

**Wisconsin's Attainment Demonstration for the
Oneida County 2010 1-Hour Sulfur Dioxide National
Ambient Air Quality Standard Nonattainment Area**

A Clean Air Act-Required State Implementation Plan Addressing the
2010 1-Hour SO₂ National Ambient Air Quality Standard

Prepared by the Wisconsin Department of Natural Resources

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I. EXECUTIVE SUMMARY

This state implementation plan (SIP) presents Wisconsin's plan to demonstrate attainment of the 2010 1-hour Sulfur Dioxide (SO₂) National Ambient Air Quality Standard (NAAQS) for the Oneida County nonattainment area by January 1, 2017. This plan describes a control strategy that reduces and limits SO₂ emitted by Expera Specialty Solutions LLC (Expera), the primary facility contributing to SO₂ nonattainment in this area. The SO₂ emitted by two other nearby facilities will continue to be regulated under existing permit requirements.

Expera operates one coal-fired boiler (designated as B26) and one gas-fired boiler with fuel oil backup (designated as B28). Administrative Order AM-01-15 establishes permanent and enforceable SO₂ requirements for these boilers as a result of an agreement between the Wisconsin Department of Natural Resources (WDNR) and Expera. This order is submitted as part of this SIP.

Administrative Order AM-01-15 establishes several requirements for boiler B26 at the Expera facility that must be met by January 1, 2017. The first requirement is to raise the flue gas stack height for boiler B26 to 296 feet above ground level. The WDNR determined that 296 feet is the good engineering practice (GEP) height for reducing negative plume dispersion impacts caused by nearby structures. The determination of GEP stack height is based on a wind-tunnel study conducted by Expera.

The order also limits boiler B26 SO₂ emissions to 3.00 pounds per mmBtu on a 24-hour basis and limits the maximum boiler load to 300 mmBtu per hour. The emission rate and boiler utilization limits are determined using the U.S. Environmental Protection Agency's (EPA's) air quality dispersion model, AERMOD. The modeling performed, which included Expera as operating under the requirements of the order, as well as all other SO₂ emissions sources within 50 kilometers under permitted conditions, shows attainment throughout the area.

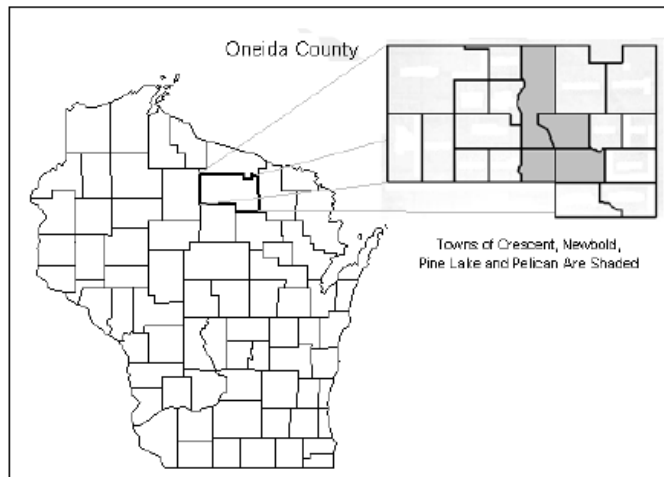
II. BACKGROUND

1. 2010 1-hour SO₂ NAAQS

In 2010, the EPA lowered the primary SO₂ NAAQS, setting a 1-hour standard of 75 parts per billion (ppb), which is attained when the 3-year average of the 99th percentile of 1-hour daily maximum concentrations does not exceed 75 ppb. The standard replaced the two primary standards initially promulgated in 1971 and retained in a subsequent review of the standard in 1996. These previous SO₂ NAAQS were 24-hour standard of 140 ppb and an annual standard of 30 ppb. EPA revoked both of these standards as part of the 2010 revision, finding that the new 1-hour standard is more protective of human health.

On August 5, 2013, (78 FR 47191) EPA designated a portion of Oneida County as nonattainment under the 2010 SO₂ NAAQS. This nonattainment area consists of four townships within Oneida County, including the city of Rhinelander (Figure 1). The nonattainment designation was based on ambient air quality data collected at the Rhinelander municipal water tower monitoring site (Rhinelander Tower monitor, AQS site ID 55-085-0996) from 2009 through 2011. The design value for this 3-year period was 151 ppb.

Figure 1. Oneida County 2010 SO₂ NAAQS Nonattainment Area.



2. Previous SO₂ NAAQS and Oneida County Nonattainment

The same portion of Oneida County was nonattainment under the 1971 primary 24-hour SO₂ standard. In order to monitor attainment status with the 1971 standard, WDNR began operating several SO₂ air quality monitors in Oneida County in the early 1980s. The monitored air concentrations for the area showed that SO₂ concentrations at the Rhinelander Tower monitor were consistently among the highest measured in the county. Therefore, monitoring at other locations was discontinued.

During the state's development of the plan demonstrating attainment with the 1971 standard, the Expera facility in Rhinelander was identified as the primary source contributing to high SO₂ ambient air concentrations in the Oneida County area. This analysis also established that air quality modeling consistently under-predicted SO₂ air concentrations compared to actual values measured by the Rhinelander Tower monitor. At that time, it was postulated that downwash from nearby buildings was causing emissions from the largest coal-fired boiler at the facility (boiler B26) to be concentrated when traveling towards the Rhinelander Tower monitor. To adjust for this effect, facility emission requirements were established by correlating real-time SO₂ emissions to the Rhinelander Tower monitored air concentrations. These emission requirements were made enforceable under Consent Order AM-94-38. EPA approved Consent Order AM-94-38 as part of the state attainment plan on December 7, 1994 (59 FR 63046).

3. Health Impacts

EPA states that scientific evidence demonstrates that health effects result from SO₂ exposure ranging from five minutes to 24 hours. Adverse respiratory effects include narrowing of the airways, which causes difficulty breathing (bronchoconstriction) and increased asthma symptoms. People with asthma are particularly vulnerable to these effects during periods of faster or deeper breathing (e.g., while exercising or playing).

Studies also show an association between short-term SO₂ exposure and increased visits to emergency rooms and hospital admissions for respiratory illnesses, particularly in at-risk populations including children, the elderly, and people with asthma.

Emissions that lead to high concentrations of SO₂ generally also lead to the secondary formation of other SO_x and fine sulfate particulates (PM_{2.5}). Control measures that reduce SO₂ can generally be expected to reduce exposure to all gaseous SO_x and PM_{2.5}. In particular, emphasis is placed on reducing PM_{2.5}, which penetrates deeply into sensitive parts of the lungs. PM_{2.5} exposure can cause or worsen respiratory disease, such as emphysema and bronchitis, and can aggravate existing heart disease, leading to increased hospital admissions and premature death.

III. PLAN ELEMENTS OVERVIEW

The State of Wisconsin is required to develop a plan showing that the 2010 SO₂ NAAQS will be attained by January 1, 2017 in the Oneida County nonattainment area. EPA identifies a number of elements that must be addressed by a plan in its “*Guidance for 1-Hour SO₂ Nonattainment Submissions*,” issued April 23, 2014. These elements and where they are addressed in this plan are listed in Table 1.

Table 1. SO₂ Attainment Plan Elements Addressed in the Wisconsin Plan

Plan Element	Section
The identification of stationary emission sources contributing to SO ₂ nonattainment	IV.1
Identification of the control strategy	IV.2
The demonstration of attainment	IV.3
Implementation of enforceable requirements	IV.4
Satisfaction of reasonably available control technology and measures (RACT and RACM)	IV.5
The fulfillment of reasonable further progress (RFP)	IV.6
The base year and attainment year projected emissions inventories	IV.7
The commitment of contingency measures in the event that the identified control strategy does not result in attainment	IV.8
The demonstration of a new source review (NSR) program meeting Clean Air Act requirements	IV.9
The demonstration of meeting Clean Air Act conformity requirements	IV.10
The demonstration that previous SO ₂ NAAQS requirements are maintained	IV.11

This document presents Wisconsin’s plan for demonstrating attainment with the 2010 SO₂ NAAQS in the Oneida County nonattainment area by January 1, 2017. The plan assesses emission sources contributing to nonattainment using EPA’s air quality dispersion model AERMOD. One facility, Expera, is identified as the primary contributor to SO₂ nonattainment. Contribution from other facilities is minimal. The AERMOD modeling protocol and results are provided in Appendix A. The plan establishes permanent and enforceable emission limitations for Expera effective January 1, 2017 through Administrative Order AM-15-01 as provided in Appendix B. Attainment will be maintained by the permitting process, which addresses any increase in emissions at existing sources or the installation of new sources within the nonattainment area. This plan also satisfies RACT, RACM, and RFP requirements for the area by January 1, 2017 and provides information addressing the balance of plan requirements listed in Table 1.

IV. THE RHINELANDER AREA 2010 SO₂ NAAQS ATTAINMENT PLAN

1. Stationary Emission Sources Contributing to SO₂ Nonattainment

The WDNR determined that Expera is the primary source causing nonattainment of the 2010 SO₂ NAAQS in the Oneida County area. This determination is based on AERMOD air quality modeling of all stationary sources within 50 kilometers of the Oneida County nonattainment area under maximum emission conditions. This modeling scenario is referred to as the Base Case. The modeling protocol and detailed results are presented in Appendix A.

Review of WDNR's emissions inventory confirms that Expera, Red Arrow Products, and the Packaging Corporation of America (PCA) comprise all the stationary source facilities located in the nonattainment area or within 50 kilometers of the nonattainment area. Expera and Red Arrow Products are within the nonattainment area; PCA is located in Tomahawk, outside of the nonattainment area. The facilities' distances to the Rhinelander Tower air quality monitor and the inventory of emission sources operating, or proposed for permitting, by these facilities as of October 2015 are summarized in Table 2. These are the facilities and emission sources modeled to determine contribution culpability at the Rhinelander Tower monitoring site.

Table 2. Facilities Modeled for Contribution to Nonattainment of the 2010 SO₂ NAAQS in the Oneida County Nonattainment Area

Parameter	Expera	Red Arrow	Packaging Corporation of America
Emission Sources	Boiler B26 - Coal Boiler B28 - Natural gas w/ distillate oil backup	Boiler B07 – Wood waste Boiler B10 - Wood waste	Boiler B24 - Coal Boiler B29 - Natural gas w/ distillate oil backup.
Modeled Fuel	B26 – Coal B28 – Distillate Oil	B07 – Wood waste B10 – Wood waste	B24 – Coal B29 – Distillate Oil
Maximum Potential SO ₂ Emissions (lbs./hr.)	1,065.23	6.46	1,306.3
Distance to the Rhinelander Tower Monitor	< 1 kilometer	< 5 kilometers	53 kilometers
Maximum Modeled Contribution (ppb)	71.6 (88.4% of 81 ppb modeled for total impact)	< SIL	< SIL

Note: Background concentration for the modeling is 7 ppb.

AERMOD modeling of the maximum potential emission levels for each facility predicted a SO₂ ambient air concentration of 81 parts per billion (ppb) in the nonattainment area. The results of the

modeling showed that the Expera facility is responsible for 88.4 percent of this modeled value. The modeling also shows that, although PCA's potential emissions are greater than the Expera facility, the PCA facility is of sufficient distance away to have minimum impact on Oneida County's attainment status. Therefore, the primary facility contributing to nonattainment in Oneida County is the Expera facility. These modeling results are also summarized in Table 2. The air quality values and contribution values for individual facilities presented in Table 2 are for the single grid point in the nonattainment area showing the highest modeled SO₂ concentration. The area within the grid showing the highest SO₂ concentrations is consistent with monitored air quality results.

2. Control Strategy

WDNR's control strategy for demonstrating attainment of the 2010 SO₂ NAAQS is to implement additional emission requirements and reductions at the Expera facility. The emissions for Red Arrow and PCA are accounted for at their currently permitted maximum allowable SO₂ emission levels. If these facilities seek to increase emissions, they will have to go through the permitting process and associated air quality modeling to ensure the NAAQS is maintained. This plan for attainment does not rely on any other emission reduction requirement or national program for controlling SO₂ emissions.

3. Attainment Demonstration

Expera SO₂ Emission Sources

As noted in Section III, Expera is the primary facility contributing to SO₂ nonattainment in Oneida County. Expera currently operates two boilers capable of emitting SO₂: boiler B26 and boiler B28. The characteristics and SO₂ emission requirements for these boilers prior to this plan are as follows:

- 1) Boiler B26 - Boiler B26 is a 300 mmBtu per hour cyclone boiler constructed in 1958. This boiler provides base load steam and power for the paper processes operated at the facility. This boiler is fired with bituminous coals or a mixture of bituminous and subbituminous coals. The mixture of coals is specific to maintain fusion and slagging characteristics necessary for firing in a cyclone boiler. Boiler gases and emissions are exhausted through stack S09. Particulate emissions are controlled by an electrostatic precipitator (ESP). Stack S09 was originally constructed with a height of 209 feet above ground level. Prior to this plan, the boiler was subject to a SO₂ emission limit of 3.5 pounds per mmBtu averaged over 24 hours under Consent Order AM-94-38. The maximum allowable mass emissions under this emission rate limit was 1,050 pounds per hour. This emission limitation was established in order to demonstrate attainment with the 1971 SO₂ NAAQS.
- 2) Boiler B28 - Boiler B28 is a 280 mmBtu per hour natural gas boiler constructed in 1996. This boiler can be fired with distillate oil as a backup fuel to a capacity of 270 mmBtu per hour. The distillate oil is restricted to a maximum sulfur content of 0.05 percent by weight under Title I permit 95-SDD-048. The maximum allowable emissions while firing distillate oil is 15.3 pounds per hour.
- 3) Boilers B20, B21, B22, & B23 - Boilers B20, B21, B22, & B23 are four coal-fired stoker boilers that are each rated at 83.5 mmBtu per hour. These boilers were subject to SO₂ emission limitations under the Consent Order AM-94-38, but were retired in 2014 after designation of the Oneida County 2010 SO₂ NAAQS nonattainment area. The decommissioning of these boilers

was made federally enforceable pursuant to condition ZZZ.12 of Title I permit 13-SDD-014. Retirement of the boilers is part of the control strategy of this plan.

Based on current permitted conditions, boiler B26 is responsible for the vast majority of SO₂ that could be emitted by the Expera facility. Therefore, the attainment strategy focuses on controlling emissions from this boiler.

Boiler B26 GEP Stack Height

Historic air quality modeling indicated that flue gas dispersion from boiler B26, the large coal-fired boiler, is negatively impacted in a manner which concentrates SO₂ emissions. Expera provided a study which evaluated the aerodynamic impacts of nearby structures on boiler B26 flue gas emissions through stack S09. This study is provided in Appendix C.

The study researchers measured plume downwash effects by using a scale model of the facility in a wind tunnel test. The tests were conducted to account for the wind direction, wind speed, and boiler load that result in worst case pollutant concentrations. During the wind tunnel tests, stack heights were increased progressively from the existing stack height of 209 feet (63.7 meters). At each stack height, surrogate pollutant concentrations were measured both with and without nearby buildings in place. This exercise demonstrated how plume effects caused by nearby structures are concentrating SO₂ emissions under certain conditions.

The stack height for achieving intended dispersion of air pollutants is termed the “Good Engineering Practice” (GEP) stack height. The GEP stack height is specific to each facility and is determined according to methods under 40 CFR 51.100. One method specifically allows for the GEP stack height to be determined based on a study or analysis of the specific facility characteristics such as the one conducted by Expera. Specifically, 40 CFR 51.100(ii) (3) provides that GEP can be determined by:

The height demonstrated by a fluid model or a field study approved by the EPA State or local control agency, which ensures that the emissions from a stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes, or eddy effects created by the source itself, nearby structures or nearby terrain features.

According to 40 CFR 51.100 (kk) (1) “excessive concentrations” for purposes of determining GEP means:

For sources seeking credit for stack height exceeding that established under §51.100(ii)(2) a maximum ground-level concentration due to emissions from a stack due in whole or part to downwash, wakes, and eddy effects produced by nearby structures or nearby terrain features which individually is at least 40 percent in excess of the maximum concentration experienced in the absence of such downwash, wakes, or eddy effects and which contributes to a total concentration due to emissions from all sources that is greater than an ambient air quality standard.

According to the definition of “excess concentrations,” the maximum allowable GEP stack height in the study is reached when pollutant concentrations with structures present are 1.4 times the pollutant concentrations with no structures present. Based on this information, WDNR has determined that a stack height of 296 feet (90 meters) meets the GEP criteria under 40 CFR 51.100(K) for boiler B26.

Further discussion of the technical basis for plume dynamics and the determination of stack S09 GEP stack height are provided under the modeling protocol discussion in Appendix A.

Boiler B26 Emission Requirements

The WDNR used the AERMOD air quality dispersion model to determine the amount of SO₂ emissions per hour that can be emitted from Expera boiler B26 while attaining the NAAQS. The modeling assumes emissions from PCA and Red Arrow and boiler B28 at the Expera facility remain at current maximum allowable emission levels.

For boiler B26, the modeling assumes the GEP stack height of 296 feet. Initial modeling runs were performed while operating the boiler at full and normal load conditions. When holding the emission rate constant, the modeling showed that the maximum air quality impact occurs while the boiler is at full load or 300 mmBtu per hour. Therefore, to determine the emission rate necessary for attainment, modeling runs were conducted with the boiler at full load while iteratively reducing the emission rate. The protocol and results of this modeling are provided in Appendix A.

To determine which modeling runs result in attainment, the 4th highest value of SO₂ concentrations each year generated by the AERMOD runs are compared to the 2010 SO₂ NAAQS value of 75 ppb. This approach mimics the methodology applied to determine attainment status from actual monitored air quality values.

The AERMOD modeling runs showed that SO₂ emissions from boiler B26 must be limited to 960 pounds per hour to reach attainment. This value of mass emissions per hour is equal to an emission rate of 3.20 pounds per mmBtu while the boiler is operating at the full load capacity of 300 mmBtu per hour. These modeled operating criteria form the basis of enforceable requirements for Expera boiler B26 for attaining the 2010 SO₂ NAAQS.

4. Enforceable Requirements

For purposes of attaining the 2010 SO₂ NAAQS, emission requirements for the Expera facility will be made permanent and enforceable under Administrative Order AM-15-01 as presented in Appendix B. This order is submitted for incorporation into the state implementation plan.

Emission requirements for the Red Arrow and PCA facilities are enforceable through Title I construction permits 15-JJW-058, 14-SDD-201, and 13-MDW-099, respectively.

Expera Boiler B28 Emission Requirements

As discussed, boiler B28 is modeled to emit SO₂ at current maximum allowable emission levels consistent with distillate fuel sulfur content of 0.05 percent by weight. Boiler B28 is currently limited to this fuel sulfur content level under construction permit 95-SDD-048. Compliance is demonstrated by fuel testing and record keeping under the permit. These same requirements are incorporated into Administrative Order AM-15-01.

Expera Boiler B26 Emission Requirements

Based on the air quality modeling, the boiler B26 emission requirements include the following:

- 1) A stack height of 296 feet.
- 2) An emission rate limit of 3.00 pounds per mmBtu on a 24-hour basis, based on the modeled emission rate of 3.20 pounds per mmBtu on an hourly basis (refer to section 4.A. for discussion).
- 3) A boiler capacity firing limitation of 300 mmBtu per hour.

Administrative Order AM-15-01 adopts these requirements and the necessary methods to demonstrate compliance with each requirement. Under the order, Expera must comply with these requirements by January 1, 2017. The emission limitation, boiler capacity limitation and compliance requirements for each are discussed in further detail below.

A. Emission Rate Limit

As stated, the modeled emission rate limit is 3.20 pounds per mmBtu on an hourly basis. EPA's SO₂ implementation guidance allows emissions to be averaged over extended periods. To incorporate this flexibility and to be consistent with practical fuel sampling methods, the order implements an equivalent emission rate limit on a 24-hour average basis of 3.00 pounds per mmBtu.

EPA provides a methodology for converting applicable emission rate limits from shorter to longer averaging periods in the SO₂ implementation guidance. This method evaluates emissions from the source or a similar source to determine a conversion ratio for the two averaging times being compared. In this case, the method is used to convert the 1-hour emission rate limit determined by air quality modeling (based on the 1-hour NAAQS) into the equivalent 24-hour emission limit.

In determining the ratio used to convert the emission limit to different averaging times, the methodology relies on the availability of hourly emissions data, presumably from sources monitored with a continuous emissions monitoring system (CEMs). Expera does not have a CEM monitor in place and therefore this source-specific data is not available. However, the SO₂ SIP guidance states that CEMs data from other sources similar in fuel and control equipment can and should be used when CEMs data is not available for the source. In developing the guidance, EPA evaluated emission rates at different averaging times for coal-fired boilers using data reported by electric utilities to the Clean Air Markets Division (CAMD). This evaluation showed a ratio value of 0.93 percent for converting a 1-hour emission rate of an uncontrolled coal-fired boiler to a 24-hour emission rate. This data is provided in Table 1, Appendix D of the SO₂ guidance.

The WDNR utilized CAMD emissions data as it is the best information available for sources similar to the Expera boiler B26. The CAMD database has tracked CEMs emissions data for a large population of coal-fired boilers over a long period. This database allows for a robust and sound analysis of emission rates over different averaging periods. In comparison, the CEMs SO₂ emissions data from uncontrolled industrial coal fired boilers is very limited. Therefore, the ratio of 0.93 percent derived from the CAMD database is the most appropriate value in converting the 1-hour emission rate limit to a 24-hour limit for Expera. Multiplying 0.93 times the 1-hour emission rate of 3.20 pounds per mmBtu equals 2.98 pounds per mmBtu averaged over 24 hours. For implementation purposes in the order, the emission rate is rounded to 3.00 pounds averaged over 24 hours.

B. Emission Rate Limit Compliance Demonstration

To demonstrate compliance with the emission rate limit, Administrative Order AM-15-01 requires Expera to perform fuel monitoring for each 24-hour period. Expera is to demonstrate compliance by

assuming that all sulfur in the fuel will be converted to SO₂. If control efficiency is applied, Expera must perform fuel monitoring as discussed in this section and follow requirements discussed in section C below.

The fuel monitoring method requires Expera to obtain a minimum of three fuel samples for each day (24-hour period) and generate a composite sample. This approach represents the average SO₂ fuel content over 24 hours which is consistent with demonstrating compliance with the 24-hour emission rate of 3.00 pounds per mmBtu.

Expera can collect more samples through each day in creating the composite sample and determining the 24-hour average emission rate. However, fewer samples mean that there is less ability to average out high values. Therefore, fewer samples create a more stringent monitoring and compliance demonstration case. The only concern would be that enough samples are collected to ensure that the SO₂ fuel content is not under-biased due to one low value or sampling error or artifact. The WDNR is requiring a minimum of three samples throughout the day to ensure the resulting SO₂ fuel content is not under-biased.

Expera will be required to randomly analyze one composite sample each week to determine compliance. Expera will also be required to analyze a composite sample on each day the air quality monitor registers a SO₂ ambient air concentration of 75 ppb or higher. Because Expera has composite samples for each day, WDNR or EPA will be able to require Expera to analyze additional samples as needed to demonstrate compliance. The composite samples will be retained on site for a period of 90 days.

Fuel sampling, as outlined in this plan, is preferred for a number of reasons. Most critical is that the compliance methodology provides a form of continuous emissions monitoring in a reasonable manner. Collecting and analyzing fuel samples for enough individual hours to demonstrate compliance with a 1-hour limit would be overly burdensome and costly. The 24-hour composite approach yields a reliable average emission rate that is consistent with demonstrating compliance with the 24-hour emission rate. Lastly, this fuel monitoring plan provides a mechanism for demonstrating compliance on a continuous basis whereas periodic performance testing as allowed under the guidance would be less robust.

Expera has historically fired solid fossil fuel only during the main operation of the boiler. The fuel monitoring required in the order covers that operating situation. However, in the case that Expera fires non-fossil solid fuel, liquid fuel, or gaseous fuel, the order requires Expera to demonstrate compliance based on a heat input weighted basis. In addition, the order requires Expera to establish a separate fuel sampling plan for these additional fuels. This plan must be approved by WDNR.

C. Compliance Demonstration if Applying a Control Efficiency

Control equipment could be required in the future to demonstrate compliance with the emission rate limit. In this case, the order requires that the control efficiency be determined by performance stack testing. Compliance would be demonstrated by applying the control efficiency to the SO₂ values resulting from the fuel monitoring requirement as outlined in section B. The performance test shall be performed according to one of EPA Methods 6, 6A, 6B, 6C or 8 provided under 40 CFR 60 Appendix A and according to all applicable procedures

and methods under s. NR 439.07, Wis. Adm. Code. The performance test shall be conducted according to a monitoring and compliance plan approved in writing by WDNR.

D. Emission Rate Limit and Compliance Demonstration During Boiler Startup

For any non-fossil solid fuel or liquid fossil fuel fired in boiler B26 during startup, the operator shall demonstrate that the SO₂ content of the fuel does not exceed 3.20 pounds per mmBtu by sampling and analyzing fuels according to a plan approved by WDNR in writing.

E. Boiler Firing Capacity Limitation and Compliance Demonstration

To demonstrate compliance with the firing capacity limit of 300 mmBtu per hour for boiler B26, Expera will be required to correlate the boiler's generated steam load to the firing capacity and continuously monitor hourly steam load. Expera will record the maximum hourly steam load for each day and the correlated firing capacity to determine compliance.

The correlation for converting steam load to heat input will be determined from twelve months of heat input and steam generation data. This factor represents the boiler efficiency rate. This rate will be updated yearly or as directed by WDNR. The heat input is determined by monitoring the total amount of fuel burned each week and applying the fuel heat content from the composite samples analyzed each week to demonstrate compliance with the emission rate requirement. Using a weekly sample to determine fuel heat content is deemed appropriate because a review of 52 samples collected in 2014 shows that heat content only deviated by an average of 2.3 percent.

An allowed alternative is for Expera to determine monthly instead of weekly heat input. This is to address the case that Expera could use a CEM in demonstrating compliance with the emission rate limit. Under this scenario, Expera would not have to analyze a composite fuel sample each week. Therefore, the option is allowed to collect one fuel sample each week and composite into a monthly sample. This monthly composite sample would be analyzed for heat content which is then used to determine the monthly heat input. Once again, this option for a monthly fuel sample is only for determining average fuel heat content for purposes of the steam load compliance methodology.

Lastly, the order allows WDNR or EPA to require additional fuel sampling if necessary to determine an appropriate boiler efficiency factor.

F. Continuous Emissions Monitoring Systems

In lieu of fuel sampling or steam monitoring, Expera has the option to directly monitor the SO₂ emission rate or boiler firing capacity by using a Part 60 compliant CEMs.

G. Alternative Monitoring

The monitoring requirements allow Expera to use alternative methods if approved in writing by both WDNR and EPA.

H. Additional Monitoring Requirements

The monitoring and compliance requirements provide that WDNR or EPA can require performance stack testing at any time for purposes of demonstrating compliance. The stack testing would be performed according to one of the EPA methods 6, 6A, 6B, 6C or 8 provided under 40 CFR 60 Appendix A and according to all applicable procedures and methods under s. NR 439.07, Wis. Adm. Code.

If stack testing is required, compliance would be determined by comparing the average of three stack test performance runs to the SO₂ emission rate limit of 3.20 pounds per mmBtu instead of the 24-hour average limit of 3.00 pounds per mmBtu.

5. Reasonably Available Control Technology and Measures (RACT and RACM)

As indicated in EPA's SO₂ guidance, the control strategy should include all reasonably available control technology (RACT) and reasonably available control measures (RACM) that can be implemented as expeditiously as practical. This implementation is to occur no later than five years after designation.

EPA has determined that both RACT and RACM are the levels of emission reduction necessary to demonstrate attainment with the 2010 SO₂ NAAQS.¹ Since the emission requirements implemented for Expera under Administrative Order AM-15-01, along with current permanent permit requirements for Red Arrow and PCA RACT, are being implemented to demonstrate attainment, these same emission requirements (emission levels) fulfill RACT and RACM for the Oneida County SO₂ nonattainment area.

The WDNR has determined that the appropriate compliance schedule satisfying an expeditious compliance date for RACM is a compliance date of January 1, 2017, the same as the attainment deadline. This schedule is necessary because the control strategy relies on increasing the stack height from 209 feet to 269 feet above ground level. This project is anticipated to be completed in the fall of 2016. Therefore, it is reasonable to set the initial compliance date as January 1, 2017 to allow for contingencies.

6. Rate of Further Progress

This SIP for the 2010 SO₂ NAAQS must fulfill requirements for Rate of Further Progress (RFP). The SIP guidance defines RFP as the amount of incremental emission reductions required during interim years to ensure that attainment is reached by the attainment date of January 1, 2017.

In this case, SO₂ emitted by one facility, Expera Specialty Solutions, will be controlled as expeditiously as practical to the level necessary to reach attainment. Since there are no interim steps for controlling emissions from this source between January 2016 and January 1, 2017, and attainment will be reached by the attainment date, all requirements for RFP are fulfilled.

¹ USEPA, 2014. Memorandum "Guidance for 1-Hour SO₂ Nonattainment Area SIP Submissions" from Stephen D. Page, Director to Regional Air Division Directors, Regions 1 – 10, April 23, 2014, Page 14.

7. Base and Attainment Year Emission Inventories

The WDNR is required to establish a base year inventory of emission sources of SO₂ within the Oneida County nonattainment area under this plan. The year 2011 is selected as the base year for this inventory, as this year is consistent with EPA's most recent emissions inventory data requirements as codified at 40 CFR subpart 51, Subpart A. The SO₂ implementation guidance also states that the inventory must account for any other sources outside of the nonattainment area contributing to nonattainment. The analysis of contributing sources presented in section I establishes that no emission sources outside of the nonattainment area contribute and therefore no additional sources need to be included in the plan emissions inventory.

Under this plan, WDNR must also establish an attainment year emissions inventory which includes the anticipated emission reductions from control requirements implemented under the attainment plan. The year of the attainment emissions inventory is 2017. The 2017 emissions inventory is projected from the 2011 base year inventory and includes emission reductions resulting from control programs and emission source shutdowns since 2011, and the Expera facility emission reductions required under this plan by January 1, 2017. For the source categories other than point sources, the 2017 attainment emissions inventory is derived by prorating projected county-wide emissions to the nonattainment area comprised of the four townships within Oneida County.

Both the 2011 and 2017 emissions inventories include all point (stationary source), area, on-road, mobile, and off-road mobile source categories in the Oneida County nonattainment area.

A. 2011 Base Year Emissions

This section provides a brief description of the methods for developing the 2011 base year emissions inventory and the summary of emissions. More detailed documentation of the development of the emissions inventories for point, area, on-road mobile and off-road mobile categories is in Appendix D.

SO₂ point source emissions in 2011 were compiled from Wisconsin's Air Reporting System (ARS) by using annually reported emissions. The review of the emissions inventory identified two point source facilities emitting SO₂. In 2011, Red Arrow reported emitting 8 tons and Expera reported 2,422 tons of SO₂. The total point source emissions in 2011 are 2,430 (rounded) tons.

Area sources collectively represent individual sources of emissions that have not been inventoried as having specific point or mobile sources. These individual sources are treated collectively as nonpoint sources that are typically too small, numerous, or difficult to inventory using the methods for other classes of sources. The 2011 area source emissions inventory for the Oneida County nonattainment area was created based on Wisconsin's 2011 base year emissions inventory submitted to the EPA in 2013. A table of 2011 area source emissions by county and source classification code (SCC) is located in Appendix B of the document submitted to EPA. SCC is a process-level code that describes the equipment and/or operation that is emitting pollutants (40 CFR 51.50).

On-road mobile source emissions were developed using MOVES2014. The key inputs used in the MOVES2014 model are as follows: vehicle age distributions based on registration data from the Wisconsin Department of Transportation (WisDOT), detailed transportation data (e.g., vehicle miles of travel [VMT] by vehicle class, road class and hour of day, and average speed distributions), and controls, including the use of reformulated gasoline.

All estimates were made in accordance with the *MOVES2014 User Guide* (U.S. EPA, Office of Transportation and Air Quality, Assessment and Standards Division, July 2014, EPA 420-B-14-055) and *Using MOVES to Prepare Emission Inventories in State Implementation Plans and Transportation Conformity: Technical Guidance for MOVES2010, 2010a and 2010b* (U.S. EPA, Office of Transportation and Air Quality, Transportation and Climate Division, April 2012, EPA-420-B-12-028).

Off-road mobile source emissions other than emissions from aircraft, commercial marine engines, and locomotives were also estimated using the MOVES2014 model (version 20141021). Emission estimates for aircraft, commercial marine engines, and locomotives were obtained from EPA’s 2011 National Emissions Inventory (NEI), version 1, or U.S. EPA’s 2011 Emissions Modeling Platform (Modeling Platform), version 6. For aircraft and locomotive emissions, the estimates in the NEI and Modeling Platform are equal.

The base year 2011 emissions inventory for the Oneida nonattainment area is summarized in Table 3.

Table 3. 2011 Emissions Inventory for the Oneida County SO₂ Nonattainment Area

Source Category	SO₂ (tons per year)
Point Sources	2,430.47
Area Sources	12.79
On-Road Mobile Sources	2.59
Off-Road Mobile Sources	4.88
Total	2,450.73

B. 2017 Attainment Year Emissions

This section describes the development of the 2017 future year emissions inventory. Unless otherwise noted below, the projected point and area source emissions in the Wisconsin nonattainment areas for 2017 were estimated using growth factors appropriate for each source. To forecast point source emissions, WDNR used a “zero growth” projection, but evaluated maximum demonstrated emissions.

The point source emissions inventory was developed by considering emissions from 2011 through 2014, the last year of available reported annual emissions. Once again, there are only two point sources: Red Arrow and Expera. The highest emissions level during that time for each facility is 8 tons for Red Arrow and 2,665 for Expera. If both facilities operate at this maximum actual level in the same year, the resulting total emission level is 2,673 (rounded) tons. The WDNR is assuming this maximum actual value as the projected 2017 point source emissions level (zero additional growth).

Expera retired boilers B20, B21, B22, and B23 in 2014. The WDNR assumes that emissions and load from the four retired boilers is picked up by the coal fired boiler B26 and/or the natural gas fired boiler B28. Therefore, annual emission levels are not anticipated to change; if anything, emissions will decrease if load is switched to the natural gas boiler.

The WDNR also evaluated the potential emission levels from boiler B26 due to the control requirements implemented under this plan. As stated, Expera will be required to operate boiler B26 at

a SO₂ emission rate of 3.20 pounds per mmBtu or less. To assess the potential difference in emission levels, the historic emission rates are compared to the new requirement. Expera has been operating the boiler at or below an emission rate of 3.20 pounds per mmBtu in order to meet the emission rate limit of 3.5 pounds per mmBtu applicable under Consent Decree AM-94-38 since 1994. Based on this information, WDNR expects that Expera will reduce emission levels further when complying with the new 3.20 pounds per mmBtu emission limit in order to maintain a compliance margin. However, as a conservative estimate for purposes of this plan, WDNR is assuming that the actual emission rate will not decrease. Therefore, assuming the same emission rate and that load from the recently retired boilers B20, B21, B22 and B23 is transferred to boiler B26, WDNR is assuming no change in the attainment year emissions inventory compared to the maximum demonstrated annual emission level.

The 2017 area source emissions inventory was created by projecting the Wisconsin 2011 base year emissions inventory submitted to EPA in 2014 for the NEI. The forecasting factors were primarily based on growth factors from the EGAS model. The “Default REMI 6.0 SCC Configuration” for EGAS was used. If growth factors were not available for a certain SCC, population based growth factors were derived from the Wisconsin Department of Administration’s Demographic Services Center population reports.

On-road mobile source emissions for 2017 were developed using the MOVES2014 model. The transportation modeling inputs to MOVES2014 for the Oneida county nonattainment area are based on data provided by WisDOT on July 17, 2014. More information about the development of the 2017 on-road emissions inventory can be found in Appendix D.

Off-road mobile source emissions projections for 2017, other than aircraft, commercial marine engines, and locomotives, were developed using the MOVES2014 model. The MOVES2014 model includes control measures for promulgated federal control requirements. 2017 attainment year emissions projections for aircraft, commercial marine engine, and locomotive emissions were developed using EPA’s 2018 modeling platform by interpolating the difference between the 2011 base year and 2018 emissions estimates. Detailed information about the development of the 2017 off-road emission inventory can be found in Appendix D.

The base year 2011 emissions inventory for the Oneida nonattainment area is summarized in Table 4.

Table 4. 2017 Emissions Inventory for the Oneida County SO₂ Nonattainment Area

Source Category	SO₂ (tons per year)
Point Sources	2,673.47
Area Sources	13.84
On-Road Mobile Sources	1.05
Off-Road Mobile Sources	4.34
Total	2,692.70

8. Contingency Measure

EPA’s SO₂ implementation guidance states that SO₂ attainment is source specific. As such, EPA indicates that requirements placed on the culpable facilities and sources provide a high degree of

certainty that attainment will be achieved. If this is not the case and attainment is not measured, then reevaluating facility emission requirements is a valid contingency measure. The guidance reads:

Since SO₂ control measures are by definition based on what is directly and quantifiably necessary to attain the SO₂ NAAQS, it would be unlikely for an area to implement the necessary emission controls yet fail to attain the NAAQS. Therefore, for SO₂ programs, the EPA; has explained that "contingency measures" can mean that the air agency has a comprehensive program to identify sources of violations of the SO₂ NAAQS and to undertake an "aggressive" follow-up for compliance and enforcement, including expedited procedures for establishing enforcement consent agreements pending the adoption of the revised SIP. 17 The EPA believes that this approach continues to be a valid approach for the implementation of contingency measures to address the 2010 SO₂ NAAQS.

In the event that SO₂ attainment is not measured in the Oneida County nonattainment area, the contingency measure Wisconsin is adopting under this plan is a commitment to reevaluate stationary source SO₂ emission limit requirements.

9. New Source Review Program

An approvable SO₂ plan requires a demonstration that Wisconsin has a New Source Review (NSR) program in place for permitting new sources in nonattainment areas as required under Clean Air Act (CAA) under sections 172(c)(5) and 173. The CAA mandates that the NSR program regulates permitting for the construction of new or modification of existing major stationary sources and require lowest achievable emission rates (LAER). In addition, the permitted source must provide offsets for the remaining balance of emissions beyond the LAER level of control.

Wisconsin has implemented ch. NR 408, Wis. Adm. Code, to fulfill NSR program requirements for nonattainment areas including the implementation of LAER and offsets for new or modified stationary sources. EPA initially approved ch. NR 408, Wis. Adm. Code as part of Wisconsin's SIP on January 18, 1995 (60 FR 3538) and the last update was approved on November 5, 2014 (79 FR 193).

10. Conformity

As discussed in EPA's SO₂ nonattainment area SIP guidance, CAA Section 176(c) requires that actions by federal agencies do not cause new air quality violations, worsen existing violations, or delay timely attainment of the relevant NAAQS or interim reductions and milestones. General conformity applies to any federal action (e.g., funding, licensing, permitting or approving) taking place in a nonattainment area, other than certain highway and transportation projects. EPA's General Conformity Rule establishes the criteria and procedures for determining if a federal action conforms to the SIP. Wisconsin meets all of EPA's general conformity procedures.

Section 176(c) of the CAA also addresses transportation conformity requirements that ensure that federally supported highway and transit project activities are consistent with the SIP. Transportation conformity applies to areas that are designated nonattainment for transportation-related criteria pollutants. On August 1, 2013, WDNR submitted signed Memorandums of Understanding (MOUs) to EPA establishing transportation conformity procedures for inclusion in Wisconsin's SIP. EPA issued a direct final rulemaking approving the MOUs on February 10, 2014 (79 FR 11050).

For purposes of the Oneida County SO₂ nonattainment area, conformity is not applicable. In its SO₂ nonattainment area SIP guidance, EPA states that, due to the relatively small, and decreasing, amounts of sulfur in gasoline and on-road diesel fuel, EPA's transportation conformity rules only apply to SO₂ nonattainment areas in two cases: (1) if the Regional Administrator or the director of a state air agency has found that transportation-related emissions of SO₂ as a precursor are a significant contributor to a PM_{2.5} nonattainment problem, or (2) if the SIP has established an approved or adequate budget for such emissions as part of the RFP, attainment or maintenance strategy (40 CFR 93.102(b)(1), (2)(v)). Although Wisconsin has an SO₂ transportation conformity budget for the Milwaukee-Waukesha-Racine 2006 PM_{2.5} NAAQS maintenance area for the years 2020 and 2025, the Oneida County SO₂ nonattainment area is attaining the 2006 PM_{2.5} NAAQS. Therefore, conformity does not apply to this area and does not need to be further addressed in this SIP.

11. Maintaining Previous NAAQS requirements

The Oneida County area was previously designated nonattainment for the 1971 1-hour SO₂ standard. As a result, Expera was required to control SO₂ emissions under Consent Order AM-94-38. As previously described, boiler B26 is subject to an emission limitation of 3.5 pounds per mmBtu under this order. Under this plan and Administrative Order AM-15-01, boiler B26 is subject to a more stringent emission rate limit of 3.00 pounds per mmBtu on a 24 hour basis (equivalent to 3.20 pounds per mmBtu on an hourly basis). In addition, boilers B20, B21, B22, & B23, which operated under the previous Consent Order AM-94-38, have been decommissioned. Therefore the emission requirements applicable under this plan are more restrictive than those implemented under the Consent Order AM-94-38. Thus, this plan and Administrative Order AM-15-01 will continue to maintain compliance with all previous SO₂ NAAQS requirements.

Because Administrative Order AM-15-01 is more restrictive than Consent Order AM-94-38 with respect to SO₂ emissions, WDNR is withdrawing Consent Order AM-94-38 from the SIP.

V. PUBLIC PARTICIPATION

In accordance with section 110(a) (2) of the CAA, WDNR is required to hold a public hearing prior to the adoption of this plan and subsequent submittal to the EPA. The WDNR must notify the public and other interested parties of an upcoming public hearing and public comment period 14 days prior to holding the hearing. The WDNR met that requirement, as follows:

- The notice of availability of this SIP was posted on WDNR's website (<http://dnr.wi.gov/topic/AirQuality/Pollutants.html>) on November 11, 2015.
- A public hearing was held on December 11, 2015 at 2:30p.m. at the Wisconsin Department of Natural Resources Building, Conference Room 713, 101 South Webster Street, Madison, WI 53707.
- A public comment period was provided from November 11, 2015 through December 15, 2015.

The WDNR received several comments on the draft SIP from the Forest County Potawatomi Community (see Appendix E). This final submittal reflects changes made to address those

comments. The WDNR also made several technical corrections and nonsubstantive edits to improve the readability in this final document.

VI. CONCLUSION

This SIP meets Wisconsin's CAA section 191(a) obligation to submit a plan for the Oneida County nonattainment area for the 2010 SO₂ NAAQS. The plan fully demonstrates attainment of the 2010 SO₂ NAAQS through air dispersion modeling of an effective control strategy, in accordance with the requirements of section 172(c).

