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Modeling and Monitoring SO_2 Characterization for the Labadie Energy Center

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1. Introduction

In 2010, the United States Environmental Protection Agency (EPA) promulgated[1] a stringent National Ambient Air Quality Standard (NAAQS) for sulfur dioxide (SO_2) with a 1-hour averaging time. EPA's implementation of this new standard has considered both monitoring and modeling approaches. On March 20, 2015, EPA issued updated guidance[2] to address implementation of the SO_2 NAAQS, and that process is being followed in this analysis to provide information to the Missouri Department of Natural Resources (MDNR) regarding SO_2 concentrations in the vicinity of the Labadie Energy Center, operated by Ameren Missouri.

In January 2014, EPA released[3] the SO_2 NAAQS Designations Modeling Technical Assistance Document and the Source-Oriented SO_2 Monitoring Technical Assistance Document (TADs). EPA developed these documents to assist state, local, and tribal air agencies to characterize ambient SO_2 air quality through modeling or monitoring in areas near emission sources. The technical assistance and procedures provided in these documents have informed AECOM's work to characterize SO_2 concentrations in the vicinity of the Labadie Energy Center.

The Labadie Energy Center ("Labadie") is located about 50 km west of St. Louis, along the Missouri River, as shown in Figures 1 and 2 (the latter figure shows locations of historical SO_2 monitoring). The plant's 700-ft (213-m) stacks are well above the surrounding terrain (less than 120 m of relief), so that any dispersion modeling application involves simple terrain.

2. Approach for Characterization of SO_2 Concentrations Around Labadie

Ameren Missouri and AECOM are employing a hybrid approach of both monitoring and modeling to characterize SO_2 concentrations around Labadie. The modeling path has been documented in a submittal[4] by Ameren to MDNR provided on September 3, 2015. The modeling showed a controlling 99th percentile peak daily 1-hour maximum concentration of

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[1] 75 FR 35520, Jun 22, 2010.

[2] http://www.epa.gov/airquality/sulfurdioxide/pdfs/20150320SO2designations.pdf

[3] Available at http://www.epa.gov/oaqps001/sulfurdioxide/pdfs/SO2ModelingTAD.pdf and http://www.epa.gov/oaqps001/sulfurdioxide/pdfs/SO2MonitoringTAD.pdf

[4] AECOM, September 2015. Characterization of 1-Hour SO_2 Concentrations in the Vicinity of the Labadie Energy Center. Document No. 60344380.100. Submitted to MDNR docket for comments on SO_2 designation for Labadie Energy Center.

193.0 µg/m^3, compared to the NAAQS of 196.5 µg/m^3. As noted in the September 3, 2015 submittal, the AERMOD model version has a documented overprediction tendency for certain light wind, morning conditions[5] and actual monitored concentration levels are lower than modeled projections.

Figure 1: Photo of Labadie Energy Center

Credit: St. Louis Post-Dispatch; see http://www.stltoday.com/news/opinion/columns/the-platform/labadie-power-plant/image_740dccb2-a72b-11df-ac73-00127992bc8b.html

An important aspect of the assessment of SO_2 concentrations in the vicinity of an emission source is the review of available monitoring data. For Labadie, this involves two periods:

- Current monitoring initiated in April 2015
- Previous multiple-year monitoring conducted during the 1980s and 1990s.

Figure 2 shows the SO_2 monitoring locations sited by MDNR that were in place during the period of 1987-1998 (through August 31, 1998). During the last few years of this period (1995-

[5] This condition involves plumes that rise or "penetrate" into the stable layer aloft. This modeling issue was described by Paine at the 11th EPA Modeling Conference; see http://www3.epa.gov/ttn/scram/11thmodconf/presentations/2-4_Penetrated_Plume_Issues.pdf

1998), MDNR moved the monitor to a location across the river from the power plant. This second location is important because plant emissions during the relevant period were significantly reduced with the switch to low-sulfur coal obtained from the Powder River Basin ("PRB") in response to the Clean Air Act's Acid Rain Phase 1 requirements. Notably, current emissions **are below** those in the mid-to-late 1990s.

The location of the "Augusta" monitor during the 1995-1998 period is also important for two additional reasons. First, the distance of the "Augusta monitor, roughly 2 km from Labadie, is consistent with peak impacts measured near similar facilities in past field studies[6]. Second and equally as important, the monitor was sited in a direction with frequent winds from Labadie. In fact, the last 36 months of Augusta monitoring (September 1995 – August 1998) resulted in a 99th percentile peak daily 1-hour maximum concentration[7] (the "design concentration") of 69.0 ppb, which is **below** the 2010 SO_2 NAAQS of 75 ppb. While MDNR has discontinued monitoring at the Augusta location, it is apparent that continued monitoring at that location would likely reflect continued maintenance of the 2010 SO_2 NAAQS near Labadie.

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[6] For example, the EPRI Kincaid SO_2 study in 1980-1981 with 28 SO_2 monitors showed that the peak monitored location was about 2-3 km from the plant, which had a 600-ft stack (see 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).

[7] Averaged over the three years (calendar years 1996 and 1997, plus the partial years of 1995 and 1998 taken as the third year)

