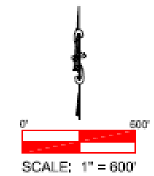
I, Mary Aline Klipstein, a Notary Public of the State of Indiana, do hereby certify that A.B. Brown and S. G. Clifford, personally known to me to be the same persons whose names are respectively as ________ President and Assistant Secretary of Southern Indiana Gas and Electric Company, a corporation of the State of Indiana, subscribed to the foregoing instrument, appeared before me this 24th day of October, 1961, in person and severally acknowledged that they, being thereunto duly authorized, signed, sealed with the corporate seal, and delivered the said instrument as the free and voluntary act of said corporation and as their free and voluntary act as such officers thereof, for the uses and purposes therein set forth.

IN WITNESS WHEREOF, I have hereunto subscribed my name and affixed my official seal.

/s/ Mary Aline Klipstein
Notary Public

My Commission Expires: July 10, 1965





PROPERTIES ENCUMBERED BY FUME EASEMENT		
MAP ID	OWNER	PARCEL ID
①	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-300-003.000-001
②	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-300-018.000-001
③	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-300-015.000-001
④	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-100-001.000-001
⑤	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-100-016.000-001
⑥	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-16-100-017.000-001
⑦	SOUTHERN INDIANA GAS AND ELECTRIC COMPANY	87-16-17-200-001.000-001

Page: 1 of: 3	Scale: 11" X 17" PLOT 1" = 600' Drawn By: KJH — Date: 8-31-2017 File Name: 17-087.dwg	Project: Plot of Fume Easement as described and recorded in Record 126 Pages 311-315 Part of Sections 16, 17, and 21 in Township 7 South, Range 8 West of the Second Principal Meridian, Warrick County, Indiana	HENNESSY SURVEYING

6085 South 50 West
Fort Branch, IN 47648
Phone: (812) 753-5941
Fax: (812) 753-4559
E-Mail: Hsurvey@sit-co.net

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Attachment C

Modeling Receptor Location Brief for ALCOA: Preclusion of Public Access and Control of Property Issues to Justify Definition of Ambient Air

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Receptor Locations – F. B. Culley Generating Station

Generally, receptors are placed in areas considered ambient air.[1] Ambient air is defined as "that portion of the atmosphere, external to buildings, to which the general public has access."[2] U.S. EPA's "longstanding interpretation"[3] of this definition has excluded "the atmosphere over land owned or controlled by the source and to which public access is precluded by a fence or other physical barriers."[4] For purposes of SO_2 designations based on modeling, U.S. EPA has also excluded areas where monitors cannot feasibly be placed.[5]

U.S. EPA reviews all receptor exclusions as "individual situations on a case-by-case basis."[6] In one SIP approval, U.S. EPA referred to the process of interpreting the definition of ambient air as "a highly individualistic matter based on the facts of each case, with no objective criteria emerging as a decision-making tool."[7]

Alcoa includes both the Alcoa Warrick Smelter and the Warrick Power Plant. The F. B. Culley Generating Station (Culley) is an adjacent power plant owned by Vectren Corporation. IDEM modeling excludes receptors on Culley property because the public is precluded from accessing the Culley property by physical barriers, no trespassing policies and signs, security patrolling, and electronic surveillance. Alcoa and Culley share control of some parts of Culley property, and placement of monitors on Culley property is not feasible. Alcoa has excluded receptors along the northern and western boundaries of the property due to fencing and signage, precluding public access.

Preclusion of Public Access to Culley Property

"The essence of the EPA's regulatory definition links ambient air to public access."[8] Whether public access is precluded "necessitate[s] a case-by-case evaluation of the facts."[9] Most importantly, "the test for determining if public access is effectively precluded requires some kind of physical barrier."[10]

In one case-by-case evaluation, the Environmental Appeals Board noted "that the test for ambient air exclusion does not require a continuous fence around the perimeter of the