APPENDIX A: Oneida County 2010 SO₂ NAAQS Nonattainment Area Air Quality Modeling Analysis

July 2015

INTRODUCTION

The Wisconsin Department of Natural Resources (WDNR) operates a sulfur dioxide (SO₂) ambient air monitor at a water tower in the City of Rhinelander, Oneida County. The monitor measured concentrations that were in excess of the 1-hour SO₂ National Ambient Air Quality Standards (NAAQS) for the period 2007-2009 such that the United States Environmental Protection Agency (USEPA) designated a portion of Oneida County Wisconsin as nonattainment. In the designation process one source at one facility, namely stack S09 at Expera Specialty Solutions in Rhinelander was identified by WDNR as primarily culpable.

Analyzing ground level concentrations using the regulatory dispersion model AERMOD with aerodynamic building downwash effects resulted in modeled concentrations lower than monitored concentrations. Expera and their consultants embarked on a series of wind tunnel studies to examine the situation and to assess whether a viable solution could be found. The wind tunnel studies determined the Good Engineering Practice (GEP) stack height for S09 to be 90 meters (296 feet). Expera proposed to use the wind tunnel studies to predict ground level concentrations, but due to the unusual nature and limitations of wind tunnel studies and based on verbal comment from USEPA, WDNR utilized the current regulatory dispersion model AERMOD in the attainment analysis.

AREA CHARACTERIZATION

The City of Rhinelander is located in north central Wisconsin, within Oneida County. The paper mill now owned by Expera has been a fixture in the middle of the city along the Wisconsin River since 1903. In the early 1980's, WDNR began monitoring for SO₂ in Rhinelander at a variety of sites including at the municipal water tower. The water tower location recorded the highest concentrations, so monitoring has continued through the present day. In the mid-1980's, concentrations exceeded the 24-hour SO₂ standard (365 µg/m³) but, as with the present day, modeling results were less than measured values. Although building downwash was suspected to be a major factor in the high measured concentrations, WDNR and the facility negotiated reductions of emissions proportionate to the amount of exceedance.

Subsequent to the emission reductions, no further violations of SO₂ standards were recorded until the NAAQS was revised to the 1-hour time period in 2010 (0.075 ppm or 196 µg/m³). Modeled results were less than the measured values, but the facility proposed to replace their stoker boilers (venting through S11) with small, natural gas fueled units and their cyclone boiler (venting through S09) with a moderate size natural gas and fuel oil boiler. This would have greatly reduced both the emission and ambient concentrations of SO₂ in the area.

The facility was purchased by Expera in 2013, and although remained committed to replacing the stoker units (S11), began evaluation on maintaining the coal fired cyclone boiler (S09). Expera hired Cermak Peterka Petersen (CPP) and Bob Paine from AECOM to study the building downwash situation at Rhinelander and to propose a solution. Their wind tunnel studies demonstrated that the primary cause of the model to monitor discrepancy is a phenomenon called the corner vortex.

The corner vortex phenomenon is referenced in the USEPA document; *Guideline for Determination of Good Engineering Practice Stack Height (revised 1985)*. Within Section 2 of the GEP document, it is stated that Peterka and Cermak in 1975 recognized that behind a rectangular building there were differences in the flow depending on the orientation of the structure to the wind. When oriented perpendicular to the wind (i.e. flow from face to face) the building effect “decayed fairly rapidly over the first 20 building heights.” However, when the wind is oriented 47 degrees from perpendicular (i.e. flow from corner to corner) the building effect dropped from its maximum and then “remained constant to 80 building heights downwind.” The GEP document continues to note that, “The existence of an (effect)... is believed evidence of a vortex pair with axes parallel to the flow direction which are a remnant of the corner vortices formed at the leading roof corner.” Other researchers also noted that the flow around a building is highly dependent on orientation. The GEP document (p. 15) mentions a study by Robins and Castro in 1977 that found, “Strong vortices generated by the top leading edges were found for an approach flow at 45 degrees to the building edge.”

As the ambient wind flow encounters the flat face of a building, the atmosphere is lifted up and over the building with strong descent and turbulence on the lee side. If the wind approaches from a building corner (especially of a building taller than it is wide), the corner knifes through the wind creating a pair of counter-rotating vortices (corner vortex) that act to enhance the descending air on the lee side. This leads to higher pollutant concentrations downwind of the building when the flow is oriented 45 degrees from perpendicular. More importantly, this feature of building downwash is not simulated in the regulatory dispersion models and this results in modeled concentrations being *less* than monitored concentrations.

AECOM and CPP provided two wind tunnel studies to WDNR and USEPA to address the issue. In the first study, the GEP stack height for Expera S09 was shown to be taller than the regulatory formula height due to the effect of the corner vortex. After review and collaboration with USEPA, the revised GEP stack height of 90 meters (296 feet) above ground level for S09 was accepted.

In the second study, CPP produced simulated ground level concentrations from their wind tunnel data using their proprietary model called HYWINMOD. This model uses traditional air pollution meteorological formulas to simulate ground level concentrations using wind tunnel information. But due to the uncertainty of the technique, the regulatory time frame, and based on verbal comments from USEPA, WDNR used the wind tunnel derived GEP stack height with AERMOD to demonstrate attainment with the NAAQS.

MODEL & METEOROLOGY

WDNR used the current regulatory version of AERMOD (AMS/EPA Regulatory Model), version 15181. Rhinelander is a small (both geographically and in terms of population) city that straddles the Wisconsin River in northern Wisconsin. Following Section 7.2.3(c) of the *Guideline on Air Quality Models*, an assessment of the land use around Expera shows that less than 50% of the land area within 3 kilometers is industrial, commercial, or dense residential. Therefore, rural dispersion coefficients were used in AERMOD.

Meteorological data was processed from 2006-2010 data collected at Rhinelander-Oneida County Airport (KRHI) using Green Bay upper air data. The surface wind data at KRHI is 2-minute average speed and direction reported each minute. This minute-based wind information was processed with AERMINUTE version 14337. The meteorological data was processed with the current AERMOD meteorological processor AERMET version 15181. Processing assumed an anemometer height of 7.9 meters above ground.

The instrumentation tower at KRHI is 4.8 kilometers west of Expera and is considered representative of meteorological conditions around the facility. Surface characteristics around KRHI were generated using AERSURFACE version 13016 following the methods described in the *AERMOD Implementation Guide*. Specifically, snow cover for each month during the period 2006-2010 was derived from National Snow and Ice Center maps. AERSURFACE was run both for snow and no-snow conditions and the albedo adjusted based on the number of days with snow cover during each month. Soil moisture for each year was a weighted average of the long-term Palmer index data from the Climate Prediction Center. The months of May, June, July, and August were weighted twice as high as the other months to account for the importance of soil moisture during the traditional growing season.

The base input information for AERSURFACE was the 1992 National Land Cover Dataset (NLCD). For an area 10 kilometers by 10 kilometers centered on KRHI, there are little differences between NLCD and the 2006-2010 period. However, when examining the data within 1 kilometer of KRHI, there were differences in the location of trees between NLCD and aerial photos taken in 2005, 2008, and 2010. The open land paralleling the east-west runway is much broader than indicated on the 1992 NLCD. To continue using AERSURFACE with the 1992 NLCD, the radius of the roughness circle in AERSURFACE was reduced and the center point adjusted until a representative match was found to a 1-kilometer circle in the 2008 leaf-on aerial photo. An independent analysis performed by consultants for Expera confirms the representativeness of this approach.

EMISSIONS INVENTORY

At Expera, the last stoker boiler venting through stack S11 was permanently shut down in April 2014, so emissions from the cyclone boiler (S09) and an existing natural gas and fuel oil boiler (S08) were analyzed using current permit allowable emission rates. Expera provided two operating conditions for stack S09, representing maximum heat input of 300 MmBtu/hr. (millions of British Thermal Units per hour) and the average, or normal heat input of 265 MmBtu/hr. Both operating conditions have different mass emission rates, volumetric flow rates and exit velocity, and exit gas temperatures. The only other SO₂ emission sources considered in the City of Rhinelander is from combustion of wood waste at Red Arrow Products, located 4.0 kilometers west-southwest of Expera. In April 2015, Red Arrow submitted an air permit application to increase the combustion of wood waste and the proposed theoretical emissions of SO₂ after expansion were considered.

In the initial analysis to determine the scope of potential SO₂ exceedances, the major sources at Packaging Corporation of America (PCA) Tomahawk, 33.0 kilometers southwest of Expera were also included. Although these emissions were shown to have limited effect on the Rhinelander area, they represent the only other large SO₂ emissions within 50 km of Expera and so were included. PCA is constructing a natural gas and fuel oil boiler to replace two large coal fueled units (B27 & B28). As the facility is in the construction phase and the two coal units will be permanently shut down no later than July 2016, these emissions will not be considered in this analysis. PCA has also applied for another air pollution control permit in November 2014, to convert their final coal fueled boiler (B10) into a mixed fuel (no coal) unit. As this action is still in the application phase and would not be operational until ~2018, the emissions from the boiler B10 when burning coal were considered.

INPUT PARAMETERS

Modeled stack parameters and building downwash data for Red Arrow, PCA, and Expera S08 were taken from the most recent WDNr analyses for those facilities. Modeled emission rates reflected the maximum short-term hourly rates with normal, or typical, exit velocity and gas temperature.

BPIP-PRIME was used to produce the building downwash information from facility provided plot plans, except for Expera stack S09. For Expera S09, due to the corner vortex issue, manual adjustments were made to the modeled input emissions data. The GEP stack height of 90 meters (296 feet) for S09 was assumed, along with flow, temp, and emission rates comparable to both maximum and nominal conditions. No building downwash was simulated for Expera S09 in AERMOD because of the model formulation. AERMOD does not consider the corner vortex and in not considering this unusual downwash, the model formulation could result in lower modeled concentrations compared to monitored values, even for stacks at GEP height.

Section 3 of the GEP document (p. 23) states that maximum ground-level concentrations from a GEP height stack downwind of a building 20 to 40 percent higher than without the building when the wind is oriented perpendicular to the structure. Pertinent to Expera, “The data for the same buildings oriented 45 degrees to the approach flow are found to have concentrations increased by roughly 40 to 80 percent. The differences are due to the presence of longitudinal vortices in the wake of buildings having a 45 degree orientation.”

Section 3 of the GEP document (p. 27) also states, “The maximum ground-level concentrations downwind of building structures should not be increased by more than 40 to 80 percent if the stack is equal to 2.5 times the building height.” For Expera, the 90 meter proposed GEP stack height is 2.6 times the influencing building height. Considering the corner vortex effect, it can be expected that ground level concentrations will be higher than if the influencing building was not present.

Further, the determination of GEP stack height in the wind tunnel also considers building downwash. In the determination, the stack height is increased in the wind tunnel until the ratio of concentrations with the building to concentrations without the building is ~1.4 (or 40 percent higher). Therefore, at 90 meters, emissions from Expera stack S09 would be expected to result in 40 percent higher concentration than if no building was present.

However, the wind tunnel studies performed for Expera demonstrate that the corner vortex downwash effects are not present for all wind speed conditions. According to the *Draft Recommended Approach for SO2 Nonattainment Modeling: Expera Specialty Solutions, Rhinelander, WI* provided by the consulting firms AECOM and CPP, “The downwash effects do not exist at wind speeds below about 2 m/s, and increase to a maximum factor of approximately 1.5 at wind speeds above 8 m/s.”

To accommodate for the variation with wind speed of the downwash, AECOM and CPP provided an equation to derive hourly ratios to apply to emission rates for each hour in the 2006-2010 KRHI meteorological data:

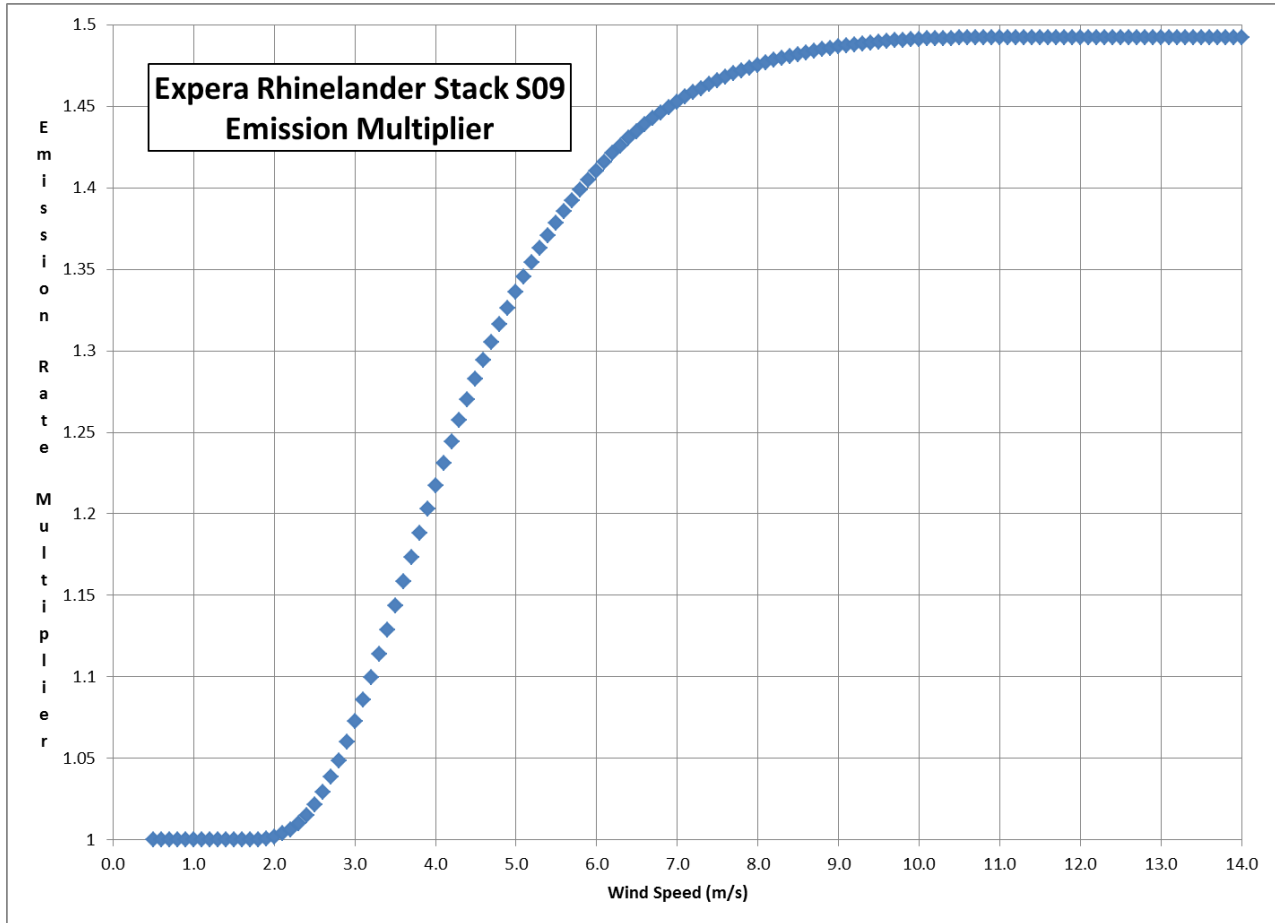
$$R = A \exp \left[- \frac{\left(\frac{1}{U_{airport}} - \frac{1}{U_{max}} \right)^2}{B^2} \right] + 1.0$$

Where $U_{airport}$ is the KRHI airport wind speed, U_{max} is assigned as the 1% wind speed of 10.8 m/s (exceeded less than 1% of the time), and A (0.492) and B (0.174) are best fit constants.

The equation produces a multiplier that varies with wind speed. For each hour of the 2006-2010 KRHI data set, the emission rate was calculated by multiplying the factor times the emission limitation. The emission rate for stack S09 for each hour was captured in a text file used in the HOUREMIS keyword within AERMOD. For wind speeds in excess of 10.8 m/s, the equation results in a slight reduction in the

factor R. It is reasonable to assume the maximum value of R (1.492) persists for higher wind speeds, so the value of R was set to 1.492 for wind speeds above 10.8 m/s.

As can be seen in the following graphic, the multiplier reaches 1.01 (or a 1% factor) at a wind speed of 2.2 m/s and reaches a value of 1.4 (or a 40% factor) at 5.8 m/s. Both values are consistent with the wind tunnel study reports and with general meteorological principles of building downwash.



RECEPTOR GRID

The receptor grid used in the analysis consisted of a series of nested rectangular grids with terrain derived from AERMAP using National Elevation Dataset information:

- 25 meter spacing out 500 meters from the sources
- 50 meter spacing to 1000 meters
- 100 meter spacing to 3 kilometers
- 250 meter spacing to 6 kilometers
- 500 meter spacing to 10 kilometers.

BACKGROUND CONCENTRATION

The closest monitoring location to Expera in Rhinelander is the Forest County Potawatomi site, located 48 kilometers east. The next closest, representative monitoring location is the Horicon (Dodge County) monitor. Horicon is located 250 kilometers south of Rhinelander, but there are no other SO₂ sources within 65 kilometers of the site. Horicon is centrally located within Wisconsin, and measured values are representative of a large area of the state. In addition, the Horicon monitoring station uses SO₂ measuring equipment that is sensitive to low concentrations. Due to these factors, the Horicon monitoring data will

be used as background concentration for many types of analyses. The 2012-2014 Horicon design value of 7 ppb ($18.3 \mu\text{g}/\text{m}^3$) was used as the background concentration for this analysis.

The modeling analysis includes all known point sources of SO₂ within 50 kilometers of Rhinelander, and the monitor location is similarly affected by distant SO₂ sources (in central, southern, and eastern Wisconsin). Nationally, the impact from locomotives and trucks has been minimized as the sulfur content in diesel fuel has been reduced to 0.015%, and the local impact of these vehicles is even smaller as the total population of Rhinelander is ~7,500 residents.

BASE CASE MODELING RESULTS

The stack parameters and emission rates for the initial (base case) modeling analysis are provided.

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Base Case Emission Rates & Stack Parameters							
ID	LOCATION (UTM83)	HEIGHT (M)	HEIGHT (ft.)	DIAM (M)	VELOCITY (M/S)	TEMP (K)	SO ₂ Rate (lbs. /./HR)
S09M	311349, 5056895	90.0	296.0	2.13	12.30	434.8	*
S09N	311349, 5056895	90.0	296.0	2.13	9.60	427.6	*
S08	311338, 5056922	35.66	117.0	1.68	20.08	439.0	15.23
<i>Red Arrow – Rhinelander Sources</i>							
S07	307592, 5055164	15.24	50.0	1.167	11.02	344.8	3.23
S10	307628, 5055186	15.24	50.0	1.524	12.16	325.9	5.38
S11	307662, 5055154	15.24	50.0	1.829	8.44	325.9	8.96
<i>PCA – Tomahawk Sources</i>							
S14	285952, 5036176	46.60	153.0	1.37	4.64	470.4	140.3
S15	285952, 5036203	60.70	199.0	3.23	16.50	468.0	1166.0

The modeled hourly emission rate for stack S09 was calculated separately for each modeled hour. The current permit allowable SO₂ emission rate is 3.5 lbs. /MmBtu, and this converts to 1,050 lbs. /hr. (assuming 300 MmBtu/hr. Maximum) and 927.5 lbs. /hr. (assuming 265 MmBtu/hr. Normal). This allowable emission rate was then adjusted based on the multiplier ‘R’ calculated for each modeled hour.

For example, the modeled emission rate (in lbs. /hr.) for S09 for a single day is provided.

EXPERA SPECIALTY SOLUTIONS – RHINELANDER Example Modeled Hourly Emission Rates					
	<i>S09Max</i>	<i>S09Norm</i>		<i>S09Max</i>	<i>S09Norm</i>
<i>Hour 01</i>	139.6	123.4	<i>Hour 13</i>	153.5	135.6
<i>Hour 02</i>	134.0	118.4	<i>Hour 14</i>	147.4	144.2
<i>Hour 03</i>	132.3	116.9	<i>Hour 15</i>	153.5	156.2
<i>Hour 04</i>	132.3	116.9	<i>Hour 16</i>	170.3	150.5
<i>Hour 05</i>	132.3	116.9	<i>Hour 17</i>	171.1	151.2
<i>Hour 06</i>	132.3	116.9	<i>Hour 18</i>	173.1	153.0
<i>Hour 07</i>	132.3	116.9	<i>Hour 19</i>	185.4	163.9
<i>Hour 08</i>	132.3	116.9	<i>Hour 20</i>	185.0	163.5
<i>Hour 09</i>	132.4	117.0	<i>Hour 21</i>	186.7	164.9
<i>Hour 10</i>	133.8	118.2	<i>Hour 22</i>	189.5	167.5
<i>Hour 11</i>	153.5	135.6	<i>Hour 23</i>	192.7	170.3
<i>Hour 12</i>	147.4	130.2	<i>Hour 24</i>	191.4	169.1

The result from the base case analysis shows concentrations above the NAAQS assuming either maximum or normal load conditions from Expera S09. Results are presented both in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) and in parts per billion (ppb), assuming a conversion factor (1 atm, 20° C) of 1 ppb = 2.616 $\mu\text{g}/\text{m}^3$.

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Base Case Modeling Results & Culpability (Concentrations in $\mu\text{g}/\text{m}^3$)		
	1-Hour SO ₂ Sources plus S09M	1-Hour SO ₂ Sources plus S09N
Modeled Impact	189.5	188.8
Background Concentration	18.3	18.3
Total Impact	207.8	207.1
NAAQS	196	196
S09 Contribution to Total	183.1 (88.1%)	182.7 (88.2%)

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Base Case Modeling Results & Culpability (Concentrations in ppb)		
	1-Hour SO ₂ Sources plus S09M	1-Hour SO ₂ Sources plus S09N
Modeled Impact	72.4	72.2
Background Concentration	7	7
Total Impact	79.4	79.2
NAAQS	75.0	75.0
S09 Contribution to Total	70.0 (88.1%)	69.8 (88.2%)

The maximum impact occurs assuming the maximum load condition (300 MmBtu/hr.) of the boiler venting through S09. In addition stack S09, when operating either at maximum or at normal load, is the largest contributor to the highest total modeled impact. Therefore, the most effective way to reduce the 1-hour SO₂ concentrations further would be to reduce the allowable emission rate of the boiler venting through S09.

FINAL MODELING RESULTS

Considering the result of the base case analysis, the emission rate from stack S09 was reduced to an allowable level of 3.2 lbs. /MmBtu. The same stack parameters and emission rates for other sources were used.

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Final Emission Rates & Stack Parameters							
ID	LOCATION (UTM83)	HEIGHT (M)	HEIGHT (ft.)	DIAM (M)	VELOCITY (M/S)	TEMP (K)	SO ₂ Rate (lbs./HR)
S09M	311349, 5056895	90.0	296.0	2.13	12.30	434.8	*
S09N	311349, 5056895	90.0	296.0	2.13	9.60	427.6	*
S08	311338, 5056922	35.66	117.0	1.68	20.08	439.0	15.23
<i>Red Arrow – Rhinelanders Sources</i>							
S07	307592, 5055164	15.24	50.0	1.167	11.02	344.8	3.23
S10	307628, 5055186	15.24	50.0	1.524	12.16	325.9	5.38
S11	307662, 5055154	15.24	50.0	1.829	8.44	325.9	8.96
<i>PCA – Tomahawk Sources</i>							
S14	285952, 5036176	46.60	153.0	1.37	4.64	470.4	140.3
S15	285952, 5036203	60.70	199.0	3.23	16.50	468.0	1166.0

The modeled hourly emission rate for stack S09 was calculated separately for each modeled hour. The assumed permit allowable SO₂ emission rate is 3.2 lbs. /MmBtu, and this converts to 960 lbs. /hr. (assuming 300 MmBtu/hr. Maximum) and 848 lbs. /hr. (assuming 265 MmBtu/hr. Normal). This proposed allowable emission rate was then adjusted based on the multiplier ‘R’ calculated for each modeled hour.

The result from the final analysis shows concentrations below the NAAQS assuming either maximum or normal load conditions from Expera S09. Results are presented both in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) and in parts per billion (ppb), assuming a conversion factor (1 atm, 20° C) of 1 ppb = 2.616 ($\mu\text{g}/\text{m}^3$).

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Final Modeling Results & Culpability (Concentrations in $\mu\text{g}/\text{m}^3$)		
	1-Hour SO ₂ Sources plus S09M	1-Hour SO ₂ Sources plus S09N
Modeled Impact	173.8	173.0
Background Concentration	18.3	18.3
Total Impact	192.1	191.3
NAAQS	196	196
S09 Contribution to Total	165.6 (86.2%)	166.9 (87.2%)

EXPERA SPECIALTY SOLUTIONS - RHINELANDER Final Modeling Results & Culpability (Concentrations in ppb)		
	1-Hour SO ₂ Sources plus S09M	1-Hour SO ₂ Sources plus S09N
Modeled Impact	66.4	66.1
Background Concentration	7	7
Total Impact	73.4	73.1
NAAQS	75.0	75.0
S09 Contribution to Total	63.3 (86.2%)	63.8 (87.2%)

APPENDIX B: Expera Specialty Solutions LLC SO₂ Emission Limitations and Requirements Administrative Order AM-01-15

**BEFORE THE STATE OF
WISCONSIN
DEPARTMENT OF NATURAL RESOURCES**

In the Matter of Expera Specialty)
Solutions LLC, located at)
515 W. Davenport St.)
Rhineland, Wisconsin 54304)

Administrative Order: AM-15-01

**FINDINGS OF FACT, CONCLUSIONS OF LAW,
AND ADMINISTRATIVE CONSENT ORDER**

Section I. Findings of Fact

The Wisconsin Department of Natural Resources (Department) finds that:

- A) Expera Specialty Solutions LLC, the “operator,” operates a manufacturing facility located at 515 W. Davenport St., Rhineland, Wisconsin (hereinafter, the “facility”) which is a “stationary source” as defined in s. 285.01(41), Wis. Stat.
- B) The facility identification (FID) number is 744008100.

Section II. Background of Applicable Sulfur Dioxide (SO₂) National Ambient Air Quality Standards (NAAQS) and Requirements

- A) Consent Order AM-94-38 was approved as a part of the Wisconsin state implementation plan (SIP) in 1994 (59 Fed. Reg. 63046) in order to demonstrate attainment and maintenance in the Rhineland, Oneida County nonattainment area with the 1971 24-Hour SO₂ NAAQS of 140 parts per billion (ppb). 40 C.F.R. s. 52.2575(c).
- B) Consent Order AM-94-38 established emission limitations regulating the amount of SO₂ emitted by coal-fired boilers operated by the facility.
- C) The Department began operating a SO₂ ambient air quality monitor in the early 1980’s at the City of Rhineland’s municipal water tower. This monitor is referred to as the “Rhineland Tower” monitor or monitoring site. The Rhineland Tower monitor was sited to coincide with high SO₂ concentration values registered from previous monitoring in the area.
- D) On June 2, 2010, the U.S. Environmental Protection Agency (U.S. EPA) established a 1-Hour SO₂ standard of 75 ppb (75 Fed. Reg. 35,520, June 2, 2010) as codified at 40 C.F.R. s. 50.17. This 1-Hour NAAQS subsumes the previous 24-Hour NAAQS.
- E) The U.S. EPA designated four townships in Oneida County, centering on the City of

Rhineland, as nonattainment for the 2010 1-Hour SO₂ NAAQS (77 Fed. Reg. 47,191, Aug. 5, 2013) based on the Rhineland Tower monitoring data for 2009 through 2011. The nonattainment designation is codified under 40 CFR Part 81, Subpart C. These four townships are referred to in this Administrative Order as the Oneida County nonattainment area.

- F) The State of Wisconsin must develop a plan that attains and maintains the 2010 1-Hour SO₂ NAAQS in the Oneida County nonattainment area as expeditiously as practicable, but no later than five years after nonattainment designation. Five years after designation is October 4, 2018. The plan must be approved by the U.S. EPA as a revision to Wisconsin's State Implementation Plan (SIP) set forth at 40 CFR Part 52, Subpart YY.
- G) U.S. EPA guidance requires that an approvable plan will implement enforceable emission control requirements and result in monitored ambient air quality values which show compliance with the 2010 NAAQS one full calendar year prior to the attainment date². Consistent with this guidance, the SO₂ emission limitation requirements under this Administrative Order become applicable beginning January 1, 2017.
- H) The approved attainment and maintenance plan must include enforceable control requirements which satisfy Clean Air Act (CAA) requirements for implementing Reasonably Available Control Technology (RACT) and Reasonably Available Control Measures (RACM) at facilities within the nonattainment area. EPA's implementation plan guidance for the 2010 SO₂ NAAQS establishes that RACT and RACM are the level of emission controls necessary to show attainment of the SO₂ NAAQS.³
- I) This Administrative Order, AM-15-01, implements enforceable emission limitations by January 1, 2017 that fulfill the Oneida County attainment demonstration for the 2010 1-Hour NAAQS and which satisfy RACT and RACM requirements for the Expera Specialty Solutions LLC facility in Rhineland Wisconsin, FID 744008100.

Section III. Facility Information

- A) *SO₂ emission sources.* As of November, 2015, the facility operated the following SO₂ emission sources:
 - 1. Boiler B26, Stack S09: A 300 mmBtu per hour coal fired cyclone boiler with an electrostatic particulate (ESP) device for controlling particulate emissions. Under Consent Order AM-94-38, the SO₂ emissions from boiler B26 could not exceed 3.5 pounds of SO₂ per mmBtu heat input averaged over a 24-hour period.

² (USEPA, 2014), page 10, Memorandum "Guidance for 1-Hour SO₂ Nonattainment Area SIP Submissions" from Stephen D. Page, Director to Regional Air Division Directors, Regions 1 – 10, April 23, 2014.

³ (USEPA, 2014) Memorandum "Guidance for 1-Hour SO₂ Nonattainment Area SIP Submissions" from Stephen D. Page, Director to Regional Air Division Directors, Regions 1 – 10, April 23, 2014.

2. Boiler B28, Stack S08: A 280 mmBtu per hour natural gas boiler with the capacity to fire 270 mmBtu heat input of distillate oil per hour. Distillate oil is used as a back-up fuel. According to construction permit 95-SDD-048, the sulfur content of the distillate fuel oil fired in boiler B28 may not exceed 0.05 percent by weight.
 3. Boilers B20, B21, B22 and B23 were four 83.5 mmbtu per hour underfeed stoker coal fired boilers located at the facility. These boilers were subject to SO₂ emission limitations under the Consent Order AM-94-38, but were retired in 2014 after designation of the Oneida County 2010 SO₂ NAAQS nonattainment area. The decommissioning of boilers B20, B21, B22, and B23 was made federally enforceable under condition ZZZ.12 of construction permit 13-SDD-014.
- B) *Stack S09 serving boiler B26.* Stack S09 was originally constructed at a height of 209 feet above ground level. In this Administrative Order, the Department is determining that Good Engineering Practice (GEP) height for stack S09 is 296 feet (90 meters) above ground level. This GEP height is the maximum height for stack S09 that is creditable towards modeling attainment of the NAAQS. The Department is making this determination in accordance with 40 C.F.R. s. 51.100(ii) based on fluid dynamic modeling results submitted by Expera Specialty Solutions LLC to the Department and U.S. EPA.⁴

Section IV. Conclusions of Law

The Department concludes that:

- A) The Department has authority under ss. 285.11(6) and 285.13(2), Wis. Stats., to implement stationary source emission limitations for purposes of demonstrating and maintaining attainment for the 2010 1-Hour SO₂ NAAQS.
- B) The Department has authority under ss. 285.11(6) and 285.13(2), Wis. Stats., to implement stationary source emission limitations for purposes of fulfilling RACT and RACM requirements for the 2010 SO₂ NAAQS.
- C) This Administrative Order, AM-15-01, accomplishes the purposes set forth in chapter 285, Wis. Stats., and is enforceable under ss. 299.95 and 299.97, Wis. Stats.
- D) This Administrative Order, AM-15-01, satisfies RACT and RACM requirements under the 2010 1-Hour SO₂ NAAQS for the facility, FID 744008100.

Section V. Administrative Order

The parties to this Administrative Order hereby agree to the following provisions:

- A) For boiler B26, stack S09; the operator shall meet all of the following requirements on and

⁴ (CPP, 2014), *Fluid Modeling Good Engineering Practice Stack Height Determination for the Rhinelander Mill Stack S09*, Report prepared for Expera Specialty Solutions, October 2014, CCP project 7835.

after January 1, 2017 unless otherwise specified:

1. Boiler Operating Requirements

- a. *Stack Height* – The height of stack S09 shall be a minimum of 296 feet above ground level and the flue gas shall be discharged vertically and without obstruction.

Note: The Department determined, as documented in section III, (B), that the good engineering practice (GEP) stack height for exhausting boiler B26 flue gas is 296 feet above ground level.

- b. *Emission Rate Limit* – Except as provided in subd. d, the operator shall not allow SO₂ emissions to exceed 3.00 pounds per mmBtu heat input on a 24-hour average basis⁵. Compliance with this emission limit shall be determined according to par. 2 or 4 of section V, par. (A).
- c. *Boiler Utilization Limit* - The operator shall not allow the operating capacity of boiler B26 to exceed 300 mmBtu heat input per hour. Compliance with this emission utilization limit shall be determined according to par. 3 or 4.
- d. *Emission Limitation for Start-up Fuels* - For any non-fossil solid fuel, liquid fuel, or gaseous fuel fired in boiler B26 during startup, the operator shall demonstrate that the SO₂ content of the fuel does not exceed 3.20 pounds per mmBtu by sampling and analyzing fuels according to a plan approved by the Department in writing.

2. Emission Rate Limitation Compliance Demonstration

Except as provided in par. 4, the operator shall monitor emissions and demonstrate compliance with the emission rate limitation in par. 1.b according to the methods and procedures of this paragraph.

- a. The operator shall collect a composite fuel sample for all solid fossil fuels fired each day (24-hour period) in boiler B26. The composite sample shall be comprised of a minimum of three samples obtained at two hour or longer intervals at locations representative of the solid fossil fuels entering the boiler. The number of samples collected and location for sampling shall be established in the monitoring plan required under subd. f.
- b. The operator shall record any change in the type of coal or mixture of coal fired in boiler B26 during the 24-hour sampling period that may affect the SO₂ fuel content.

⁵ The emission limitation for complying on a 24-hour basis is determined by multiplying the 1-hour emission limitation of 3.20 by a factor of 0.93. This factor was derived by U.S. EPA for relating emission limitations between 1-hour to 24-hour timeframes for uncontrolled coal-fired boilers. The U.S. EPA presented this factor in Appendix D of the Memorandum “Guidance for 1-Hour SO₂ Nonattainment Area SIP Submissions” from Stephen D. Page, Director to Regional Air Division Directors, Regions 1 – 10, April 23, 2014.

- c. The composited daily sample shall be analyzed for compliance for any day when the Rhinelander Tower ambient air quality monitor measures an SO₂ concentration of 75 ppb or greater on an hourly basis. If the monitor does not equal or exceed 75 ppb, then one composited daily sample each week shall be randomly analyzed for compliance. The Department shall determine the sample to be randomly analyzed each week. The Department may require additional samples to be analyzed at any time for purposes of demonstrating compliance.
- d. The composited daily samples shall be retained on site for a period of at least 90 days.
- e. Analysis for compliance means the requisite daily composite sample shall be analyzed for percent sulfur content by weight and heat content in mmBtu per ton and the SO₂ fuel concentration determined in pounds per mmBtu heat content.
- f. The operator shall submit a fuel monitoring plan to the Department for written approval which meets the requirements of subd. a through e. The plan shall identify the location and number of samples to be collected each day that will be used in creating the requisite composite sample. The plan shall also provide a method for substituting data in the event that fuel samples or analysis information is not available due to circumstances beyond Expera's control.
- g. If control equipment is operated in order to meet the emission limitation in par. 1.b, the operator must conduct a performance stack test. The performance test shall determine control efficiency and associated minimum operating parameters for the control equipment. The control efficiency shall be used in conjunction with the requisite composite daily samples analyzed under subd. c to determine the compliance emission rate. The performance test shall be performed according to one of EPA Methods 6, 6A, 6B, 6C or 8 provided under 40 CFR 60 Appendix A and according to all applicable procedures and methods under s. NR 439.07, Wis. Adm. Code. The performance test shall be conducted according to a monitoring and compliance plan approved in writing by the Department.
- h. If non-fossil solid fuel, liquid fuel, or gaseous fuel is fired in boiler B26 other than for boiler startup, the operator shall demonstrate compliance with the 24-hour emission limitation on a heat input weighted basis for all fuels. The operator shall sample and analyze any non-fossil solid fuel, liquid fuel, or gaseous fuel according to a fuel monitoring plan approved by the Department in writing.

3. Boiler Utilization Compliance Demonstration

Except as provided in par. 4, the operator shall demonstrate compliance with the boiler B26 utilization limit in par. 1.c according to the following methods and procedures.

- a. The operator shall maintain and operate a steam load monitoring and data recorder system capable of determining the hourly average steam load generated by boiler B26.

- b. The operator shall continuously monitor and record the hourly steam load generated by boiler B26 in thousand pounds of steam per hour (klbs per hour). The maximum hourly steam load for each operating day shall be converted to an hourly boiler utilization rate in mmBtu heat input per hour according to the following equation:

$$\begin{aligned} \text{Eq. 1: Boiler Utilization } \left(\frac{\text{mmBtu}}{\text{hr}} \right) \\ = \text{Hourly Steam Load } \left(\frac{\text{Klbs}}{\text{hr}} \right) \times \text{Boiler Efficiency } \left(\frac{\text{mmBtu}}{\text{Klbs}} \right) \end{aligned}$$

- c. The boiler efficiency factor applied in equation 1 shall be determined for each calendar year compliance period beginning January 1, 2017. This boiler efficiency factor shall be updated for each subsequent calendar year compliance period that spans January 1st to December 31st.
- d. The boiler efficiency factor for each calendar year compliance period shall be determined using the total heat input and steam load for the twelve month period ending on September 30th of the year preceding the applicable compliance period. The operator may use an alternative period of heat input and steam load data with written approval by the Department. The request for an alternative period must be due to changes in boiler operation or fuel which have affected the boiler efficiency. The boiler efficiency is calculated as follows:

$$\begin{aligned} \text{Eq. 2: Boiler Efficiency } \left(\frac{\text{mmBtu}}{\text{Klbs}} \right) \\ = \text{Total Heat Input (mmBtu)} \div \text{Total Steam Load (Klbs)} \end{aligned}$$

- e. Except as provided in subd. f, the operator shall determine the total heat input by summing the weekly heat input over the applicable twelve month period. The weekly heat input shall be determined by measuring and recording the tons of each fuel fired each week during the applicable twelve month period. The weekly heat input shall be calculated by multiplying the weekly tons of each fuel fired by the weekly heat content of each fuel. The weekly heat content will be the value determined from the analyzed daily composited solid fossil fuel sample for that week and, as applicable, the samples for solid non-fossil fuels or liquid fossil fuels, as required under par. 2. The calculation of the total heat input is as follows:

$$\begin{aligned} \text{Eq. 3: Total Heat Input (mmBtu)} \\ = \sum \left[\text{Weekly Fuel Consumption (tons)} \right. \\ \left. \times \text{Weekly Fuel Heat Content } \left(\frac{\text{mmBtu}}{\text{ton}} \right) \right] \end{aligned}$$

- f. If fuel monitoring is not performed to fulfill requirements of par. 2 in order to demonstrate compliance with the emission rate limitation, the operator may determine total heat input by summing the heat input determined on a monthly basis. The heat input

for each month is determined by applying the monthly fuel heat content to the monthly fuel consumption. The monthly fuel heat content for solid fossil fuels will be determined by obtaining one fuel sample each week which is composited into a monthly fuel sample and analyzed for heat content. All fuel sampling shall be conducted in accordance with applicable methods and procedures under par. 8. If solid non-fossil fuels are fired other than for startup, the operator shall determine fuel heat content according to a sampling plan approved in writing by the Department. The calculation of the total heat input using this approach is as follows:

Eq. 4: Total Heat Input (mmBtu)

$$= \sum \left[\text{Monthly Fuel Consumption (tons)} \right. \\ \left. \times \text{Monthly Fuel Heat Content} \left(\frac{\text{mmBtu}}{\text{ton}} \right) \right]$$

- g. The operator shall determine the total steam load in thousand pounds by summing the measured hourly average steam load over the applicable twelve month period.
 - h. The operator shall submit a boiler utilization and steam generation monitoring plan to the Department for written approval which meets the requirements of this subd. a. through g. The plan shall describe the steam load monitoring and data recording system, identify any steam loss points between the boiler and steam load monitor and any additional monitoring needed at these points to determine boiler efficiency, a method for determining periods of time when the steam monitoring and recording system are unavailable, provide a method for substituting data for determining compliance in the event that the steam monitoring system is not available, and establish the fuel sampling and consumption monitoring plan used in determining total heat input.
 - i. The Department or U.S. EPA may require the operator to update the boiler efficiency value at any time based on information indicating a change may have occurred in actual boiler operating efficiency. The update may require use of heat input and steam load data from a time period other than that required under subd. d. The Department or U.S. EPA may also require additional analysis of fuel samples in determining fuel heat input as necessary to characterize the representative boiler efficiency.
4. Continuous Emissions Monitoring (CEM) Compliance Demonstration

The operator may elect to demonstrate compliance with the SO₂ emission rate or the boiler utilization limitation in par. 1 by monitoring SO₂ emissions or heat input, respectively for each requirement, with a continuous emissions monitoring (CEM) system according to the following methods and procedures.

- a. If determining compliance with the emission rate limit in par 1.b, the operator shall install, certify, and operate a CEM system which measures and records the hourly average SO₂ emission rate in pounds per mmBtu heat input for each hour boiler B26 is

operating. The CEM shall at a minimum include a SO₂ continuous emissions analyzer, a data recording system and, as applicable, a moisture analyzer.

- b. If determining compliance with the boiler utilization limit in par. 1.c, the operator shall install, certify, and operate a CEM system which measures and records the hourly heat input for each hour boiler B26 is operating. The emissions monitoring system shall at a minimum include a data recording system, a volumetric flow monitor, a diluent monitor, and as applicable a moisture analyzer.
- c. The SO₂ CEM shall be calibrated, maintained, and operated according to the applicable methods and procedures of s. NR 439.09, Wis. Adm. Code and 40 CFR 60.13, and the applicable performance, quality assurance, and data management and calculation procedures of Specification 2 of 40 CFR Part 60 Appendix B and 40 CFR Part 60 appendix F.
- d. The operator shall submit a CEM quality assurance/quality control plan for approval by the Department in accordance with NR 439.095(6), Wis. Adm. Code.
- e. If applicable, the SO₂ emission rate in pounds per mmBtu heat input shall be determined using the F-factor method according to procedures in Method 19 of 40 CFR Part 60, Appendix A.
- f. If the CEM system is not operating for a continuous period of 48 hours, the facility operator shall comply, as applicable, with the fuel monitoring procedures in par. 2 and the boiler utilization monitoring procedures in par. 3 within 60 hours of the CEM discontinuing operation. The operator shall notify the Department of a CEM outage lasting longer than 48 hours and shall return the CEM system to operation as expeditiously as practical.
- g. The operator shall submit a CEM monitoring plan to the Department for written approval which incorporates and meets the requirements of this paragraph.