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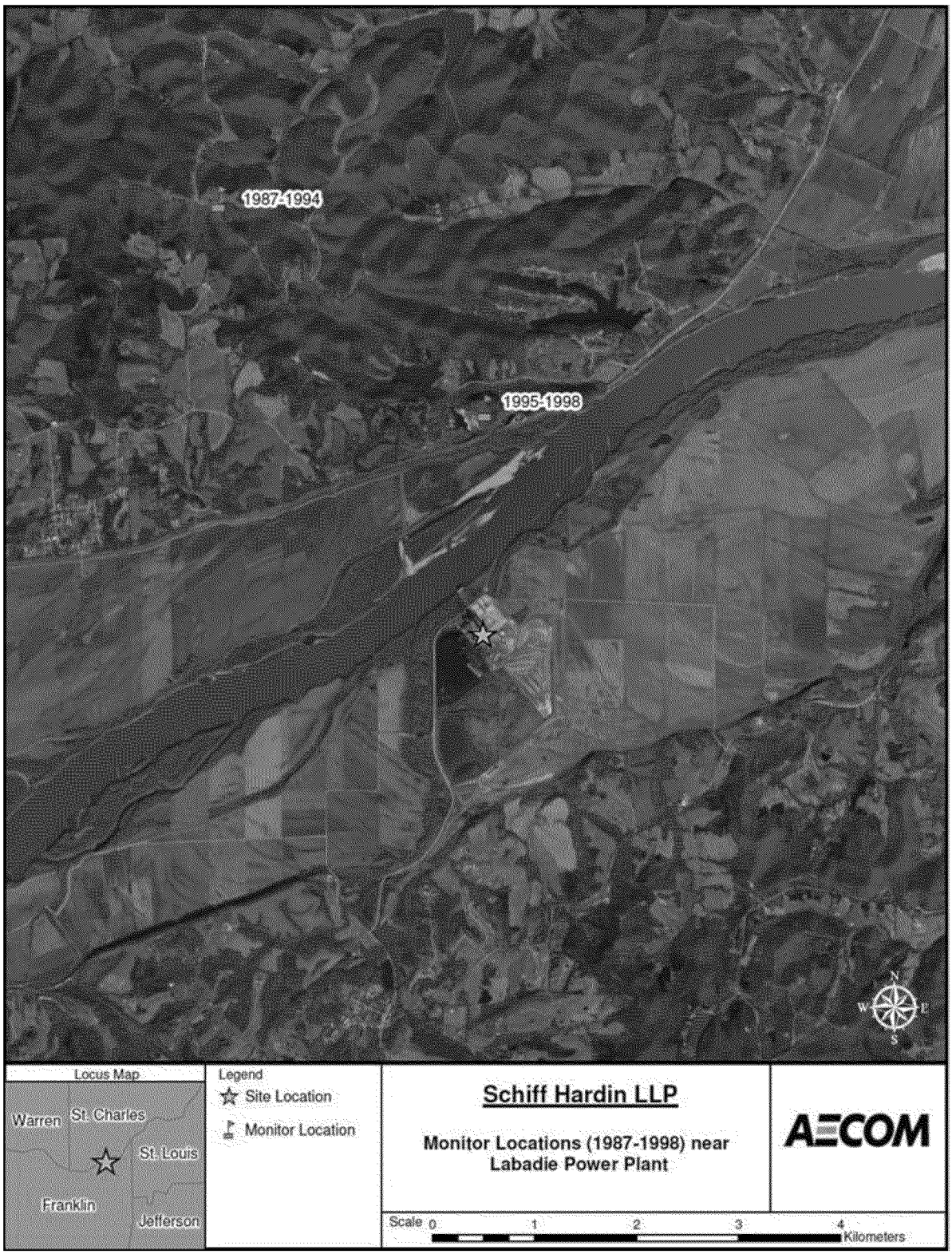
Figure 2: Map of Labadie Energy Center with Historical Monitor Locations



3. Review of Available Monitoring Data Near Labadie: Current Data

In April 2015, Ameren initiated a new SO_2 monitoring program to evaluate the air quality impact attributable to Labadie, pursuant to a monitoring plan approved by the MDNR. The locations of the monitors are shown in Figure 3, which correspond to distances and directions expected to be in peak impact locations, based upon sectors of peak frequencies of wind data from an historical 85-m on-site meteorological tower (see Figure 4). As noted below, the results of the current monitoring support the past monitoring results, and provide very strong evidence of SO_2 NAAQS compliance in the vicinity of Labadie. Ameren is committed to continuing the monitoring program for at least 3 years.

Figure 3: Current SO_2 Monitors in the Vicinity of Labadie

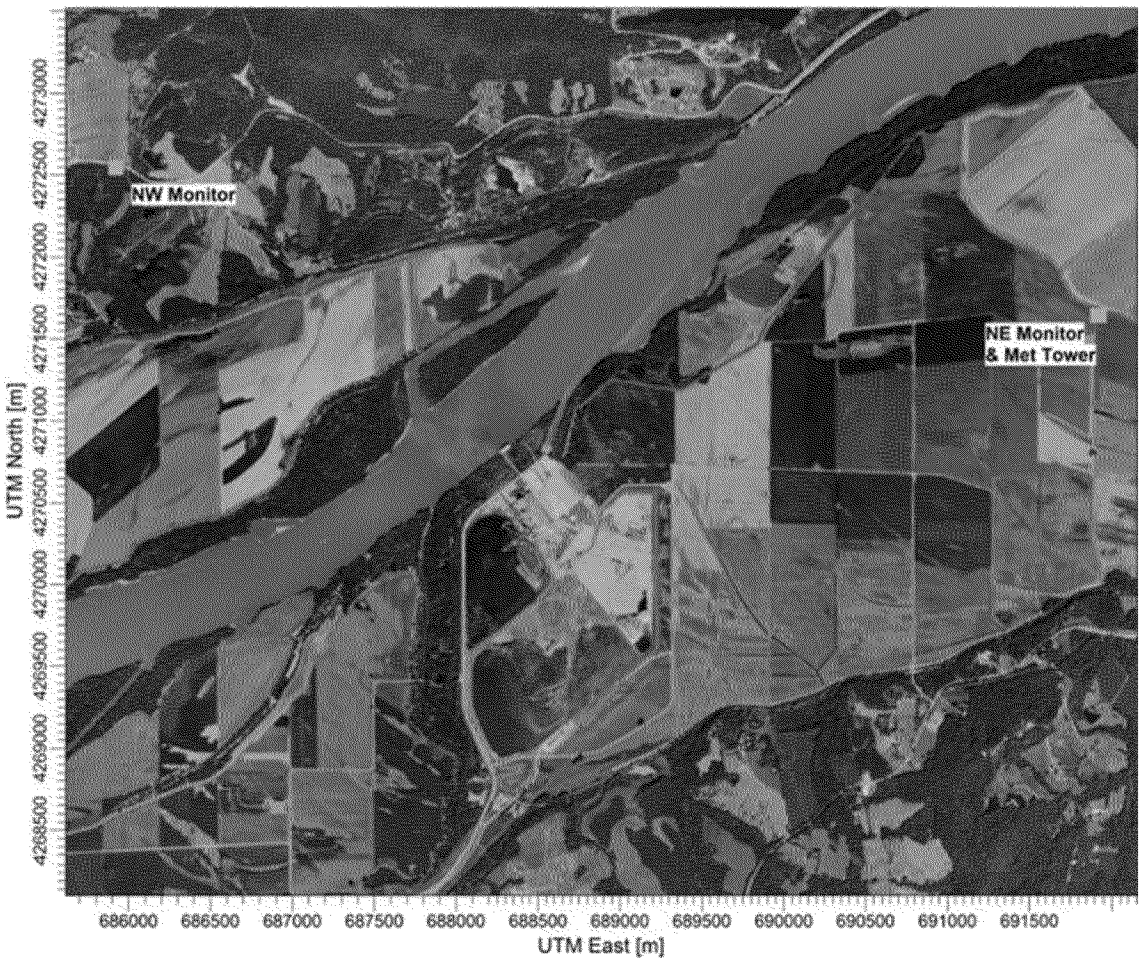
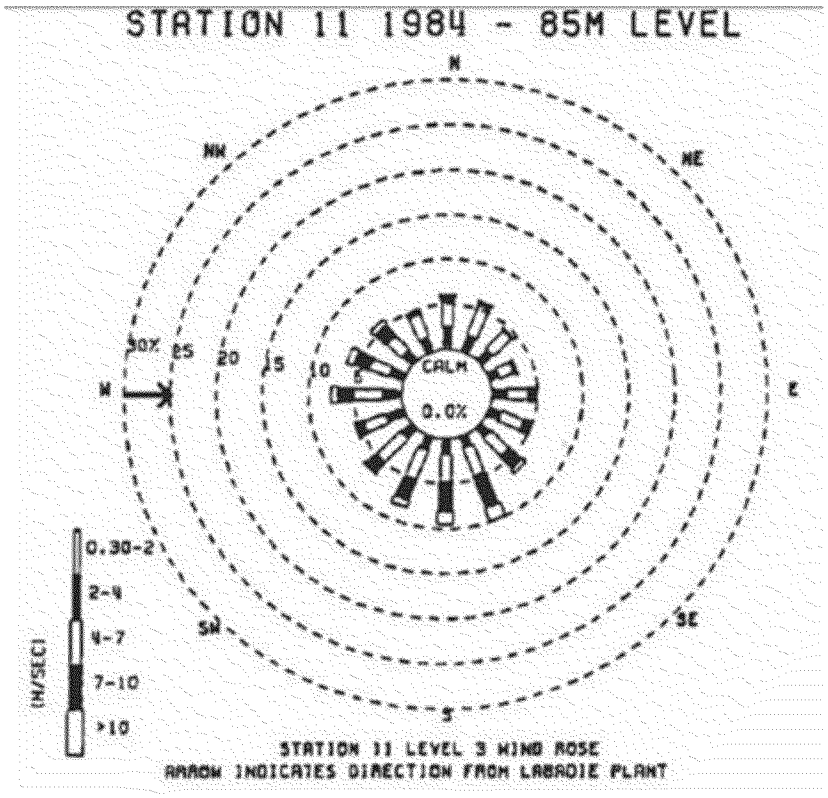