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[1] U.S. EPA, SO2 NAAQS Designations Modeling Technical Assistance Document at 8–9 (Aug. 2016) [hereinafter *Modeling TAD*].
[2] 40 C.F.R. § 50.1(e).
[3] Resisting Envtl. Destruction on Indigenous Lands v. U.S. EPA, 716 F.3d 1155, 1165 (9th Cir. 2013) [hereinafter *REDOIL*].
[4] Letter from Douglass M. Costle, Administrator, U.S. EPA, to Senator Jennings Randolph, Chairman, Environment and Public Works Committee (Dec. 19, 1980) [hereinafter *Costle Letter*].
[5] Modeling TAD at 9.
[6] Costle Letter.
[7] Approval and Promulgation of State Implementation Plans; Utah Sulfur Dioxide Plan, 50 Fed. Reg. 7056, 7057 (Feb. 20, 1985).
[8] REDOIL at 1165.
[9] 50 Fed. Reg. at 7057.
[10] Memorandum from Walter C. Barber, Director, Office of Air Quality Planning and Standards, U.S. EPA, to Gordon M. Rapier, Director Air and Hazardous Materials Division, Region II, U.S. EPA, re: Applicability of PSD Increments over Company Property (May 23, 1977).

property."[11] Other types of physical barriers, such as access roads blocked by gates, could effectively preclude access.[12] The Board also noted that the agency could require installation of barriers to preclude access where needed.[13] U.S. EPA had acknowledged prior that the exclusion "enables the property owner to determine what constitutes 'ambient air' since he may fence his property and thereby preclude public access."[14]

In another case-by-case evaluation, U.S. EPA considered all aspects of the source's exclusion of the public—including fences, posts, man-made barriers, no trespassing policies and signs, security patrolling, other security measures, anecdotal evidence of access, termination of limited hunting practices, and the rugged terrain—and found support for the exemption from ambient air.[15] U.S. EPA stated that evaluation of an exclusion from ambient air can consider "where lands adjacent to a source are clearly restricted from the public."[16]

Those wishing to claim the exemption must provide "sufficient assurance" that the public is physically excluded from the area.[17] Those who disagree with the claim of the exemption, must "present contradictory factual evidence for EPA to review."[18]

IDEM modeling excludes receptors on Culley property because the public is precluded from access by physical barriers, including fences, access roads blocked by gates, the Ohio River bank, no trespassing signs, posted plant personnel, patrolling plant personnel, and policies that ensure trespassers are removed from the site. Photographs and maps included in Attachment 1 show areas that Alcoa asserts are precluded from public access.

Alcoa and IDEM are willing to provide any additional photographs or documentation U.S. EPA requires to conduct a case-by-case individualized analysis of whether the adjacent Culley property is precluded from public access. If U.S. EPA determines that additional barriers are required, Alcoa and IDEM request the opportunity to consider installation of such additional barriers.

Control of Culley Property

U.S. EPA's longstanding interpretation of the definition of ambient air excludes land owned or controlled by the source.[19] IDEM modeling excludes receptors on Culley property where Alcoa and Culley share ownership or control. Alcoa and Culley are adjacent sources that have interconnected operations and joint ownership of some Alcoa and Culley properties. Alcoa and Culley jointly own Warrick Unit 4 and a 138-kilovolt substation on the Alcoa property. To connect Warrick Unit 4 to the Culley plant, Alcoa and Culley jointly own and operate the "Tie

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[11] Hibbing Taconite Company, 2 E.A.D. 838, 849 (EAB 1989).
[12] *Id*.
[13] *Id*. at 853.
[14] Memorandum from Michael A. James, Attorney, U.S. EPA to Jack R. Farmer, Chief Plans Management Branch, U.S. EPA, Ambient Air Quality Monitoring by U.S. EPA (Sep. 28, 1972) , *available at* https://www.epa.gov/sites/production/files/2015-07/documents/incremen.pdf.
[15] 50 Fed. Reg. at 7057.
[16] *Id*.
[17] U.S. EPA, Guidelines for Implementation of a Regional New Source Review Program for Stationary Sources, OAQPS NO. 1.2-046, at 38 (Mar. 1976), *available at* https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9101Y316.txt.
[18] 50 Fed. Reg. at 7057.
[19] Costle Letter.