5. Required Continuous Emissions Monitoring (CEM)

Within twelve months of the Department determining that CEM monitoring is required according to subd. a. and b., the operator shall begin CEM emission monitoring in order to determine the SO₂ emission rate for compliance purposes. The applicable CEM monitoring shall be performed in accordance with all applicable requirements under par. 4. The operator shall continue to monitoring emissions and boiler utilization according to par. 2 and 3 until the applicable CEM monitoring is fully implemented.

- a. If the operator is complying with the emission rate limit by following the fuel monitoring methods under par. 2 and three of the requisite analyzed composite fuel samples have exceeded 3.00 pounds per mmBtu heat input during any twelve month rolling period, the operator is required to implement CEM emissions monitoring.

- b. If the Rhinelander Tower ambient air quality monitor measures SO₂ concentrations exceeding 75 ppb on an hourly basis during four or more individual days over any twelve month rolling period, the operator is required to implement CEM emissions monitoring.

6. Emission Monitoring Plan Submittals and Deadlines

The operator shall comply with the following plan submittal requirements:

- a. Except as provided in subd. a., the operator shall submit a monitoring plan by October 1, 2016 to the Department for written approval. The plan shall identify whether the operator will demonstrate compliance according to par. 2, 3, or 4, as allowed for the boiler limitations in par. 1. The plan shall provide all information required under par. 2, 3, or 4 regarding plan content.
- b. After January 1, 2017, the operator shall comply with approved monitoring plans until a different monitoring plan is approved in writing by the Department or until alternative monitoring requirements are approved under par. 11.

7. Performance Stack Testing

The Department or U.S. EPA may require the operator to conduct performance testing at any time to demonstrate compliance with the emission rate or boiler utilization limitations in par. 1. Performance testing for SO₂ emissions shall be conducted according to one of EPA Method 6, 6A, 6B, 6C or 8 under 40 CFR 60 Appendix A and all applicable procedures and methods under s. NR 439.07, Wis. Adm. Code. The performance stack testing shall demonstrate compliance with the 1-hour emission rate limit of 3.20 pounds per mmBtu.

8. Fuel Collection and Analysis Methods

All fuel sampling and analyses required under this Administrative Order shall be performed according to the methods specified below or their future updated or replacement methods.

- a. The grab sampling of each as-fired solid fossil fuel sample shall be performed according to ASTM D2234-89, Collection of a Gross Sample of Coal or other method that results in data at least as reliable as classification I-B-1, defined in ASTM D2234-04 as automatic sampling --- full stream cut – systemic spacing.
- b. The individual grab solid fossil fuel samples shall be prepared and composited according to ASTM D2013-86, Preparing Coal Samples for Analysis.
- c. The solid fossil fuel sample shall be analyzed for sulfur content according to ASTM D3177-89, Total Sulfur in the Analysis of Sample of Coal and Coke, or ASTM D4239-85, Sulfur in the Analysis Sample of Coal and Coke using High Temperature Tune Furnace Combustion Methods.

- d. The solid fossil fuel sample shall be analyzed for heat content according to ASTM D2015-85, Gross Calorific Value of Solid Fuel by the Adiabatic Bomb Calorimeter.

9. Recordkeeping

The operator shall maintain the following records on site for a period of five years:

- a. The compliance reports as required under par. 10.
- b. During periods when complying with the emission rate limitation according to par. 2, the fuel analysis records for heat and sulfur content and the SO₂ emission rate in pounds per mmBtu for each requisite composite daily sample analyzed or other fuels analyzed according to an approved plan.
- c. During periods when complying with the boiler utilization limitation according to par. 3, the maximum daily steam load and boiler utilization and the boiler efficiency factors and supporting information used in determining the boiler efficiency factor.
- d. During periods when complying with CEM monitoring according to par. 4, the hourly SO₂ emission rate in pounds per mmBtu and heat input in mmBtu.
- e. Records of any additional analysis or performance testing required by the Department or U.S. EPA for purposes of determining compliance with the requirements of this Administrative Order.

10. Reporting

The operator shall submit to the Department a quarterly report no later than 60 days after the end of each calendar quarter. The report shall provide the following:

- a. The date and the maximum monitored SO₂ ambient air concentration value for days during which the Rhineland Tower monitor registered an ambient air quality concentration equal of 75 ppb or greater on an hourly basis.
- b. The SO₂ emission rate in pounds per mmBtu and maximum boiler utilization in mmBtu per hour determined during days when the Rhineland Tower monitor registers an SO₂ ambient air concentration of 75 ppb or greater on an hourly basis.
- c. Any SO₂ emission rate value, in pounds per mmBtu, or boiler utilization value, in mmBtu per hour, determined for compliance purposes under this Administrative Order which exceeds the emission rate limit or boiler utilization limit, respectively.
- d. The identification of any periods when fuel samples could not be obtained or the applicable monitoring systems were not operating and the reasons why.
- e. The period of use and value of alternative data used in determining compliance when

fuel samples could not be obtained or the required monitoring systems were not operating.

11. Alternative Monitoring, Compliance Determination, Recordkeeping, or Reporting

The operator may use alternative methods and procedures to any monitoring, compliance demonstration, recordkeeping, or reporting requirement in par 2, 3, 4, 6, 8, 9, or 10 with written approval by both the Department and U.S. EPA.

B) For boiler B28, stack S08. The operator shall meet the following requirements for boiler B28 when fuel oil is fired.

1. Emission Limitation - The sulfur content of distillate fuel fired in boiler B28 shall not exceed 0.05 percent by weight.
2. Compliance Demonstration - The operator shall demonstrate compliance with the fuel sulfur content by obtaining fuel supplier certifications pursuant to 40 CFR section 60.45. The facility operator shall obtain certification that the supplier determined fuel sulfur and heat content according to applicable procedures under s. NR 439.08(2), Wis. Adm. Code.
3. Recordkeeping - The operator shall retain records of the certifications required under par. 2 on site for a period of 5 years.

C) This Administrative Order, AM-15-01, may require modification in satisfying facility RACT and RACM requirements if additional SO₂ emission sources other than those specified under section V. (A) are proposed for operation in a construction permit for the facility and if the revisions to the requirements of this Administrative Order are determined through air quality modeling analysis to be required in order to ensure that the proposed additional sources do not cause an exceedance of the 2010 SO₂ NAAQS.

D) The operator shall submit an application to incorporate the requirements of this Administrative Order into the facility's applicable operating permit no later than December 31, 2016.

Section VI. Disposition of Consent Order AM-94-38

Consent Order AM-94-38 was established and entered for the purpose of demonstrating and maintaining attainment of the 1992 24-Hour SO₂ standard. EPA has established that requirements for the 24-Hour SO₂ NAAQS will be subsumed when all requirements for the 2010 SO₂ NAAQS are satisfied and approved to the SIP⁶. Therefore, demonstrating compliance with Administrative Order AM-15-01 constitutes fulfillment and compliance with the emission reduction achieved under Consent Order AM-94-38. Further, Consent Order AM-94-38 is withdrawn from the SIP

⁶ (USEPA, 2014) Memorandum "Guidance for 1-Hour SO₂ Nonattainment Area SIP Submissions" from Stephen D. Page, Director to Regional Air Division Directors, Regions 1 – 10, April 23, 2014.

upon federal approval of Administrative Order AM-15-01 and Wisconsin's plan for attaining the 2010 SO₂ NAAQS.

Section VII. Waiver and Stipulation

Expera Specialty Solutions LLC consents to, and agrees not to contest, the Department's jurisdiction to issue this Administrative Order and to enforce its terms. To that end Expera Specialty Solutions LLC stipulates to the issuance of this Administrative Order and hereby waives further notice or hearing before the Department regarding the foregoing Findings of Fact, Conclusions of Law and Administrative Order, and waives its rights, if any, to challenge this Administrative Order in circuit court under ss. 227.52 and 227.53, Stat., or any other provision of law. Expera Specialty Solutions LLC further stipulates and agrees that this Administrative Order is effective and enforceable after being signed by both parties and that it may be enforced in accordance with ss. 299.95, and 299.97, Stat. Expera Specialty Solutions LLC understands that the Department intends to submit this Administrative Order to EPA for purposes of satisfying Wisconsin SIP requirements, and Expera Specialty Solutions LLC stipulates and agrees that this Administrative Order is federally enforceable by EPA upon EPA approval and incorporation of this Administrative Order into the Wisconsin SIP. The undersigned further certifies that he or she is authorized to execute such Administrative Order, Waiver and Stipulation on behalf of Expera Specialty Products.

Nothing in this Administrative Order, however, shall be construed as an admission on the part of Expera Specialty Solutions for any purpose other than for an action taken by the Department or the U.S. EPA for failure to comply with the terms of this Order. This stipulation and waiver does not affect the right of Expera Specialty Solutions LLC to assert any equitable or legal defense or to challenge the interpretation or application of this Administrative Order in any challenge or alleging of violation brought by a party other than the Wisconsin Department of Natural Resources or the U.S. EPA.

STATE OF WISCONSIN DEPARTMENT OF NATURAL RESOURCES for the Secretary

By: Gail E. Good
Gail Good
Director, Air Management

1.14.2016
Date

EXPERA SPECIALTY PRODUCTS LLC

Russ Wanke
Russ Wanke
Chief Executive Officer

1-15-2016
Date

APPENDIX C: Analysis of the GEP Stack Height for Boiler B26, Stack S09

**Prepared for
Expera Specialty Solutions**



CERMAK
PETERKA
PETERSEN

WIND ENGINEERING AND AIR QUALITY CONSULTANTS



Protocol – Revision I

Fluid Modeling Good Engineering Practice
Stack Height Determination for
Rhineland Mill
Stack S09

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Fluid Modeling Good Engineering Practice

Stack Height Determination for

Rhineland Mill

Stack S09

CPP Project 7835

August 5, 2014

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LIST OF SYMBOLS

AGL	Above Ground Level	(m)
A	Calibration Constant	(-)
B	Calibration Constant	(-)
B_o	Buoyancy Ratio	(-)
C	Concentration	(ppm or $\mu\text{g}/\text{m}^3$)
C_o	Tracer Gas Source Strength	(ppm or $\mu\text{g}/\text{m}^3$)
C_{max}	Maximum Measured Concentration	(ppm or $\mu\text{g}/\text{m}^3$)
C_s	Concentration of Calibration Gas	(ppm or $\mu\text{g}/\text{m}^3$)
	Concentration Estimate for Full-scale Sampling Time, t_s	($\mu\text{g}/\text{m}^3$)
C_k	Concentration Estimate for Wind-tunnel Sampling Time, t_k	($\mu\text{g}/\text{m}^3$)
Δ	Difference Operator	(-)
$\Delta\theta$	Potential Temperature Difference	(K)
δ	Boundary-Layer Height	(m)
d	Stack Diameter	(m)
E	Voltage Output	(Volts)
Fr	Froude Number	(-)
g	Acceleration Due to Gravity	(m/s^2)
h	Stack Height Above Roof Level	(m)
H	Stack Height Above Local Grade	(m)
H_t	Terrain Height	(m)
H_b	Building Height	(m)
I_s	Gas Chromatograph Response to Calibration Gas	(Volts)
I_{bg}	Gas Chromatograph Response to Background	(Volts)
k	von Kármán Constant	(-)
L	Length Scale	(m)
λ	Density Ratio	(-)
M_o	Momentum Ratio	(-)
n	Calibration Constant, Power Law Exponent	(-)
ν	Kinematic Viscosity	(m^2/s)
m	Emission Rate	(g/s)
ρ_a	Density of Ambient Air	(kg/m^3)
ρ_s	Density of Stack Gas Effluent	(kg/m^3)
R	Velocity Ratio	(-)
R_i	Richardson Number	(-)
Re_b	Building Reynolds Number	(-)
Re_k	Roughness Reynolds Number	(-)
Re_s	Effluent Reynolds Number	(-)

T	Mean Temperature	(K)
t_s	Full-scale sampling time	(s)
t_k	Wind-tunnel sampling time	(s)
U_a	Wind Speed at Anemometer	(m/s)
U_H	Wind Speed at Stack Height	(m/s)
U_r	Wind Speed at Reference Height Location	(m/s)
U_∞	Free Stream Wind Velocity	(m/s)
U_*	Friction Velocity	(m/s)
U	Mean Velocity	(m/s)
U'	Longitudinal Root-Mean-Square Velocity	(m/s)
V	Volume Flow Rate	(m ³ /s)
V_e	Exhaust Velocity	(m/s)
z	Height Above Local Ground Level	(m)
z_o	Surface Roughness Factor	(m)
z_r	Reference Height	(m)
z_∞	Free Stream Height – 600 m above ground level	(m)

Subscripts

m	pertaining to model
f	pertaining to full scale

1. INTRODUCTION

This protocol describes the wind-tunnel study that will be conducted by CPP, Inc (CPP) on behalf of Expera Specialty Solutions (Expera) to determine the “Good Engineering Practice” stack height for Rhinelander Mill Stack S09. The Rhinelander Mill is located in Rhinelander, WI, as shown in Figure 1. Air monitoring data for the City of Rhinelander, Wisconsin (Oneida County) shows SO₂ concentrations exceeding the 1-hour standard at the water tower monitoring location (WTM). As a result, this area has been formally designated a SO₂ non-attainment area (August 5, 2013 Federal Register). An analysis of emission sources and air quality modeling indicates that the Expera Rhinelander Mill appears to be the primary contributor to the ambient air impact at this monitor, specifically the cyclone boiler stack (S09). The WTM is about 600 m (2000 ft) NNE of the cyclone boiler stack (S09).

A review of the Rhinelander Water Tower monitoring data for 2007-2009 (Paine and Petersen, 2013) indicates that the “design value” concentration that should be compared to the SO₂ NAAQS of 196.5 µg/m³ is 512.7µg/m³. The predicted “design value” concentration based on AERMOD at the WTM is more than a factor of two lower than observed. After investigating the building geometry, it was noticed that the Boiler 7 building corner is directly upwind of the stack when the wind blows directly toward the WTM (Paine and Petersen, 2011). When the wind blows along a building corner, building corner vortices are generated that enhance building downwash. This enhancement effect is not included in AERMOD. Past wind tunnel modeling studies (EPA, 1985) have shown that these corner vortices can increase concentrations by as much as a factor of two over that observed for wind directions normal to a building face; even at the formula Good Engineering Practice (GEP) stack height. Based on EPA (1981), the formula GEP stack height is 75 m based on Boiler 7 (38.4 m height and 24.4 m projected width). The wind tunnel results presented in EPA (1985) suggest that the actual GEP stack could be up to 2.5 times the building height, or 95 m, for this corner vortex situation.

There are several optional methods whereby the concentration levels at the Water Tower Monitor and all other locations can be reduced to levels below the 1-hr SO₂ NAAQS, as follows: 1) increase the stack height; 2) install additional emission control; and/or 3) additional controls in conjunction with merged flues. This purpose of this study is to evaluate option 1 using wind tunnel modeling with an ultimate goal of helping develop a strategy for showing compliance with the 1-hr SO₂ NAAQs at the WTM.

As discussed in Section 2.1, a source can increase the height of a stack to any height but must use the GEP stack height for purposes of setting an emission limit. Hence, the purpose of this study is to determine the maximum creditable S09 stack height (i.e., the wind tunnel determined GEP stack height) that can be used for dispersion modeling purposes.

To meet the objectives of the study, a 1:240 scale model of the Rhinelander Mill and nearby surroundings within a 450 m (1360 ft) radius will be constructed and placed in CPP's boundary-layer wind tunnel on a turntable. Terrain and/or roughness elements will be added downwind of the turntable so downwind distances out to 1,500 m can be evaluated. Model operating conditions will be set to simulate actual meteorological and Stack S09 operating conditions. For the GEP stack height determination, ground-level concentrations of hydrocarbon tracer gases released from Stack S09 will be measured with and without the nearby buildings present for various meteorological conditions. The results will then be analyzed to determine the actual GEP stack height.

This protocol describes the technical aspects and project plan for conducting the wind tunnel study designed to meet the stated project objectives. The methods outlined in this protocol have been used on many previous GEP stack height evaluations (see Table 1), many of which have been reviewed and approved by the appropriate State and/or EPA agency.

2. TECHNICAL CONSIDERATIONS

2.1 DEFINITION OF GEP STACK HEIGHT

In the stack height regulation (40 CFR 51.100 (ii)), GEP stack height is defined to be

the greater of [emphasis added]:

DEFAULT MINIMUM GEP STACK HEIGHT

“(1) 65 meters, measured from the ground level elevation at the base of the stack;

FORMULA GEP STACK HEIGHT

- (2) (i) for stacks in existence on January 12, 1979, and for which the owner or operator had obtained all applicable permits or approvals required under 40 CFR Parts 51 and 52,

$$H_g = 2.5H \quad (1)$$

provided that the owner or operator produces evidence that this equation was actually relied on in establishing an emission limitation:

- (ii) for all other stacks,

$$H_g = H + 1.5L \quad (2)$$

where

H_g = good engineering practice stack height, measured from the ground-level elevation at the base of the stack,

H = height of nearby structure(s) measured from the ground-level elevation at the base of the stack,

L = lesser dimension, height or projected width, of nearby structure(s),

provided that the EPA, State, or local control agency may require the use of a field study or fluid model to verify GEP stack height for the source; or

WIND TUNNEL DETERMINED MAXIMUM GEP STACK HEIGHT

- (3) The height demonstrated by a fluid model or a field study approved by the EPA, State, or local control agency, which ensures that the emissions from a stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes, or eddy effects created by the source itself, nearby structures or nearby terrain features.”

Equation (1) is essentially the formula specified by Congress in the Clean Air Act. Equation (2) is a more restrictive formula (for tall-thin structures) which simplifies to Equation (1) for structures that are wider than they are tall. EPA (1985, pp 36-37) makes it clear that the highest height resulting from the application of the formula to multiple structures is the formula height. Formula height is GEP unless a verification is required or unless a higher height is demonstrated under 40 CFR 51.100 (ii)(3), a wind tunnel modeling evaluation.

To quantitatively determine the GEP height through wind tunnel modeling, the stack height regulation goes on to define an excessive concentration as (40 CFR 51.100 (kk) (1)):

“A maximum ground-level concentration due to emissions from a stack due in part or whole to downwash, wakes, or eddy effects produced by nearby structures or terrain features which individually is at least 40% in excess of the maximum concentration experienced in the absence of such downwash, wakes, or eddy effects and which contributes to a total concentration due to emissions from all sources that is greater than an ambient air quality standard.”

Based on this definition, wind tunnel testing is conducted for various stack heights until the maximum credible GEP stack height is found. If that height is higher than the formula GEP stack height, the wind tunnel determined height is the actual GEP stack height.

40 CFR Part 51 (pages 27892 and 27899) goes on to say that:

“Section 123 of the Clean Air Act as amended, requires EPA to promulgate regulations to ensure that the degree of emission limitation required for the control of any air pollutant under an applicable State implementation plan (SIP) is not affected by that portion of any stack height which exceeds good engineering practice (GEP) or by any other dispersion technique.”

“No source is precluded from building a stack height greater than formula height if such height is believed to be needed to avoid excessive downwash. However, the design and purpose of section 123 prohibit SIP credit for that effort unless a relatively rigorous showing can be made.”

These statements in effect say that a source can build a stack taller than the formula but must set the emission limit (using AERMOD or other approved model) based on the formula height or GEP stack height that is taller than the formula determined from a wind tunnel modeling study.

2.2 SETTING MODEL OPERATING CONDITIONS AND SIMILARITY REQUIREMENTS

General

For GEP type studies, the criteria that are used for simulating plume trajectories and the ambient air flow are summarized below. These are the criteria that are recommended by EPA (1981) and that have been used on past GEP studies conducted by CPP (Greenway et al., 1981; Halitsky et al., 1986; Petersen and Parce, 1993; Petersen, 1987). Hence, the criteria discussed below will be used for setting modeling operating conditions.

Modeling Plume Trajectories

To model plume trajectories, EPA(1981) states that the following ratios must be matched in model and full scale:

$$\frac{V_e}{U_h} \quad (3)$$

$$\frac{\rho_s}{\rho_a} \quad (4)$$

$$\frac{d}{H_s} \quad (5)$$

- U_h = wind velocity at stack top (m/s),
 V_e = stack gas exit velocity (m/s),
 ρ_s = stack gas density (kg/m³),
 ρ_a = ambient air density (kg/m³)
 d = stack diameter (m), and
 H_s = stack height (m).

which is the same as matching momentum length scale, M_o , or

$$M_o = \frac{\rho_s}{\rho_a} \left(\frac{d V_e}{H_s U_h} \right)^2 \quad (6)$$

For this study, density ratio will be distorted but the Momentum ratio will be matched in model and in full scale. This ensures that model and full scale plume rise are equal.

In addition, the stack gas flow in the model was fully turbulent upon exit as it is in the full scale. This criteria is met if the stack Reynolds number ($Re_s = dV_e/\nu_s$), where d is exhaust diameter and ν_s is the exhaust gas viscosity, is greater than 670 for buoyant plumes such as those simulated in this study (Arya and Lape, 1990). Even though the stack Reynolds number will be greater than 670, a trip will be installed inside the model stack to ensure fully turbulent flow in the exhaust stream prior to exiting the stack.

It should be noted that Froude number similarity is not used, as recommended by EPA (1981), as it would require extremely low wind tunnel speeds and building wake effects would be incorrectly modeled.

Modeling the Airflow and Dispersion

To simulate the airflow and dispersion around the buildings, the following criteria will be met as recommended by EPA (1981) or Snyder (1981):

- all significant structures within a 415 m (1360 ft) radius of the stacks will be modeled at a 1:240 scale reduction. Upwind of this area, roughness elements will be installed to represent the upwind roughness within 3.2 km of the stack. Terrain and/or roughness elements will be added downwind of the turntable so downwind distances out to 1,500 m can be evaluated.
- the mean velocity profile through the entire depth of the boundary layer will be represented by a power law $U/U_\infty = (z/z_\infty)^n$ where U is the wind speed at height z , U_∞ is the freestream velocity at z_∞ and the power law exponent, n , is dependent on the surface roughness length, z_o , through the following equation:

$$n = 0.24 + 0.096 \log_{10} z_o + 0.016 (\log_{10} z_o)^2 ; \quad (7)$$

- Reynolds number independence will be ensured: the building Reynolds number ($Re_b = U_b H_b / \nu_a$; the product of the wind speed, U_b , at the building height, H_b , times the building height divided by the viscosity of air, ν_a) will be greater than 11,000 as recommended by Snyder (1981) for rectangular structures.
- a neutral atmospheric boundary layer will be established (Pasquill–Gifford C/D stability) by setting the bulk Richardson number (R_{ib}) equal to zero in model and full scale.

Summary

Using the above criteria and the source characteristics shown in Table 2, the model test conditions for this site have been computed for the stacks under evaluation. The model test conditions were computed for D stability at the simulated wind speeds (see Section 2.5) and are provided in Appendix A. Appendix A also includes a more detailed discussion on wind tunnel scaling issues.

2.3 EXHAUST SOURCES, SOURCE PARAMETERS AND EMISSION RATES

The cyclone boiler stack location (S09) is shown in Figure 3. The full-scale exhaust parameters simulated in the wind tunnel for the cyclone boiler stack S09 are listed in Table 2.

To determine the maximum creditable GEP stack height, three emission scenarios will be evaluated as follow:

- maximum load: the PTE allowed in the permit at the boiler's rated capacity (3.5 lbs SO_x/MMBtu @ 300 MMBtu/hr);
- nominal load: the typical or average loading; and
- minimum load: a theoretical scenario that represents maximum sulfur content (3.5 lbs SO_x/MMBtu @ 300 MMBtu/hr) at the minimum thermal input rate (minimum exit velocity and temperature).

The stack and emission parameters for these scenarios are provided in Table 2.

2.4 NEARBY STRUCTURES AND TERRAIN

Figure 2 shows an aerial view of the Rhinelander Mill. In general the terrain rises to a maximum of about 1660 ft, MSL to the NNE of the mill or 30 m (100 ft) above plant grade. The terrain is just sufficiently high in this direction to qualify for a terrain GEP demonstration study (terrain must rise to 0.4 Hg or 30 m). However, since Boiler 7 is closer and taller than the nearby terrain, its effect on the GEP stack height will be more significant and will be the focus of this evaluation.

The adjacent plant structures are nearby and are configured such that excessive concentrations may occur mainly due to the Boiler 7 structure as discussed in Section 1. To evaluate the effects of structures, shown in Figures 3 and 4, tests are first conducted with all structure in place (referred to as the "Building In" tests). All nearby structures are then removed (referred to as the "Building Out" tests) and the resulting concentrations are compared to those measured with the buildings in. Figures 5 and 6 show the wind tunnel configuration with nearby

structures removed. If the ratio of maximum concentration with the “Buildings In” to that with “Buildings Out” is equal to 1.4 and if the maximum concentration with “Buildings In” exceeds a NAAQS limit, excessive concentrations will have been demonstrated and that stack height will be the GEP stack height.

When conducting the “Building Out” tests, all structures that are nearby are removed. A structure is defined a nearby if the distance from the stack to the building is less than or equal to five times the lesser of the height of width of the structure. Since most of the Rhinelander Mill structures are connected or touching, most Rhinelander Mill structures will be removed.

2.5 SURFACE ROUGHNESS

Rhineland Site

To simulate full scale wind profiles in the wind tunnel, it is necessary to match the surface roughness length used in the model to that of the actual site. The surface roughness lengths for the Rhinelander Mill site were specified using AERSURFACE (EPA, 2008). To define surface roughness values for the flow approaching the Rhinelander Mill Stack S09, the AERSURFACE tool with a radius of 3.2 km around the site was used (based on the model scale and approximate length of upwind fetch in the wind tunnel). Table 3 shows the AERSURFACE results in 30 degree intervals around the Rhinelander Mill. It is evident that two approach flows are necessary to accurately represent the full scale wind profiles in the wind tunnel. For wind directions of 300 through 30 degrees, the surface roughness values are small with a mean of 0.062 m representing the water to the north of the site. For wind directions of 30 through 300 degrees, the mean surface roughness is 0.489 m.

Rhineland Airport

The surface roughness length around the Rhinelander-Oneida County Airport was initially specified using the AERSURFACE tool with a radius of 1 km around the anemometer location using 1992 NLCD. The average surface roughness length was determined to be 0.56 m for the airport as shown in Table 3.

In a July 2, 2014 email to Tom Emonds, John Roth (WDNR, Dispersion Modeling Team Leader), indicated that the 1992 NLCD information for the Rhinelander airport is not representative of current conditions. The 1992 NLCD has more forest (high surface roughness) around the anemometer than current conditions. He concluded that either the 1992 NLCD data was incorrect, as published, or many trees were removed after 1992 along each side of the main E-W runway. This means that the actual average surface roughness around the Rhinelander

airport anemometer is potentially lower than estimated using the 1992 NLCD. Hence, John Roth developed a method to adjust AERSURFACE using a 2008 aerial photograph. That method included artificially moving the anemometer to account for the distance to the tree line and using a 0.3 km radius. His analysis predicts that the average surface roughness at the airport is 0.25 m as shown in Table 3.

EPA, however, recommends that a 1 km radius be used when calculating the airport surface roughness. To account for this, CPP used the Alaska Department of Environmental Conservation (ADEC, 2009) Guidance for calculation surface roughness when AERSURFACE is not a viable option. Based on ADEC (2009), the following approach was used:

- Use EPA's stated guidance for determining the applicable areas/sectors for calculating the Surface Roughness Length.
- Use 2008 Google Earth photograph to determine the types of land classifications for the given area/sector.
- Estimate the fraction of land (area) that each classification covers within the given sector.
- Estimate the approximate distance (in kilometers) from the airport anemometer to the centroid of each classification area within the sector.
- Assembled a table associating each Surface Roughness value to the land fraction and distance to the centroid for each roughness classification.
- When calculating the inverse weighted geometric mean surface roughness length, weight each value by the applicable land fraction divided by the distance.

The results of the ADEC analysis using a 1 km radius about the anemometer are shown in Table 3. The average surface roughness is 0.26 m which agrees quite well with the value recommended by John Roth. Hence, an airport surface roughness length of 0.25 m as recommended by John Roth will be used for this evaluation.

Appendix C includes complete documentation on the surface roughness calculations for the Rhinelander Airport.

2.6 TEST WIND SPEEDS

The EPA stack height guideline (EPA, 1981) recommends that the design wind speed for GEP stack height and excessive concentration evaluations be less than the 2 percent wind speed (the wind speed that is exceeded less than 2 percent of the time) unless it can be demonstrated

that higher wind speeds cause an exceedance of NAAQS limits. This speed was set as the limiting speed for all wind tunnel tests.

The 2 percent wind speed for the was based on meteorological observations at the Rhineland-Oneida County Airport 10 m anemometer for the period 1998-2010. The wind rose for that period is shown in Figure 7. Figure 8 shows that the 2 percent wind speed is 7.9 m/s. All concentration tests to determine GEP stack height will be conducted with speeds at or below the 2 percent wind speed.

Wind speeds in the tunnel will be set at a reference height of 240 m above stack grade. The speed at this reference height is determined by scaling the anemometer wind speed up to the freestream height, 600 m (Snyder, 1981) above ground level. At this height, it is assumed that wind speeds at the site and at the anemometer location are the same (i.e., local topographic effects are not important). Next, the wind speed over the site at the reference height is calculated using the wind speed at the freestream height and scaling down to the lower height using the following power law equation:

$$U_{ref} = U_{\infty} \left(\frac{z_{ref}}{z_{\infty}} \right)^{n_s} = U_{anem} \left(\frac{z_{\infty}}{z_{anem}} \right)^{n_a} \left(\frac{z_{ref}}{z_{\infty}} \right)^{n_s} \quad (8)$$

where

U_{ref}	=	wind speed at reference height (m/s),
z_{ref}	=	reference height above plant grade (240 m),
U_{∞}	=	wind speed at freestream height (m/s),
z_{∞}	=	freestream height (600 m),
U_{anem}	=	wind speed at appropriate anemometer (m/s),
z_{anem}	=	height above grade for U_{anem} (10 m),
n_a	=	wind power law exponent at the anemometer (0.19 at the Airport),
n_s	=	wind power law exponent at the site (0.21 at the site).

Tables AA-AC in Appendix provide the calculated results using the above equations. It should be noted that the power law exponents were calculated using Equation 4 with z_o equal to 0.25 m at the airport and 0.49 m at the site.

2.7 DATA ACQUISITION

The EPA stack height guideline (EPA, 1981) requires that certain information be collected for GEP stack height demonstrations. The data that are recommended to be collected are summarized below and in Table 4.

- Three vertical profiles of mean velocity, and vertical and longitudinal turbulence intensity and shear stress—for Atmospheric Dispersion Comparability (ADC) and excessive concentration tests (see Section 3.3 for a discussion on the ADC tests).
- Lateral profiles of mean velocity and turbulence intensity along the model surface and at a height close to plume altitude near the stack location and near the end of the planned study area (six profiles)—for ADC and GEP stack heights tests.
- Vertical and lateral concentration profiles through the plume centerline—three for ADC tests and four for GEP stack height tests.
- Ground-level longitudinal profiles of concentration along the plume centerline—for ADC, Reynolds number and GEP stack heights tests.
- Two to four lateral ground-level concentration profiles including one at the position of maximum ground-level concentration—GEP stack heights tests.

CPP has collected much of this information on past projects of a similar nature. For this study no ADC tests will be conducted. This study will mainly focus those items outlined in Table 4. Table 5 summarizes the concentration measurements that are planned.

The wind tunnel and instrumentation that will be used to collect the data are described in Appendix B.

2.8 QUALITY CONTROL

To ensure that accurate and reliable data are collected for assessing the plume transport and dispersion, certain quality control steps will be taken. These include:

- use of blended mixtures or pure gases or certified mixtures for stack source gas;
- multipoint calibration of hydrocarbon analyzer with certified standard gas;
- calibration of stack flow measuring device with soap bubble meter;
- calibration of velocity measuring device against pitot tube;

- wind tunnel testing to show the Reynolds number independence of the concentration measurements.

3. PROJECT PLAN

To meet the project objectives, six tasks are planned. The six tasks, which are discussed in detail below, are: 1) protocol development and approval; 2) model construction and setup; 3) wind tunnel testing - documentation tests; 4) visualization and meeting at CPP; 5) wind tunnel testing – GEP stack tests; and 6) analysis and reporting.

3.1 TASK 1 - TEST PROTOCOL DEVELOPMENT

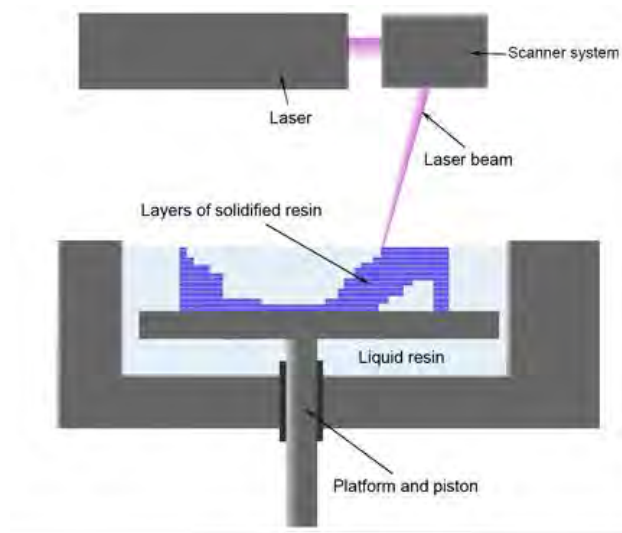
During this phase of the project, this test protocol will be developed and finalized. The protocol defines the methods used to conduct the study, the area and sources to be modeled, the wind directions and wind speeds to be simulated and the results that will be provided.

3.2 TASK 2 - MODEL CONSTRUCTION AND SETUP

A 1:240 scale model of the Stack S09 and nearby surroundings will be constructed and placed on a turntable. The turntable model will include all significant structures within a 415 m (1360 ft) radius of the Stack S09. Residential areas will be represented by roughness elements designed to simulate the roughness lengths listed in Table 3 (i.e., column with heading “Roughness on Turntable”). The 415 m radius includes all significant nearby structures as identified by BPIP. Upwind of the turntable, roughness elements will be installed to represent the approach roughness within a 3.2 km radius of stack. Downwind of the turntable, terrain and/or roughness elements will be installed so the measurements can be obtained out to 1,500 m. The turntable area modeled is depicted in Figure 3. A close-up plan view of the area that includes detailed structural models is provided in Figure 4.

The Boiler 7 building model will be constructed utilizing the 3D drawing files developed from plan and elevations drawings. These files are used to generate a file that is used directly to construct the scale model of the the Boiler 7 Building using either a Stereolithography (SLA) or 3D printing process. Both Stereolithography and 3D printing processes use the same file output type to create the models. Also, both processes typically build the models in layers of 0.004" per layer. For this project both processes will be used to construct various structural elements depending upon the needed durability.

In the way of background, Stereolithography is a process that uses a vat of liquid resin that is hardened by using a laser to cure the material one layer at a time. The models tend to be more flexible, thus they can withstand impacts better. Below is a simplified image of the process. 3D printing is a process that uses a polymer powder and 2D printing technologies combined to build 3D parts. Once created, the parts go through post-processing to strengthen them.



The process creates rigid parts that are more stable over time than SLA but are also more brittle. Similar to the SLA process, 3D printing involves building the model one layer at a time. Above is a simple schematic that illustrate the SLA process. The 3D printing process is very similar. Figure 9 shows 3D drawings of the model that will be used as the basis for model construction. It should be noted that simple site buildings will be constructed manually out of Styrofoam.

The stack will be constructed of brass tubes and will be supplied with an air-hydrocarbon mixture of the appropriate density. Measures will be taken to ensure that the flow is fully turbulent upon exit. Precision gas flow meters will be used to monitor and regulate the discharge velocity.

All testing will be carried out in CPP's closed-circuit wind tunnel shown in Figure 10. Turning vanes at the tunnel elbows were used to maintain a homogeneous flow at the test-section entrance. Spires and a trip at the leading edge of the test section begin the development of the atmospheric boundary layer. The long boundary layer development region between the spires and the site model was filled with roughness elements, as indicated in the wind-tunnel schematic presented in Figures 11 and 12. Figure 11 shows an example wind tunnel setup that will be used when testing with all site structures present and Figure 12 shows an example wind tunnel setup that will be used for testing with nearby structure removed. These roughness patterns are experimentally set to develop the appropriate approach boundary layer wind profile and approach

surface roughness length. Testing will be conducted with the target approach surface roughness length specified in Table 3.

For all testing, concentration measurements will be obtained at various locations on the surface of the wind tunnel so that at approximately 45 locations will be sampled for each simulation. A typical sampling grid consists of 5 to 9 measurement points located in each of 5 or 6 rows that are spaced perpendicular to the wind direction. The lateral and longitudinal spacing of measurement points is designed so that the maximum concentrations are defined in the lateral and longitudinal directions. Initial testing is conducted to confirm the sampling grid design and to alter the design if necessary. A schematic of a typical sampling grid is shown in Figure 13. It should be noted that one background sample is taken upwind of the stack so that the background can be subtracted from the all other measurements.

3.3 TASK 3 - WIND TUNNEL TESTING – DOCUMENTATION TESTS

Before conducting the detailed wind tunnel testing, a series of wind tunnel documentation tests are typically conducted as recommended by EPA. The tests include: 1) atmospheric dispersion comparability (ADC) tests, and 2) Reynolds number tests.

The atmospheric dispersion comparability (ADC) tests are conducted in the absence of buildings, other surface structures, large roughness and/or elevated terrain to show that dispersion in the wind tunnel is comparable to that described for the atmosphere by the basic Gaussian plume distribution. The stack height used for the tests is 50 or 100 m based on CPP's past experience conducting such studies. Concentration measurements for these tests must show comparability to the equations developed for predicting dispersion in flat terrain (i.e., Pasquill–Gifford stability class C or D; Turner, 1994). CPP conducted such tests on a past project with the same 1:240 scale reduction and these tests will not be repeated.

For the Reynolds number tests, a scale model of the Rhinelander Mill and vicinity will be installed in the wind tunnel. A tracer gas will be emitted from the new stack with the stack height set equal to the GEP stack height. Ground-level concentration measurements will then be taken downwind of the power station for three different Reynolds numbers. If Reynolds number effects are negligible, the normalized concentration results should be equivalent (within 10 percent). The minimum test speed for the remaining tests will be chosen such that Reynolds number effects are negligible. Table 5 lists the tests that will be conducted.

3.4 TASK 4 - MEETING AT CPP

Before detailed testing in the wind tunnel is carried out it is recommended that representatives from the client (and if possible, appropriate government officials) be present at CPP to inspect the model for accuracy and review the test plan. Visualizations of exhaust behavior are then conducted. The visualization will provide those present with a qualitative understanding of the effect of the structures on the dispersion and will provide information that can be used to finalize the test plan.

3.5 TASK 5 - WIND TUNNEL TESTING – GEP STACK HEIGHT TESTING

The actual GEP stack height will be determined for Stack S09. To determine the GEP stack height, the tests summarized in Table 5 will be conducted. The first series of tests will be conducted with the stack height set equal to 75 m, the formula GEP stack height. A series of five wind directions, with the building corner upwind, will then be evaluated to determine the wind direction giving the highest ground level concentration and highest concentration ratio with and without the upwind building present (i.e., greatest downwash effect). Other wind directions may be added if deemed appropriate. At the critical wind direction, a series of tests will then be conducted to define the wind speed that results in the highest ground level concentration and greatest downwash effect. Next, a series of tests will be conducted at various stack heights at the critical wind direction and wind speed. Once these tests are completed, testing at additional wind speeds, wind directions, and load conditions will be conducted at the preliminary GEP stack height to zero-in on the final GEP stack height. Once the GEP stack height is found, selected documentation tests and analyses as recommended by EPA (1981) will be conducted. These tests/analyses include:

- Repetitive tests with and without nearby structures present to demonstrate the tests were repeatable and that the maximum ground-level concentration was measured;

The following other documentation tests recommended by EPA (1981), will not be conducted as they have been carried out on past similar projects and offer no additional information regarding the GEP stack height.

- Elevated measurements of horizontal and vertical concentration distributions at several locations downwind of the stack under evaluation; and
- Calculations of horizontal and vertical dispersion coefficients, and their variation with downwind distance.

- Vertical and horizontal measurements of air flow characteristics within the region over which concentration measurements were obtained.

3.6 ANALYSIS AND REPORTING

The data will be analyzed shortly after it is collected and put in a form ready for report. The analyses will include:

- conversion of wind tunnel concentrations to full-scale hourly average normalized concentrations using the equation recommended by Snyder (1981); and
- specification of GEP stack height for Stack S09.

Upon completion of all analyses, a concise, comprehensive report will be prepared and submitted to the client for review and comment. After comments on the report are received, final bound copies will be provided.