Figure 4: 1984 Wind Rose for 85-m On-site Meteorological Data

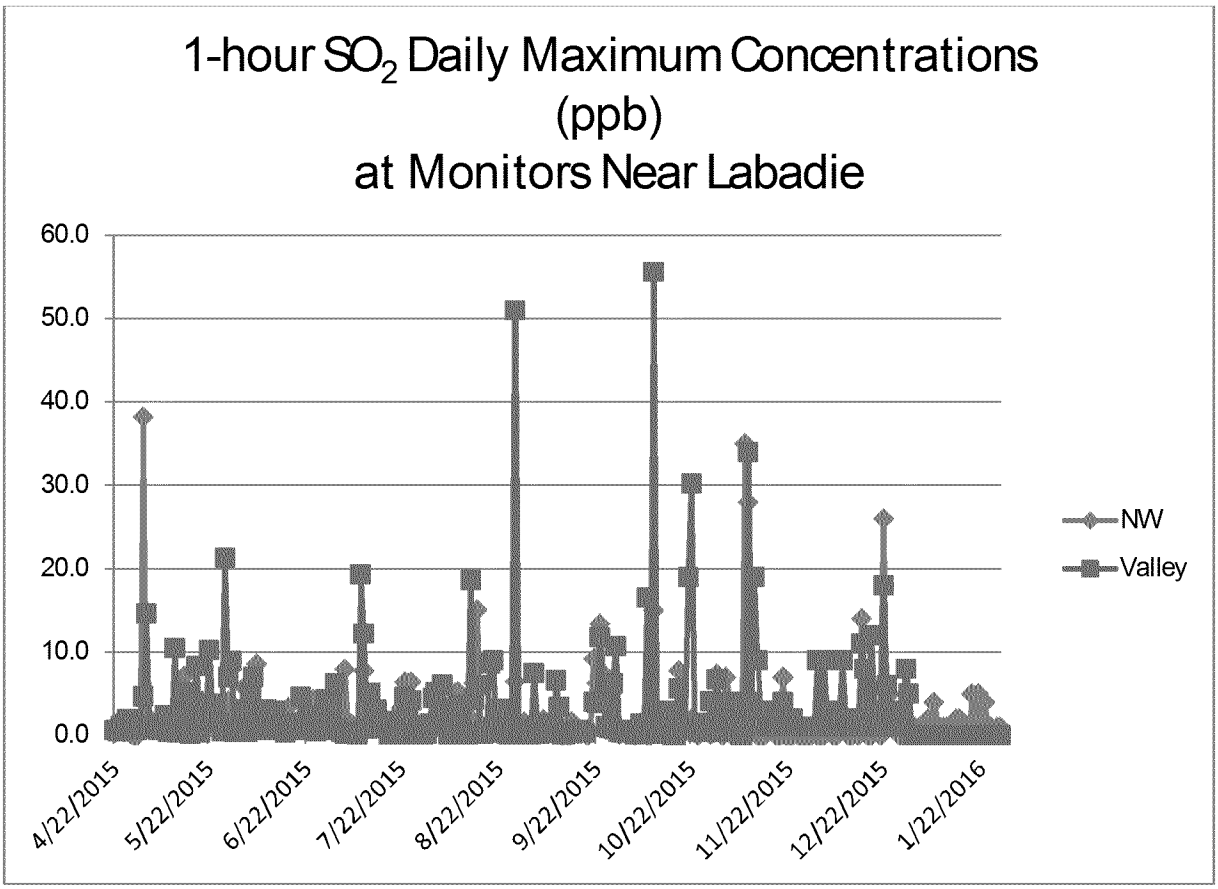


Specifically, monitored concentrations through the new monitoring network are available for an 8-month period for the NW and NE sites (see Figure 5 for a time series concentration plot of peak daily 1-hour maxima), and indicate the following:

- The highest 1-hour SO_2 concentrations are 38 ppb at the NW site and 56 ppb at the NE site.
- The 99th percentile (3rd highest peak daily 1-hour maximum) concentrations are 29 ppb at the NW site and 34 ppb at the NE site – both less than 50% of the 75 ppb NAAQS.

Again, "actual" monitored levels of SO_2 around Labadie obtained through the new monitoring network clearly indicate attainment by a wide margin.

Figure 5: Time Series of Daily Maximum SO_2 Concentrations for the NW and NE Labadie Monitors



4. Dispersion Modeling Approach for Labadie

The modeling conducted by AECOM and submitted to MDNR in early September 2015 utilize inputs which the Sierra Club and the Washington University Legal Clinic ("Clinic") have criticized in comments to MDNR and in subsequent modeling submittals[8] to MDNR and EPA Region 7. The specific points of most concern include:

- **AERMOD Low Wind Options.** AECOM used the EPA-proposed[9] low wind options: ADJ_U* in AERMET and LOWWIND3 in AERMOD. As described below, the use of the EPA proposed low wind options have solid support through peer-reviewed journal articles and supplementary documents including:

  - The adjustment to the planetary boundary layer parameterization in AERMET is supported by the research documented in Qian, W. and A. Venkatram. 2011. Performance of steady-state dispersion models under low wind-speed conditions. *Boundary Layer Meteorology, 138*, pp 475-491.