Line 3 facility", a 2.2 mile, 138-kilovolt line on both Alcoa and Culley properties. Alcoa and Culley jointly own Tie Line 3's foundations, towers, conductors, insulators, switching equipment, and protective equipment. Alcoa and Culley also jointly own and operate a similar line connecting the Warrick Smelter and the Warrick Power Plant on Alcoa property. Additional distribution lines connect Culley to the Alcoa plant, are jointly owned, and are used to meet the energy needs of Alcoa's smelting and rolling mill operations.[20]

IDEM modeling also excludes receptors on Culley property where Alcoa does not share ownership for two reasons. First, Alcoa exercises some level of control over these areas. U.S. EPA has not provided guidance on interpreting control when two sources share ownership of some, but not all, of their adjacent properties. But, U.S. EPA has provided guidance on exclusions from ambient air on leased land.[21] U.S. EPA's analysis seems to focus on which source controls public access and who requires permission from whom to be on the property.[22] U.S. EPA says that those who "are expressly granted access to a plant site by the owner are not the general public, but instead are considered 'business invitees.'"[23]

Alcoa and Culley personnel routinely work on equipment on both Alcoa and Culley properties. Culley controls access to the Culley property, but Alcoa personnel regularly enter the property to test metering equipment associated with the interconnected facilities. Alcoa and Culley personnel either do not require permission from one another to enter the properties, or the permission is more akin to courtesy. Alcoa and Culley personnel should be considered business invitees on the other's property.

Second, IDEM modeling excludes receptors on Culley property because Alcoa and Culley have business agreements going back over 50 years that exclude the Culley property from being considered ambient air in relation to the Alcoa property. These agreements are in the form of Fume Easements, which allow Alcoa to release wholly unrestricted amounts of smoke, dust, fumes, gases, chemicals, etc. to be carried over the Culley property regardless of damage to property or harm to persons (expressly including personal discomfort, sickness, and loss of life). IDEM modeling excludes receptors on Culley property because Culley granted to Alcoa significant control of the atmosphere over the Culley property.[24]

Infeasibility of Monitor Placement on Culley Property

U.S. EPA's Modeling TAD lays out the methodology for designations based on modeling under the Data Requirement Rule (DRR).[25] The Modeling TAD differs in some ways from modeling used to evaluate New Source Review sources.[26] Importantly for Alcoa, the Modeling TAD calls

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[20] Information about Alcoa and Culley joint ownership and control can be found at *Alcoa Power Generating Inc.*, 145 FERC ¶ 61,201 (2013), *available at* https://www.ferc.gov/CalendarFiles/20131206161329-OA13-6-000.pdf.

[21] Memorandum from Stephen D. Page, Director OAQPS, U.S. EPA, to Regional Air Division Directors, U.S. EPA, re: Interpretation of "Ambient Air" in Situations Involving Leased Land under the Regulations for Prevention of Significant Deterioration (PSD) (Jun. 22, 2007).

[22] *Id*. at 2; *Id*., attachment at 5.

[23] *Id*., attachment at 5.

[24] Note that not all easement land has been excluded from modeling by IDEM because not all of the land excludes public access.

[25] Modeling TAD at 1.

[26] *Id*. at 4.

for receptors to be placed only in areas where it is feasible to place a monitor.[27] The feasibility exception comes from the fact that modeling is acting as a surrogate for monitoring.[28] If a monitor cannot be placed in the location, a receptor should not be placed there either.

IDEM modeling excludes receptors on Culley property because placement of monitors on Culley property is not feasible for two reasons. First, Culley management has indicated that it will not allow Alcoa to place monitors in the areas where Culley has sole control and ownership of the property. Feasibility can include considerations of access and permission.[29] As discussed above, areas of which Alcoa and Culley share control of the property are not ambient air. Areas of which Culley alone controls the property are also excluded because Culley has denied access to place a monitor there. Because in the DRR context, modeling acts as a surrogate for monitoring, denial of access makes monitoring infeasible and thus justifies exclusion of receptors in that area.

Second, much of the excluded Culley property is either ash ponds or the actual Culley power plant, neither of which are appropriate for monitoring. Placement of a monitor in an ash pond is infeasible for obvious reasons. Placement of a monitor among the buildings of the power plant is equally infeasible. Even as a source-oriented monitor for Alcoa, the Culley power plant would likely not meet the siting criteria for ambient monitor placement. Again, because modeling acts as a surrogate for monitoring here, infeasibility of monitor placement justifies exclusion of receptors on the Culley property.