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FIGURES

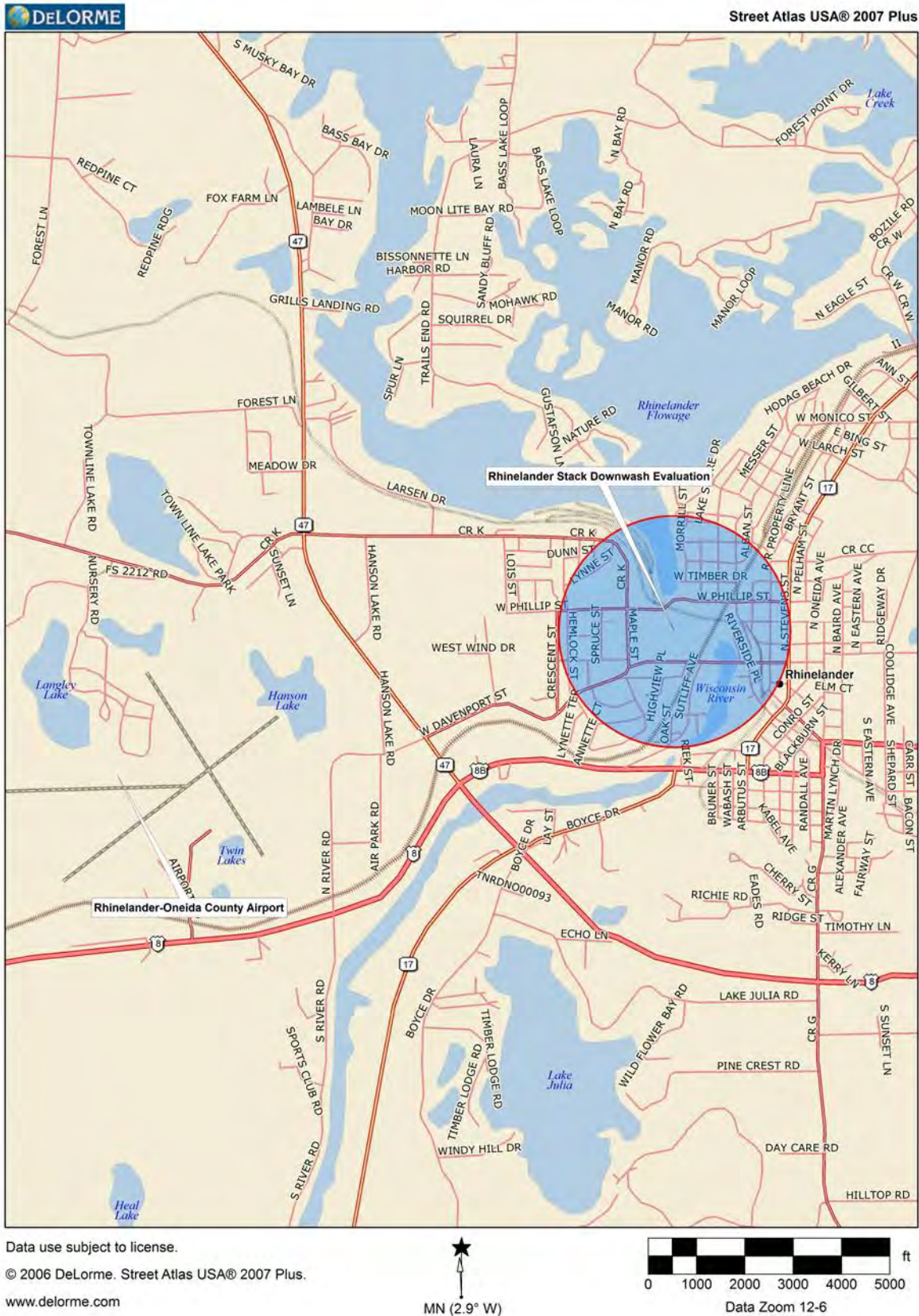


Figure 1. Site location and project anemometer.



Figure 2. Aerial view of Rhinelander Mill.

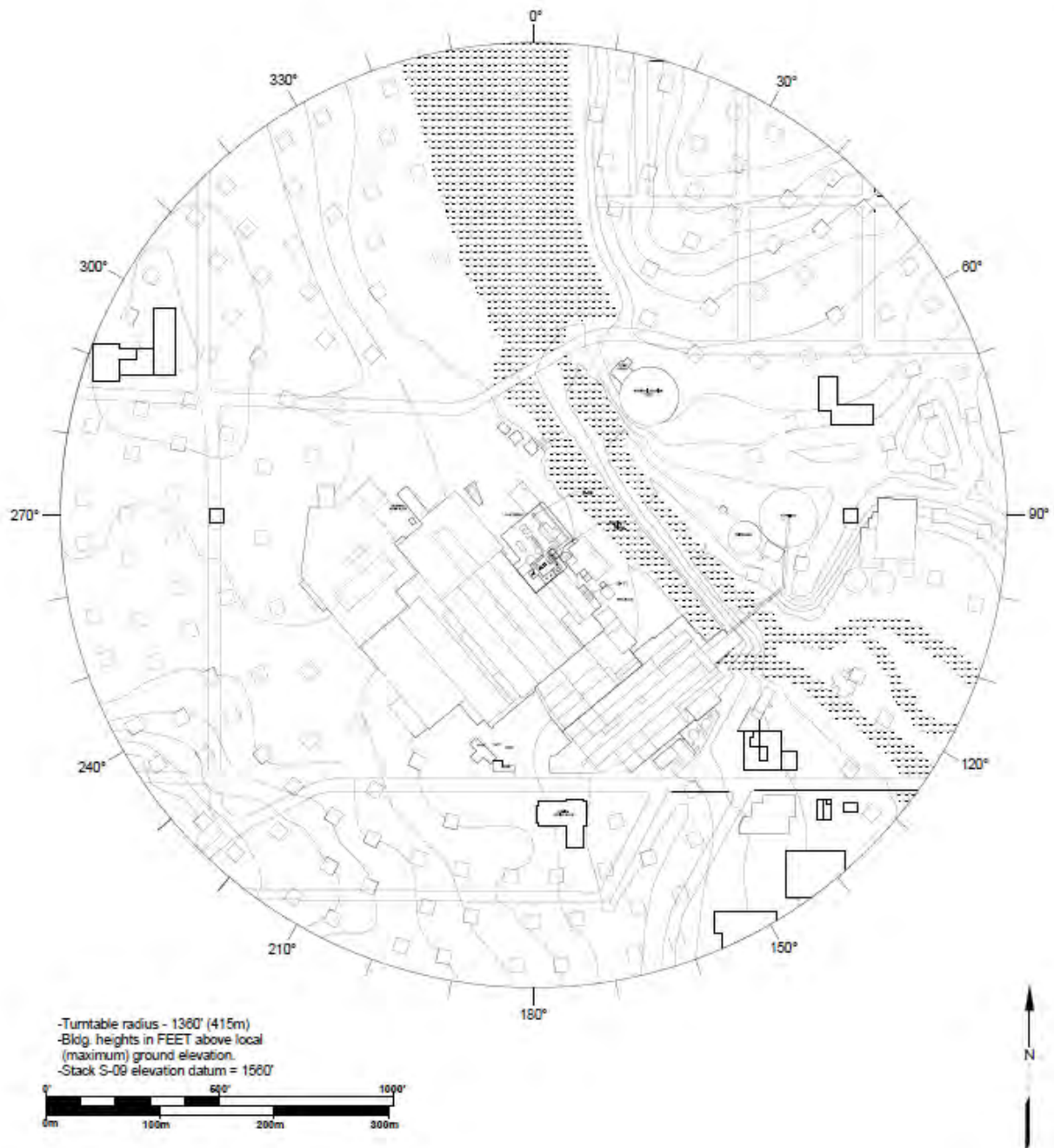


Figure 3. Model turntable drawing showing the test configuration with all building present.

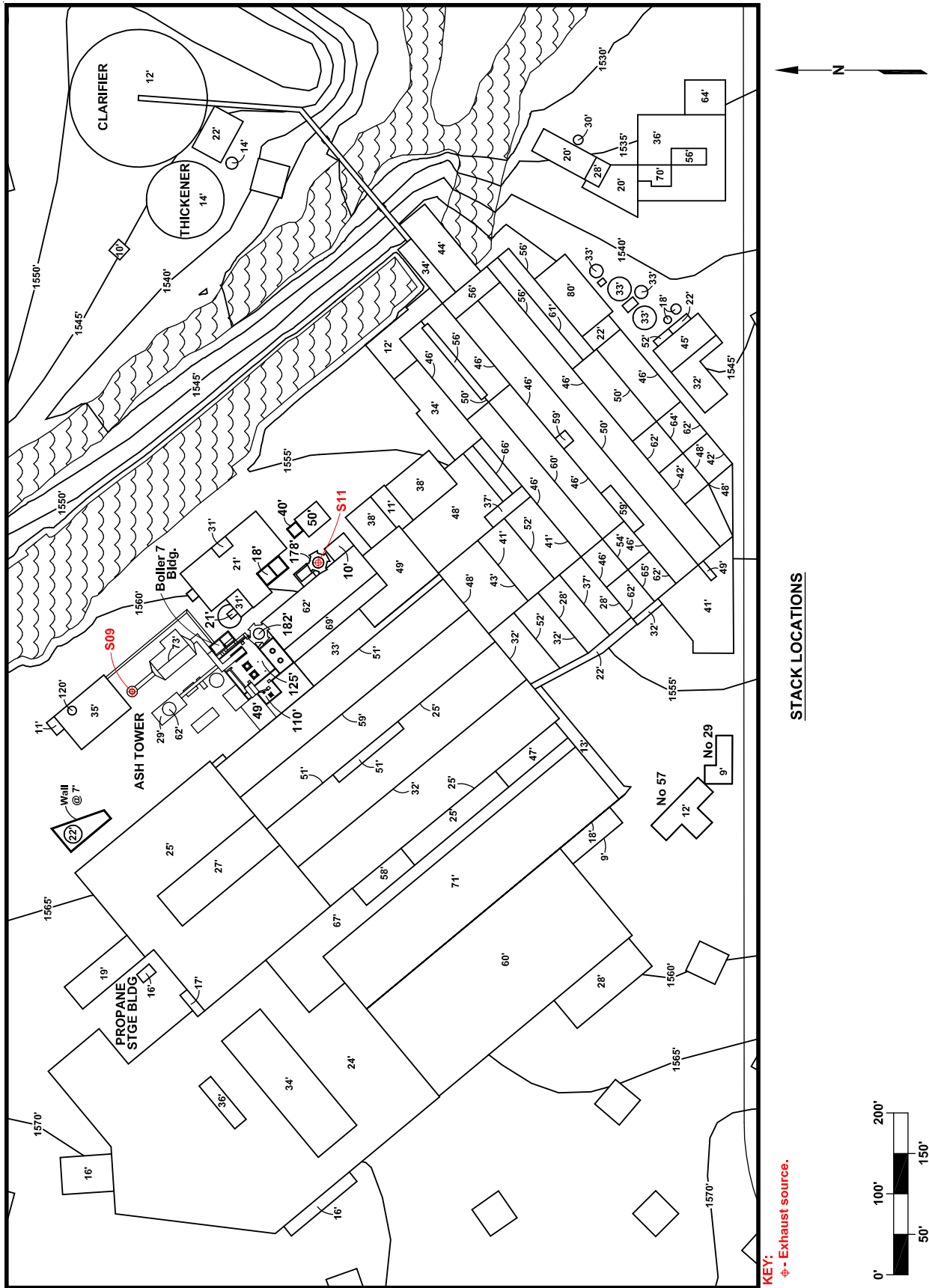


Figure 4. Close-up plan view of buildings and stacks, all building in configuration.

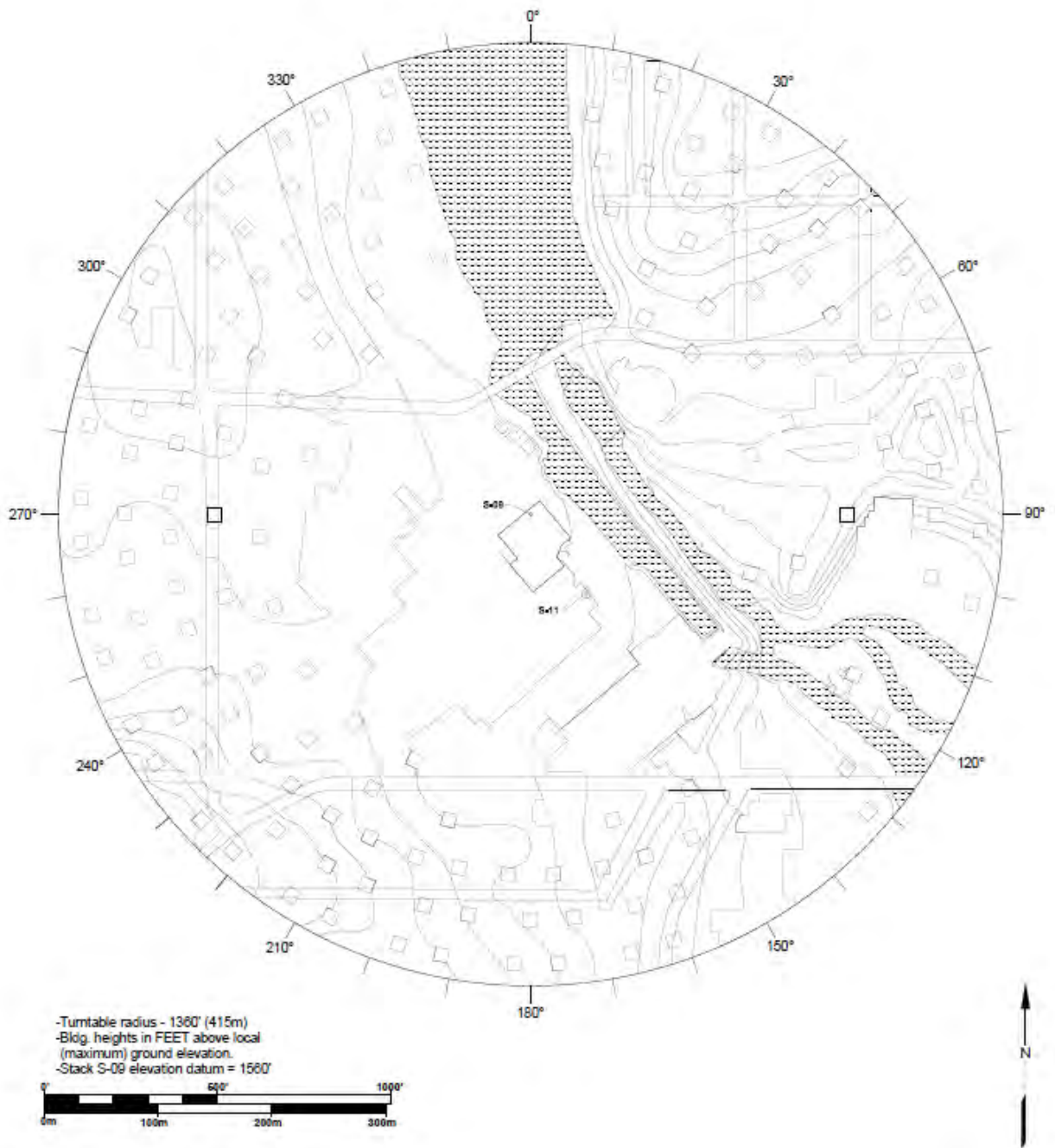


Figure 5. Model turntable drawing showing the test configuration with nearby building removed.

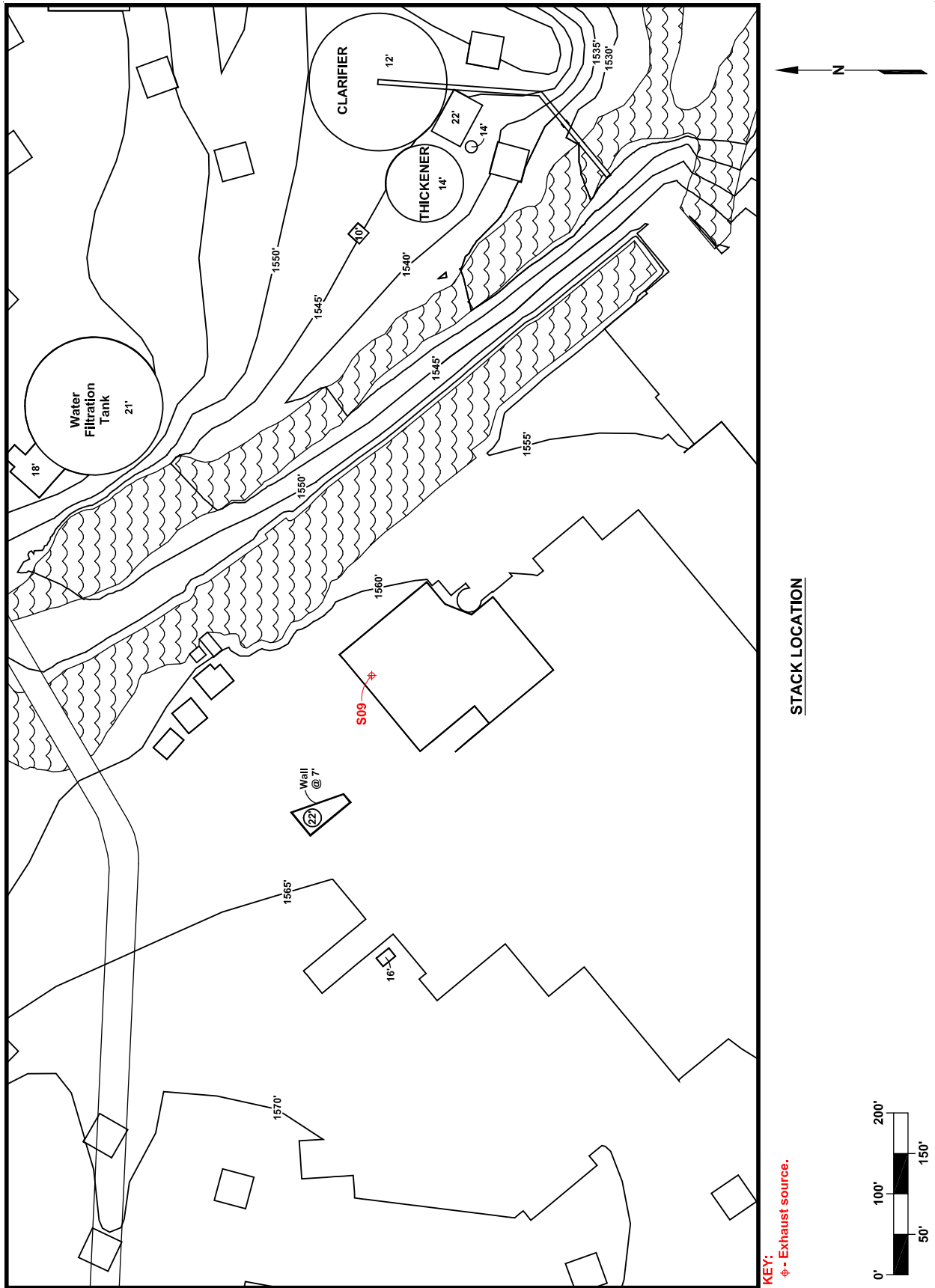


Figure 6. Close-up plan view of buildings and the stack, nearby buildings out configuration.

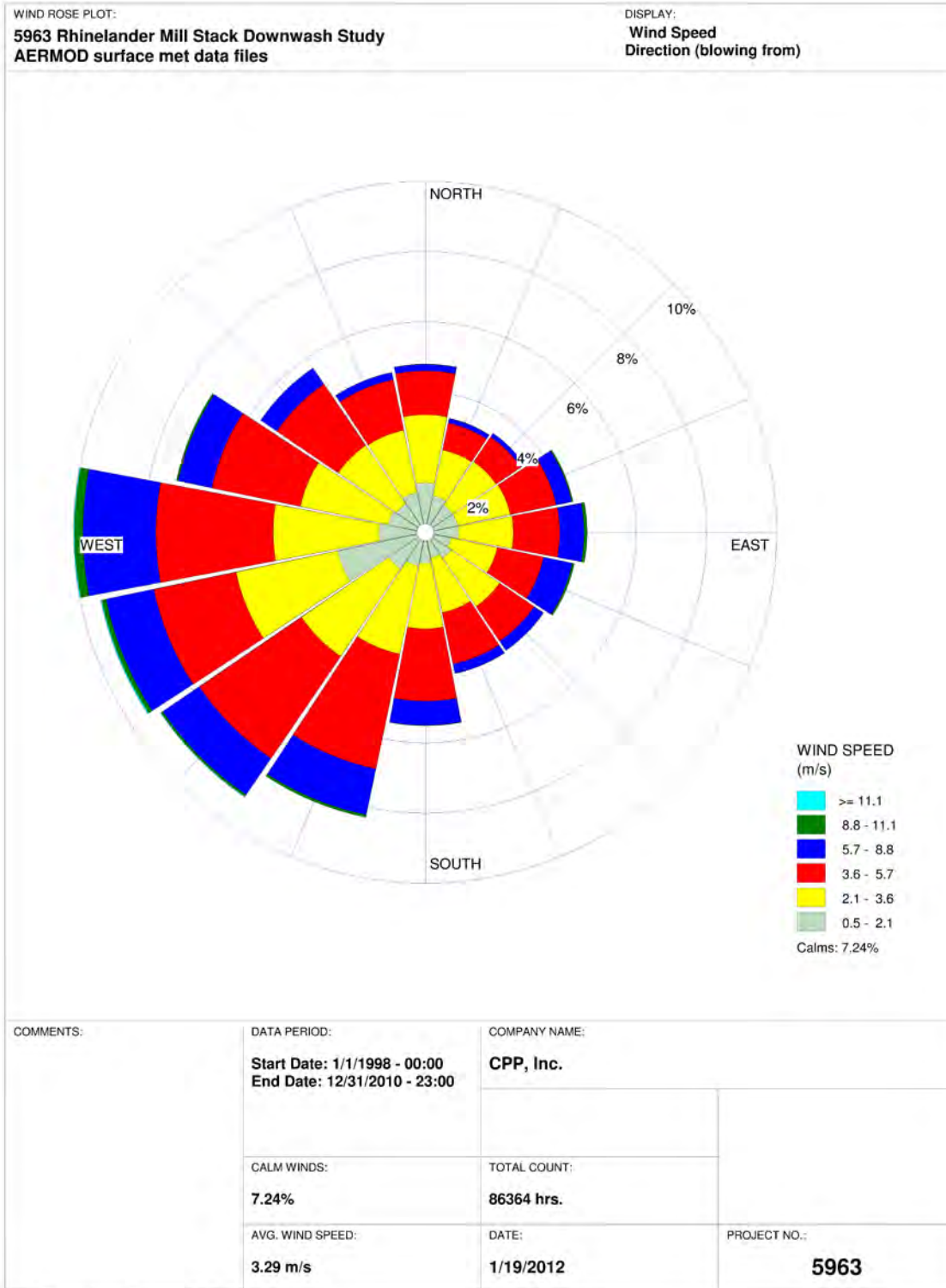
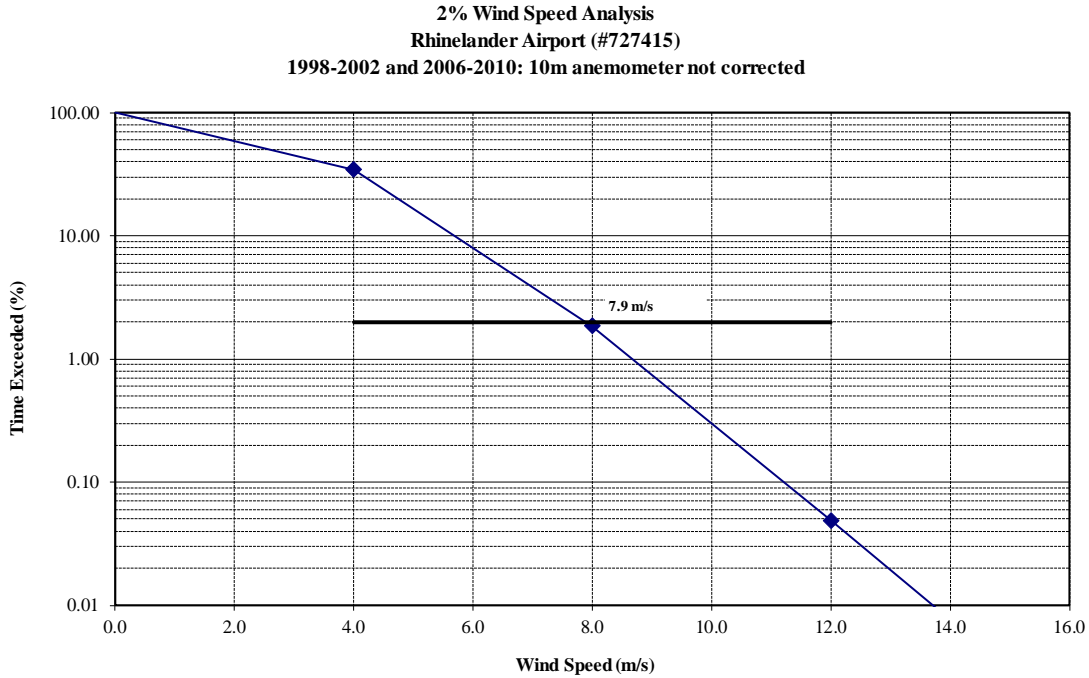


Figure 7. Wind rose for the Rhinelander-Oneida County Airport anemometer.



Joint Probability Distribution of Wind Speed and Wind Direction at the Rhineland Airport (#727415) Anemometer

Category: Maximum Wind Speed (m/s):	1 4.0	2 8.0	3 12.0	4 16.0	5 >16	Totals by Direction (%)
N	3.701	1.011	0.014	0.002	0.000	4.728
NNE	2.811	0.655	0.010	0.001	0.000	3.477
NE	2.723	0.651	0.008	0.000	0.000	3.383
ENE	2.983	1.334	0.066	0.005	0.000	4.387
E	2.876	1.564	0.145	0.004	0.000	4.588
ESE	2.511	1.781	0.143	0.002	0.000	4.437
SE	2.875	1.119	0.025	0.000	0.000	4.019
SSE	2.812	1.350	0.006	0.000	0.000	4.169
S	3.226	2.137	0.054	0.000	0.000	5.417
SSW	4.470	3.805	0.139	0.001	0.000	8.415
SW	5.092	3.703	0.173	0.011	0.000	8.979
WSW	6.181	3.029	0.341	0.010	0.000	9.561
W	5.192	4.125	0.506	0.011	0.001	9.835
WNW	4.458	2.974	0.144	0.001	0.000	7.576
NW	3.521	2.003	0.023	0.000	0.000	5.547
NNW	3.539	1.291	0.008	0.000	0.000	4.837
Calm	6.650					
Totals by Category (%):	65.620	32.530	1.805	0.048	0.001	100
Time Exceeded (%):	34.384	1.854	0.049	0.001	0.000	

Figure 8. Wind speed and direction distribution for the Rhineland-Oneida County Airport anemometer.

3D Drawings of Boiler 7 Building and S09 Stack

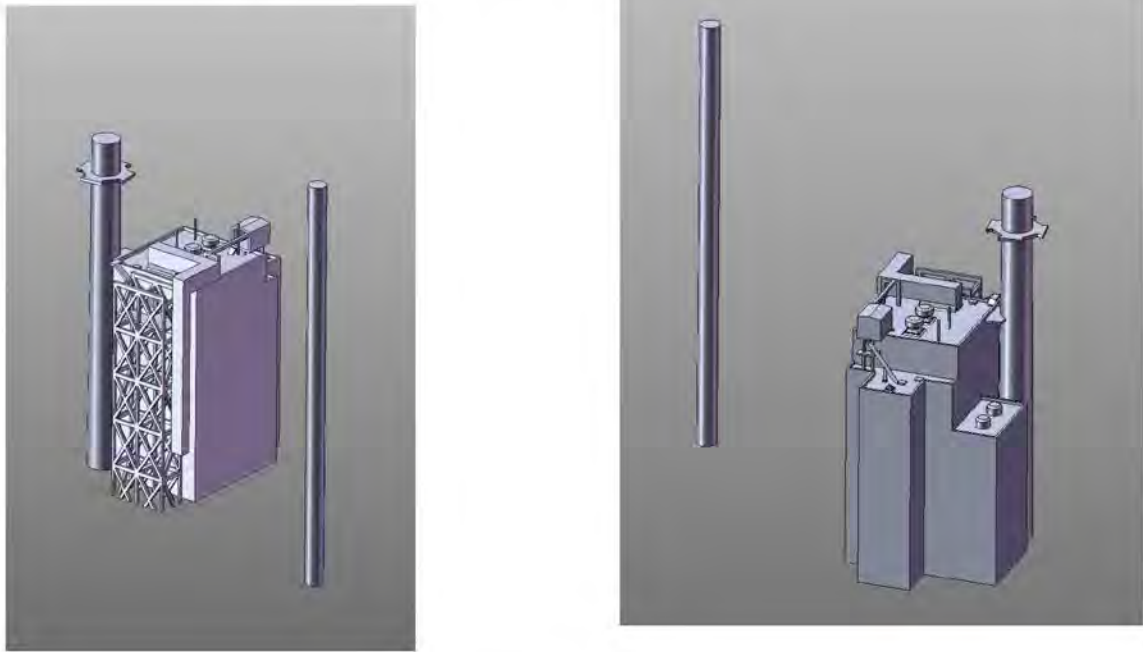


Figure 9. 3D views of the Boiler 7 model.

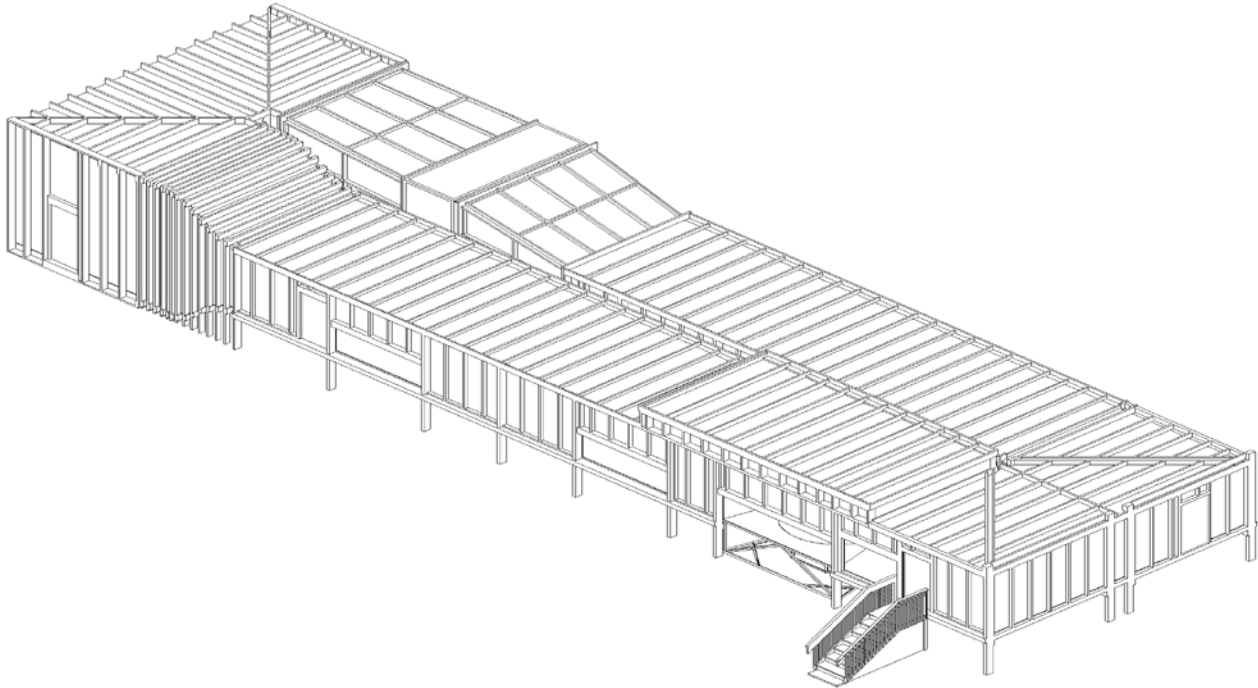


Figure 10. CPP's closed-circuit wind tunnel & performance specifications used for testing

1. Dimensions

<i>Test Section Length</i>	<i>68.0 ft (20.7 m)</i>
<i>Test Section Width</i>	<i>12.0 ft (3.66 m)</i>
<i>Ceiling Height</i>	<i>7.0 ft (2.1 m)</i>

2. Wind-Tunnel Fan

<i>Horse Power</i>	<i>4 X 15 hp (4 X 11.2 kW)</i>
<i>Drive Type</i>	<i>6 blade axial fan, variable speed motor</i>
<i>Speed Control</i>	<i>Fine: blade pitch control</i>

3. Boundary-Layer

<i>Free Stream Velocities</i>	<i>0.0 fps to 45.0 fps (0.0 to 13.7 m/s)</i>
<i>Boundary-Layer Thickness</i>	<i>Up to 5.0 ft (1.5 m)</i>

4. Stream wise Pressure Gradient

Zeroed by slotted roof over test section

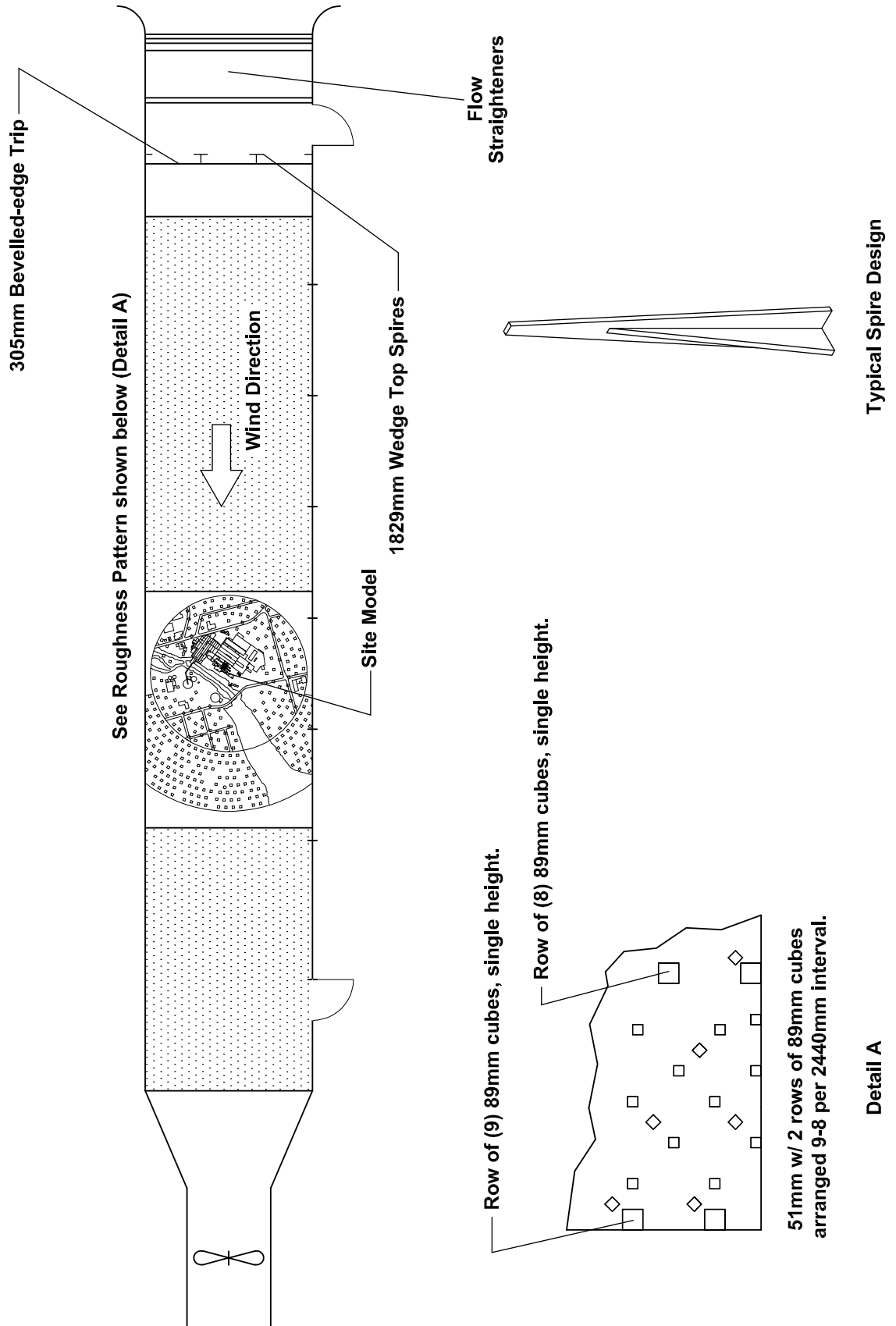


Figure 11. Schematic of example wind tunnel setup for GEP test with all site structures present.

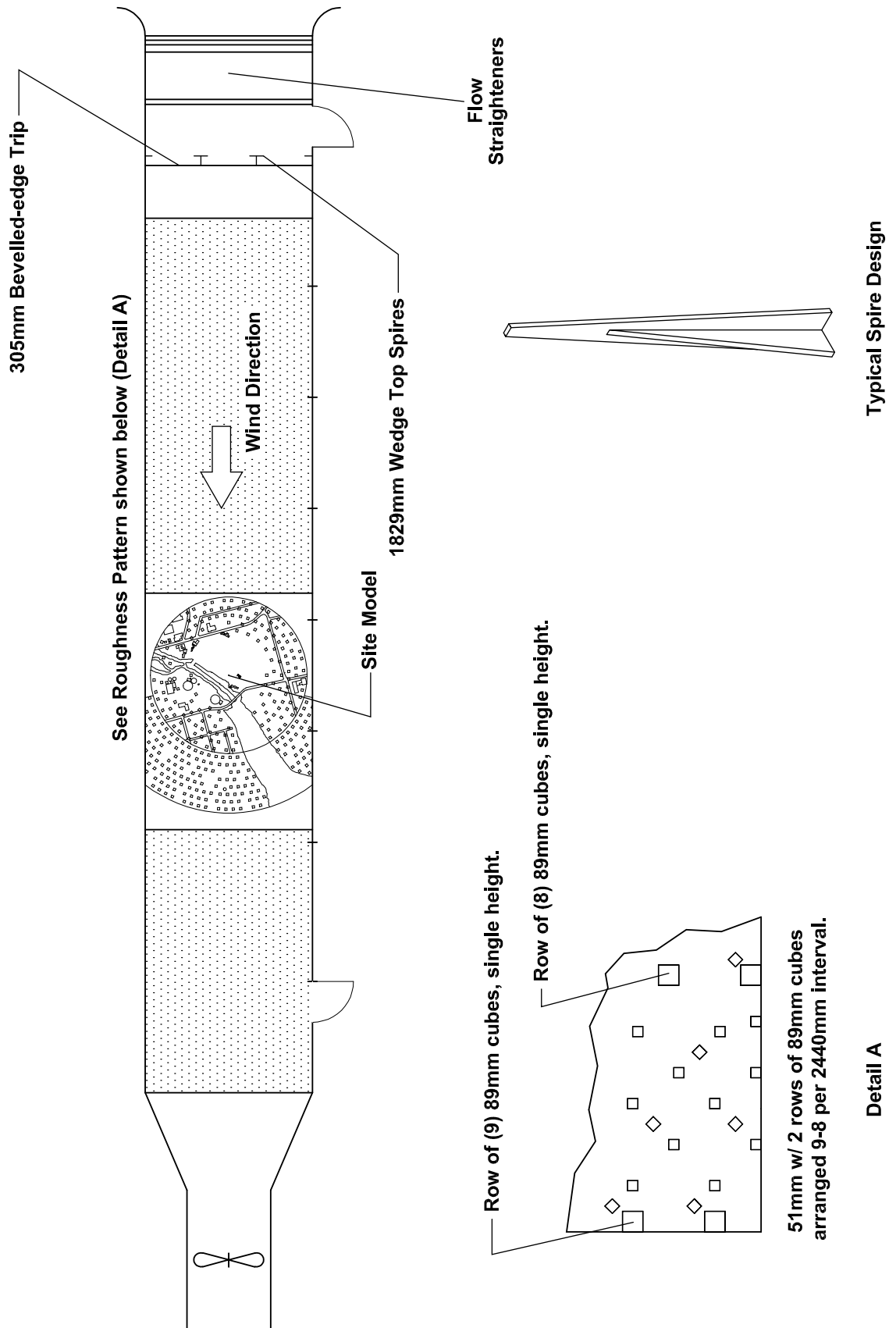


Figure 12. Schematic of example wind tunnel setup for GEP test with nearby structures removed.

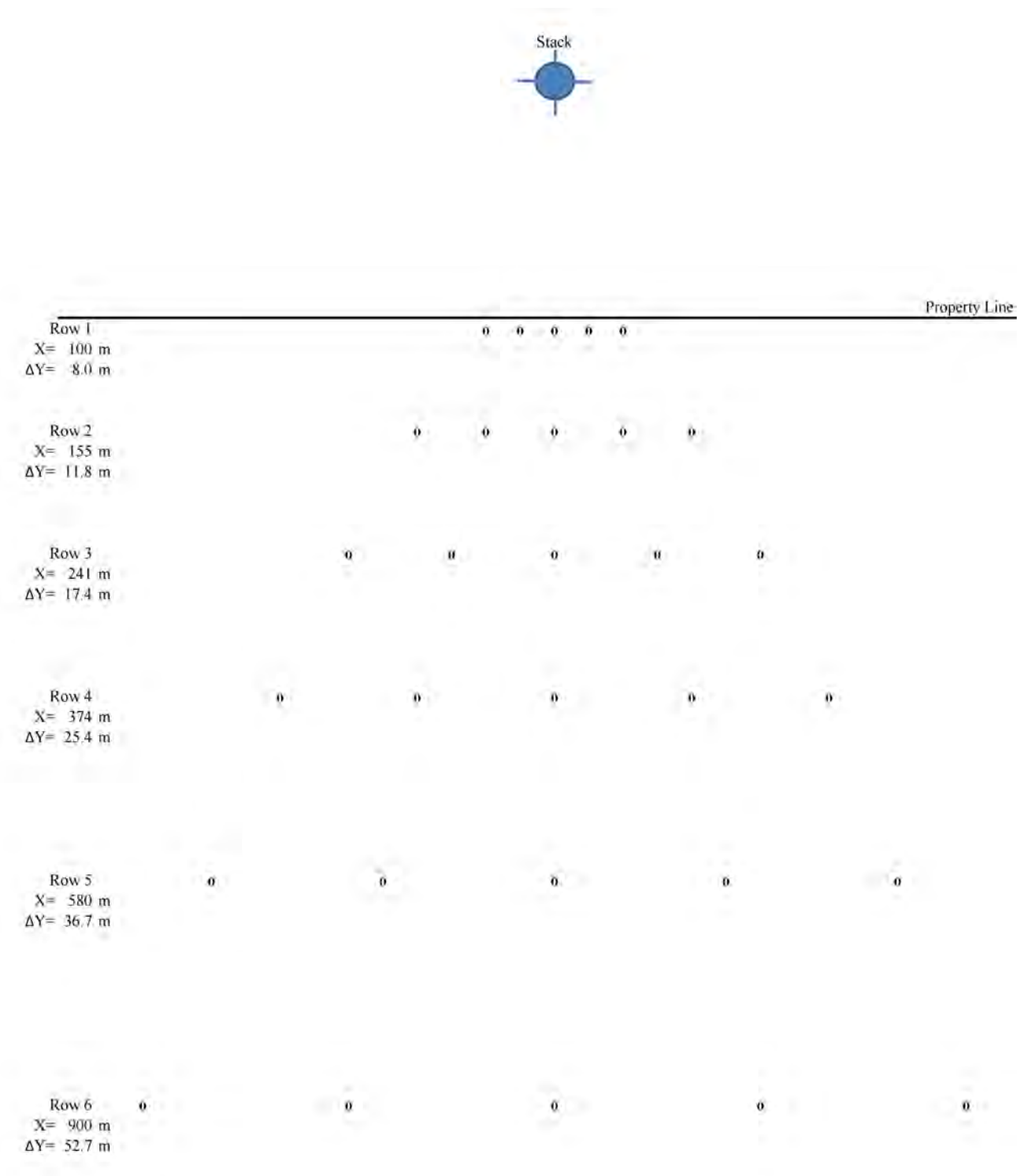


Figure 13. Schematic of typical ground-level concentration sampling grid. Note: X denotes the distance to the stack and ΔY is the distance between sampling points for a specific row.