  - The LOWWIND2 option in AERMOD (similar to the LOWWIND3 option) in addition to the ADJ_U* option, is supported by the research documented in Paine, R., O. Samani, M. Kaplan, E. Knipping and N. Kumar (2015) Evaluation of low wind modeling approaches for two tall-stack databases, *Journal of the Air & Waste Management Association, 65*(11, 1341-1353, DOI: 10.1080/10962247.2015.1085924. A supplemental evaluation done when LOWWIND3 was released provides nearly identical results, and that analysis was submitted to MDNR in early September.

In contrast, the Sierra Club relied on AERMOD default options in all of their modeling submittals. Due to the expectation that EPA will promulgate the low wind options in AERMOD prior to July 2, 2016, we believe that use of these options is appropriate. Additional discussion in support of the low wind AERMOD modeling options is presented in a separate section below.

- **ACFM v. SCFM Data.** In December, 2015, the Clinic presented modeling to EPA using stack flow rates based on standard cubic feet per minute (SCFM) instead of stack flow rates based on actual cubic feet per minute as used by AECOM in its modeling. The Clinic's use of stack flow rates based on SCFM rather than ACFM is erroneous. In fact, EPA attempted to guide the Clinic to the correct data source by referring the Clinic's modeler to a useful Oklahoma Department of Environmental Quality website (https://www.deq.state.ok.us/aqdnew/emissions/SCFMvsACFM.PDF) which states the following about the use of ACFM vs SCFM data:

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[8] Two modeling submittals, using different approaches, have been submitted on behalf of the Sierra Club to MDNR and/or EPA Region 7. One was an analysis conducted by Wingra Engineering and was submitted to MDNR (and subsequently to EPA) in early September 2015. A second analysis, conducted by the Washington University Environmental Law Clinic, was recently submitted to EPA on December 16, 2015.

[9] As documented in the proposal (July 29, 2015) at 80 FR 45340.

ACFM is based on actual conditions of the gas. The stack flow rate and temperature are used in dispersion models to calculate the plume height, the height to which pollutants rise before they begin to disperse. If the flow rate is low it will result in lower plume heights and cause a higher pollutant concentration at ground level. ***Since SCFM is lower than the ACFM it incorrectly results in higher ground level pollutant concentrations. This is misleading for agencies and persons using this information for planning, public review, or testing.***

As a result of this modeling error, the Clinic's modeling analysis is unreliable and should be disregarded.

- **Labadie Units 3 and 4 Share a Common Stack.** AECOM combined in the modeling the flows from the dual-flued Labadie Units 3 and 4, since they are in the same stack, as shown in Figure 5. The flue exhaust flows were merged in the modeling, consistent with *EPA Model Clearinghouse memo 91-II-01*. The Sierra Club modeling submittals have continued to assume that the stacks are separate, even though it is quite evident from Figure 5 that the flues in the stack serving Units 3 and 4 are merged.

Figure 5: Google Earth View of Labadie Stacks, Showing Dual Flue for Units 3 and 4

- **Use of Representative Background Concentrations.** AECOM used regional background concentration data from a rural monitor (Nilwood, Illinois) that is more representative of the rural setting of Labadie. The Sierra Club utilized concentration values from urbanized East St. Louis, Illinois. AECOM also appropriately employed the seasonal, hour-of-day approach that is documented in EPA's March 1, 2011 Model Clearinghouse memo[10], something that the Sierra Club did not do in its modeling.

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

5. Evaluation of Low Wind Options for Several Tall- Stack Evaluation Databases

On July 29, 2015, EPA initiated a rulemaking[9] to update Appendix W, which details the procedures for conduction dispersion modeling analyses. While most commenters supported the proposed AERMOD low wind options, the Sierra Club (not surprisingly) opposed them, recommending that EPA should not adopt the proposed low wind options as defaults in the AERMOD modeling system.[11] As part of their comments (provided separately), Camille Sears (commissioned by the Sierra Club) conducted additional evaluations on some of the evaluation databases that EPA has posted for AERMOD studies. The specific evaluation databases selected by the Sierra Club included Baldwin, Kincaid, Lovett, Tracy, and Prairie Grass, with features noted below.

- Baldwin (1-hr SO_2): Rural, flat terrain, 3 stacks, stack height = 184.4 m, 1 full year
- Kincaid (1-hr SO_2): Rural, flat terrain, 1 stack, stack height = 187 m, about 7 months
- Lovett (1-hr SO_2): Rural, complex terrain, stack height, HS = 145 m, 1 full year
- Tracy (1-hr SF_6): Rural, complex terrain, 1 stack, stack height = 90.95 m, several tracer release hours
- Prairie Grass (1-hr SF_6): Rural, flat terrain, 1 stack, release height = 0.46 m (no plume rise), several tracer release hours

AECOM has reviewed the Sierra Club comments and modeling analysis summary submitted to EPA on use of the low wind options. The results of the review will be submitted to MDNR as a separate report. A summary of our findings are as follows:

- The Sierra Club used an outdated statistical metric developed prior to the current form of the NAAQS, focusing upon the 100th percentile statistic rather than the 99th percentile.

- The Sierra Club's approach has shortcomings in that they combined concentrations from all monitors, so that a minority of the monitors could dominate the statistics, and there could be inconsistent monitor representation between observations and predictions.

- The Sierra Club evaluation procedures use all 1-hour values rather than the highest daily value, which is also inconsistent with the new ambient standards.

A separate AECOM evaluation report[12] that addresses the above deficiencies and other shortcomings in the Sierra Club analysis indicates that the AERMOD performance with low wind options is reliable and, in fact, slightly conservative for the purpose of modeling the 1-hour SO_2 NAAQS.

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[11] http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2015-0310-0114

[12] AECOM, 2016. Supplemental Evaluation of AERMOD Low Wind Options for Selected Tall Stack Databases.

6. Evaluation of AERMOD Low Wind Options for 2015 Labadie Monitoring Data: Confirms that Air Quality Fully Complies with SO_2 NAAQS

In addition to the evaluation databases described in Section 5, we present evaluation results for AERMOD with default and low wind options run with actual Labadie emissions for the period of monitoring in 2015. As noted above, the monitoring started in late April 2015, so there is more than half a year of measurements available for the evaluation. Our evaluation with actual monitored emissions again confirms the appropriateness of use of the low wind option and that air quality fully complies with the SO_2 NAAQS.