Preclusion of Public Access to Alcoa's Property

Alcoa has fencing along the northern, western and eastern boundaries of the property as well as security patrols that preclude public access, as shown below in Figure 1. The southern property of Alcoa is bordered by the Ohio River. The northwest area of the Alcoa property, in particular, has drawn interest from U.S. EPA – Region 5 staff to determine accurate placement of modeling receptors to characterize air quality in the area. The area is precluded from public access with fencing that runs inside the Alcoa property boundary. There are two buildings owned by Alcoa; one is leased to the Warrick County Emergency Management System and a second building that is owned by Alcoa and serves as an employee sales building. Photographs #4 through #12 provide evidence of the physical barriers and signage that demonstrate the Alcoa property is not accessible by the public and is excluded from ambient air receptor placement.

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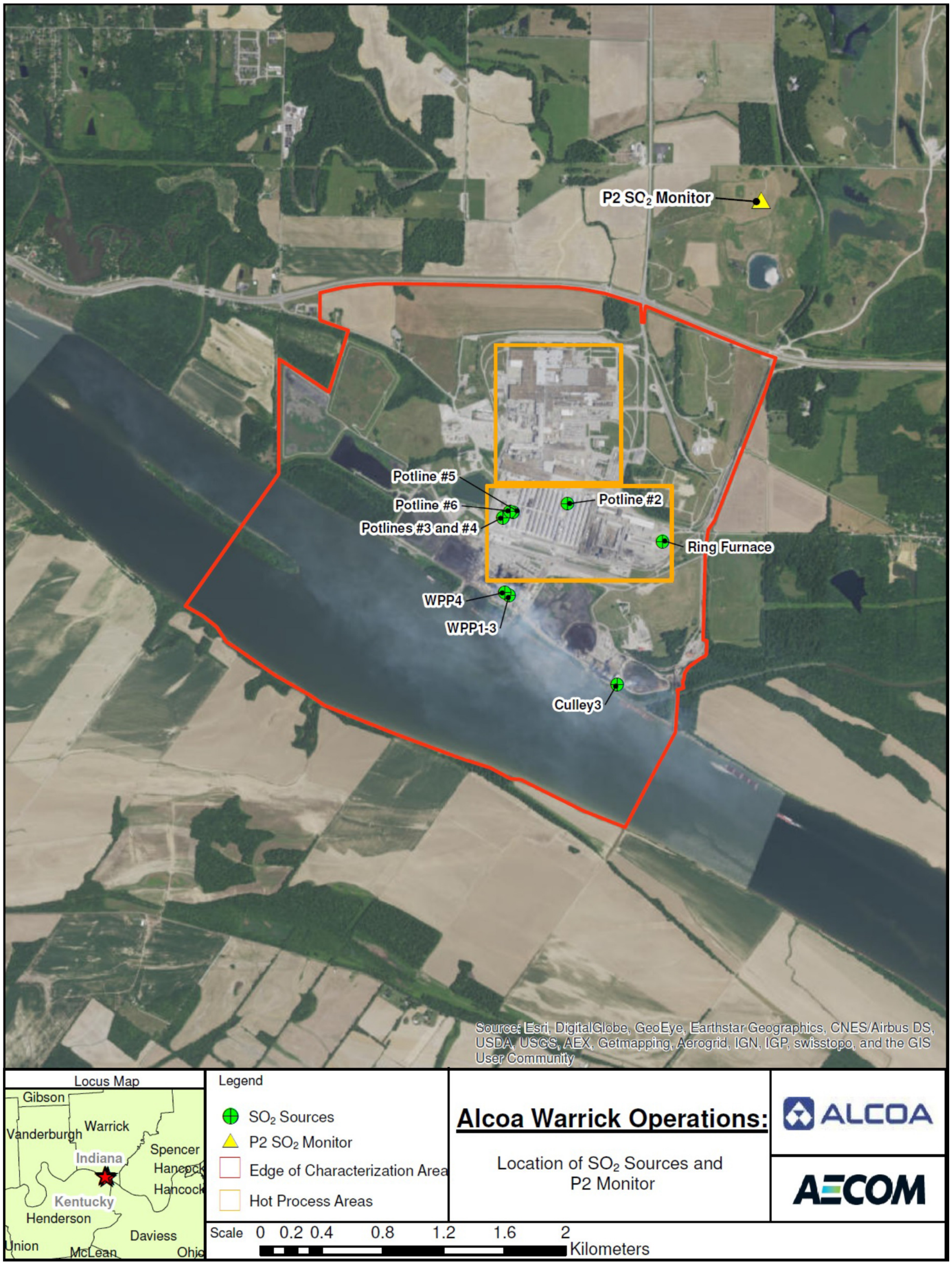
[27] *Id*. at 4.