TABLES

Table 1. Summary of GEP Stack Height Studies Carried out by CPP Principals

1979	ASARCO, Inc.	Arizona Smelter	GEP
	Toledo Edison	Bayshore Power Plant	GEP
1980	Allegheny Power Service Corporation	Armstrong Power Plant	GEP
	Monongahela Power Company	Albright Power Plant	GEP
	The Bunker Hill Company	Idaho Smelter	GEP
1981	Grain Processing Corporation	Iowa Grain Processing Plant	GEP
	Cleveland Electric Illuminating	East Lake Power Plant, OH	GEP
	Muscatine Power and Water	Muscatine Power Plant, IA	GEP
	Cleveland Electric Illuminating	Avon Power Plant, OH	GEP
1982	City Water Light and Power	Dallman Power Plant, IL	GEP
1985	Kennecott	Utah Smelter	GEP
1986	Dairyland Power Cooperative	Alma Power Plant, WI	GEP
	Thilmany Pulp and Paper	Kaukauna Mill, WI	GEP
	Westvaco	Covington Mill, WV	GEP
	Pennsylvania Electric Co.	Homer City Station, PA	GEP
	Pennsylvania Electric Co.	Seward Power Station, PA	GEP
	Pennsylvania Electric Co.	Shawville Power Station, PA	GEP
	Penn Power Company	Bruce Mansfield Station, PA	GEP
	Cincinnati Gas & Electric	Miami Fort Power Station, OH	GEP
1987	Jefferson Smurfit Corporation	Alton Paper Mill, IL	GEP
	Penn Power	Stack Height Evaluation, PA	GEP
	Hawaiian Electric Co.	Kahe Generating Station, HI	GEP
	Public Service of Indiana	Gibson Station, IN	GEP
	Indianapolis Power & Light	Pritchard Station, IN	GEP
1988	No. Indiana Public Service Company	Mitchell Station, IN	GEP
1989	Stanley Consultants	Archer Daniels Midland, IA	GEP
1990	Kodak	Kodak Park, NY	GEP
	Cincinnati Gas & Electric	Miami Fort Station, OH	GEP
	Amoco Corporation	Whiting Refinery, IN	GEP
1991	Wisconsin Power & Light	Rock River Station, WS	GEP
	ENSR	West Point Mill, VA	GEP
	Dayton Power & Light	Power Plant Evaluation, OH	GEP
1992	Metropolitan Edison	Titus Station, PA	GEP
	HMM Associates	Taunton Lighting Plant, MA	GEP
	Louisville Gas & Electric	LG&E, KY	GEP
1993	Penelec	Homer City Unit #3	GEP
1994	Montana Sulphur SRU Stack	Montana Sulphur & Chemical Co.	GEP
1998	EarthTech	Mystic Power Station	GEP
1999	Black & Veatch	Sempra Energy Resources Power Plant	GEP
2001	Duke Power	Duke Power	GEP
	Washington Group	Allegheny Energy Systems	GEP
	Duke Power	Duke Power Allen Plant	GEP
2006	Reliant Energy and ENSR	Cheswick Generating Station	GEP

Table 2. Source Parameters and Emission Scenarios

Source Description	Source ID	Height Above Base	Exit Diameter	Exit Temp. (°F)	Volume Flow Rate (cfm)	Exit Velocity (fpm)	SO ₂ Emission Rate (lbs/hr)
Rhineland S09 - maximum load	S09 max	206.9	83.8	315.0	100,000	2,608.6	1,050
Rhineland S09 - nominal	S09 nom	206.9	83.8	300.0	72,426	1,889.3	690
Rhineland S09 - minimum load	S09 min	206.9	83.8	300.0	56,100	1,463.4	760

Site Parameters:

Scale Reduction:	240	
Grade Elevation (m):	475.5	1560 ft msl
Typical Building Height (m):	38.1	
Ambient Temperature (°K):	279.1	Annual Average Temperature
Anemometer Height (m):	10.00	Rhineland-Oneida County Airport
Anemometer Surface Roughness (m):	0.25	Rhineland-Oneida County Airport
Site Anemometer Height (m):	10.00	
Site Surface Roughness (m):	0.49	
2 Percent Wind Speed (m/s):	7.9	Rhineland-Oneida County Airport (Period of Record: 1998 - 2010)

Metric Units

Source Description	Source ID	Height Above Base	Exit Diameter	Exit Temp. (K)	Volume Flow Rate (m ³ /s)	Exit Velocity (m/s)	SO ₂ Emission Rate (g/s)
Rhineland S09 - maximum load	S09 max	63.09	2.13	430.4	47.23	13.25	132.30
Rhineland S09 - nominal	S09 nom	63.09	2.13	422.0	34.21	9.60	86.94
Rhineland S09 - minimum load	S09 min	63.09	2.13	422.0	26.50	7.44	95.76

Table 3. AERSURFACE Surface Roughness Results*Rhinelanders Site*

AERSURFACE Sector (degrees)	AERSURFACE Sector (number)	AERSURFACE Calculated surface roughness (m)		Roughness on Turntable (m)	Averaged Wind Tunnel Roughness on TT and Petals (m)	Wind Tunnel Approach Roughness (m)
		415 m radius (68" TT)	3.2 km radius (WT approach)			
0 - 30	1	0.443	0.054	0.676	0.598	0.062
30 - 60	2	0.862	0.428	0.676	0.598	0.489
60 - 90	3	0.766	0.639	0.676	0.598	0.489
90 - 120	4	0.623	0.635	0.676	0.598	0.489
120 - 150	5	0.785	0.556	0.676	0.598	0.489
150 - 180	6	0.459	0.570	0.676	0.598	0.489
180 - 210	7	0.599	0.200	0.676	0.598	0.489
210 - 240	8	0.406	0.411	0.676	0.598	0.489
240 - 270	9	0.695	0.415	0.676	0.598	0.489
270 - 300	10	0.851	0.549	0.676	0.598	0.489
300 - 330	11	0.945	0.114	0.676	0.598	0.062
330 - 360	12	0.075	0.018	0.075	0.035	0.062

Rhinelanders Airport

Sector	1992 NLCD Image ADEC Manual Calculation ¹	2008 Google Earth Image ADEC Modified Manual Calculation ¹	AERSURFACE (1 km) Annual	AERSURFACE (1 km) Monthly ²	AERSURFACE (300 m) Monthly ^{2,3}
1	0.38	0.24	0.49	0.56	0.59
2	0.59	0.37	0.70	0.58	0.33
3	0.50	0.13	0.59	0.17	0.10
4	0.18	0.10	0.18	0.17	0.07
5	0.49	0.22	0.46	0.73	0.39
6	0.61	0.27	0.58	0.49	0.26
7	0.35	0.18	0.42	0.35	0.18
8	0.44	0.20	0.43	0.50	0.11
9	0.33	0.10	0.40	0.19	0.06
10	0.65	0.18	0.75	0.31	0.09
11	0.59	0.39	0.76	0.61	0.34
12	0.69	0.69	0.92	0.63	0.49
Mean	0.48	0.26	0.56	0.44	0.25

Notes:

- 1) Calculations performed following the Alaska Department of Environmental Conservation (ADEC) Guidance re AERMET Geometric Means (ADEC, 2009).
- 2) Latitude and Longitude coordinates relocated to center of runway (approximately 140 m south of anemometer location).
- 3) Calculation performed by John Roth, Wisconsin Dept. of Natural Resources.

Table 4. Summary of Test Measurements as recommended by EPA (1981)

Test Type	Measured Quantity	Measurement Locations			Traverse Direction	No. of Tests
		x	y	z		
Documentation	$U, U/U, W/U, U/U$	0, L/2, L	0	v	z	3
With Buildings Present	$U, U/U$	0, L	v	$h/2, h, 1.5h$	y	6
	C	1, 2, 3, 4	v	v	y, z	4
	C	v	v	0	x, y	3 repeats
Documentation	$U, U/U, W/U, U/U$	0, L/2, L	0	v	z	3
With Buildings Removed	$U, U/U$	0, L	v	$h/2, h, 1.5h$	y	6
	C	1, 2, 3, 4	v	v	y, z	4
	C	v	v	0	x, y	3 repeats

Notation:

- T — Ambient Temperature
 U — Mean Velocity
 U/U — Longitudinal Turbulence Intensity
 W/U — Vertical Turbulence Intensity
 U/U — Normalized Friction Velocity
 C — Concentration
 h — Stack Height
 L — Length of Test Area from Stack
 v — Variable
1, 2, 3, 4 — Locations to be Determined
 x — Longitudinal
 y — Lateral
 z — Vertical

Table 5. GEP Stack Height Determination Test Plan

Run No.	Source ID	Stack Height Above Base (ft)	Stack Height Above Base (m)	Anemometer Wind Speed (m/s)	Wind Direction (Deg.)	Surface Roughness Length (m)
Reynolds Number Tests - Three Tunnel Speeds or 2, 4 and 8 m/s						
<i>Buildings in place</i>						
1	S09 max	246.0	75.0	7.9	195	0.489
2	S09 max	246.0	75.0	7.9	195	0.489
3	S09 max	246.0	75.0	7.9	195	0.489
<i>Buildings removed</i>						
6	S09 max	246.0	75.0	7.9	195	0.489
7	S09 max	246.0	75.0	7.9	195	0.489
8	S09 max	246.0	75.0	7.9	195	0.489
Preliminary GEP Stack Height Tests						
<i>Buildings in place</i>						
<i>Worst wind direction tests</i>						
101	S09 max	246.0	75.0	7.9	185	0.489
102	S09 max	246.0	75.0	7.9	190	0.489
103	S09 max	246.0	75.0	7.9	195	0.489
104	S09 max	246.0	75.0	7.9	200	0.489
105	S09 max	246.0	75.0	7.9	205	0.489
<i>Worst Wind Speed Tests</i>						
111	S09 max	246.0	75.0	6	WWD	0.489
112	S09 max	246.0	75.0	5	WWD	0.489
<i>Worst Load Tests</i>						
121	S09 nom	246.0	75.0	WWS	WWD	0.489
122	S09 min	246.0	75.0	WWS	WWD	0.489
<i>Stack Height Tests</i>						
131	WL	SH1	SH1	WWS	WWD	0.489
132	WL	SH2	SH2	WWS	WWD	0.489
133	WL	SH3	SH3	WWS	WWD	0.489
<i>Buildings removed</i>						
<i>Worst wind direction tests</i>						
201	S09 max	246.0	75.0	7.9	185	0.489
202	S09 max	246.0	75.0	7.9	190	0.489
203	S09 max	246.0	75.0	7.9	195	0.489
204	S09 max	246.0	75.0	7.9	200	0.489
205	S09 max	246.0	75.0	7.9	205	0.489
<i>Worst Wind Speed Tests</i>						
211	S09 max	246.0	75.0	6	WWD	0.489
212	S09 max	246.0	75.0	5	WWD	0.489
<i>Worst Load Tests</i>						
221	S09 nom	246.0	75.0	WWS	WWD	0.489
222	S09 min	246.0	75.0	WWS	WWD	0.489
<i>Stack Height Tests</i>						
231	WL	SH1	SH1	WWS	WWD	0.489
232	WL	SH2	SH2	WWS	WWD	0.489
233	WL	SH3	SH3	WWS	WWD	0.489
Final GEP Stack Height Tests						
<i>Buildings in place</i>						
<i>Documentation Tests</i>						
141	WL	GEP	GEP	WWS	WWD	0.489
142	WL	GEP	GEP	WWS	WWD	0.489
143	WL	GEP	GEP	WWS	WWD	0.489
<i>Buildings removed</i>						
<i>Documentation Tests</i>						
141	WL	GEP	GEP	WWS	195	0.489
142	WL	GEP	GEP	WWS	195	0.489
143	WL	GEP	GEP	WWS	195	0.489

Notes: WWD: Worst Wind Direction; WWS: Worst Wind Speed; SH1: Stack Height 1; WL: Worst Load

APPENDIX

A

WIND-TUNNEL SIMILARITY REQUIREMENTS

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A.1. EXACT SIMILARITY REQUIREMENTS

An accurate simulation of the boundary-layer winds and stack gas flow is an essential prerequisite to any wind-tunnel study of diffusion. The similarity requirements can be obtained from dimensional arguments derived from the equations governing fluid motion. The basic equations governing atmospheric and plume motion (conservation of mass, momentum and energy) may be expressed, using Einstein notation, in the following dimensionless form (Cermak, 1975; Petersen, 1978):

$$\frac{\partial \rho^*}{\partial t^*} + \frac{\partial(\rho^* U_i^*)}{\partial x_i^*} = 0 \quad (\text{A.1})$$

$$\begin{aligned} \frac{\partial U_i^*}{\partial t^*} + U_j^* \frac{\partial U_i^*}{\partial x_j^*} - \left[\frac{L_o \Omega_o}{U_o} \right] 2 \epsilon_{ijk} \Omega_j^* U_k^* = \\ - \frac{\partial \rho^*}{\partial x_i^*} + \left[\frac{\Delta T_o L_o g_o}{T_o U_o^2} \right] \Delta T^* g^* \delta_{i3} + \left[\frac{v_o}{U_o L_o} \right] \frac{\partial^2 U_i^*}{\partial x_k^* \partial x_k^*} + \frac{\partial}{\partial x_k^*} - \overline{(U_i^* U_j^*)} \end{aligned} \quad (\text{A.2})$$

and

$$\begin{aligned} \frac{\partial T^*}{\partial t^*} + \frac{U_i^* \partial T^*}{\partial x_i^*} = \\ \left[\frac{K_o}{\rho_o C_{p_o} v_o} \right] \left[\frac{v_o}{L_o U_o} \right] \frac{\partial^2 T^*}{\partial x_k^* \partial x_k^*} + \frac{\partial}{\partial x_i^*} \overline{(-T^* U_i^*)} + \left[\frac{v_o}{U_o L_o} \right] \left[\frac{U_o^2}{C_{p_o} (\Delta T)_o} \right] \phi \end{aligned} \quad (\text{A.3})$$

where

- T = temperature;
- ρ = density;
- U = velocity;
- L = length scale;
- g = acceleration due to gravity;
- C_p = specific heat at constant pressure;
- x_i = Cartesian coordinates in tensor notation;
- v = kinematic viscosity;

- K = thermal conductivity;
- Ω = angular velocity of earth;
- Φ = dissipation;

and the subscript “ o ” denotes a reference quantity. The dependent and independent variables have been made dimensionless (indicated by an “*”) by choosing the appropriate reference values. The prime (') refers to a fluctuating quantity and ϵ_{ijk} is the alternating unit tensor.

For exact similarity, the bracketed quantities and boundary conditions must be the same in the wind tunnel as they are in the corresponding full-scale case. The complete set of requirements for similarity is:

- undistorted geometry;
- equal Rossby number:

$$Ro = \frac{U_o}{L_o \Omega_o} \quad (\text{A.4})$$

- equal gross Richardson number:

$$Ri = \frac{\Delta T_o g_o L_o}{T_o U_o^2} \quad (\text{A.5})$$

- equal Reynolds number:

$$Re = \frac{U_o L_o}{\nu_o} \quad (\text{A.6})$$

- equal Prandtl number:

$$Pr = \frac{\nu_o \rho_o C_{po}}{K_o} \quad (\text{A.7})$$

- equal Eckert number:

$$Ec = \frac{U_o^2}{C_{po} \Delta T_o} \quad (\text{A.8})$$

- similar surface-boundary conditions; and

- similar approach-flow characteristics.

For exact similarity, each of the above dimensionless parameters must be matched in the model and in full scale for the exhaust flow and ambient flow separately. To ensure that the exhaust plume dispersion is similar relative to the air motion, three additional similarity parameters are required (EPA, 1981) for modeling plume trajectories:

- velocity ratio:

$$R = \frac{U_s}{U_a} \quad (\text{A.9})$$

- densimetric Froude number:

$$Fr = \frac{U_s}{\sqrt{(g\gamma L)}} \quad (\text{A.10})$$

where

$$\gamma = \frac{\rho_s - \rho_a}{\rho_s} \quad (\text{A.11})$$

and

- density ratio:

$$\lambda = \frac{\rho_s}{\rho_a} \quad (\text{A.12})$$

where the subscripts “s” and “a” denote source and ambient quantity, respectively. All of the above requirements cannot be simultaneously satisfied in the model and full scale. However, some of the quantities are not important for the simulation of many flow conditions. The parameters that can be neglected and those which are important will be discussed in the next section.

A.2. SCALING PARAMETERS THAT CANNOT BE MATCHED

For most studies, simultaneously equalizing Reynolds number, Rossby number, Eckert Number and Richardson number for the model and the prototype is not possible. However, these inequalities are not serious limitations, as will be discussed below.

Reynolds number independence is an important feature of turbulent flows which allows wind-tunnel modeling to be used. The Reynolds number describes the relative importance of inertial forces to viscous forces in fluid flow. Atmospheric wind flows around buildings are characterized by high Reynolds numbers ($>10^6$) and turbulence. Matching high Reynolds numbers in the wind tunnel for the scale reduction of this study would require tunnel speeds 180 to 300 times typical outdoor wind speeds; an impossibility because of equipment limitations and since such speeds would introduce compressible flow (supersonic) effects. Beginning with Townsend (1956), researchers have found that in the absence of thermal and Coriolis (earth rotation) forces, the turbulent flow characteristics are independent of Reynolds number provided the Reynolds number is high enough. EPA (1981) specifies a Reynolds number criterion of about 11,000 for sharp-edged building complexes.

The Reynolds number related to the exhaust gas is defined by

$$Re_s = \frac{V_e d}{\nu_s} \quad (\text{A.13})$$

Plume rise becomes independent of the exhaust Reynolds number if the plume is fully turbulent at the stack exit (Hoult and Weil, 1972; EPA, 1981). Hoult and Weil (1972) reported that plumes appear to be fully turbulent for stack Reynolds numbers greater than 300. Their experimental data showed that the plume trajectories were similar for Reynolds numbers above this critical value. In fact, the trajectories appeared similar down to $Re_s = 28$ if only the buoyancy dominated portion of the plume trajectory was considered. Hoult and Weil's study was in a laminar cross flow (water tank) with low ambient turbulence levels, and, hence, the rise and dispersion of the plume was primarily dominated by the plume's own self-generated turbulence. Arya and Lape (1990) showed similar plume trajectories for Reynolds numbers greater than 670 for buoyant plumes and greater than 2000 for neutrally buoyant plumes. Care should be taken to ensure Re_s exceeds the minimum values or trips should be installed in the stack to augment the turbulence.

The mean flow field will become Reynolds number independent and characteristic of the atmospheric boundary layer if the flow is fully turbulent (Schlichting, 1978). The critical Reynolds number for this criterion to be met is based on the work of Nikuradse, as summarized by Schlichting (1978), and is given by:

$$Re_{z_o} = \frac{z_o u_*}{\nu} > 2.5 \quad (\text{A.14})$$

In this relation, z_o is the surface roughness factor. If the scaled down roughness gives a Re_{z_o} less than 2.5, then exaggerated roughness would be required. The roughness elements must be larger than about $11 z_f$ where z_f is the friction length ν/u_* . Below this height, the flow is smooth.

In the event the Reynolds numbers are not sufficiently high, testing should be conducted to establish the expected errors. Recent arguments suggest that Re_{z_o} can be as low as 1.0 without introducing serious errors into the simulations. It should be noted that this guidance is based on a neutral atmosphere. For stable stratification, it has been often assumed that a similar limit applies, but no systematic studies have been conducted to confirm this assumption.

Another scaling parameter that has been shown to be important is the Peclet-Richardson number ratio, Pe/Ri . The Peclet-Richardson number measures the relative rates of turbulent entrainment and molecular diffusion. If the wind-tunnel simulation is affected by molecular diffusion, the concentrations measured in the wind tunnel will be lower than those in the atmosphere for the same condition. Meroney (1987) reported that researchers at Shell concluded that molecular diffusion may play an important role in the laboratory when the scaled turbulent diffusivity is very small. They found that when the Pe/Ri number is less than a critical value, simulations were inaccurate. Their parameter was defined as follows:

$$\frac{Pe}{Ri} = \frac{U_r^3}{(g' \epsilon)} \quad (\text{A.15})$$

where U_r is the reference wind speed, ϵ is a molecular diffusivity, and $g' = g(\rho_s - \rho_a)/\rho_a$. The criterion has a problem in that two flows with the same reference speed but different turbulence (i.e., neutral versus stable or grassland versus an urban area) will have the same criterion which does not seem appropriate. For this reason, Meroney (1987) suggests the following criterion:

$$\frac{Pe^*}{Ri^*} = \frac{U^{*3}}{(g' \epsilon)} > 2.0 \quad (\text{A.16})$$

Meroney (1987) found that errors in wind-tunnel simulations were noticed when Pe^*/Ri^* was less than 0.2; hence, all tests should be designed to meet or exceed this value. If tests are needed such that this restriction must be violated, additional tests should be conducted to assess the potential errors when using lower Pe^*/Ri^* values.

The Rossby number, Ro , is a quantity which indicates the effect of the earth's rotation on the flow field. In the wind tunnel, equal Rossby numbers between model and prototype cannot be achieved without a spinning wind tunnel. The effect of the earth's rotation becomes significant if the distance scale is large. EPA (1981) set a conservative cutoff point at 5 km for diffusion studies. For most air quality studies, the maximum range over which the plume is transported is less than 5 km in the horizontal and 100 m in the vertical.

When equal Richardson numbers are achieved, equality of the Eckert number between model and prototype cannot be attained. This is not a serious compromise since the Eckert number is equivalent to a Mach number squared. Consequently, the Eckert number is small compared to unity for laboratory and atmospheric flows and can be neglected.

A.3. WIND-TUNNEL SCALING METHODS

This section discusses the methods commonly used to set up wind-tunnel model operating conditions. Based on CPP's past experience with diffusion studies (Petersen, 1991, 1989, 1987, and 1978) and the requirements in the EPA fluid modeling guideline (EPA, 1981; 1985), the criteria that are used for conducting these wind-tunnel simulations are:

- match (equal in model and full scale) momentum ratio, M_o :

$$M_o = \lambda \left(\frac{V_e}{U_H} \right)^2 \quad (\text{A.17})$$

- match buoyancy ratio, B_o :

$$B_o = \frac{gdV_e(\rho_a - \rho_s)}{\rho_a U_h^3} = \left(\frac{\rho_s}{\rho_a} \right) \left(\frac{(V_e/U_h)^3}{Fr_s^2} \right) \left(\frac{d}{z_r} \right) \quad (\text{A.18})$$

where

$$Fr_s^2 = \frac{\rho_s V_e^2}{g(\rho_a - \rho_s)d} \quad (\text{A.19})$$

- ensure a fully turbulent stack gas flow [stack Reynolds number ($Re_s = V_e d/\nu$) greater than 670 for buoyant plumes or 2000 for turbulent jets (Arya and Lape, 1990), or in-stack trip];
- ensure a fully turbulent wake flow [terrain or building Reynolds number ($Re_b = U_H H_b/\nu$) greater than 11,000 or conduct Reynolds number independence tests];
- identical geometric proportions;
- equivalent stability [Richardson number [$Ri = (g\Delta\theta H_b)/(T U_H^2)$] in model equal to that in full scale, equal to zero for neutral stratification]; and
- equality of dimensionless boundary and approach flow conditions;

where

V_e = stack gas exit velocity (m/s);

U_H = ambient velocity at building top (m/s);

- d = stack diameter (m);
- ρ_a = ambient air density (kg/m^3);
- $\Delta\theta$ = potential temperature difference between H_b and the ground (K);
- T = mean temperature (K);
- ρ_s = stack gas density (kg/m^3);
- ν = viscosity (m^2/s);
- H_b = typical building height (m); and
- λ = density ratio, ρ_s/ρ_a (-).

For certain simulations it is advantageous to conduct simulations at model scale Reynolds numbers less than 11,000. When this situation arises, Reynolds number sensitivity tests are conducted. The Reynolds number independence tests consist of setting up a simulation with a neutral density exhaust and an approach wind speed to exit velocity ratio of 1.50. Initial tests are conducted with the a high model approach wind speed so that the building Reynolds number meets or exceeds 11,000. The simulation is subsequently repeated at incrementally lower approach wind speeds, thus incrementally lower building Reynolds numbers. Concentrations during each of these simulations are measured at one or more receptor locations. The concentration distribution measured for the simulation with a building Reynolds number at or greater than 11,000 is used as the baseline. The concentration distribution from the subsequent, lower building Reynolds number simulations, are then compared to this baseline distribution. If the two distributions are within $\pm 10\%$ of the maximum measured value, the two simulations are assumed to be equivalent. The building Reynolds number for the simulation with the lowest approach wind speed which meets this criteria is established as the site specific critical building Reynolds number. All subsequent simulations are conducted with building Reynolds numbers at least as great as this site specific building Reynolds number.

For buoyant sources, the ideal modeling situation is to simultaneously match the stack exit Froude number, momentum ratio and density ratio. Achieving such a match requires that the wind speed in the tunnel be equal to the full scale wind speed divided by the square root of the length scale. For example, for a 1:180 length scale reduction, the wind speed ratio would be approximately 1:13, meaning the tunnel speeds would be 13 times lower than the full scale wind speeds. Such a low tunnel speed would produce low Reynolds numbers and is operationally difficult to achieve. Hence, Froude number scaling is typically not used. Instead, for buoyant sources, the buoyancy ratio defined above is matched between model and full scale. Using this

criterion, the exhaust density of the source can be distorted which allows higher wind-tunnel speeds.

Even with distorting the density, there may still be situations in which the buoyancy ratio cannot be matched without lowering the wind-tunnel speed below the value established for the critical building Reynolds number. When this conflict exists, the buoyancy ratio is distorted and the building Reynolds number criterion is not relaxed. The impact of distorting the buoyancy ratio will result in lower plume rise which in turn will result in higher predicted concentrations. Hence, the results of the study will be conservative.

Testing is typically performed under neutral stability ($Ri = 0$). Meroney (1990) cites a Colorado State University report which determined that the effect of atmospheric stability on dispersion within five building heights of a building complex is relatively small due to the dominance of mechanical turbulence generated within the building complex.

Another factor to consider when setting up a wind-tunnel simulation is the blockage (model cross-sectional area perpendicular to the flow divided by wind tunnel cross-sectional area). EPA (1981) states that blockage should be limited to 5% unless the roof can be adjusted. In the later case a 10% blockage is acceptable. The model-scale reduction factor used for CPP studies are established to ensure that the blockage is less than 10%, since CPP's wind-tunnel roof is adjustable.

Using the above criteria and source parameters supplied by the client, as noted in the main body of this report, the model test conditions were computed for each of the exhaust sources under evaluation. CPP has developed a spreadsheet to facilitate the design of wind-tunnel tests based on full-scale source parameters and pertinent modeling restrictions. A description of each of the parameters shown on the similarity tables included at the end of this appendix is presented Section A.5. Values shown in square brackets are parameter numbers which correspond to the number of the parameter in the similarity table. Depending upon the type of wind-tunnel study being conducted, building or terrain effects may dominate the flow patterns on the model. For parameters which may have this distinction, the terrain parameter description is contained in parentheses following the first description. Parameter subscripts f and m indicate reference to the full scale or model scale parameter value, respectively.

A.4. EVALUATION OF SIMULATED BOUNDARY LAYER

An important similarity criterion discussed in Section A.1 is the similarity of the approaching wind conditions, particularly the variation of mean wind speed and turbulence intensity with height. The atmospheric boundary-layer wind tunnels employed by CPP are specifically designed to simulate the mean wind speed and turbulence intensity profiles which occur in the atmosphere. The boundary layer is achieved with the use of screens, flow straighteners, trips, spires, and roughness elements. The screens and flow straighteners (long horizontal tubes) are located at the entrance of the wind tunnel to produce a homogeneous flow across the entrance region. Development of the boundary layer is initiated with a series of vertical spires and a horizontal trip located downwind of the entrance region. The floor of the boundary-layer development region, which resides between the trip and spires and the test section, is filled with roughness elements that are specifically designed to simulate the atmospheric boundary layer approaching the project site. When the approach conditions vary with wind direction, i.e., a site which is partially bounded by a large body of water or a site which is located on the outskirts of a large city, multiple roughness configurations may be necessary. The tunnel setup drawings in the main report show the wind-tunnel configuration(s) utilized during this study.

In order to document the appropriateness of the wind-tunnel configuration(s), vertical profiles of mean velocity and longitudinal turbulence intensity were obtained upwind of the model test area. The profiles were collected using a hot-film anemometer mounted on a vertical traverse device. The procedures for measuring the velocity profiles are discussed in Appendix B.

An analysis of the mean velocity profile was conducted to determine whether the shape was characteristic of that expected in the atmosphere. The starting point in any analysis of the mean velocity profile characteristics is to consider the equations which are commonly used to predict the distribution of wind and turbulence in the atmosphere. The most common equation, which has a theoretical basis, is referred to as the “log-law” and is given by:

$$\frac{U}{U_*} = \frac{1}{k} \ln \left(\frac{z}{z_o} \right) \quad (\text{A.20})$$

where

- U = the velocity at height z ;
- z = elevation above ground-level;

- z_o = the surface roughness length;
 U_* = the friction velocity; and
 k = the von Kàrmàn's constant (which is generally taken to be 0.4).

Another equation which is commonly used to characterize the mean wind profile is referred to as the “power-law” and is given by:

$$\frac{U}{U_r} = \left(\frac{z}{z_r} \right)^n \quad (\text{A.21})$$

where

- z_r = is some reference height;
 U_r = is the wind speed at the reference height; and
 n = is the “power-law” exponent.

Another consistency check is to relate the power-law exponent, n , to the surface roughness length, z_o . Counihan (1975) presents a method for computing the “power-law” from the surface roughness length, z_o , using the following equation:

$$n = 0.24 + 0.096 \log_{10} z_o + 0.016 (\log_{10} z_o)^2 \quad (\text{A.22})$$

The variation of longitudinal turbulence intensity with height has been quantified by EPA (1981). EPA gives the following equation for predicting the variation of longitudinal turbulence intensity in the surface layer:

$$\frac{U'}{U} = n \frac{\ln \left(\frac{30}{z_o} \right)}{\ln \left(\frac{z}{z_o} \right)} \quad (\text{A.23})$$

where all heights are in full-scale meters. This equation is only applicable between 5 and 100 m (16 and 330 ft). Above 100 m, the turbulence intensity is assumed to decrease linearly to a value of 0.01 at a height of roughly 600 m (2000 ft) above ground level.

A.5. DEFINITION OF PARAMETERS IN SIMILARITY TABLE

- [1] *Building Height, H_b (Terrain Height, H_t) m*
This is the height of the dominating building (terrain peak) relative to the grade ($z=0$) which is used for all entries.
Full scale value: Input.
Model scale value: Computed by dividing H_b (or H_t) [1_f] by SF [29_f].
- [2] *Base Elevation Above Mean Sea Level, $z = 0$ (m)*
This is the altitude of the grade ($z = 0$) relative to mean sea level.
Full scale value: Input.
Model scale value: Constant for CPP's facility in Fort Collins, Colorado: 1524 m.
- [3] *Stack Height Above Grade, h (m)*
This is the height of the stack top relative to the grade ($z = 0$) which is used for all height entries.
Full scale value: Input.
Model scale value: Computed by dividing h [3_f] by SF [29_f].
- [4] *Stack Inside Diameter, d (m)*
This is the inside diameter at the stack exit.
Full scale value: Input or Computed.
Model scale value: Computed by dividing d [4_f] by SF [29_f]. Actual modeled stack diameters are rounded to the nearest $1/32^{\text{nd}}$ of an inch due to the restrictions of commercially available brass tubing. Minimum value is $2/32^{\text{nds}}$ to ensure turbulent exhaust.
- [5] *Stack Inside Area, A_e (m^2)*
This is the inside area of the stack exit, which is computed from d [4] using the following equation:¹

¹ Only two of the three parameters d [4], V_e [6] or V [8] are input. The third parameter is then computed using Equations (A.24) and (A.25).

$$A_e = \frac{\pi d^2}{4} \quad (\text{A.24})$$

Full scale value: Computed using Equation A.24 with d equal to [4_f].

Model scale value: Computed using Equation A.24 with d equal to [4_m].

This parameter is related to V [8] and V_e [6] by the following equation:

$$A_e = \frac{V}{V_e} \quad (\text{A.25})$$

[6] *Exit Velocity, V_e (m/s)*

This is the exit velocity of the stack gas effluent.

Full scale value: Input or Computed.¹

Model scale value: Computed by multiplying U_r [18_m] by R [33_m].

[7] *Exit Temperature, T_s (K)*

This is the temperature of the stack gas effluent at the stack exit.

Full scale value: Input.

Model scale value: Constant at the laboratory room temperature ~293K.

[8] *Volume Flow Rate, V (m³/s)*

This is the actual volume flow rate through the stack at the pressure and temperature given by P_a [10] and T_a [11], respectively.

Full scale value: Input or Computed.¹

Model scale value: Computed by multiplying A_e [5_m] by V_e [6_m].

[9] *Emission Rate, m (g/s)*

This is the emission rate of any chemical species or gas component. This value is used to compute full scale concentrations based on concentration measurements made in the wind tunnel.

Full scale value: Input.

Model scale value: Since only a tracer gas is used in the wind tunnel, the emission rate of the chemical species or gas component is not applicable (#NA) at the model scale.

[10] *Ambient Pressure, P_a (hPa)*

This is the ambient atmospheric pressure at the site (model) location.

Full scale value: Estimated based on the grade elevation of the site $z = 0$ [2_f]. For sites at mean sea level, P_a is ≈ 1013 hPa. The ambient pressure for sites at other locations is

determined using the following equation which was obtained by fitting a curve to the U.S. Standard Atmosphere (1962):

$$P_a = 1013 \exp\left[\frac{x}{-8350}\right] \quad (\text{A.26})$$

where x (m) is the base elevation of the site above mean sea level $z = 0$ [2_f].

Model scale value: Estimated using Equation A.26 and the elevation of CPP's facility in Fort Collins, Colorado, $z = 1524$ m [2_m].

[11] *Ambient Temperature, T_a (K)*

This is the ambient annual average temperature at the site (model) location.

Full scale value: Input.

Model scale value: Constant at the laboratory room temperature ~ 293 K.

[12] *Air Density, ρ_a (kg/m³)*

This is the density of the ambient air. Assuming air behaves as an ideal gas, the following relationship can be used to relate the density of air to temperature and pressure:

$$P_a = 28.96 \frac{\text{g}}{\text{mole}} \div 22.4 \frac{1}{\text{mole}} \times 273.15 \text{K} \div T (\text{K}) \times P (\text{atm}) \quad (\text{A.27})$$

Full scale value: Computed using Equation A.27 with P equal to [10_f] and T equal to [11_f].

Model scale value: Computed using Equation A.27 with P equal to [10_m] and T equal to [11_m].

[13] *Exhaust Density, ρ_s (kg/m³)*

This is the density of the stack effluent.

Full scale value: Computed, treating the effluent as air, using Equation A.27 with P equal to [10_f] and T equal to [7_f].

Model scale value: Computed using the following equation, where ρ_a is [12_m], λ is [40_m]:

$$\rho_s = \rho_a \lambda \quad (\text{A.28})$$

[14] *Air Viscosity, v_a (m²/s)*

This is the viscosity of the ambient air. It is computed using the following equation from Vasserman *et al.* (1966):

$$V = \frac{145.8 T^{3/2}}{\rho (T + 110.4) 10^8} \quad (\text{A.29})$$

Full scale value: Computed using Equation A.29 where T is equal to [11_f] and ρ is equal to [12_f].

Model scale value: Computed using Equation A.29 where T is equal to [11_m] and ρ is equal to [12_m].

[15] *Gas Viscosity, ν_s (m^2/s)*

This is the viscosity of the stack effluent.

Full scale value: Computed using Equation A.29 where T is equal to [7_f] and ρ is equal to [13_f].

Model scale value: Computed based on the composition of the simulant gas mixture, using the following equations by Wilke (1950):

$$\mu_{mix} = \sum_{i=1}^n \left[\frac{X_i \mu_i}{\sum_{j=1}^n X_j \Phi_{ij}} \right] \quad (\text{A.30})$$

$$\Phi_{ij} = \frac{1}{\sqrt{8}} \left(1 + \frac{M_i}{M_j} \right)^{-1/2} \left[1 + \left(\frac{\mu_i}{\mu_j} \right)^{1/2} \left(\frac{M_j}{M_i} \right)^{1/4} \right]^2 \quad (\text{A.31})$$

where n is the number of chemical species in the mixture; X_i and X_j are the mole fractions of species i and j ; μ_i and μ_j are the viscosities of species i and j at 1 atm and ~293K; and M_i and M_j are the corresponding molecular weights. Note that Φ_{ij} is dimensionless, and when $i = j$, $\Phi_{ij} = 1$.

[16] *Free Stream Wind Speed, U_∞ (m/s)*

This is the wind speed found at the top of the atmospheric boundary layer where ground based obstructions have no significant influence on the mean wind speed.

Full scale value: Computed using the power law equation which is as follows:

$$U_{z_1} = U_{z_2} \left(\frac{z_1}{z_2} \right)^n \quad (\text{A.32})$$

Where U_{z_2} is [20_f], z_1 is [17_f], z_2 is [21_f] and n is [31_f].

Model scale value: Computed using Equation A.32 where U_{z_2} is [18_m], z_1 is [17_m], z_2 is [19_m] and n is [32_m].

[17] *Free Stream Height, z_∞ (m)*

This is the height above the grade ($z = 0$) where ground based obstructions have no significant influence on the mean wind speed.

Full scale value: Constant at 600 m (Counihan, 1975).

Model scale value: Computed by dividing z_∞ [17_f] by SF [29_f].

[18] *Reference Wind Speed, U_r (m/s)*

This is the wind speed measured by the instrumentation CPP uses to monitor the wind tunnel speed.

Full scale value: Computed using Equation A.32 where U_{z_2} is [16_f], z_1 is [19_f], z_2 is [17_f] and n is [32_f].

Model scale value: Input.

[19] *Reference Height, z_r (m)*

This is the height above grade where the instrumentation CPP uses to monitor the wind-tunnel speed is mounted in the wind tunnel.

Full scale value: Computed by multiplying z_r [19_m] by SF [29_f].

Model scale value: Input.

[20] *Anemometer Wind Speed, U_a (m/s)*

This is the wind speed which would be measured by the anemometer referenced in the study.

Full scale value: Input.

Model scale value: Computed using Equation A.32 where U_{z_2} is [16_m], z_1 is [21_m], z_2 is [17_m] and n is [31_m].

[21] *Anemometer Height, z_a (m)*

This is the height above grade at which the anemometer referenced in the study is mounted.

Full scale value: Input.

Model scale value: Computed by dividing z_a [21_f] by SF [29_f].

[22] *Site Wind Speed, U_s (m/s)*

This is the wind speed which would be measured by an anemometer located at the site, at the height given by [23_f] relative to the grade ($z = 0$).

Full scale value: Computed using Equation A.32 where U_{z_2} is [16_f], z_1 is [23_f], z_2 is [17_f] and n is [32_f].

Model scale value: Computed using Equation A.32 where U_{z_2} is [16_m], z_1 is [23_m], z_2 is [17_m] and n is [32_m].

[23] *'Site Anemometer' Height, z_s (m)*

This is the height above the grade ($z = 0$) at which a hypothetical anemometer exists at the site. This value differs from [21] only when there is a significant difference in elevation between the anemometer and site locations.

Full scale value: Input.

Model scale value: Computed by dividing z_s [23_f] by SF [29_f].

[24] *Stack Height Speed, U_h (m/s)*

This is the wind speed at the top of the stack.

Full scale value: Computed using Equation A.32 where U_{z_2} is [16_f], z_1 is [3_f], z_2 is [17_f] and n is [32_f].

Model scale value: Computed using Equation A.32 where U_{z_2} is [16_m], z_1 is [3_m], z_2 is [17_m] and n is [32_m].

[25] *Building Height Speed, U_b (Terrain Height Speed, U_t) (m/s)*

This is the wind speed at the top of the dominating building (terrain peak).

Full scale value: Computed using Equation A.32 where U_{z_2} is [16_f], z_1 is [1_f], z_2 is [17_f] and n is [32_f].

Model scale value: Computed using Equation A.32 where U_{z_2} is [16_m], z_1 is [1_m], z_2 is [17_m] and n is [32_m].

[26] *Anemometer Surface Roughness Length, $z_{o,a}$ (m)*

This is the surface roughness length estimated for the area surrounding the anemometer referenced in the study.

Full scale value: Input.

Model scale value: Computed by dividing $z_{o,a}$ [26_f] by SF [29_f].

[27] *Site Surface Roughness Length, $z_{o,s}$ (m)*

This is the surface roughness length estimated for the site and surrounding area.

Full scale value: Input.

Model scale value: Computed by dividing $z_{o,s}$ [27_f] by SF [29_f].

[28] *Surface Friction Velocity, U^* (m/s)*

This is defined as the square root of the surface shear stress divided by the flow density and is determined empirically from the ratio of U^*/U_∞ [45].

Full scale value: Computed by multiplying U^*/U_∞ [45_f] by U_∞ [18_f].

Model scale value: Computed by multiplying U^*/U_∞ [45_m] by U_∞ [18_m].

[29] *Length Scale, SF*

This is the ratio of the full scale to model scale length units. For example, a model scale of 1:300 indicates that 300 m at full scale is represented by 1 m at model scale.

Full scale value: Input.

Model scale value: Constant equal to unity.

[30] *Time Scale, TS*

This is the ratio of the full scale (real world) to model scale (wind-tunnel) time units. Because of the reduced model scale used in the wind tunnel, time based observations (such as video of a looping plume) appear faster than would the same observations made in the real world. For example, in viewing a video of wind-tunnel visualization tests, the observations will appear realistic if the playback speed of the video is slowed down by this factor.

Full scale value: Computed using the following equation:

$$t_f = t_m SF \left(\frac{U_{\infty_m}}{U_{\infty_f}} \right) \quad (\text{A.33})$$

Model scale value: Input.

[31] *Anemometer Power Law Exponent, n_a*

This is the power law exponent based on the surface roughness length estimated for the area surrounding the anemometer referenced in the study, computed using the following equation (Counihan, 1975):

$$n = 0.24 + 0.096 \log_{10} z_o + 0.016 (\log_{10} z_o)^2 \quad (\text{A.34})$$

Full scale value: Computed using Equation A.34 with z_o equal to [26_f].

Model scale value: Equal to n_a [31_f].

[32] *Site Power Law Exponent, n_s*

This is the power law exponent based on the surface roughness length estimated for the site and surrounding area.

Full scale value: Computed using Equation A.34 with z_o equal to [27_f].

Model scale value: Equal to n_s [32_f].