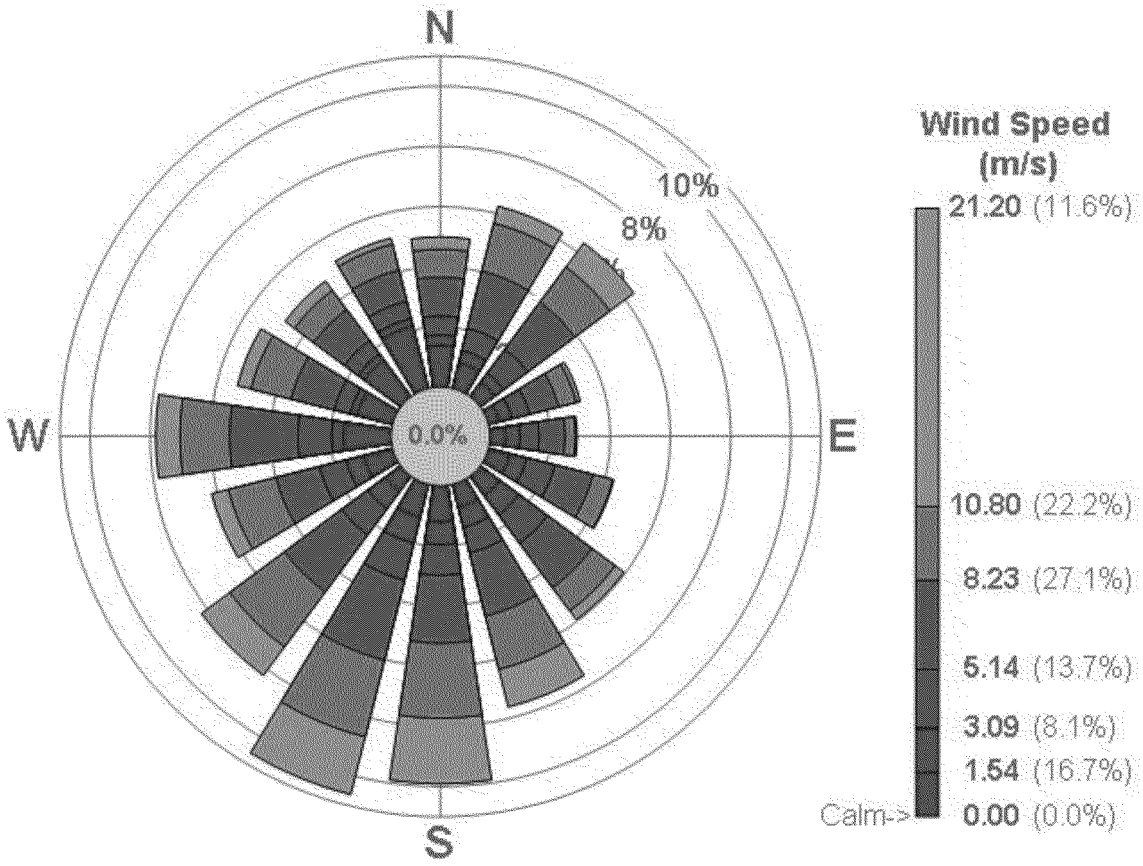
Ameren obtained meteorological data for 2015 using prognostic meteorological data from the Weather Research Forecast (WRF) model in order to evaluate wind data (for monitor siting) at and above stack height. Table 2 lists the WRF options used.

Table 2: WRF Modeling Options Used by Ameren

Grids:	**36, 12, 4, 1.33, and two 0.444 km grids around Labadie and Rush Island**
Nudging:	**Analysis Nudging on 36 and 12 km; observation nudging on the 4 km winds**
Runs:	**Run on 5 day segments with 12 hour spin up**
Initialization:	**With 40 km ETA AWIP model analysis**
mp_physics:	**opt: 3 WRF Single-Moment 3-class water microphysics scheme**
ra_lw_physics	**opt: 4 RRTMG long-wave radiation scheme**
ra_sw_physics	**opt: 4 RRTMG short-wave radiation scheme**
sf_sfclay_physics	**opt: 1 Revised MM5 surface layer scheme**
sf_surface_physics	**opt: 2 Noah land-surface model**
bl_pbl_physics	**opt: 1 YSU planetary boundary layer scheme**
cu_physics	**opt: 5 New Grell (G3) cumulus scheme (36km and 12km only)**

Figure 6 below is from the WRF modeling at the 94-m level and is consistent with the 85-m on-site wind data shown in Figure 4. Both wind roses (in Figures 4 and 6) support the selection of the monitor sites due to frequent winds from the south and the west.

Figure 6: 94-m Wind Rose for2015 from WRF Modeling



A review of the 2015 monitoring data indicates that a typical Labadie non-impact produces a background concentration of about 4 ppb. The Labadie Energy Center is located in a rural setting with only a few small isolated industrial facilities in the area, located 8 km or greater in distance from the Energy Center. In fact, MDNR's analysis had only 2 additional facilities included in their modeling, each with SO_2 emission rates under 5 tons per year. The background concentrations described below were determined for both the monitoring sites, using the NE (Valley) monitor meteorological data from April 22, 2015 thru November 29, 2015, and by excluding measured wind directions in a 90-degree sector from the plant to each monitor. After exclusion of the wind directions from the plant to each monitor site, the 99th percentile of the ranked hourly SO_2 concentrations remaining was used to determine the background. For both sites, this background was determined to be about 4 ppb SO_2.

The NE (Valley) monitor sites' 10-m meteorological data was processed by AERMET along with KSUS (Chesterfield Airport) and KILX (Lincoln, IL Upper Air) to produce a single period from April 22, 2015 thru November 29, 2015 for use as input to AERMOD.

Figures 7, 8 and 9 show quantile-quantile (Q-Q) plots for the default, ADJ_U* and the low wind (ADJ_U* and LOWWIND3) modeling for the 2015 period starting April 22 through November 29th for the Northwest station. Figures 10, 11 and 12 show similar Q-Q plots for the NE (Valley) site. Both sets of plots indicate that the 99th percentile ranked value (3rd highest value, circled in red) shows a model overprediction for the default and ADJ_U* options and an unbiased or slight overprediction for the low wind options.

This result is consistent with the other evaluation studies that indicate that the low wind options result in model predictions that are at or above observations for the appropriate statistic (99th percentile daily 1-hour maxima). This site-specific model evaluation analysis lends further support to the EPA approval of the low wind options (ADJ_U* and LOWWIND3) for Labadie SO_2 modeling.

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Figure 7: Quantile-Quantile Plot for AERMOD with Default Options for AERMET and AERMOD, Northwest Site