[28] *Id*. at 9.

[29] U.S. EPA, SO_2 NAAQS Designations Source-Oriented Monitoring Technical Assistance Document, at 14 (Feb. 2016) [hereinafter *Monitoring TAD*] ("to determine where one or more monitor sites may be feasible (including considerations for access, permissions, and utilities)"). The Modeling TAD says to follow the Monitoring TAD when determining where monitor siting is feasible. Modeling TAD at 9 ("When modeling to site a monitor, the recommendations in the SO_2 monitoring TAD should be followed.").

Figure 1. Alcoa Property Boundaries



Conclusion

Exclusions from ambient air receptor placement are allowed for land owned or controlled by a source, to which public access is precluded, and on which monitors cannot feasibly be placed. An individualized evaluation of the Culley property adjacent to Alcoa justifies exclusion from receptor placement for ambient air modeling. Public access is precluded from the property by physical barriers. The property is partially controlled by Alcoa through joint ownership or mixed control of some land and easements to control the atmosphere over the entire land. It would be infeasible to place monitors on Culley property because Culley has denied access and the land is inappropriate for siting due to terrain and buildings. Alcoa has fencing along the northern and western boundaries of the property as well as security patrols that preclude public access and the southern boundary is bordered by the Ohio River.

Figure 2. Map of Excluded Receptors on Culley Property Showing Fume Easement Boundaries

Blue line shows boundary of receptor grid.

White lines show boundaries of Fume Easements.

Black arrows portray the camera location and view of the Alcoa Warrick Power Plant and Culley properties

Photograph #1

Taken along the northern Culley fence line, facing west-southwest towards the Alcoa Warrick Power Plant, overlooking the northern ash pond area.

Photograph #2

Taken along the northern Culley fence line, facing south, overlooking the ash pond area.

Photograph #3

Taken along the northern Culley fence line, facing southeast towards Culley Generating Station, overlooking the ash pond area.

Photograph #4

View of northwest portion of ALCOA's property, describing the buildings located on Alcoa property (Google Map – Screenshot – September 2015)

Photograph #5

Photograph of northwest portion of ALCOA property, taken from north side of Darlington Road, facing southeast showing the fencing and signage south of the road (October 2017)

Photograph #6

Photograph of northwest portion of ALCOA property, taken from the north side of Darlington Road, facing southeast and showing fencing and signage north of the road (October 2017)

Photograph #7

Photograph of northwest portion of ALCOA property, taken from north side of Darlington Road, facing north (October 2017)

Photograph #8

Photograph of northwestern most portion of ALCOA property, taken from the Heritage Federal Credit Union parking (adjacent to Alcoa), facing northeast (October 2017)

Photograph #9

Taken along the northwestern ALCOA fence line along Route 66, facing southeast towards ALCOA (Google Map – Street view – September 2015)

Photograph #10

Taken along the northern ALCOA fence line along Route 66, facing south towards ALCOA (Google Map – Street view – September 2015)

Photograph #11

Taken along the northern ALCOA fence line along Route 66, facing south-southeast towards ALCOA (Google Map – Street view – September 2015)

Photograph #12

Taken along the north-northeastern ALCOA fence line along Route 66 west of the main gate, facing south towards ALCOA (Google Map – Street view – September 2015)

Photograph #13

Taken along the northeastern ALCOA fence line along Route 66 east of the main gate, facing south-southwest towards ALCOA (Google Map – Street view – September 2015)

Photograph #14

Taken along the northeastern ALCOA fence line along Route 66, facing southwest towards ALCOA (Google Map – Street view – September 2015)

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