[33] *Velocity Ratio, R*

This is the ratio of the stack exit velocity to the reference wind speed.

Full scale value: Computed by dividing V_e [6_f] by U_r [18_f].

Model scale value: Computed using the following equation:

$$R = \left[\frac{M_o}{\lambda \left(\frac{d}{h} \right)^2} \right]^{1/2} \quad (\text{A.35})$$

where M_o is [37_m], λ is [40_m], d is [4_m] and h is [3_m].

[34] *Stack Velocity Ratio, R_s*

This is the ratio of the stack exit velocity to the wind speed at the top of the stack.

Full scale value: Computed by dividing V_e [6_f] by U_h [24_f].

Model scale value: Computed by dividing V_e [6_m] by U_h [24_m].

[35] *Stack Height to Building Height Ratio, h/H_b*

(Stack Height to Terrain Height Ratio, h/H_t)

This is the ratio of the stack height to the dominating building (terrain peak) height, where both heights are determined relative to the same grade ($z = 0$).

Full scale value: Computed by dividing h [3_f] by H_b (or H_t) [1_f].

Model scale value: Computed by dividing h [3_m] by H_b (or H_t) [1_m].

[36] *Diameter to Stack Height Ratio, d/h*

This is the ratio of the inside stack diameter to the height of the stack above grade.

Full scale value: Computed by dividing d [4_f] by h [3_f].

Model scale value: Computed by dividing d [4_m] by h [3_m].

[37] *Momentum Ratio, M_o*

This factor is computed using the following equation:

$$M_o = \left(\frac{V_e}{U_r} \right)^2 \lambda \left(\frac{d}{h} \right)^2 \quad (\text{A.36})$$

Full scale value: Computed using Equation A.36 where (V_e/U_r) is [33_f], λ is [40_f], d is [4_f] and h is [3_f].

Model scale value: Computed using Equation A.36 where (V_e/U_r) is [33_m], λ is [40_m], d is [4_m] and h is [3_m].

[38] *Froude Number, Fr_s*

This factor is computed using the following equation:

$$Fr_s = \left[\frac{V_e^2}{d g \left(\frac{1}{\lambda} - 1 \right)} \right]^{1/2} \quad (\text{A.37})$$

Full scale value: Computed using Equation A.37 where V_e is $[6_f]$, d is $[4_f]$, g is gravitational acceleration (9.81 m/s^2), and λ is $[40_f]$.

Model scale value: Computed using Equation A.37 where V_e is $[6_m]$, d is $[4_m]$, g is gravitational acceleration (9.81 m/s^2), and λ is $[40_m]$.

[39] *Buoyancy Ratio, B_o*

This factor is computed using the following equation:

$$B_o = \frac{1}{4} \frac{\lambda R^3 d}{Fr_s^2 h} \quad (\text{A.38})$$

Full scale value: Computed using Equation A.38 where λ is $[40_f]$, R is $[33_f]$, d is $[4_f]$, Fr_s is $[38_f]$ and h is $[3_f]$.

Model scale value: Computed using Equation A.38 where λ is $[40_m]$, R is $[33_m]$, d is $[4_m]$, Fr_s is $[38_m]$ and h is $[3_m]$.

[40] *Density Ratio, λ*

This factor is the ratio of the density of the ambient air to the density of the stack effluent.

Full scale value: Computed by dividing ρ_s $[13_f]$ by ρ_a $[12_f]$.

Model scale value: Input based on actual gas mixture used in the wind tunnel.

[41] *Stack Reynolds Number (Exterior), $d U_f/v_a$*

The Reynolds number is given by the following equation:

$$Re = \frac{L U}{\nu} \quad (\text{A.39})$$

Full scale value: Computed using Equation A.39 where L is $[4_f]$, U is $[24_f]$ and ν is $[14_f]$.

Model scale value: Computed using Equation A.39 where L is $[4_m]$, U is $[24_m]$ and ν is $[14_m]$.

[42] *Stack Flow Reynolds (Interior) Number, Re_s*

Full scale value: Computed using Equation A.39 where L is $[4_f]$, U is $[6_f]$ and ν is $[15_f]$.

Model scale value: Computed using Equation A.39 where L is $[4_m]$, U is $[6_m]$ and ν is $[15_m]$.

[43] *Building Reynolds Number, Re_b (Terrain Reynolds Number, Re_t)*

Full scale value: Computed using Equation A.39 where L is [1_f], U is [25_f] and ν is [14_f].

Model scale value: Computed using Equation A.39 where L is [1_m], U is [25_m] and ν is [14_m].

[44] *Surface Reynolds Number, $z_{o,s} U^*/\nu_a$*

Full scale value: Computed using Equation A.39 where L is [27_f], U is found as the product of U^*/U_∞ [45_f] and U_∞ [16_f], and ν is [14_f].

Model scale value: Computed using Equation A.39 where L is [27_m], U is found as the product of U^*/U_∞ [45_m] and [16_m], U_∞ and ν is [14_m].

[45] *Site Friction Velocity Ratio, U^*/U_∞*

This factor is computed using the following equation:

$$\frac{U^*}{U_\infty} = \sqrt{0.00275 + 0.0006 \log(z_o)} \quad (\text{A.40})$$

Full scale value: Computed using Equation A.40 where z_o is equal to [27_f].

Model scale value: Set equal to U^*/U_∞ [45_f].

For Atmospheric Dispersion Comparability (ADC) tests, the following distinctions apply to the definitions given above:

- H_b (or H_t) [1] is not applicable since ADC tests are conducted in the absence of buildings, elevated terrain, or other obstructions;
- h [3], the height of the ADC stack, is usually chosen to be an even increment of 50 m (i.e., 50, 100, 150, 200 m...);
- d [4] is chosen by first computing $0.05h$ or $0.025h$ (whichever stack to diameter ratio will be more representative of the stack being evaluated in the study). Using the procedure previously described for d [4_m], an actual size of tubing is selected for the model. The equivalent full scale diameter which is exactly equal to the actual model diameter (tubing size) is then input as d [4_f];
- V_e [6] is set equal to $1.5 U_h$, where U_h is given by [24_f];
- T_s [7] is set equal to T_a , where T_a is [11];
- V [8] is computed from d [4] and V_e [6] using Equations A.24 and A.25;
- m [9] is set equal to unity; and
- $z_{o,s}$ [27] is set equal to 0.1 m for a “rural” ADC test, and 1 m for an “urban” ADC test.

For Reynolds number independence tests, the following distinctions apply to the definitions given above:

- according to the EPA guideline (1985), h [3] should be set equal to H_b (or H_i) [1];
- V_e [6] is set equal to $1.5 U_h$, where U_h is given by [24_f];
- T_s [7] is set equal to T_a , where T_a is [11];
- V [8] is computed from d [4] and V_e [6] using Equations A.24 and A.25; and
- m [9] is set equal to unity.

A.6. REFERENCES

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TABLES

Table A-AA
Full and Model Scale Similarity Parameters
Rhineland S09 - maximum load (S09 max)

Anemometer Wind Speed =7.9 m/s

	Full Scale	Model Scale
<i>Dimensional Parameters</i>		
1 . Typical Building Height, H _b (m)	38.11	0.16
2 . Grade Elevation Above Mean Sea Level, z=0 (m)	475.49	1,524.00
3 . Stack Height above grade, h (m)	63.09	0.26
4 . Stack Inside Diameter, d (m)	2.13	8.873E-03
5 . Stack Inside Area, A _e (m ²)	3.56	6.183E-05
6 . Exit Velocity, V _e (m/s)	13.25	3.78
7 . Exit Temperature, T _s (K)	430.37	293.15
8 . Volume Flow Rate, V (m ³ /s)	47.23	2.335E-04
9 . Exhaust rate, Q (kg/s)	#N/A	#N/A
10 . Ambient Pressure, P _a (hPa)	956.93	844.00
11 . Ambient Temperature, T _a (K)	279.09	293.15
12 . Air Density, ρ _a (kg/m ³)	1.19	1.00
13 . Exhaust Density, ρ _s (kg/m ³)	0.77	0.65
14 . Air Viscosity, ν _a (m ² /s)	1.46E-05	1.81E-05
15 . Gas Viscosity, ν _s (m ² /s)	3.11E-05	1.77E-05
16 . Free Stream Wind Speed, U _{inf} (m/s)	17.06	4.86
17 . Free Stream Height, z _{inf} (m)	600.00	2.50
18 . Reference Wind Speed, U _{ref} (m/s)	14.05	4.00
19 . Reference Height, z _{ref} (m)	240.00	1.00
20 . Anemometer Wind Speed, U _a (m/s)	7.90	2.25
21 . Anemometer Height, z _a (m)	10.00	0.04
22 . Site Wind Speed, U _s (m/s)	7.17	2.04
23 . Site Anemometer' Height, z _s (m)	10.00	0.04
24 . Stack Height Speed, U _h (m/s)	10.59	3.02
25 . Building Height Speed, U _b (m/s)	9.52	2.71
26 . Anemometer Surface Roughness Length, z _{o, a} (m)	0.25	1.04E-03
27 . Site Surface Roughness Length, z _{o, s} (m)	0.49	2.04E-03
28 . Site Surface Friction Velocity, U* (m/s)	0.86	0.25
<i>Dimensionless Parameters</i>		
29 . Length Scale, SF	240.00	1.00
30 . Time Scale, TS	68.35	1.00
31 . Anemometer Power Law Exponent, n _a	0.19	0.19
32 . Site Power Law Exponent, n _s	0.21	0.21
33 . Velocity Ratio, R = V _e /U _r	0.94	0.94
34 . Stack Velocity Ratio, R _s = V _e /U _h	1.25	1.25
35 . Stack Height to Building Height Ratio, h/H _b	1.66	1.66
36 . Diameter to Stack Height Ratio, d/h	0.03	0.03
37 . Momentum Ratio, M _o	6.58E-04	6.58E-04
38 . Froude Number, Fr _s	3.94	17.38
39 . Buoyancy Ratio, B _o	2.96E-04	1.52E-05
40 . Density Ratio, λ	0.65	0.65
41 . Stack Reynolds Number (Exterior), d U _h / ν _a	1.54E+06	1,479.87
42 . Stack Flow Reynolds Number (Interior), Re _s = d V _e / ν _s	9.09E+05	1,893.96
43 . Building Reynolds Number, Re _b = H _b U _b / ν _a	2.48E+07	23,803.57
44 . Surface Reynolds Number, z _{o, s} U* / ν _a	2.89E+04	27.72
45 . Site Friction Velocity Ratio, U _s /U _{inf}	0.05	0.05

Table A-AB
Full and Model Scale Similarity Parameters

Rhineland S09 - nominal (S09 nom)

Anemometer Wind Speed =7.9 m/s

	Full Scale	Model Scale
<i>Dimensional Parameters</i>		
1 . Typical Building Height, H _b (m)	38.11	0.16
2 . Grade Elevation Above Mean Sea Level, z=0 (m)	475.49	1,524.00
3 . Stack Height above grade, h (m)	63.09	0.26
4 . Stack Inside Diameter, d (m)	2.13	8.873E-03
5 . Stack Inside Area, A _e (m ²)	3.56	6.183E-05
6 . Exit Velocity, V _e (m/s)	9.60	2.73
7 . Exit Temperature, T _s (K)	422.04	293.15
8 . Volume Flow Rate, V (m ³ /s)	34.21	1.691E-04
9 . Exhaust rate, Q (kg/s)	#N/A	#N/A
10 . Ambient Pressure, P _a (hPa)	956.93	844.00
11 . Ambient Temperature, T _a (K)	279.09	293.15
12 . Air Density, ρ _a (kg/m ³)	1.19	1.00
13 . Exhaust Density, ρ _s (kg/m ³)	0.79	0.66
14 . Air Viscosity, ν _a (m ² /s)	1.46E-05	1.81E-05
15 . Gas Viscosity, ν _s (m ² /s)	3.01E-05	1.53E-05
16 . Free Stream Wind Speed, U _{inf} (m/s)	17.06	4.86
17 . Free Stream Height, z _{inf} (m)	600.00	2.50
18 . Reference Wind Speed, U _{ref} (m/s)	14.05	4.00
19 . Reference Height, z _{ref} (m)	240.00	1.00
20 . Anemometer Wind Speed, U _a (m/s)	7.90	2.25
21 . Anemometer Height, z _a (m)	10.00	0.04
22 . Site Wind Speed, U _s (m/s)	7.17	2.04
23 . Site Anemometer' Height, z _s (m)	10.00	0.04
24 . Stack Height Speed, U _h (m/s)	10.59	3.02
25 . Building Height Speed, U _b (m/s)	9.52	2.71
26 . Anemometer Surface Roughness Length, z _{o, a} (m)	0.25	1.04E-03
27 . Site Surface Roughness Length, z _{o, s} (m)	0.49	2.04E-03
28 . Site Surface Friction Velocity, U* (m/s)	0.86	0.25
<i>Dimensionless Parameters</i>		
29 . Length Scale, SF	240.00	1.00
30 . Time Scale, TS	68.35	1.00
31 . Anemometer Power Law Exponent, n _a	0.19	0.19
32 . Site Power Law Exponent, n _s	0.21	0.21
33 . Velocity Ratio, R = V _e /U _r	0.68	0.68
34 . Stack Velocity Ratio, R _s = V _e /U _h	0.91	0.91
35 . Stack Height to Building Height Ratio, h/H _b	1.66	1.66
36 . Diameter to Stack Height Ratio, d/h	0.03	0.03
37 . Momentum Ratio, M _o	3.52E-04	3.52E-04
38 . Froude Number, Fr _s	2.93	12.95
39 . Buoyancy Ratio, B _o	2.07E-04	1.06E-05
40 . Density Ratio, λ	0.66	0.66
41 . Stack Reynolds Number (Exterior), d U _h / ν _a	1.54E+06	1,479.87
42 . Stack Flow Reynolds Number (Interior), Re _s = d V _e / ν _s	6.80E+05	1581.545091
43 . Building Reynolds Number, Re _b = H _b U _b / ν _a	2.48E+07	23,803.57
44 . Surface Reynolds Number, z _{o, s} U* / ν _a	2.89E+04	27.72
45 . Site Friction Velocity Ratio, U _s /U _{inf}	0.05	0.05

Table A-AC
Full and Model Scale Similarity Parameters

Rhineland S09 - minimum load (S09 min)

Anemometer Wind Speed =7.9 m/s

	Full Scale	Model Scale
<i>Dimensional Parameters</i>		
1 . Typical Building Height, H _b (m)	38.11	0.16
2 . Grade Elevation Above Mean Sea Level, z=0 (m)	475.49	1,524.00
3 . Stack Height above grade, h (m)	63.09	0.26
4 . Stack Inside Diameter, d (m)	2.13	8.873E-03
5 . Stack Inside Area, A _e (m ²)	3.56	6.183E-05
6 . Exit Velocity, V _e (m/s)	7.44	2.12
7 . Exit Temperature, T _s (K)	422.04	293.15
8 . Volume Flow Rate, V (m ³ /s)	26.50	1.310E-04
9 . Exhaust rate, Q (kg/s)	#N/A	#N/A
10 . Ambient Pressure, P _a (hPa)	956.93	844.00
11 . Ambient Temperature, T _a (K)	279.09	293.15
12 . Air Density, ρ _a (kg/m ³)	1.19	1.00
13 . Exhaust Density, ρ _s (kg/m ³)	0.79	0.66
14 . Air Viscosity, ν _a (m ² /s)	1.46E-05	1.81E-05
15 . Gas Viscosity, ν _s (m ² /s)	3.01E-05	1.53E-05
16 . Free Stream Wind Speed, U _{inf} (m/s)	17.06	4.86
17 . Free Stream Height, z _{inf} (m)	600.00	2.50
18 . Reference Wind Speed, U _{ref} (m/s)	14.05	4.00
19 . Reference Height, z _{ref} (m)	240.00	1.00
20 . Anemometer Wind Speed, U _a (m/s)	7.90	2.25
21 . Anemometer Height, z _a (m)	10.00	0.04
22 . Site Wind Speed, U _s (m/s)	7.17	2.04
23 . Site Anemometer' Height, z _s (m)	10.00	0.04
24 . Stack Height Speed, U _h (m/s)	10.59	3.02
25 . Building Height Speed, U _b (m/s)	9.52	2.71
26 . Anemometer Surface Roughness Length, z _{o, a} (m)	0.25	1.04E-03
27 . Site Surface Roughness Length, z _{o, s} (m)	0.49	2.04E-03
28 . Site Surface Friction Velocity, U* (m/s)	0.86	0.25
<i>Dimensionless Parameters</i>		
29 . Length Scale, SF	240.00	1.00
30 . Time Scale, TS	68.35	1.00
31 . Anemometer Power Law Exponent, n _a	0.19	0.19
32 . Site Power Law Exponent, n _s	0.21	0.21
33 . Velocity Ratio, R = V _e /U _r	0.53	0.53
34 . Stack Velocity Ratio, R _s = V _e /U _h	0.70	0.70
35 . Stack Height to Building Height Ratio, h/H _b	1.66	1.66
36 . Diameter to Stack Height Ratio, d/h	0.03	0.03
37 . Momentum Ratio, M _o	2.11E-04	2.11E-04
38 . Froude Number, Fr _s	2.27	10.03
39 . Buoyancy Ratio, B _o	1.60E-04	8.23E-06
40 . Density Ratio, λ	0.66	0.66
41 . Stack Reynolds Number (Exterior), d U _h / ν _a	1.54E+06	1,479.87
42 . Stack Flow Reynolds Number (Interior), Re _s = d V _e / ν _s	5.27E+05	1,225.04
43 . Building Reynolds Number, Re _b = H _b U _b / ν _a	2.48E+07	23,803.57
44 . Surface Reynolds Number, z _{o, s} U* / ν _a	2.89E+04	27.72
45 . Site Friction Velocity Ratio, U _s /U _{inf}	0.05	0.05

**APPENDIX
B
DATA COLLECTION**

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B.1. DATA COLLECTION TECHNIQUES

B.1.1 CONCENTRATION MEASUREMENTS

B.1.1.1 Data Collection Procedure

After the desired atmospheric condition has been established in the wind tunnel, a mixture of inert gas and a tracer (ethane, methane and/or propane) of predetermined concentration is released from an emission source at the required rate to simulate the prototype plume rise. The flow rate of the gas mixture is controlled and monitored by a precision mass flow controller. The concentration of the tracer gas at each sampling point is analyzed using a high frequency flame ionization detector (HFFID).

Using the HFFID allows for real-time concentrations measurements to be obtained. This allows the operator to get immediate feed-back on the concentration levels at the receptor. With this information the operator can search for the meteorological condition (wind speed and wind direction) which results in the highest concentration from a single source at a single receptor. To conduct the search for the worse case meteorological condition, the operator collects 30 second samples at various wind directions for a single wind speed to determine the worse case wind direction. For each 30 second sample, the full scale concentration at the sampling point is calculated from the average voltage output from the HFFID using the procedure described below. Once the wind direction has been identified, the operator collects 30 second samples at various simulated wind speeds to determine the worse case wind speed. If the resulting worse case wind speed differs from the wind speed used to define the worst case wind direction, an additional search is conducted at the worse case wind speed to confirm the worst case wind direction. Once the worst case meteorological condition has been identified, an additional 220 second sample is collected for this simulated condition.

B.1.1.2 Calculation of Full-scale Normalized Concentrations

Measured model concentrations are converted to full-scale normalized concentrations by equating the non-dimensional concentration, $K = CUL^2/m$, in both model and full scale, as noted

in the following equation presented in the Guideline for Use of Fluid Modeling of Atmospheric Diffusion (EPA 1981):

$$\left(\frac{C}{m}\right)_f = \left(\frac{CU_r}{C_oV}\right)_m \left(\frac{1}{U_r}\right)_f \left(\frac{L_m}{L_f}\right)^2 \times 10^6 \quad (\text{B.1})$$

where

$$C_m = \left[\left(\frac{E_{meas} - E_o}{E_{cal}} \right)_{rec} - \left(\frac{E_{meas} - E_o}{E_{cal}} \right)_{bg} \right] \times C_{cal} \quad (\text{B.2})$$

- C_f = full scale concentration of pollutant ($\mu\text{g}/\text{m}^3$);
- C_m = model scale concentration of tracer gas (ppm);
- C_{cal} = calibration gas concentration (ppm);
- C_o = tracer gas concentration at source (ppm);
- E_{meas} = voltage reading from HFFID for measured sample (V);
- E_o = zero offset voltage reading from HFFID (V);
- E_{cal} = voltage reading from HFFID for calibration gas sample (V);
- L = length scale (m);
- m = chemical mass emission rate (g/s);
- U_r = reference wind speed (m/s);
- V_m = model volume flow rate (m^3/s);
- 10^6 = conversion from g to μg ; and

the subscripts *rec* and *bg* denote measurements at the receptor and background, respectively.

The 220 second sample, discussed in Section B.1.1.1 is representative of a steady-state average. In the full scale, a steady-state average concentration corresponds to a 15 minute to 1 hour average concentration due to the natural fluctuations in both wind speed and wind direction present within the atmosphere.

Full scale concentration estimates for averaging times less than 24 hours can be obtained using the following power law relationship defined by Turner (1974):

$$\left(\frac{C}{m}\right)_s = \left(\frac{C}{m}\right)_k \times \left(\frac{t_k}{t_s}\right)^p \quad (\text{B.3})$$

where:

- $(C/m)_s$ = normalized concentration estimate for averaging time t_s ;
 $(C/m)_k$ = normalized concentration estimate for averaging time t_k ; and
 p = power law exponent between 0.17 and 0.20.

B.1.1.3 Error Analysis

The full-scale concentration results have certain experimental errors associated with them. To estimate the experimental error, referred to as uncertainty interval, the technique outlined by Kline and McClintock (1953) is used, which results in the following error equation:

$$\left(\frac{\Delta C}{C}\right)_f = \left[\left(\frac{\Delta C}{C}\right)_m^2 + \left(\frac{\Delta C_{cal}}{C_{cal}}\right)_m^2 + \left(\frac{\Delta C_o}{C_o}\right)_m^2 + \left(\frac{\Delta L}{L}\right)_m^2 + \left(\frac{\Delta U_r}{U_r}\right)_m^2 + \left(\frac{\Delta V}{V}\right)_m^2 \right]^{1/2} \quad (\text{B.4})$$

where

- $(\Delta C/C)_m$ = uncertainty in measured concentration,
 ± 0.15 for low concentrations, and
 ± 0.05 for high concentrations;
 $(\Delta C_{cal}/C_{cal})_m$ = uncertainty in calibration gas concentration, ± 0.02 ;
 $(\Delta C_o/C_o)_m$ = uncertainty in initial tracer gas concentration, ± 0.02 ;
 $(\Delta L/L)_m$ = uncertainty in length scale reduction, ± 0.01 ;
 $(\Delta U_r/U_r)_m$ = uncertainty in reference wind speed, ± 0.05 , and
 $(\Delta V/V)_m$ = uncertainty in volume flow setting, ± 0.02 .

Substituting the above uncertainty estimates into Equation B.4 gives the following uncertainty for the full-scale concentrations:

$$\begin{aligned} (\Delta C/C)_f &= \pm 0.16 \text{ for low concentrations } (C_f < 100 \mu\text{g}/\text{m}^3), \\ &= \pm 0.08 \text{ for high concentrations } (C_f > 100 \mu\text{g}/\text{m}^3). \end{aligned}$$

B.1.1.4 Quality Control

To ensure that the data collected is accurate and reliable, certain quality control steps are taken. To summarize, these include:

- multi point calibration of hydrocarbon analyzer using certified standard gases;

- calibration of flow measuring devices with a soap bubble meter;
- adjustment of tunnel roof so that blockage effects (i.e., reduction of cross-sectional area) are less than 5 percent; and
- periodical testing of the linearity of the voltage response of the HFFID.

B.1.2 VELOCITY MEASUREMENTS

Split-film (dual hot-film sensor) and hot-film or hot-wire (single sensor) probes are used to measure velocities. The dual sensor probe is used to measure mean velocity (U), longitudinal turbulence intensity (U'), vertical turbulence intensity (W') and surface friction velocity (U^*) while the single sensor probe was used to measure U and U' . The theory of operation for split-film and hot-film sensors is based on the physical principle that heat transferred from a sensor equals heat supplied to that sensor by an anemometer. This physical principle can be represented by the following equations.

For the hot-film sensor:

$$\frac{E_1^2}{K_1} = A + BU^c \quad (\text{B.5})$$

and for the split-film sensor:

$$\left(\frac{E_1^2}{K_1} \right) + \left(\frac{E_2^2}{K_2} \right) = [A + B(U_n)^c] \quad (\text{B.6})$$

and

$$\left(\frac{E_1^2}{K_1} \right) - \left(\frac{E_2^2}{K_1} \right) = (a + bU_n)(\theta_o - \theta) + c \quad (\text{B.7})$$

where

E_i	=	output voltage from a sensor;
K_i	=	$R_{Hot, i} (R_{Hot, i} - R_{Cold, i})$;
U, U_n	=	the velocity sensed;
A, B, C, a, b, c	=	constants determined by calibration;
R_{Cold}	=	Resistance across hot film with baseline voltage applied;
θ	=	angle formed by plane of sensor splits and the velocity vector;
θ_o	=	change in θ ;

$$R_{Hot} = \text{resistance across hot film with overheat ratio applied} \left(\frac{R_{Hot}}{R_{Cold}} = 1.5 \right).$$

Sensor calibrations are accomplished immediately prior to each velocity measurement activity. For low flow calibrations (<1.5 m/s) the sensor is placed within a Thermo-Systems, Inc. calibration nozzle and a Hastings Mass Flow meter is used to provide a metered air flow through the calibrator. High flow calibrations (> 1.5 m/s) are accomplished by placing the sensor adjacent to a pitot-static tube mounted in the wind tunnel. The constants A , and C (or A , B , C , a , b , c and θ_o) are obtained by calibrating the sensors over a range of known velocities (or velocities and angles) and determined by a least squares analysis utilizing the appropriate previously referenced equations. A representative calibration curve of sensor output voltage versus sensed velocity is included as Figure B.1.

A hot-film probe (TSI Model No. 121020) is used to obtain one-dimensional measurements of mean (U) and fluctuating (U') wind speed (i.e., turbulence). A split-film probe (TSI Model No. 1287) is used to obtain the two-dimensional measurements of mean (U and W or V) and fluctuating (U' and W' or V') wind speed. Lateral and vertical profiles of mean velocity and turbulence are obtained by affixing the probe to a traversing carriage which relates height (z) or lateral position (y) to voltage output. All data are obtained by sampling the probe output at sample rates ranging from 30 Hz to 400 Hz depending upon the approach wind speed. The data is then reduced by the computer in real-time and stored in files for later analysis.

B.1.3 VOLUME FLOW MEASUREMENTS

The volume flow rate of tracer gas from the model stack is an important variable in any wind-tunnel study of atmospheric dispersion. Various volume flow rates are calculated prior to testing to simulate multiple wind speeds or source flow rates. Tylan General and/or Porter mass flow controllers are calibrated using a Gillian Air Flow Calibrator to determine the settings necessary to obtain the calculated volume flows at stack exit. The gases used for the calibration are the same as those used in the study tests. Figure B.2 contains a typical mass flow controller calibration.

B.1.4 COLLECTION SOFTWARE PROGRAM SPECIFICATION AND PROCEDURES

B.1.4.1 Introduction

The collection of tracer gas concentrations and the subsequent calculation of full scale concentrations is accomplished through an in-house developed software program. The program

specification for this software collection program (vbDIFCOLLECT) is described below. The primary features of the program are:

- recording of data and settings into output files;
- output in the form of full scale C/m and voltages;
- determination of mean and standard deviation C/m values for each wind condition;
- prompting of the operator when collection is completed;
- monitoring of wind tunnel speed;
- well-defined zero and calibration stages;
- over-voltage detection;
- background concentrations recorded during data collection; and
- input of flow calibrations to determine mass flow meter settings.

B.1.4.2 Program Logic

The program starts with a main screen, Figure B.3. Note the grayed-out Option buttons on the left. These program features cannot be accessed until all program settings are entered and reviewed, as shown in Figure B.4, the settings screen. Each Option accesses the input screens for the appropriate data set. All settings are updated as changes are made. When all settings are input and reviewed, the user is returned to the main screen, where the remaining buttons in the top half of the Options menu are now active. The Zero, Check Cal, and Set Velocity options are used according to the Quality Control (QC) schedule defined in the Settings screen.

When all of the settings have been input and validated, the user proceeds to the Define Run Parameters screen, Figure B.5a. Within each run, many wind conditions can be evaluated for a given stack/receptor combination. These conditions are input at the Define Trial screen, Figure B.5b. Figure B.6 shows the Sampling Concentrations screen, which displays the full scale C/m values during data collection, as well as the current Run Definition and the conditions for the current maximum C/m value. The tunnel speed is monitored during each trial. After a wind condition is tested (i.e., a trial is collected), the operator can either collect more data (i.e., more trials) or finalize the run by taking a longer steady-state average of the worst case. The Main screen, containing the current results for the active run, is displayed after each trial is collected, as shown in Figure B.7. After the long average has been collected, the results are saved to an output file using the End + Save button. The program then returns to the Main screen, with the top buttons in the main menu active.

When the run is over, a new run can be started with the old calibration, or a new calibration can be taken. The tunnel speed can be set again if needed.

B.1.4.3 Mean C/m and Standard Deviation Calculations

The goal of a run is to find the full scale maximum normalized concentration C/m for a given stack/receptor combination, where C is concentration in $\mu\text{g}/\text{m}^3$ and m is the mass emission rate in g/sec . Concentrations are calculated point by point from the measured voltage output from the HFFID using the equations defined in Section B.1.1. Mean concentrations are calculated as the average calculated concentration over a specified averaging window. The standard deviation of the measured normalized concentration values are computed by computing C_{sd} from the standard deviation of the measured voltages, where:

$$C_{\text{sd}} = C_{\text{cal}} \frac{V_{\text{sd}}}{V_{\text{cal}}} \quad (\text{B.8})$$

where

$$V_{\text{sd}} = \sqrt{\frac{\sum_{i=1}^N (V_i - V_{\text{mean}})^2}{N}} \quad (\text{B.9})$$

[Note that this equation is the longer but computationally more accurate form of the standard deviation calculation which requires a separate pass through the data after the mean is computed. This is the prescribed manner standard deviations are computed at CPP.]

The full scale value for the concentration standard deviation is calculated by substituting the value for C_{sd} for C_m in Equation B.1. The standard deviation calculation assumes that the background concentration has a zero standard deviation value.

B.1.4.4 Calculations for Averaging and Windowing

Averages for the HFFID readings during an actual run are typically 30 seconds while searching for the worst wind condition, and 220 seconds for the final average. However, an updated value is reported every 3 to 5 seconds. The reported value on the screen applies to a window extending for the last 30 or 220 seconds. Voltages recorded before the window are discarded.

The following example of this averaging window procedure assumes a 30-second window and a 3-second reporting interval. The 30-second window can be viewed as having ten 3-second blocks. Previous blocks of 3 seconds are discarded, and a new block of 3 seconds is recorded

while the most recent result is displayed. When computing 30-second averages, all data for the 30 seconds could be made available to compute mean and standard deviation, but this is computationally intensive. Instead, subsequent values of the mean and standard deviation can be calculated by saving the means and the sums of squares from each 3-second block. The mean of the window is:

$$V_{\text{mean,window}} = \frac{1}{\# \text{blocks}} \times (V_{\text{mean},1} + V_{\text{mean},2} + \dots) \quad (\text{B.10})$$

where the individual block means are means of voltages with the zeros subtracted. The standard deviation of the window is:

$$V_{\text{sd,window}} = \sqrt{\frac{1}{\# \text{blocks} \times N} \times \left(\sum_{\text{block1}}^N V_i^2 + \sum_{\text{block2}}^N V_i^2 + \dots \right) - (V_{\text{mean,window}})^2} \quad (\text{B.11})$$

where $\sum_{\text{block}}^N V_i^2$ is the sum of squares for each 3 second block, and N is the number of readings in a 3-second block. The sum of squares for each block can be computed from the standard deviation of each block from:

$$\sum_{\text{block}}^N V_i^2 = N(V_{\text{sd}}^2 + V_{\text{mean}}^2) \quad (\text{B.12})$$

where V_{mean} is the mean of each block with the zero removed. This method is based on the "short form" of computing standard deviation, which is mathematically similar to but computationally different from the standard deviation calculation for the calibration voltage. [Note that the standard deviation for a window is not the simple mean of standard deviations of the blocks.]

B.1.4.5 Tunnel Speed Computations with the Pitot-static Tube

Tunnel wind speed $U_{m,\text{ref}}$ is computed from the pitot-static tube dynamic pressure, Δp , as follows:

$$\Delta p = \frac{1}{2} \rho_{\text{atmos}} U_{m,\text{ref}}^2 \quad (\text{B.13})$$

Δp = pitot-static tube dynamic pressure; i.e., [total pressure – static pressure] (Pa);

ρ_{atmos} = atmospheric density (kg/m³); and

$U_{n,\text{ref}}$ = mean wind speed (m/s).

A calibration constant is needed for computation of Δp from voltages. The calibration factor is presented in units of psi/volt, which is not SI but is compatible with other programs. The pitot dynamic pressure is computed from:

$$\Delta p [V_{pitot} - V_{pitot,zero}] \times Calfactor \times 6897.4 \quad (B.14)$$

where

Δp	=	pitot static tube total pressure-static pressure (Pa);
V_{pitot}	=	voltage out from pressure transducer connected to the pitot tube (volt);
$V_{pitot, zero}$	=	voltage obtained with no input to the pressure transducer (volt);
$Calfactor$	=	calibration factor to relate pressure transducer output to pressure (lbf/in ²)/ volt; and
6894.7	=	factor to convert (lbf/in ²) to Pa.

Density is computed from barometric pressure, ρ_{atmos} , and tunnel air temperature with the ideal gas law:

$$\rho_{atmos} (kg/m^3) = \frac{\rho_{atmos} (in.Hg) \times 3377}{RT} \quad (B.15)$$

ρ_{atmos}	=	atmospheric density (kg/m ³) (inches Hg);
3377	=	factor to inches Hg to Pa.
R	=	ideal gas constant for air,
	=	287 (Pa) / [(Kg/m ³) x K];

On the user screen, 5-second, 1-minute, and 3-minute averages are displayed. Five second means can be computed from the voltage data with Equation B.10. In principle, the U should be computed from the square root of Δp with each voltage point before averaging, but for small variations in tunnel speed, averaging Δp first is acceptable and is done in this program. The 1-minute average is computed from the simple average of the last twelve 5-second averages. Similarly, the 3-minute average is the average of the last three 1-minute averages. Standard deviations of the wind tunnel speed are not computed.

B.1.4.6 Flow Meter Calibration Data and Curve Fits

Flow meter settings are calculated as follows:

$$Setting = A \times V^B \quad (B.16)$$

where *Setting* is the flow metering device setting, and *A* and *B* are fit parameters, assuming volume flow rate *V* is in ml/s.

B.1.4.7 Input and Output Files

There are four input files required to run vbDIFCOLLECT and three output files are created. The four input files are ppppPROJ.INP, ppppFLOW.INP, ppppFCAL.INP and ppppVSET.INP, where pppp is the four-digit project number. The PROJ.INP file is shown in Figure B.8 and consists of basic project information. The FLOW.INP file, shown in Figure B.9, consists of source flow settings and tunnel speeds for each stack/approach/anemometer-wind-speed combination, as determined by the test plan. The FCAL.INP file, shown in Figure B.10, contains flow calibrations for the flow meters to be used. The VSET.INP file, shown in Figure B.11, stores variable information generated by the user when the program is initialized.

The output files consist of a large file to document all trial information (the trial log), a file containing all of the run definition information, including a time stamp recording the date and time the run was completed (the run log) and a smaller file suitable for reports.

The report-quality output file can either be an SI version or an English version. For the English version, anemometer information and stack heights are converted to English units. The concentrations will remain as *C/m* in $\mu\text{g}/\text{m}^3$ per g/s. The version selection is made in the initial setup menu. An output file with SI (metric) outputs is shown in Figure B.12.

The trial log and run log files are used for “book keeping” so that vbDIFCOLLECT can keep track of what runs have been conducted to date. Along with the run numbers and run letters, the log file also tracks the source and receptor identifications, the tracer concentration of the source exhaust gas, the source gas density ratio, the stack height and other information of interest.

B.1.4.8 Hardware Environment

The program assumes the use of a high frequency flame ionization detector HFFID. Background concentrations are collected on one HFFID channel, while concentrations at various receptor locations are collected on the other channels (currently up to two receptor locations). The background concentrations are measured using the most sensitive settings, while the sensitivity settings for the receptor channels may vary according to the amount of signal available.

Tunnel speed is monitored with a pitot-static tube using an electronic pressure measuring device to measure dynamic pressures. The voltage outputs from the various instruments are input into the computer through use of an Analog to Digital (A/D) conversion card. The A/D channels

used for the HFFID and pressure measurements are listed in from the VSET.INP file. The source gas flow meters operate manually with no electronic monitoring by the program.

B.1.4.9 Quality Assurance

Several subprograms or program units are individually checked with shell programs which provide sample inputs and record outputs. The individual program units checked are:

- the four subroutines reading and checking ranges of the four input files;
- the C/m computation;
- the tunnel speed computation and display;
- flow settings calculations from the flow calibration inputs;
- the HFFID zero; and
- the HFFID calibration.

The integrity of the final compiled version of vbDIFCOLLECT is evaluated using a defined bench test. The bench tests consists of running the program with predefined input files (as shown in Figures B.8 through B.11). Voltage inputs for each A/D channel are set at specified levels to artificially set the measured reference wind speed, the HFFID calibration voltages, and the receptor and background concentration voltages. To pass, the “measured” concentrations must be equivalent to those values calculated independently from the program.

B.2. REFERENCES

- EPA, *Guideline for Use of Fluid Modeling of Atmospheric Diffusion*. U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, North Carolina, EPA-600/8-81-009, April 1981.
- Kline, S.J., and F.A. McClintock, "Describing Uncertainties in Single-Sample Experiments," *Mechanical Engineering*, Vol. 75, January 1953.
- Turner, B.D., "Workbook of Atmospheric Dispersion Estimates," Air Resources Field Office, Environmental Science Services Administration, Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina, No. AP-26, January 1974

FIGURES

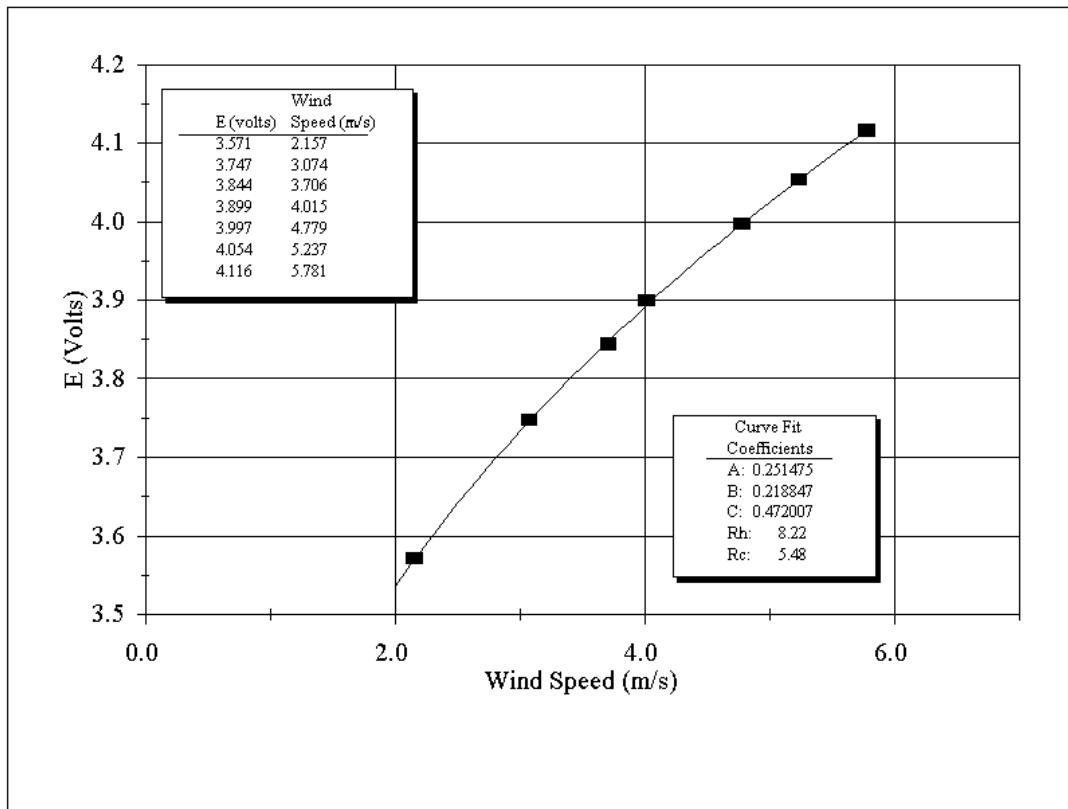


Figure B.1. Sample hot-film calibration curve.

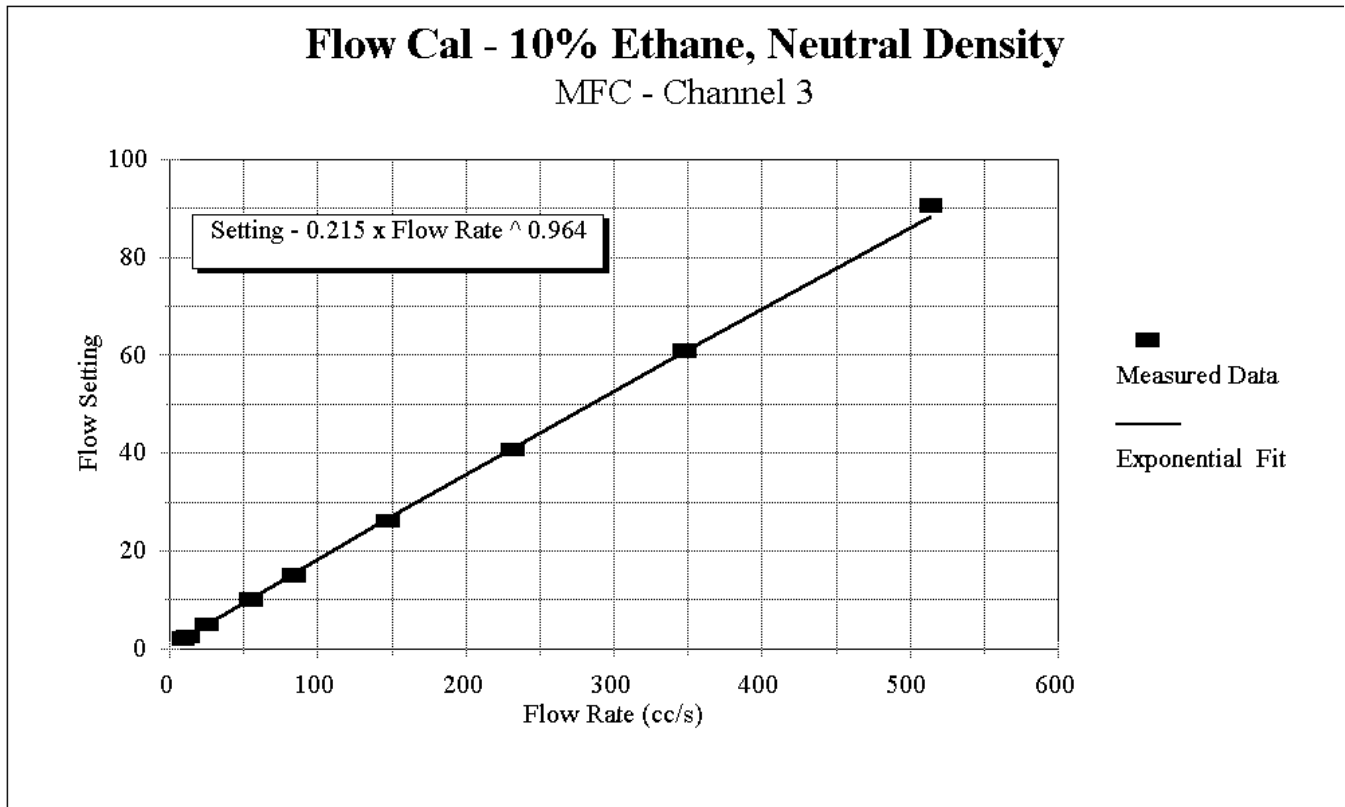


Figure B.2. Sample mass flow controller calibration curve.