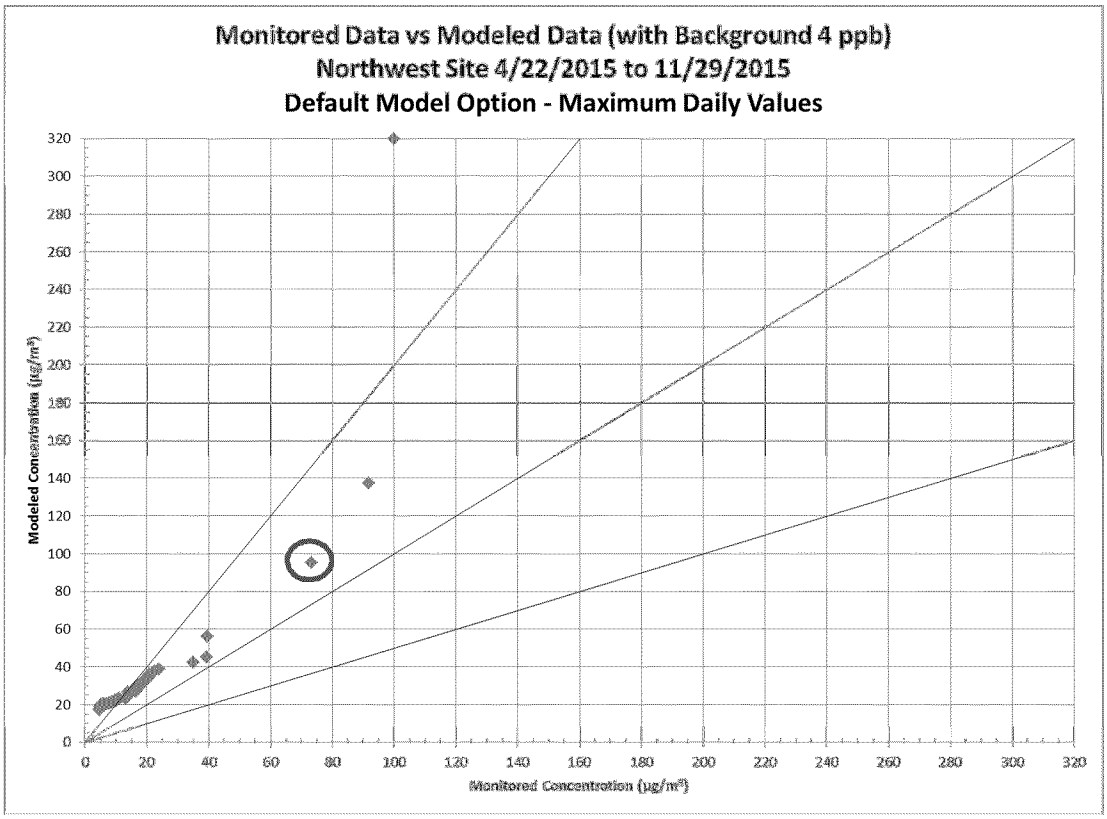

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Figure 8: Quantile-Quantile Plot for AERMOD with AERMET ADJ_U* and ADJ_U* AERMOD, Northwest Site

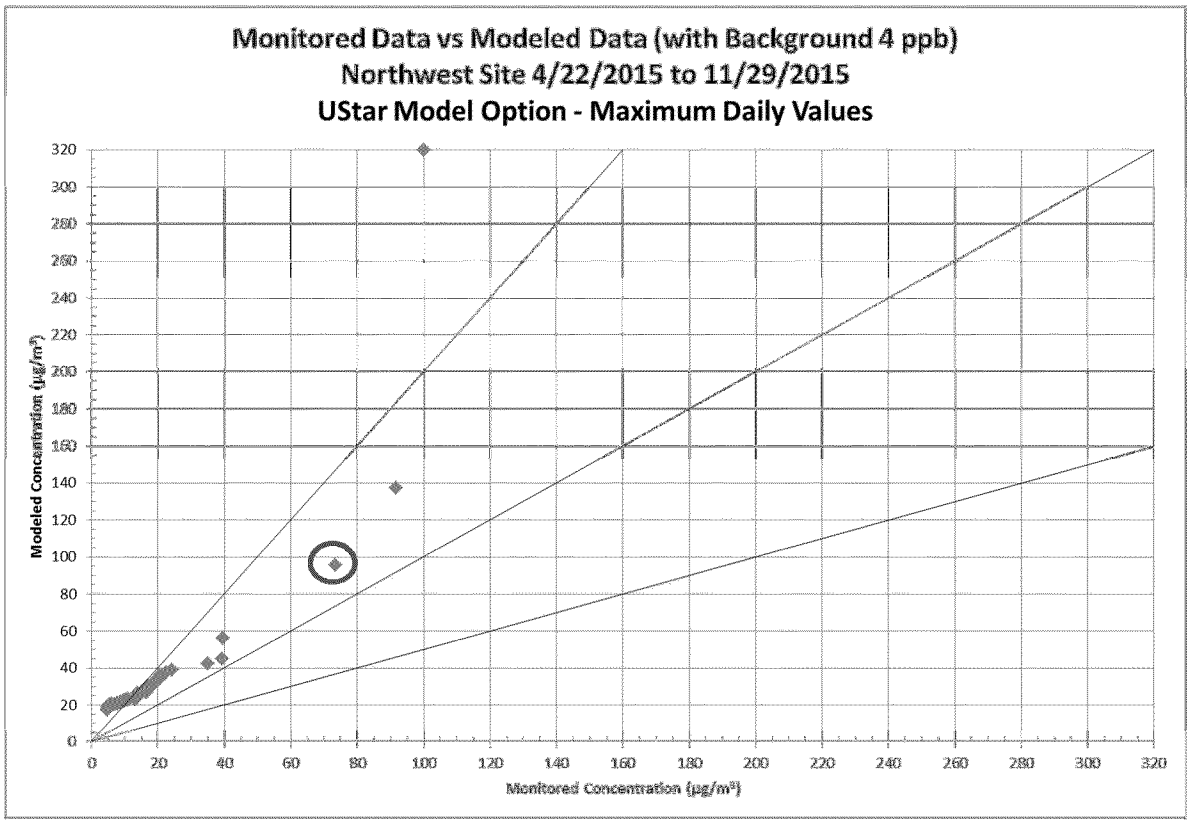

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Figure 9: Quantile-Quantile Plot for AERMOD with AERMET ADJ_U* and AERMOD LOWWIND3, Northwest Site