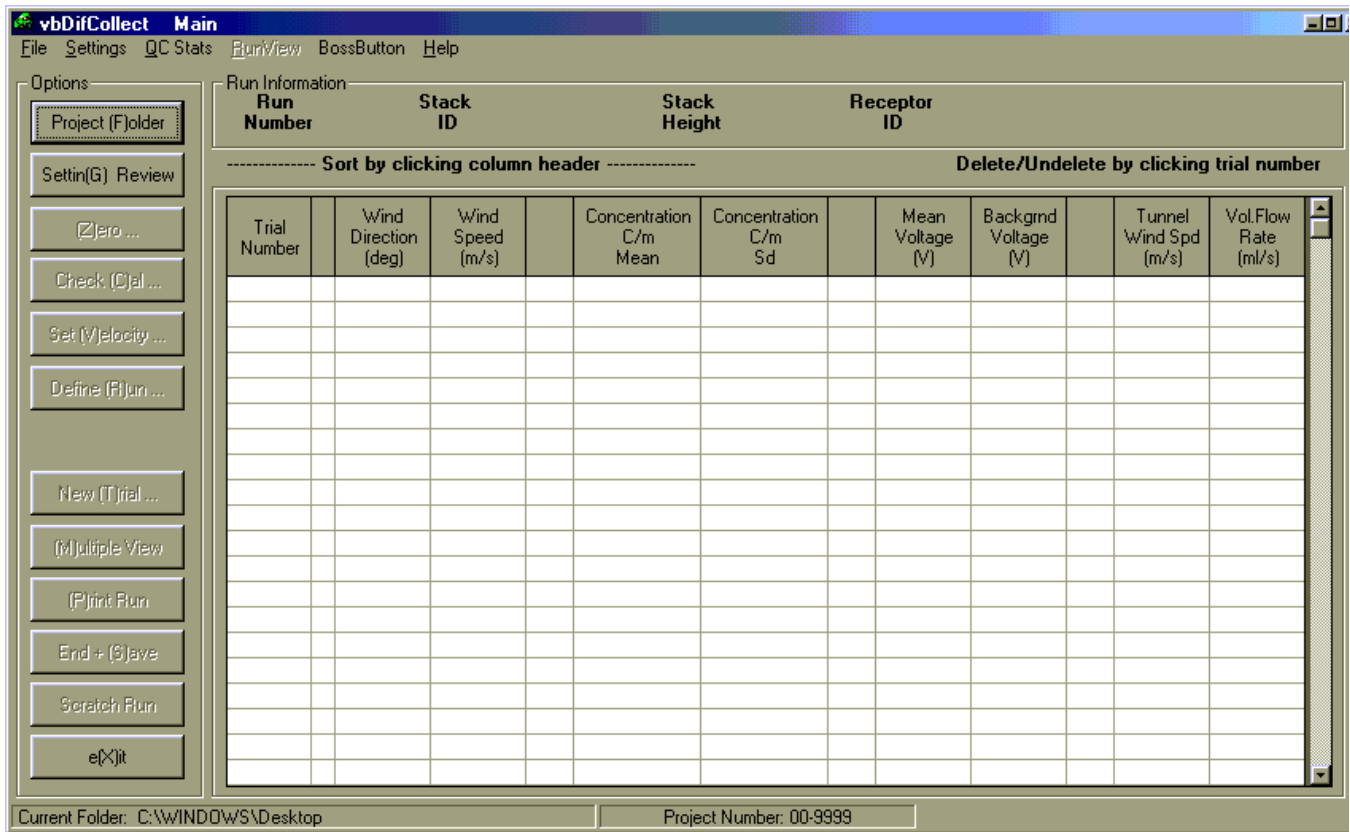


Figure B.3. vbDIFCOLLECT main screen - prior to setup and data collection.

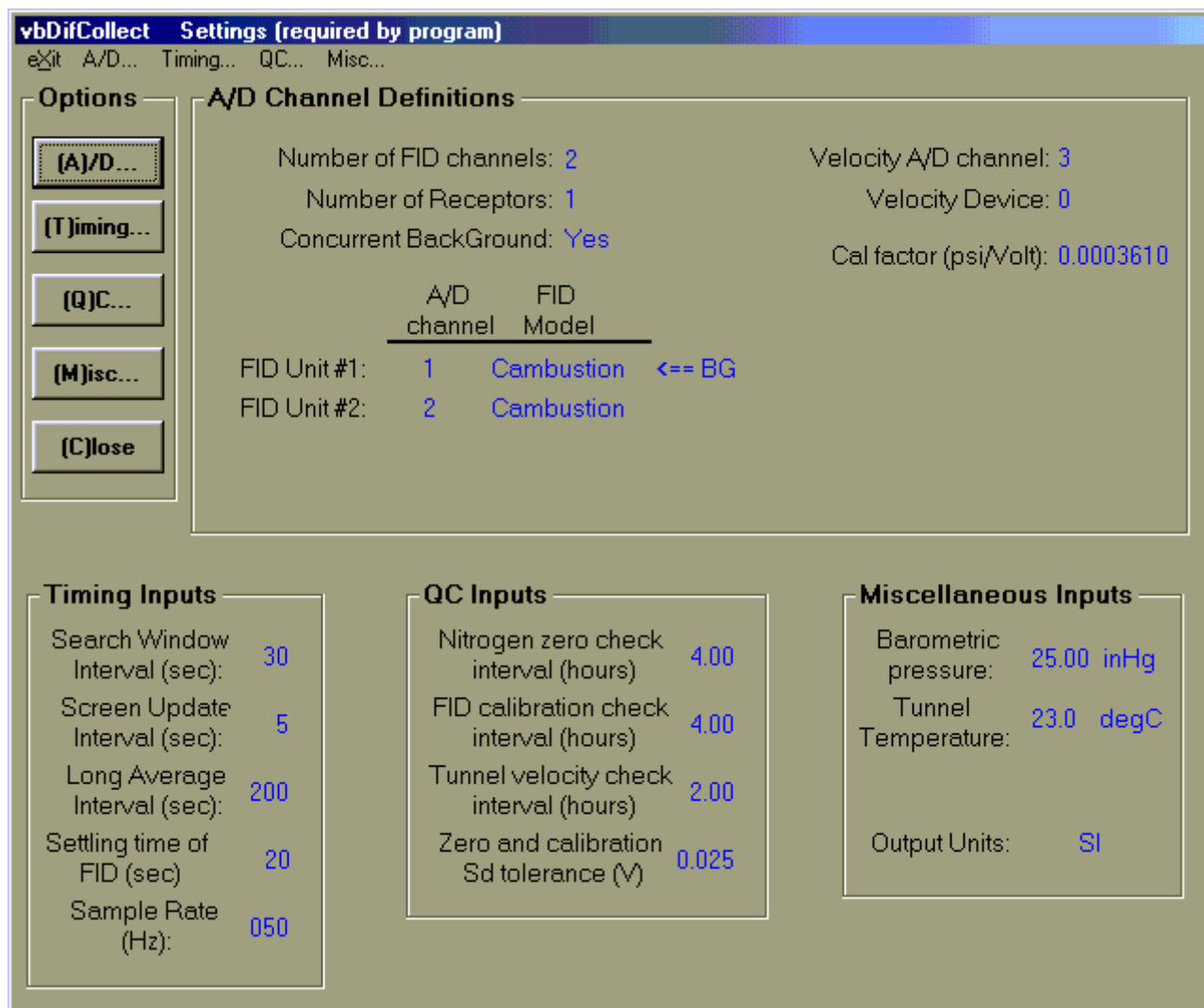


Figure B.4. vbDIFCOLLECT settings screen.

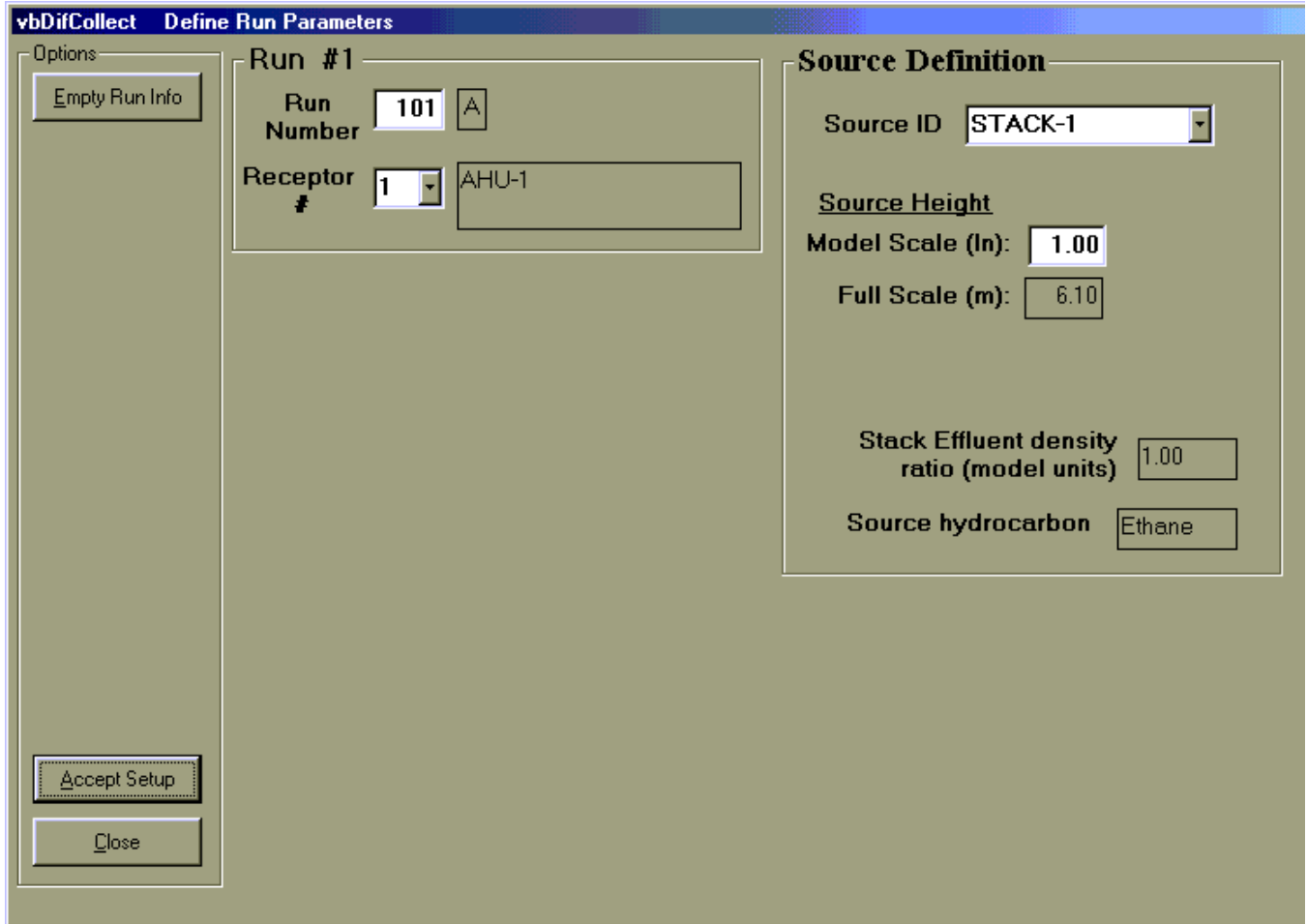


Figure B.5a. vbDIFCOLLECT define run parameters screen.

vbDifCollect Define Trial Parameters

Options

Run Definition

Model	Run	Receptor
FID #1	Cambustion	BkGrnd
FID #2	Cambustion	101A 1-AHU-1

Source ID: STACK-1
 Source: Ethane
 Source Effluent Density Ratio: 1.00
 Model Stack Height (in): 1.00

Trial Definition

Wind Direction (deg): 0
 Approach definition: Land
 Operator initials: EARL
 Anemometer wind speed Full Scale (m/s): 1
 Wind Tunnel Reference Wind Speed (m/s): 4
 Long Average:

Flow Calibration

Tracer gas concentration (%): .1
 Volume Flow Rate (cc/s): 398.1

Tracer Gas		Inert Gas					
Mixture	Device	Gas	#1 Device	Gas	#2 Device	Gas	#3 Device
0.1%PROP, AIR	MFC-6	AIR	TELE				

Device Settings: 32.6 | 180.8

Figure B.5b. vbDIFCOLLECT define trial parameters screen.

vbDifCollect Sampling Concentrations

Options

Accept Results

Clear Averages

Timer: 00:17

Normalized Concentrations - Short Sample

Run #	Receptor ID	Mean ($\mu\text{g}/\text{m}^3$ per g/s)	Sd ($\mu\text{g}/\text{m}^3$ per g/s)	Mean (Volts)	% bad
101A	1-AHU-1	2,930.1	356.1	0.76	0

Previous Max.

Run #	Wind Direction (Deg)	Wind Speed (m/s)	C/m Mean	C/m Sd

Run Definition

Source ID: STACK-1 WD (deg): 0

WS (m/s): 1.00 Vol FloRate (cc/s): 398.1

Tunnel Spd (m/s): 4.04 Bkgnd (V): 0.83

Reject Trial

Figure B.6. vbDIFCOLLECT concentration sampling screen.

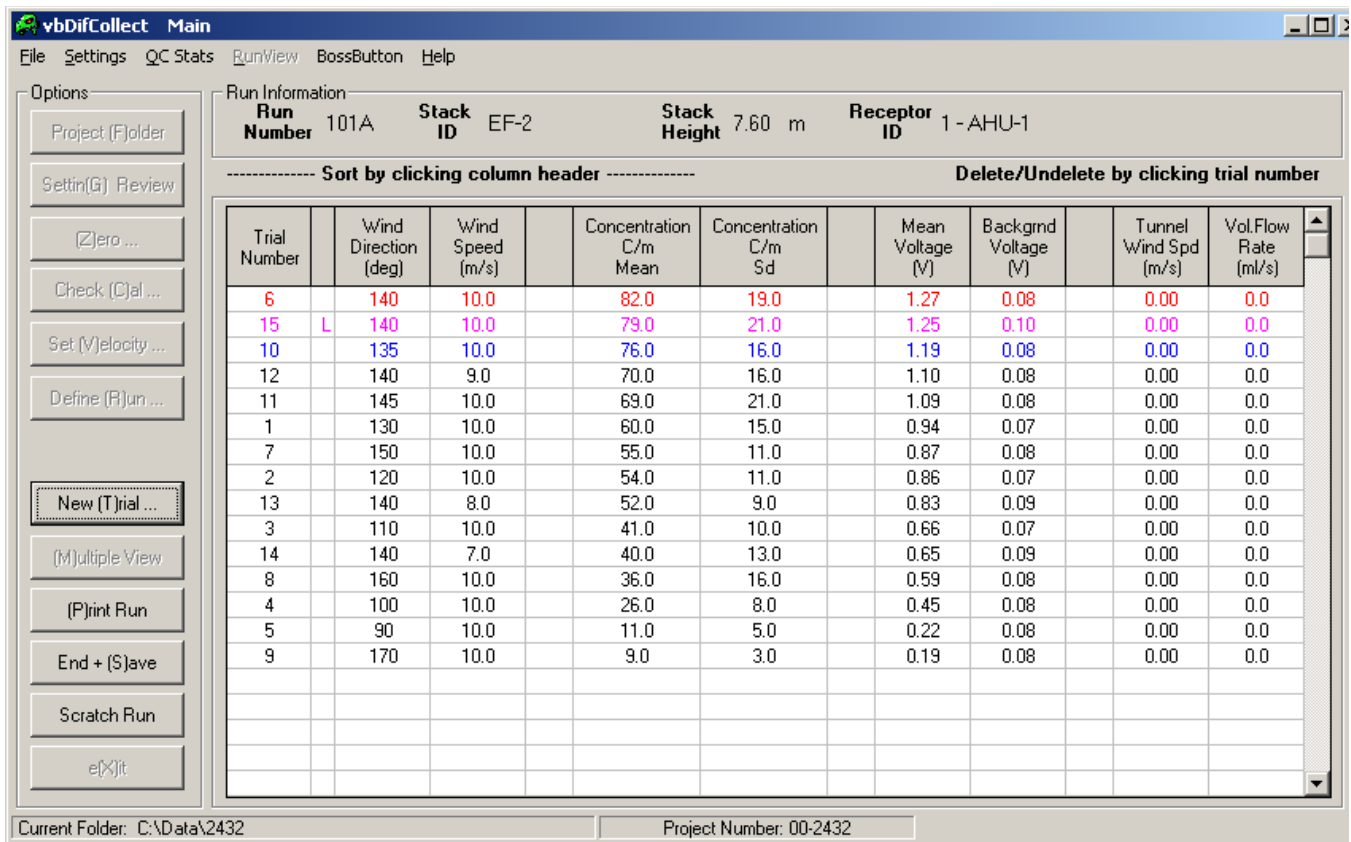


Figure B.7. vbDIFCOLLECT main screen - after data collection.


```

* Vent program project information file: 9999PROJ.INP          *
*
*
* Project   Project Title
* Year ##### (as desired to appear on outputs, in ", 65 char max)
*   -----1-----2-----3-----4-----5-----6-----+
* 03 9999 "vbDIFCOLLECT Bench Test"
*
* Approach Info:
*           WD
*   Number   Range
*   of       Label Id (deg)
* Scale  Apprch (9 char max)  Start  End
*-----+-----+-----+-----+-----+-----+-----+
* 240   1   "Land "         0     359
*
* Measurement Location Descriptions
*
*   Recep.
* Recep.  Loc.
* Loc.    Description
* Number  (30 char max; in double quotes)
* -----+-----1-----2-----3"
* 1       "AHU-1           "
* 2       "AHU-2           "
* 3       "AHU-3           "
* 4       "AHU-4           "
* 5       "AHU-5           "
* 6       "North Courtyard "
* 7       "North Entrance  "
* 8       "South Courtyard "
* 9       "South Entrance  "
* -1
*

```

Figure B.8. Sample vbDIFCOLLECT project input file.

```

* Stack Flow Rate vs. Wind Speed Input file: 9999FLOW.INP
* Used with Ventilation Projects using High-frequency FID
*
* Number of stack/flow rate setups
* (one for each stack design with differing flow rates and
* for each approach flow)
* -----
2
*
* Number of Wind Speeds (max 15):
* -----
7
*
* Flow Rates/Tunnel Speed vs. Anemometer & Reference Wind Speeds:
*
* Full Scale (m/s)
* -----
Anemometer Wind Speeds (m/s)      1.00  2.00  3.00  4.00  5.00  7.00 10.00
Reference Wind Speeds (m/s)      1.58  3.17  4.75  6.34  7.92 11.09 15.85
* -----
*
* Stack Label      Approach Label  Dens.  FR - Flow Rates (ml/s)
* "-----+-----1--" "-----+-----"  ---    TV - Tunnel Speeds (m/s)
*
"STACK-1      " "Land      "    1.00  FR 979.68 489.84 326.56 244.92 195.94 139.95 97.97
*                                     TV 4.00   4.00   4.00   4.00   4.00   4.00   4.00
*
"STACK-2      " "Land      "    1.00  FR 90.56  45.28  30.19  22.64  18.11  12.94  9.06
*                                     TV 4.00   4.00   4.00   4.00   4.00   4.00   4.00
*

```

Figure B.9. Sample vbDIFCOLLECT project flow rate input file.

```

* Flow Meter Calibration Data for project, 9999FCAL.INP
*
* Calibration Number 4 and 2
*
* # of Tracer gas Tracer conc Specific wt.
* components "-----" (%) (1 = neutral)
* 2 "Ethane " 10.0 1.00
*
* Component 1 Calibration Information
*
* Gas Calibration
* Label Volume Device Date Operator Standard
* "-----" (%) "-----" "-----" "----" "-----"
* "Ethane " 10.0 "MFC-2 " "04-16-02" "JTG" "Gilibrator"
*
* Power law fit Applicable range of settings
* Setting = A * (Flow rate (cc/s))**B Lower Upper
* A B Setting Setting
* 2.28020 1.00752 3 117
*
* Component 2 Calibration Information
*
* Gas Calibration
* Label Volume Device Date Operator Standard
* "-----" (%) "-----" "-----" "----" "-----"
* "N2 " 90.0 "MFC-1 " "08-28-01" "JWL" "Gilibrator"
*
* Power law fit Applicable range of settings
* Setting = A * (Flow rate (cc/s))**B Lower Upper
* A B Setting Setting
* 0.15771 0.99440 3 117
*

```

Figure B.10. Sample vbDIFCOLLECT flow calibration input file.

```

* vbDIFCOLLECT, Setup file: 9999VSET.INP
*
* Search   Screen   Final   FID
* Window  Update   Average Settling
* Interval Interval Interval time
* (sec)   (sec)   (sec)   (sec)
* -----
*    30.0    5.0    220.0   20.0
*
* Velocity
* Measurement Calibration
* Equipment   Factors
* -----
*    0   'Pitot'  0.0003762  <--  psi/V
*
* Input
* Temperature          Barometric   Sample
* flag                Tunnel          Pressure   Rate
* (0-degC, 1-degF)   Temperature (inHg)    (Hz)
* -----
*    0      'degC'  21.20      25.21      50.00
*
* Pitot   Number   Continuous FID
* A/D     of FID   Background A/D
* channel channels 0-No      channels
* (0-15) (1-4)   1-Yes   (0-15)
* -----
*    1     2       1       2 3
*
* Nitrogen          Tunnel   Zero /   English
* Zero             Calibration Velocity Cal.     Output
* Check           Check       Check    Sd       Units
* Interval        Interval   Interval Tolerance 0-No
* (hr)            (hr)      (hr)    (V)     1-Yes
* -----
*    3.0    3.0      1.0    0.085   0
*
* Nitrogen Zero Time Stamp   FID   FID
* --Time--  ---Date---  --Model-- --Range--
* '09:33 PM 01-01-2003'
* 01 0.024          1       100
* 02 0.064          0       500
* 03 0.000          0       500
* 00 0.000          0       500
*
* Tracer Calibration Time Stamp   Cal Gas
* --Time--  ---Date---  -Tracer-- Conc.  Bot ID
* '09:33 PM 01-01-2003' 'Ethane'  500   'c3367ax'
* 01 5.096
* 02 4.173
* 03 3.196
* 00 0.000
*

```

Figure B.11. Sample vbDIFCOLLECT variable setting input file.

```

CPP project: 03-9999   vbDIFCOLLECT Bench Test
                        Date: 01-01-2003
                        Maximum C/m
Run: 901A
Stack: STACK-1
Stack Height (m): 3.0
Receptor: 1 AHU-1
Scale: 240
(C/m) max 1080  µg/m3 per g/s
Wind Speed 2.0  m/s
Wind Direction 325.0 deg
    
```

Trial Results:

Trial No.	Wind Dir. (deg)	Wind Speed (m/s)	Mean FID (V)	Range FID (-)	100 Bkgd (V)	C/m	Sd (µg/m3 per g/s)
1	310.0	1.0	.34	500	.07	536	95
2	310.0	1.0	3.38	500	.08	628	95
3	320.0	1.0	6.34	500	.09	1186	135
4	330.0	1.0	5.09	500	.10	949	133
5	340.0	1.0	2.18	500	.11	397	56
6	350.0	1.0	1.81	500	.12	325	52
7	.0	1.0	1.85	500	.13	331	52
8	10.0	1.0	1.66	500	.14	295	52
9	20.0	1.0	1.60	500	.15	281	36
10	325.0	1.0	6.69	500	.16	1243	163
11	315.0	1.0	5.28	500	.17	974	127
12	300.0	1.0	1.00	500	.18	163	41
13	325.0	.7	4.49	500	.20	823	139
14	325.0	.5	2.40	500	.23	420	67
15	325.0	2.0	6.89	500	.25	1264	107
16	325.0	3.0	4.57	500	.25	827	87
17	325.0	4.0	3.93	500	.25	706	76
18	325.0	5.0	3.04	500	.25	538	52
19	320.0	2.0	5.75	500	.24	1049	91
20	330.0	2.0	4.52	500	.24	818	92
21 L	325.0	2.0	5.91	500	.24	1080	82

Confirmation reading:

21	325.0	2.0	5.91	500	.24	1080	82
----	-------	-----	------	-----	-----	------	----

Figure B.12. Sample vbDIFCOLLECT run output file.

**APPENDIX
C
SURFACE ROUGHNESS DOCUMENTATION**

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C.1 Rhinelander Airport Surface Roughness Documentation

To accurately represent full scale wind profiles in the wind tunnel it is necessary to match the surface roughness length used in the model to that of the actual site. The surface roughness length for the approach to the site was specified using AERSURFACE (EPA, 2008). AERSURFACE uses land cover data from the U.S. Geological Survey (USGS) National Land Cover Data (NLCD) archives and computes weighted averages of surface roughness lengths for a specified radius. Several different methods were evaluated as discussed in the following sections.

C.2 CPP Initial AERSURFACE Calculation

The surface roughness length around the Rhinelander-Oneida County Airport was initially specified using the AERSURFACE tool with a radius of 1 km around the anemometer location using annual 1992 NLCD (shown below in Figure C.1).

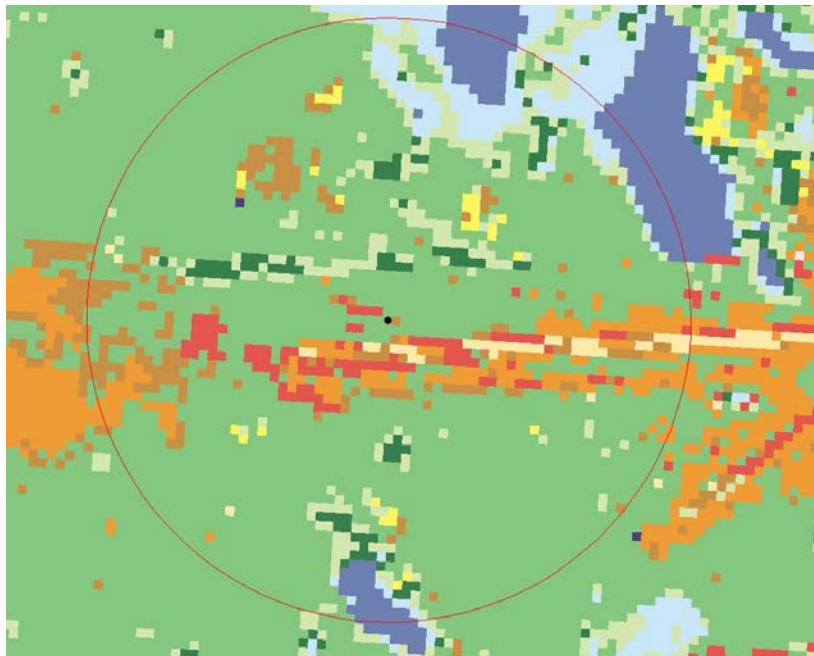


Figure C.1: 1992 NLCD with 1km radius used for initial AERSURFACE calculation

The AERSURFACE program analyzes the NLCD image by characterizing each 30m by 30m cell. The class number characterizations are as follows:

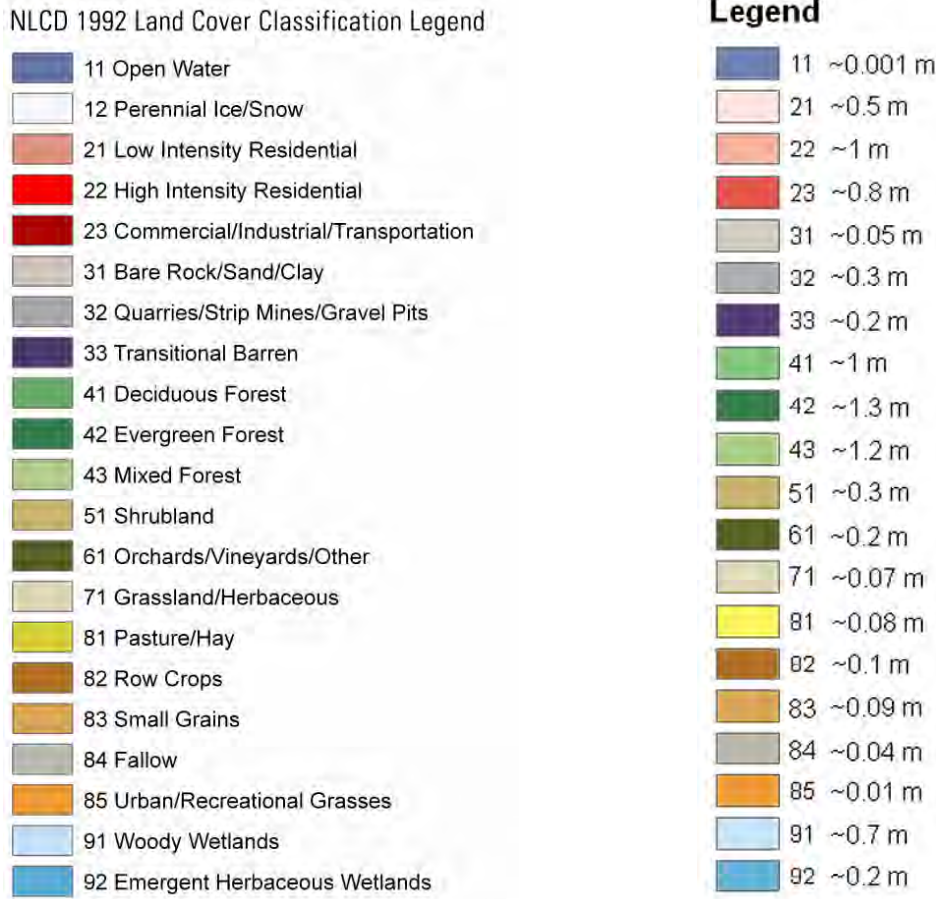


Figure C.2: NLCD Land Cover Classifications

The surface roughness length was calculated for each sector (12 total sectors of 30 degrees each). AERSURFACE assigns a surface roughness classification for each sector, based on seasonal land data. The default seasonal classifications are as follows:

Table C.1: AERSURFACE Seasonal Classification – AERSURFACE default values

Category	Comment	Months
1	Midsummer with lush vegetation	6, 7, 8
2	Autumn with un-harvested cropland	9, 10, 11
3	Late autumn after frost and harvest, or winter with no snow	12, 1, 2*
4	Winter with continuous snow on ground	12, 1, 2†
5	Transitional spring with partial green coverage or short annuals	3, 4, 5

The user can also custom-define which months experience the different land classification categories. If “annual” is used, the default seasonal months listed above are used.

* If the area does not experience continuous snow cover.

† If the area experiences continuous snow cover.

Below is a summary of the AERSURFACE input used for the initial surface roughness calculation, using the 1992 NLCD image and default seasonal classifications for an area that does not experience continuous snow cover.

```
** Generated by AERSURFACE, dated 08009
** Center Latitude (decimal degrees):    45.631404
** Center Longitude (decimal degrees):   -89.482458
** Datum: NAD83
** Study radius (km) for surface roughness:  1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11
```

The AERSURFACE output is shown in Sub-Appendix C.1 in Figure C.1.1. The calculated average surface roughness length was determined to be 0.56 m by averaging the roughness length for each individual sector.

C.3 AERSURFACE Calculation Performed by John Roth

In a July 2, 2014 email to Tom Emonds, John Roth (WDNR, Dispersion Modeling Team Leader), indicated that the 1992 NLCD information for the Rhinelander airport is not representative of current conditions. He concluded that either the 1992 NLCD data was incorrect, as published, or many trees were removed after 1992 along each side of the main E-W runway (as shown below).

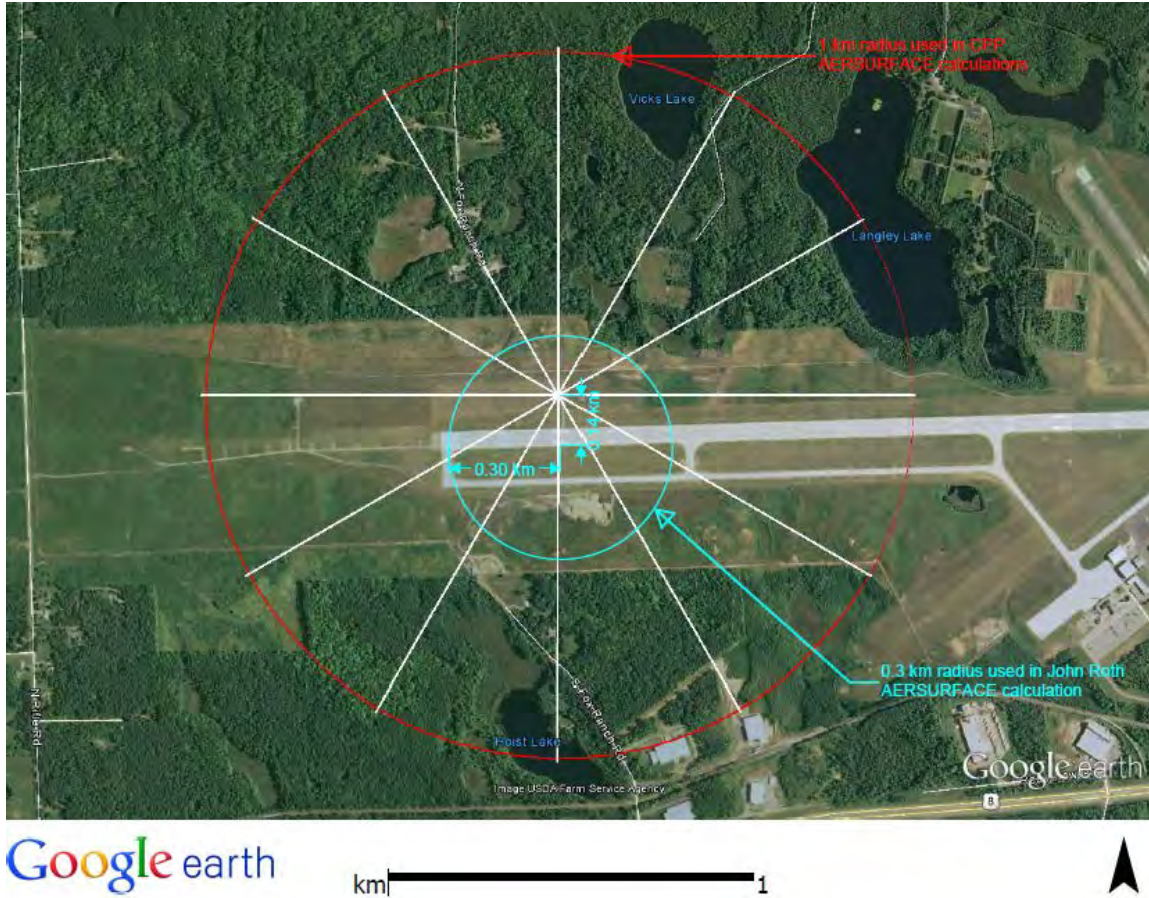


Figure C.3: Comparison of area evaluated by CPP and John Roth.

To account for the tree line, John Roth adjusted the AERSURFACE inputs by artificially relocating the anemometer location to the center of the runway (approximately 140 m south of the anemometer location). In addition, John Roth limited the radius of the AERSURFACE calculation to 0.3 km. These adjustments accounted for the area most-near the airport runway, and effectively disregard the surrounding deciduous forest. The NLCD input used for the John Roth AERSURFACE calculation is shown below:

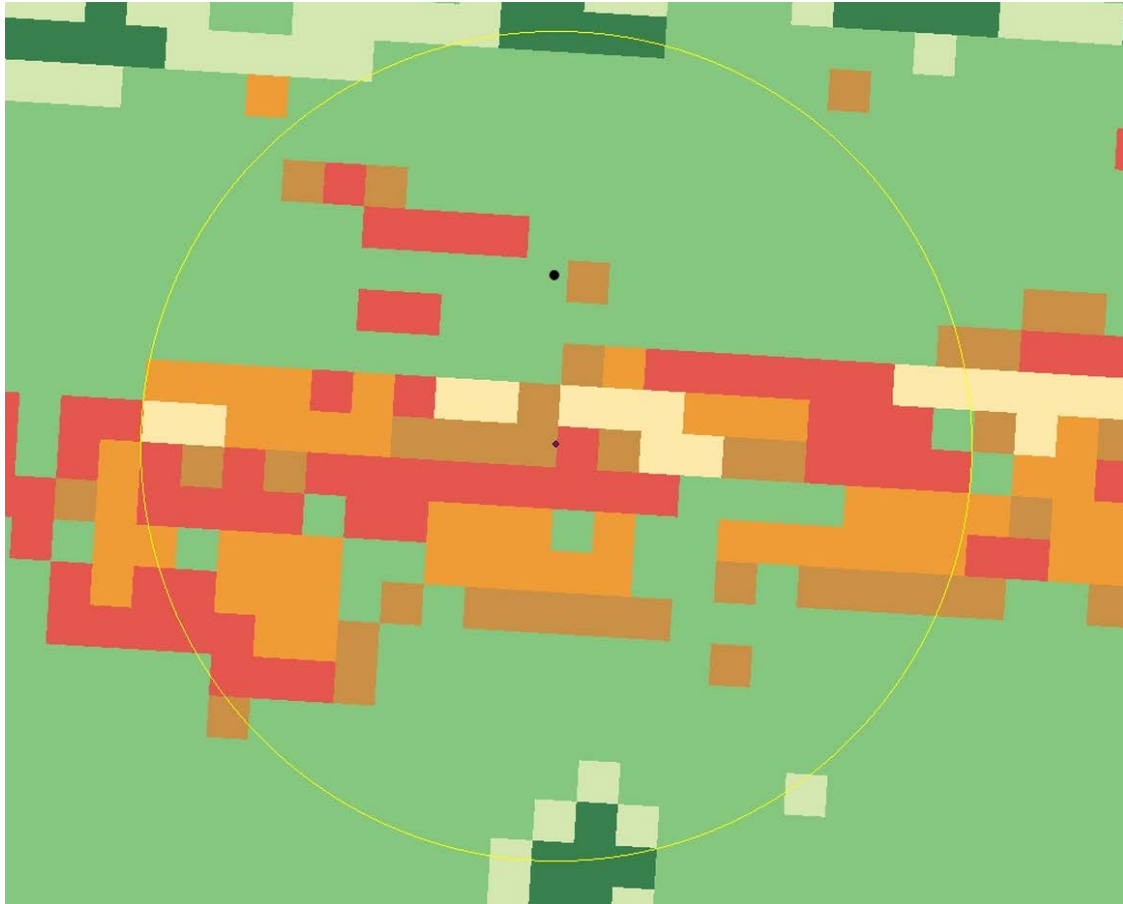


Figure C.4: 1992 NLCD with 0.3km radius used for John Roth AERSURFACE calculation

Note that the 0.3 km NLCD input is has a smaller radius, but is exactly similar to the initial 1 km input file used for the initial AERSURFACE calculation.

In addition to adjusting the anemometer location and radius, John Roth performed the AERSURFACE calculation with custom monthly classifications as follows:

Table C.2: AERSURFACE Seasonal Classification – Monthly Classification defined by John Roth

Category	Comment	Months	
		AERSURFACE Default	Defined by John Roth
1	Midsummer with lush vegetation	6, 7, 8	6, 7, 8
2	Autumn with un-harvested cropland	9, 10, 11	9, 10
3	Late autumn after frost and harvest, or winter with no snow	12, 1, 2 [‡]	11
4	Winter with continuous snow on ground	12, 1, 2 [§]	12, 1, 2, 3
5	Transitional spring with partial green coverage or short annuals	3, 4, 5	4, 5

[‡] If the area does not experience continuous snow cover.

[§] If the area experiences continuous snow cover.

Below is a summary of the AERSURFACE input used for John Roth's surface roughness calculation, using the 1992 NLCD shown in Figure 4 and the seasonal classifications shown in Table C.2:

```

** Generated by AERSURFACE, dated 13016
** Generated from "nlcd\wisconsin_nlcd_flat_052000.bin"
** Center Latitude (decimal degrees): 45.630300
** Center Longitude (decimal degrees): -89.482500
** Datum: NAD83
** Study radius (km) for surface roughness: 0.3
** Airport? Y, Continuous snow cover? Y
** Surface moisture? Average, Arid region? N
** Month/Season assignments? User-specified
** Late autumn after frost and harvest, or winter with no snow: 11
** Winter with continuous snow on the ground: 12 1 2 3
** Transitional spring (partial green coverage, short annuals): 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10

```

The AERSURFACE output is listed in Figure C.1.2 in Sub-Appendix C.1. By averaging the monthly surface roughness for each sector, the overall average surface roughness is determined to be 0.25 m. This is significantly different than the initial calculation of 0.56.

C.4 CPP AERSURFACE Calculation with Modified Inputs

The EPA recommends that a 1km radius be used when calculating the airport surface roughness. Since the John Roth calculation described above only extended to 0.3km, CPP replicated the John Roth AERSURFACE calculation, using a 1km radius as opposed to a 0.3 km radius. Below is a summary of the AERSURFACE input:

```

** Generated by AERSURFACE, dated 13016
** Generated from "wisconsin_NLCD_erd_052000.tif"
** Center Latitude (decimal degrees): 45.630300
** Center Longitude (decimal degrees): -89.482500
** Datum: NAD83
** Study radius (km) for surface roughness: 1.0
** Airport? Y, Continuous snow cover? Y
** Surface moisture? Average, Arid region? N
** Month/Season assignments? User-specified
** Late autumn after frost and harvest, or winter with no snow: 11
** Winter with continuous snow on the ground: 12 1 2 3
** Transitional spring (partial green coverage, short annuals): 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10

```

The AERSURFACE output can be found in Figure C.1.3 in the C.1 Sub-Appendix. Using the same inputs as John Roth, but with a 1km radius, the average surface roughness was determined to be 0.44 m. The higher surface roughness length is due to the inclusion of the surrounding deciduous forest. Since these calculations are based on the 1992 NLCD, and a large portion of the

deciduous forest has been cleared out, an additional analysis was needed to determine the surface roughness at the airport based on the current landscape.