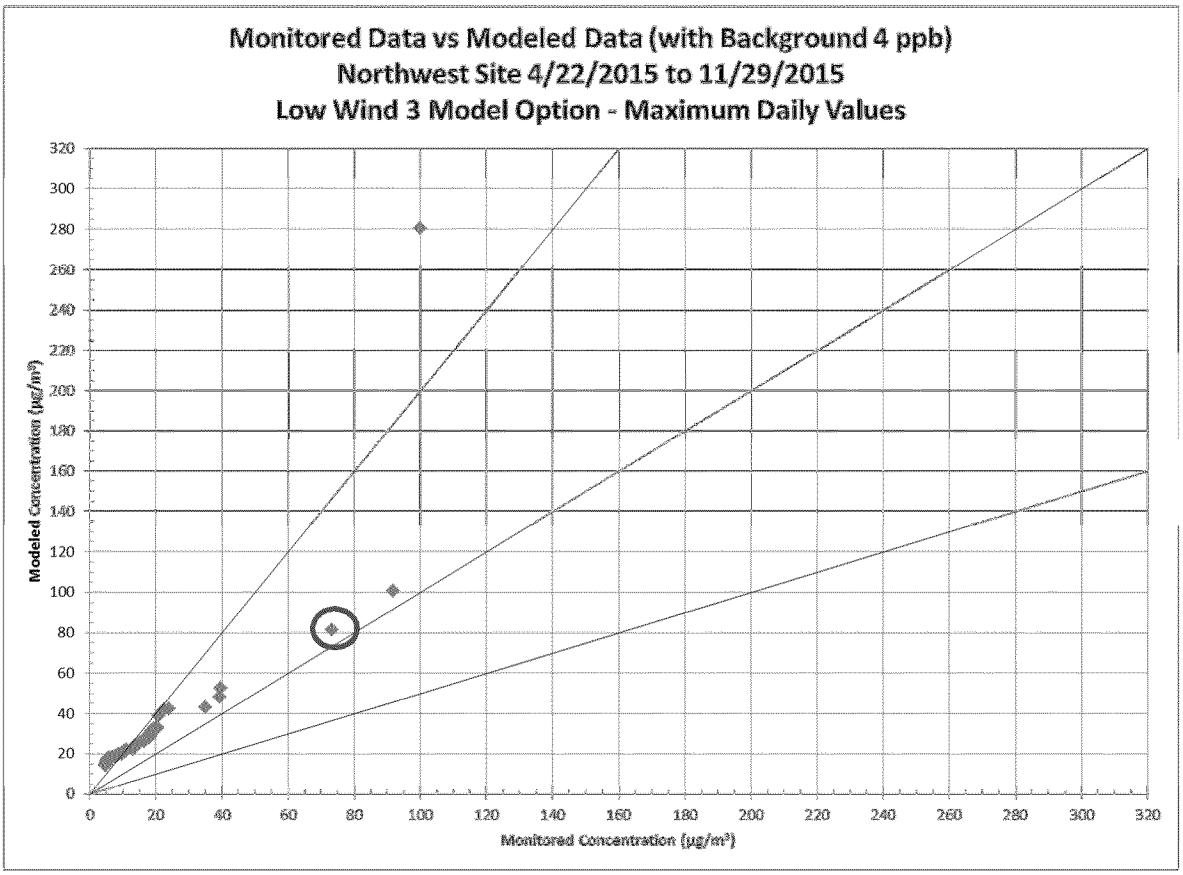

Figure 10: Quantile-Quantile Plot for AERMOD with Default Options for AERMET and AERMOD, Northeast (Valley) Site

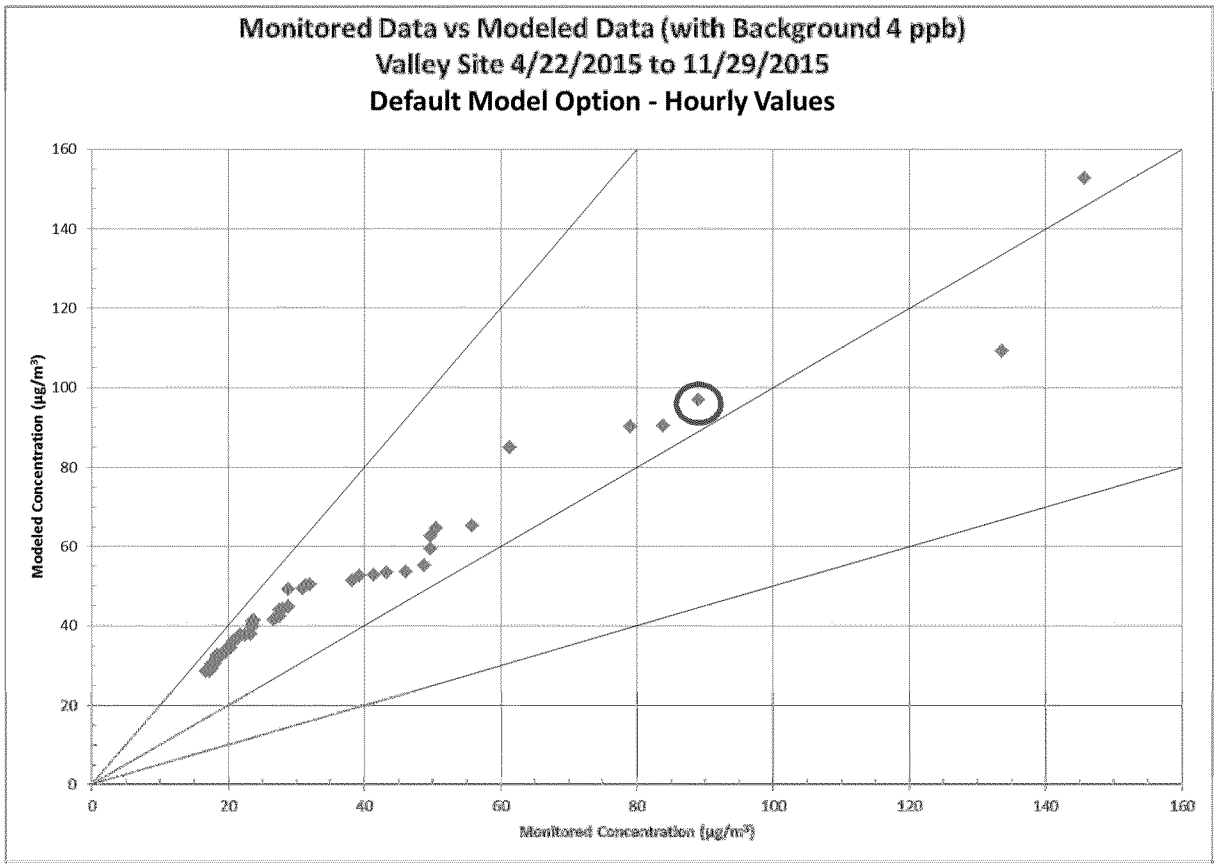

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Figure 11: Quantile-Quantile Plot for AERMOD with AERMET ADJ_U* and AERMOD ADJ_U* , Northeast (Valley) Site

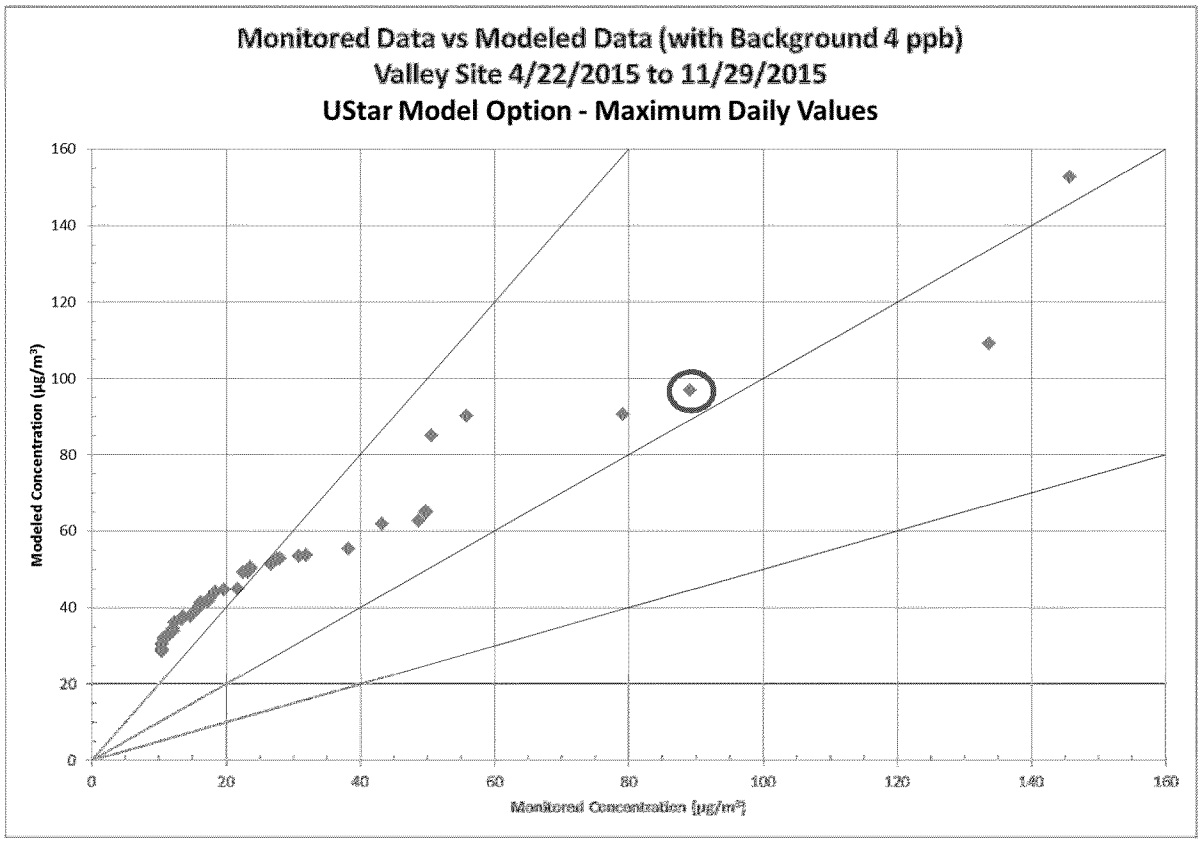
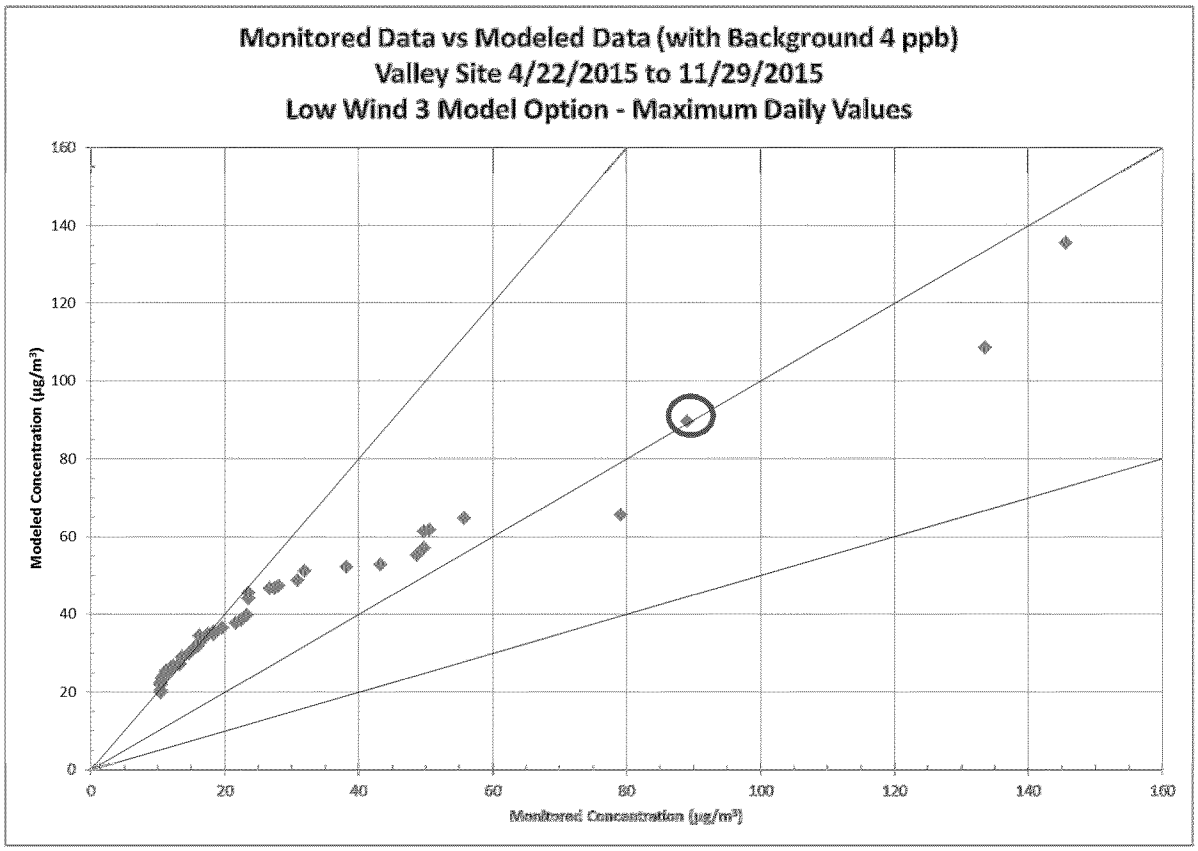


Figure 12: Quantile-Quantile Plot for AERMOD with AERMET ADJ_U* and AERMOD LOWWIND3, Northeast (Valley) Site



7. Conclusions

Ameren Missouri and AECOM are actively characterizing the SO_2 concentration pattern around Labadie using both dispersion modeling and monitoring. The dispersion modeling approach used by AECOM, which has documented over-prediction tendencies, shows compliance with the 1-hour SO_2 NAAQS by a small margin. The monitoring data to date shows compliance with the NAAQS by a large margin, as expected.

In comments filed with MDNR and EPA, the Sierra Club and the Clinic challenged several of the modeling approaches used by AECOM, especially the use of the EPA-proposed low wind options. This report provides clear support for the use of the low wind options as well as the other appropriate modeling approaches/inputs not adopted by the Sierra Club: specifically, use of actual cubic feet per minute flow rates, merged flue stack for Labadie Units 3 and 4, and a rural regional background characterization. The use of the low wind options in AERMOD is supported by both an evaluation of several tall-stack databases as well as a site-specific evaluation for the 2015 monitoring data near Labadie.

Ameren also conducted a meteorological modeling analysis of winds for 2015 with the WRF model to determine the likely characterization of wind flow at elevations well above the ground. The winds aloft in 2015 are consistent with those taken in 1984 during a period of site-specific meteorological monitoring, and support the siting locations of the NW and NE ("Valley") SO_2 monitors.

The evaluations and findings in this Report support the Missouri recommendation of an unclassifiable designation status, if not an attainment designation status, for the 1-hour SO_2 NAAQS for Labadie. EPA should agree with MDNR's recommendation and proceed accordingly.