C.5 Surface Roughness Calculation using the ADEC Approach

To evaluate 1km surface roughness length that represents the current land use at the airport, CPP used the Alaska Department of Environmental Conservation (ADEC, 2009) Guidance for calculation surface roughness when AERSURFACE is not a viable option. This method hand-calculates the geometric mean from estimated fractions of the surface characteristics found within a given area. Based on ADEC (2009), the following approach was used:

- Use EPA's stated guidance for determining the applicable areas/sectors for calculating the Surface Roughness Length.
- Use 2008 Google Earth photograph to determine the types of land classifications for the given area/sector.
- Estimate the fraction of land (area) that each classification covers within the given sector.
- Estimate the approximate distance (in kilometers) from the airport anemometer to the centroid of each classification area within the sector.
- Assembled a table associating each Surface Roughness value to the land fraction and distance to the centroid for each roughness classification.
- When calculating the inverse weighted geometric mean surface roughness length, weight each value by the applicable land fraction divided by the distance (equation C.1)

$$\bar{x} = (x_1^{w_1} \cdot x_2^{w_2} \cdot \dots \cdot x_n^{w_n})^{\frac{1}{\sum w}} \quad (C0.1)$$

Where:

\bar{x} = weighted geometric mean

w_i = weighted value for each point = Fraction of total area/Distance

Initially, the ADEC method was used to determine the accuracy of the AERSURFACE calculations. The ADEC method was used on the original 1992 NLCD image as follows:

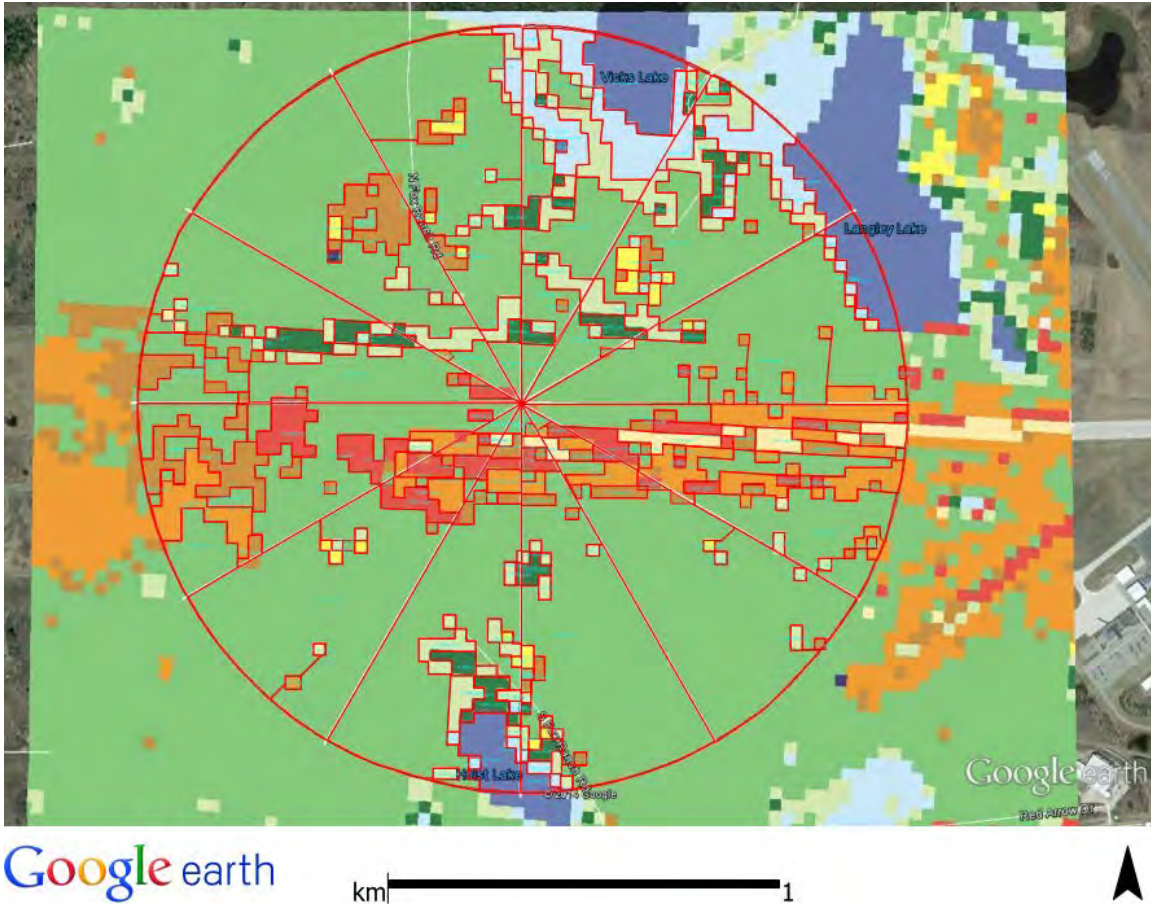


Figure 5: 1992 NLCD with land fraction areas determined using ADEC approach

For each sector, the areas of each land classification were determined, and the distance from the airport anemometer for each land use fraction estimated. Using equation C.1, the weighted geometric mean (surface roughness) were calculated for each sector (see Figure C.2.1 in Sub-Appendix C.2). Averaging all of the sectors gives an overall surface roughness of 0.48 m, which agrees with the AERSURFACE calculation described in Section C.2. This validates that the ADEC method is an acceptable approximation to the AERSURFACE calculation.

To account for the updated land use, the ADEC method was used with a 2008 Google Earth image of the airport site from 2008 (shown below).

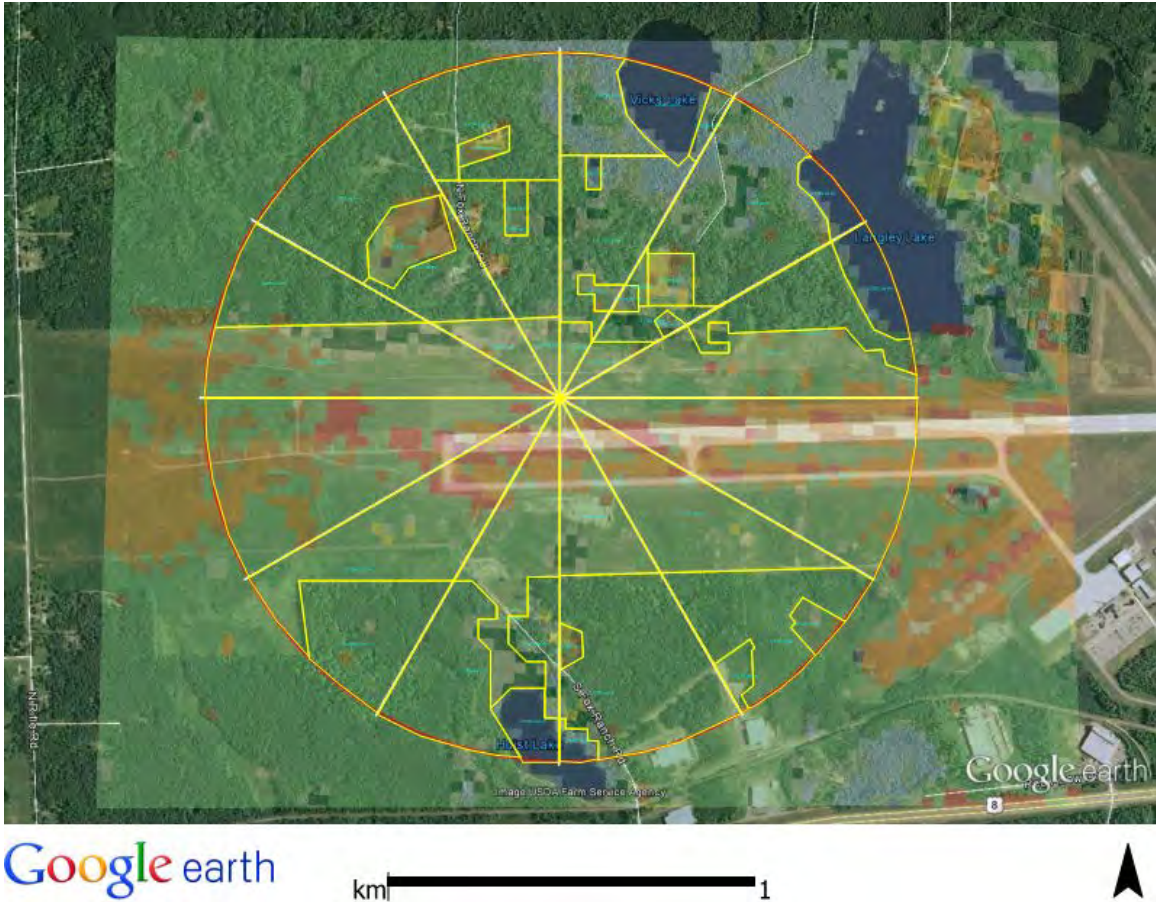


Figure C.6: 2008 Google Earth Image with transparent 1992 NLCD overlay

From Figure C.6 it can be seen that the deciduous forest area around the runway has changed significantly when compared to the 1992 NLCD. The ADEC method was repeated using the Google Earth image (Figure 6) to determine a more current surface roughness classification (see Figure C.2.2 in Sub-Appendix C.2). Averaging all of the calculated sectors, the average surface roughness was determined to be 0.26 m. This updated surface roughness value agrees with the value recommended by John Roth (Section C.3).

C.6 Surface Roughness Selection

It Section C.5, the ADEC method was evaluated with the 1992 NLCD, and was shown to agree well with CPP's original AERSURFACE calculation. When the ADEC method was used with a current Google Earth image, the surface roughness length agreed well with the John Roth AERSURFACE calculation. Therefore, the surface roughness used for this study will be 0.25 m as recommended by John Roth.

C.7 REFERENCES

- ADEC, *ADEC Guidance re AERMET Geometric Means – How to Calculate the Geometric Mean Bowen Ratio and the Inverse-Distance Weighted Geometric Mean Surface Roughness Length In Alaska*. Alaska Department of Environmental Conservation, Air Permits Program, Revised June 17, 2009.
- EPA, *AERSURFACE User's Guide*, EPA-454/B-08-001, USEPA Office of Air Quality Planning and Standards, Air Quality Assessment Division, Air Quality Modeling Group, Research Triangle Park, North Carolina, 2008.

SUB-APPENDIX C.1 – AERSURFACE OUTPUT DATA

```

** Generated by AERSURFACE, dated 08009
** Center Latitude (decimal degrees):      45.631404
** Center Longitude (decimal degrees):     -89.482458
** Datum: NAD83
** Study radius (km) for surface roughness:  1.0
** Airport? Y, Continuous snow cover? N
** Surface moisture? Average, Arid region? N
** Month/Season assignments? Default
** Late autumn after frost and harvest, or winter with no snow: 12 1 2
** Winter with continuous snow on the ground: 0
** Transitional spring (partial green coverage, short annuals): 3 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10 11
**
  FREQ_SECT  ANNUAL 12
  SECTOR    1     0  30
  SECTOR    2    30  60
  SECTOR    3    60  90
  SECTOR    4    90 120
  SECTOR    5   120 150
  SECTOR    6   150 180
  SECTOR    7   180 210
  SECTOR    8   210 240
  SECTOR    9   240 270
  SECTOR   10   270 300
  SECTOR   11   300 330
  SECTOR   12   330 360
**
  SITE_CHAR  1      Sect  Alb      Bo      Zo
  SITE_CHAR  1      1     0.15   0.47   0.487
  SITE_CHAR  1      2     0.15   0.47   0.698
  SITE_CHAR  1      3     0.15   0.47   0.594
  SITE_CHAR  1      4     0.15   0.47   0.183
  SITE_CHAR  1      5     0.15   0.47   0.463
  SITE_CHAR  1      6     0.15   0.47   0.577
  SITE_CHAR  1      7     0.15   0.47   0.419
  SITE_CHAR  1      8     0.15   0.47   0.429
  SITE_CHAR  1      9     0.15   0.47   0.398
  SITE_CHAR  1     10     0.15   0.47   0.746
  SITE_CHAR  1     11     0.15   0.47   0.755
  SITE_CHAR  1     12     0.15   0.47   0.915
                                     avg 0.555

```

Figure C.1.1. AERSURFACE Output for original CPP calculation.

```

** Generated by AERSURFACE, dated 13016
** Generated from "nlcd\wisconsin_nlcd_flat_052000.bin"
** Center Latitude (decimal degrees): 45.630300
** Center Longitude (decimal degrees): -89.482500
** Datum: NAD83
** Study radius (km) for surface roughness: 0.3
** Airport? Y, Continuous snow cover? Y
** Surface moisture? Average, Arid region? N
** Month/Season assignments? User-specified
** Late autumn after frost and harvest, or winter with no snow: 11
** Winter with continuous snow on the ground: 12 1 2 3
** Transitional spring (partial green coverage, short annuals): 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10
    
```

```

FREQ_SECT MONTHLY 12
SECTOR 1 0 30
SECTOR 2 30 60
SECTOR 3 60 90
SECTOR 4 90 120
SECTOR 5 120 150
SECTOR 6 150 180
SECTOR 7 180 210
SECTOR 8 210 240
SECTOR 9 240 270
SECTOR 10 270 300
SECTOR 11 300 330
SECTOR 12 330 360
**
Month Sect Alb Bo Zo
SITE_CHAR 1 1 0.41 0.40 0.257
SITE_CHAR 1 2 0.41 0.40 0.136
SITE_CHAR 1 3 0.41 0.40 0.043
SITE_CHAR 1 4 0.41 0.40 0.030
SITE_CHAR 1 5 0.41 0.40 0.203
SITE_CHAR 1 6 0.41 0.40 0.133
SITE_CHAR 1 7 0.41 0.40 0.092
SITE_CHAR 1 8 0.41 0.40 0.056
SITE_CHAR 1 9 0.41 0.40 0.025
SITE_CHAR 1 10 0.41 0.40 0.027
SITE_CHAR 1 11 0.41 0.40 0.163
SITE_CHAR 1 12 0.41 0.40 0.219
SITE_CHAR 2 1 0.41 0.40 0.257
SITE_CHAR 2 2 0.41 0.40 0.136
SITE_CHAR 2 3 0.41 0.40 0.043
SITE_CHAR 2 4 0.41 0.40 0.030
SITE_CHAR 2 5 0.41 0.40 0.203
SITE_CHAR 2 6 0.41 0.40 0.133
SITE_CHAR 2 7 0.41 0.40 0.092
SITE_CHAR 2 8 0.41 0.40 0.056
SITE_CHAR 2 9 0.41 0.40 0.025
SITE_CHAR 2 10 0.41 0.40 0.027
SITE_CHAR 2 11 0.41 0.40 0.163
SITE_CHAR 2 12 0.41 0.40 0.219
SITE_CHAR 3 1 0.41 0.40 0.257
SITE_CHAR 3 2 0.41 0.40 0.136
SITE_CHAR 3 3 0.41 0.40 0.043
SITE_CHAR 3 4 0.41 0.40 0.030
SITE_CHAR 3 5 0.41 0.40 0.203
SITE_CHAR 3 6 0.41 0.40 0.133
    
```

Figure C.1.2. AERSURFACE Output for John Roth calculation. (1 of 3)

SITE_CHAR	3	7	0.41	0.40	0.092
SITE_CHAR	3	8	0.41	0.40	0.056
SITE_CHAR	3	9	0.41	0.40	0.025
SITE_CHAR	3	10	0.41	0.40	0.027
SITE_CHAR	3	11	0.41	0.40	0.163
SITE_CHAR	3	12	0.41	0.40	0.219
SITE_CHAR	4	1	0.14	0.43	0.535
SITE_CHAR	4	2	0.14	0.43	0.359
SITE_CHAR	4	3	0.14	0.43	0.113
SITE_CHAR	4	4	0.14	0.43	0.062
SITE_CHAR	4	5	0.14	0.43	0.399
SITE_CHAR	4	6	0.14	0.43	0.255
SITE_CHAR	4	7	0.14	0.43	0.183
SITE_CHAR	4	8	0.14	0.43	0.112
SITE_CHAR	4	9	0.14	0.43	0.046
SITE_CHAR	4	10	0.14	0.43	0.074
SITE_CHAR	4	11	0.14	0.43	0.359
SITE_CHAR	4	12	0.14	0.43	0.448
SITE_CHAR	5	1	0.14	0.43	0.535
SITE_CHAR	5	2	0.14	0.43	0.359
SITE_CHAR	5	3	0.14	0.43	0.113
SITE_CHAR	5	4	0.14	0.43	0.062
SITE_CHAR	5	5	0.14	0.43	0.399
SITE_CHAR	5	6	0.14	0.43	0.255
SITE_CHAR	5	7	0.14	0.43	0.183
SITE_CHAR	5	8	0.14	0.43	0.112
SITE_CHAR	5	9	0.14	0.43	0.046
SITE_CHAR	5	10	0.14	0.43	0.074
SITE_CHAR	5	11	0.14	0.43	0.359
SITE_CHAR	5	12	0.14	0.43	0.448
SITE_CHAR	6	1	0.15	0.27	0.925
SITE_CHAR	6	2	0.15	0.27	0.498
SITE_CHAR	6	3	0.15	0.27	0.158
SITE_CHAR	6	4	0.15	0.27	0.106
SITE_CHAR	6	5	0.15	0.27	0.567
SITE_CHAR	6	6	0.15	0.27	0.390
SITE_CHAR	6	7	0.15	0.27	0.267
SITE_CHAR	6	8	0.15	0.27	0.164
SITE_CHAR	6	9	0.15	0.27	0.105
SITE_CHAR	6	10	0.15	0.27	0.152
SITE_CHAR	6	11	0.15	0.27	0.511
SITE_CHAR	6	12	0.15	0.27	0.763
SITE_CHAR	7	1	0.15	0.27	0.925
SITE_CHAR	7	2	0.15	0.27	0.498
SITE_CHAR	7	3	0.15	0.27	0.158
SITE_CHAR	7	4	0.15	0.27	0.106
SITE_CHAR	7	5	0.15	0.27	0.567
SITE_CHAR	7	6	0.15	0.27	0.390
SITE_CHAR	7	7	0.15	0.27	0.267
SITE_CHAR	7	8	0.15	0.27	0.164
SITE_CHAR	7	9	0.15	0.27	0.105
SITE_CHAR	7	10	0.15	0.27	0.152
SITE_CHAR	7	11	0.15	0.27	0.511
SITE_CHAR	7	12	0.15	0.27	0.763
SITE_CHAR	8	1	0.15	0.27	0.925
SITE_CHAR	8	2	0.15	0.27	0.498
SITE_CHAR	8	3	0.15	0.27	0.158
SITE_CHAR	8	4	0.15	0.27	0.106
SITE_CHAR	8	5	0.15	0.27	0.567
SITE_CHAR	8	6	0.15	0.27	0.390

Figure C.1.2. AERSURFACE Output for John Roth calculation. (2 of 3)

SITE_CHAR	8	6	0.15	0.27	0.390
SITE_CHAR	8	7	0.15	0.27	0.267
SITE_CHAR	8	8	0.15	0.27	0.164
SITE_CHAR	8	9	0.15	0.27	0.105
SITE_CHAR	8	10	0.15	0.27	0.152
SITE_CHAR	8	11	0.15	0.27	0.511
SITE_CHAR	8	12	0.15	0.27	0.763
SITE_CHAR	9	1	0.15	0.58	0.925
SITE_CHAR	9	2	0.15	0.58	0.487
SITE_CHAR	9	3	0.15	0.58	0.151
SITE_CHAR	9	4	0.15	0.58	0.101
SITE_CHAR	9	5	0.15	0.58	0.554
SITE_CHAR	9	6	0.15	0.58	0.377
SITE_CHAR	9	7	0.15	0.58	0.251
SITE_CHAR	9	8	0.15	0.58	0.151
SITE_CHAR	9	9	0.15	0.58	0.101
SITE_CHAR	9	10	0.15	0.58	0.141
SITE_CHAR	9	11	0.15	0.58	0.511
SITE_CHAR	9	12	0.15	0.58	0.763
SITE_CHAR	10	1	0.15	0.58	0.925
SITE_CHAR	10	2	0.15	0.58	0.487
SITE_CHAR	10	3	0.15	0.58	0.151
SITE_CHAR	10	4	0.15	0.58	0.101
SITE_CHAR	10	5	0.15	0.58	0.554
SITE_CHAR	10	6	0.15	0.58	0.377
SITE_CHAR	10	7	0.15	0.58	0.251
SITE_CHAR	10	8	0.15	0.58	0.151
SITE_CHAR	10	9	0.15	0.58	0.101
SITE_CHAR	10	10	0.15	0.58	0.141
SITE_CHAR	10	11	0.15	0.58	0.511
SITE_CHAR	10	12	0.15	0.58	0.763
SITE_CHAR	11	1	0.15	0.58	0.336
SITE_CHAR	11	2	0.15	0.58	0.184
SITE_CHAR	11	3	0.15	0.58	0.061
SITE_CHAR	11	4	0.15	0.58	0.042
SITE_CHAR	11	5	0.15	0.58	0.258
SITE_CHAR	11	6	0.15	0.58	0.174
SITE_CHAR	11	7	0.15	0.58	0.125
SITE_CHAR	11	8	0.15	0.58	0.079
SITE_CHAR	11	9	0.15	0.58	0.036
SITE_CHAR	11	10	0.15	0.58	0.043
SITE_CHAR	11	11	0.15	0.58	0.208
SITE_CHAR	11	12	0.15	0.58	0.284
SITE_CHAR	12	1	0.41	0.40	0.257
SITE_CHAR	12	2	0.41	0.40	0.136
SITE_CHAR	12	3	0.41	0.40	0.043
SITE_CHAR	12	4	0.41	0.40	0.030
SITE_CHAR	12	5	0.41	0.40	0.203
SITE_CHAR	12	6	0.41	0.40	0.133
SITE_CHAR	12	7	0.41	0.40	0.092
SITE_CHAR	12	8	0.41	0.40	0.056
SITE_CHAR	12	9	0.41	0.40	0.025
SITE_CHAR	12	10	0.41	0.40	0.027
SITE_CHAR	12	11	0.41	0.40	0.163
SITE_CHAR	12	12	0.41	0.40	0.219

Figure C.1.2. AERSURFACE Output for John Roth calculation. (3 of 3)

```

** Generated by AERSURFACE, dated 13016
** Generated from "wisconsin_NLCD_erd_052000.tif"
** Center Latitude (decimal degrees): 45.630300
** Center Longitude (decimal degrees): -89.482500
** Datum: NAD83
** Study radius (km) for surface roughness: 1.0
** Airport? Y, Continuous snow cover? Y
** Surface moisture? Average, Arid region? N
** Month/Season assignments? User-specified
** Late autumn after frost and harvest, or winter with no snow: 11
** Winter with continuous snow on the ground: 12 1 2 3
** Transitional spring (partial green coverage, short annuals): 4 5
** Midsummer with lush vegetation: 6 7 8
** Autumn with unharvested cropland: 9 10
    
```

```

FREQ_SECT MONTHLY 12
SECTOR 1 0 30
SECTOR 2 30 60
SECTOR 3 60 90
SECTOR 4 90 120
SECTOR 5 120 150
SECTOR 6 150 180
SECTOR 7 180 210
SECTOR 8 210 240
SECTOR 9 240 270
SECTOR 10 270 300
SECTOR 11 300 330
SECTOR 12 330 360
**
Month Sect Alb Bo Zo
SITE_CHAR 1 1 0.41 0.40 0.330
SITE_CHAR 1 2 0.41 0.40 0.299
SITE_CHAR 1 3 0.41 0.40 0.070
SITE_CHAR 1 4 0.41 0.40 0.080
SITE_CHAR 1 5 0.41 0.40 0.390
SITE_CHAR 1 6 0.41 0.40 0.265
SITE_CHAR 1 7 0.41 0.40 0.214
SITE_CHAR 1 8 0.41 0.40 0.261
SITE_CHAR 1 9 0.41 0.40 0.083
SITE_CHAR 1 10 0.41 0.40 0.138
SITE_CHAR 1 11 0.41 0.40 0.315
SITE_CHAR 1 12 0.41 0.40 0.307
SITE_CHAR 2 1 0.41 0.40 0.330
SITE_CHAR 2 2 0.41 0.40 0.299
SITE_CHAR 2 3 0.41 0.40 0.070
SITE_CHAR 2 4 0.41 0.40 0.080
SITE_CHAR 2 5 0.41 0.40 0.390
SITE_CHAR 2 6 0.41 0.40 0.265
SITE_CHAR 2 7 0.41 0.40 0.214
SITE_CHAR 2 8 0.41 0.40 0.261
SITE_CHAR 2 9 0.41 0.40 0.083
SITE_CHAR 2 10 0.41 0.40 0.138
SITE_CHAR 2 11 0.41 0.40 0.315
SITE_CHAR 2 12 0.41 0.40 0.307
SITE_CHAR 3 1 0.41 0.40 0.330
SITE_CHAR 3 2 0.41 0.40 0.299
SITE_CHAR 3 3 0.41 0.40 0.070
SITE_CHAR 3 4 0.41 0.40 0.080
SITE_CHAR 3 5 0.41 0.40 0.390
SITE_CHAR 3 6 0.41 0.40 0.265
    
```

Figure C.1.3. AERSURFACE Output with Modified Inputs. (1 of 3)

SITE_CHAR	3	7	0.41	0.40	0.214
SITE_CHAR	3	8	0.41	0.40	0.261
SITE_CHAR	3	9	0.41	0.40	0.083
SITE_CHAR	3	10	0.41	0.40	0.138
SITE_CHAR	3	11	0.41	0.40	0.315
SITE_CHAR	3	12	0.41	0.40	0.307
SITE_CHAR	4	1	0.14	0.43	0.580
SITE_CHAR	4	2	0.14	0.43	0.609
SITE_CHAR	4	3	0.14	0.43	0.177
SITE_CHAR	4	4	0.14	0.43	0.170
SITE_CHAR	4	5	0.14	0.43	0.774
SITE_CHAR	4	6	0.14	0.43	0.501
SITE_CHAR	4	7	0.14	0.43	0.373
SITE_CHAR	4	8	0.14	0.43	0.527
SITE_CHAR	4	9	0.14	0.43	0.167
SITE_CHAR	4	10	0.14	0.43	0.292
SITE_CHAR	4	11	0.14	0.43	0.627
SITE_CHAR	4	12	0.14	0.43	0.608
SITE_CHAR	5	1	0.14	0.43	0.580
SITE_CHAR	5	2	0.14	0.43	0.609
SITE_CHAR	5	3	0.14	0.43	0.177
SITE_CHAR	5	4	0.14	0.43	0.170
SITE_CHAR	5	5	0.14	0.43	0.774
SITE_CHAR	5	6	0.14	0.43	0.501
SITE_CHAR	5	7	0.14	0.43	0.373
SITE_CHAR	5	8	0.14	0.43	0.527
SITE_CHAR	5	9	0.14	0.43	0.167
SITE_CHAR	5	10	0.14	0.43	0.292
SITE_CHAR	5	11	0.14	0.43	0.627
SITE_CHAR	5	12	0.14	0.43	0.608
SITE_CHAR	6	1	0.15	0.27	0.773
SITE_CHAR	6	2	0.15	0.27	0.836
SITE_CHAR	6	3	0.15	0.27	0.265
SITE_CHAR	6	4	0.15	0.27	0.258
SITE_CHAR	6	5	0.15	0.27	1.033
SITE_CHAR	6	6	0.15	0.27	0.694
SITE_CHAR	6	7	0.15	0.27	0.482
SITE_CHAR	6	8	0.15	0.27	0.718
SITE_CHAR	6	9	0.15	0.27	0.294
SITE_CHAR	6	10	0.15	0.27	0.476
SITE_CHAR	6	11	0.15	0.27	0.889
SITE_CHAR	6	12	0.15	0.27	0.950
SITE_CHAR	7	1	0.15	0.27	0.773
SITE_CHAR	7	2	0.15	0.27	0.836
SITE_CHAR	7	3	0.15	0.27	0.265
SITE_CHAR	7	4	0.15	0.27	0.258
SITE_CHAR	7	5	0.15	0.27	1.033
SITE_CHAR	7	6	0.15	0.27	0.694
SITE_CHAR	7	7	0.15	0.27	0.482
SITE_CHAR	7	8	0.15	0.27	0.718
SITE_CHAR	7	9	0.15	0.27	0.294
SITE_CHAR	7	10	0.15	0.27	0.476
SITE_CHAR	7	11	0.15	0.27	0.889
SITE_CHAR	7	12	0.15	0.27	0.950
SITE_CHAR	8	1	0.15	0.27	0.773
SITE_CHAR	8	2	0.15	0.27	0.836
SITE_CHAR	8	3	0.15	0.27	0.265
SITE_CHAR	8	4	0.15	0.27	0.258
SITE_CHAR	8	5	0.15	0.27	1.033
SITE_CHAR	8	6	0.15	0.27	0.694

Figure C.1.3. AERSURFACE Output with Modified Inputs. (2 of 3)

SITE_CHAR	8	7	0.15	0.27	0.482
SITE_CHAR	8	8	0.15	0.27	0.718
SITE_CHAR	8	9	0.15	0.27	0.294
SITE_CHAR	8	10	0.15	0.27	0.476
SITE_CHAR	8	11	0.15	0.27	0.889
SITE_CHAR	8	12	0.15	0.27	0.950
SITE_CHAR	9	1	0.15	0.58	0.773
SITE_CHAR	9	2	0.15	0.58	0.830
SITE_CHAR	9	3	0.15	0.58	0.254
SITE_CHAR	9	4	0.15	0.58	0.244
SITE_CHAR	9	5	0.15	0.58	1.027
SITE_CHAR	9	6	0.15	0.58	0.687
SITE_CHAR	9	7	0.15	0.58	0.473
SITE_CHAR	9	8	0.15	0.58	0.701
SITE_CHAR	9	9	0.15	0.58	0.283
SITE_CHAR	9	10	0.15	0.58	0.465
SITE_CHAR	9	11	0.15	0.58	0.887
SITE_CHAR	9	12	0.15	0.58	0.950
SITE_CHAR	10	1	0.15	0.58	0.773
SITE_CHAR	10	2	0.15	0.58	0.830
SITE_CHAR	10	3	0.15	0.58	0.254
SITE_CHAR	10	4	0.15	0.58	0.244
SITE_CHAR	10	5	0.15	0.58	1.027
SITE_CHAR	10	6	0.15	0.58	0.687
SITE_CHAR	10	7	0.15	0.58	0.473
SITE_CHAR	10	8	0.15	0.58	0.701
SITE_CHAR	10	9	0.15	0.58	0.283
SITE_CHAR	10	10	0.15	0.58	0.465
SITE_CHAR	10	11	0.15	0.58	0.887
SITE_CHAR	10	12	0.15	0.58	0.950
SITE_CHAR	11	1	0.15	0.58	0.403
SITE_CHAR	11	2	0.15	0.58	0.376
SITE_CHAR	11	3	0.15	0.58	0.099
SITE_CHAR	11	4	0.15	0.58	0.110
SITE_CHAR	11	5	0.15	0.58	0.476
SITE_CHAR	11	6	0.15	0.58	0.328
SITE_CHAR	11	7	0.15	0.58	0.259
SITE_CHAR	11	8	0.15	0.58	0.329
SITE_CHAR	11	9	0.15	0.58	0.115
SITE_CHAR	11	10	0.15	0.58	0.185
SITE_CHAR	11	11	0.15	0.58	0.390
SITE_CHAR	11	12	0.15	0.58	0.389
SITE_CHAR	12	1	0.41	0.40	0.330
SITE_CHAR	12	2	0.41	0.40	0.299
SITE_CHAR	12	3	0.41	0.40	0.070
SITE_CHAR	12	4	0.41	0.40	0.080
SITE_CHAR	12	5	0.41	0.40	0.390
SITE_CHAR	12	6	0.41	0.40	0.265
SITE_CHAR	12	7	0.41	0.40	0.214
SITE_CHAR	12	8	0.41	0.40	0.261
SITE_CHAR	12	9	0.41	0.40	0.083
SITE_CHAR	12	10	0.41	0.40	0.138
SITE_CHAR	12	11	0.41	0.40	0.315
SITE_CHAR	12	12	0.41	0.40	0.307

Figure C.1.3. AERSURFACE Output with Modified Inputs. (3 of 3)

SUB-APPENDIX C.2 – ADEC ROUGHNESS CLASSIFICATIONS

Sector Number 1						
Land Cover Category	Area (km2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	zo (m)	AVG sz (m)
Open Water	0.0422	0.1744	0.9	0.193755739	0.001	0.26226
	0.0008	0.0033	0.7	0.00472255	0.001	0.967904
Urban/Recreational Grasses	0.0008	0.0033	0.4	0.008264463	0.01	0.962656
Shrubland	0.0313	0.1293	0.8	0.161673554	0.07	0.650553
	0.0017	0.0070	0.9	0.007805326	0.07	0.979458
	0.0034	0.0140	0.7	0.020070838	0.07	0.948026
	0.0013	0.0054	0.9	0.005968779	0.07	0.984253
	0.0082	0.0339	0.4	0.084710744	0.07	0.798302
	0.0018	0.0074	0.2	0.037190083	0.07	0.905835
Woody Wetlands	0.0178	0.0736	0.6	0.122589532	0.7	0.957218
	0.0326	0.1347	0.6	0.224517906	0.7	0.923043
	0.0049	0.0202	0.8	0.025309917	0.7	0.991013
	0.002	0.0083	0.9	0.009182736	0.7	0.99673
Deciduous Forest	0.0067	0.0277	0.1	0.276859504	1	1
	0.0159	0.0657	0.2	0.328512397	1	1
	0.0377	0.1558	0.3	0.519283747	1	1
	0.0116	0.0479	0.5	0.095867769	1	1
	0.0081	0.0335	0.7	0.047815821	1	1
	0.0015	0.0062	0.9	0.006887052	1	1
Evergreen Forest	0.0032	0.0132	0.1	0.132231405	1.3	1.035302
	0.0008	0.0033	0.8	0.004132231	1.3	1.001085
	0.0039	0.0161	0.3	0.053719008	1.3	1.014194
	0.0016	0.0066	0.4	0.016528926	1.3	1.004346
	0.0008	0.0033	0.4	0.008264463	1.3	1.002171
	0.0014	0.0058	0.8	0.007231405	1.3	1.001899
TOTAL	0.242	1.0000		2.403095894		0.097195
Roughness Calculation sz (m)	0.379078					

Sector Number 2						
Land Cover Category	Area (km2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	zo (m)	AVG sz (m)
Open Water	0.0146	0.0591	0.9	0.065703614	0.001	0.635169
Shrubland	0.0067	0.0271	0.8	0.033920616	0.7	0.987974
	0.026	0.1053	0.7	0.150436845	0.7	0.947757
	0.0008	0.0032	0.5	0.006480356	0.7	0.997691
	0.0007	0.0028	0.5	0.005670312	0.7	0.99798
	0.0006	0.0024	0.5	0.004860267	0.7	0.998268
	0.0097	0.0393	0.3	0.130957203	0.7	0.954365
	0.001	0.0041	0.2	0.020251114	0.7	0.992803
Pasture/Hay	0.0087	0.0352	0.4	0.088092345	0.08	0.800517
Row Crops	0.0011	0.0045	0.8	0.005569056	0.1	0.987259
	0.007	0.0284	0.7	0.040502228	0.1	0.910957
Woody Wetlands	0.0041	0.0166	0.5	0.033211827	0.1	0.926378
	0.0249	0.1009	0.9	0.112056163	0.7	0.960821
	0.0026	0.0105	0.7	0.015043685	0.7	0.994649
Deciduous Forest	0.0061	0.0247	0.7	0.035294798	0.7	0.98749
	0.0188	0.0761	0.2	0.38072094	1	1
	0.0954	0.3864	0.6	0.643985419	1	1
Evergreen Forest	0.0025	0.0101	0.9	0.011250619	1	1
	0.0057	0.0231	0.3	0.076954232	1.3	1.020395
	0.0007	0.0028	0.6	0.00472526	1.3	1.001241
	0.0083	0.0336	0.7	0.04802407	1.3	1.01268
TOTAL	0.2469	1.0000		1.918267469		0.365178
Roughness Calculation sz (m)	0.591469					

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (1 of 6)

Sector Number 3						
Land Cover Category	Area (km ²)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	z ₀ (m)	AVG z ₀ (m)
Open Water	0.0233	0.0936	0.9	0.104013214	0.001	0.487484
Urban/Recreational Grasses	0.0011	0.0044	0.3	0.014731485	0.01	0.934409
	0.0006	0.0024	0.4	0.006026517	0.01	0.972628
	0.0007	0.0028	0.4	0.007030936	0.01	0.96814
	0.0007	0.0028	0.5	0.005624749	0.01	0.97443
	0.0013	0.0052	0.6	0.008704969	0.01	0.960705
	0.0009	0.0036	0.7	0.005165586	0.01	0.976492
Shrubland	0.0065	0.0261	0.8	0.032643632	0.01	0.860424
	0.0018	0.0072	0.8	0.009039775	0.07	0.976248
	0.0011	0.0044	0.8	0.005524307	0.07	0.985417
Pasture/Hay	0.0033	0.0133	0.4	0.033145842	0.07	0.91563
	0.0007	0.0028	0.5	0.005624749	0.08	0.985894
Row Crops	0.0007	0.0028	0.6	0.004687291	0.1	0.989265
Woody Wetlands	0.0016	0.0064	0.6	0.010713807	0.1	0.975632
	0.0038	0.0153	0.8	0.019083969	0.7	0.993216
Transportation	0.0007	0.0028	0.4	0.007030936	0.1	0.983941
Deciduous Forest	0.0005	0.0020	0.9	0.002232043	0.1	0.994874
	0.198	0.7955	0.5	1.591000402	1	1
Evergreen Forest	0.0016	0.0064	0.5	0.012856569	1.3	1.003379
TOTAL	0.2489	1.0000		1.884880777		0.275854
Roughness Calculation z ₀ (m)	0.504963					

Sector Number 4						
Land Cover Category	Area (km ²)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	z ₀ (m)	AVG z ₀ (m)
Urban/Recreational Grasses	0.0144	0.0592	0.4	0.147965475	0.01	0.505905
	0.0219	0.0900	0.7	0.128589044	0.01	0.553123
	0.0283	0.1163	0.7	0.166167577	0.01	0.465227
	0.0038	0.0156	0.9	0.017353975	0.01	0.923192
Shrubland	0.0075	0.0308	0.3	0.102753802	0.07	0.760903
	0.0067	0.0275	0.7	0.039340027	0.07	0.900671
	0.001	0.0041	0.7	0.005871646	0.07	0.984507
	0.0014	0.0058	0.7	0.008220304	0.07	0.978377
	0.001	0.0041	0.8	0.00513769	0.07	0.98643
	0.0072	0.0296	0.9	0.032881217	0.07	0.916274
Row Crops	0.003	0.0123	0.3	0.041101521	0.1	0.909701
	0.0007	0.0029	0.3	0.009590355	0.1	0.978159
	0.0009	0.0037	0.4	0.009247842	0.1	0.978931
	0.0024	0.0099	0.6	0.016440608	0.1	0.962852
	0.0014	0.0058	0.6	0.009590355	0.1	0.978159
	0.0039	0.0160	0.7	0.022899419	0.1	0.948638
	0.0024	0.0099	0.8	0.012330456	0.1	0.972007
	0.0018	0.0074	0.9	0.008220304	0.1	0.98125
	0.0007	0.0029	0.9	0.003196785	0.1	0.992666
	0.0077	0.0316	0.2	0.158240855	0.1	0.694639
Transportation	0.0006	0.0025	0.4	0.006165228	0.1	0.985904
	0.0057	0.0234	0.5	0.046855734	0.1	0.897727
	0.0016	0.0066	0.7	0.009394633	0.1	0.9786
	0.0022	0.0090	0.7	0.012917621	0.1	0.970694
	0.0008	0.0033	0.7	0.004697317	0.1	0.989242
	0.0008	0.0033	0.9	0.003653469	0.1	0.991623
Deciduous Forest	0.021	0.0863	0.2	0.431565968	1	1
	0.002	0.0082	0.3	0.027401014	1	1
	0.0012	0.0049	0.6	0.008220304	1	1
	0.021	0.0863	0.7	0.123304562	1	1
	0.0683	0.2807	0.7	0.40103341	1	1
TOTAL	0.2433	1.0000		2.020348515		0.03027
Roughness Calculation z ₀ (m)	0.177075					

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (2 of 6)

Sector Number 5						
Land Cover Category	Area (km2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	zo (m)	AVG sz (m)
Urban/Recreational Grasses	0.003	0.0117	0.2	0.058388478	0.01	0.764228
	0.0075	0.0292	0.3	0.09731413	0.01	0.63881
Shrubland	0.0023	0.0090	0.2	0.0447645	0.07	0.887772
	0.001	0.0039	0.6	0.006487609	0.07	0.982896
	0.001	0.0039	0.8	0.004865707	0.07	0.987144
	0.0019	0.0074	0.9	0.008217638	0.07	0.978384
Pasture/Hay	0.0007	0.0027	0.6	0.004541326	0.08	0.988595
Row Crops	0.0017	0.0066	0.2	0.033086804	0.1	0.926645
	0.0044	0.0171	0.3	0.057090956	0.1	0.876817
	0.0007	0.0027	0.3	0.009082652	0.1	0.979304
Transportation	0.0007	0.0027	0.9	0.003027551	0.1	0.993053
	0.0018	0.0070	0.1	0.070066174	0.1	0.851008
	0.0015	0.0058	0.2	0.029194239	0.1	0.934987
Deciduous Forest	0.002	0.0078	0.4	0.019462826	0.1	0.956175
	0.0017	0.0066	0.1	0.066173608	1	1
	0.225	0.8758	0.6	1.45971195	1	1
TOTAL	0.2569	1.0000		1.971476147		0.244512
Roughness Calculation sz (m)		0.489469				

Sector Number 6						
Land Cover Category	Area (km2)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	zo (m)	AVG sz (m)
Open Water	0.0043	0.0170	0.9	0.018899437	0.001	0.87761
Shrubland	0.0021	0.0083	0.2	0.04153481	0.07	0.895429
	0.0024	0.0095	0.4	0.023734177	0.07	0.938835
	0.0008	0.0032	0.4	0.007911392	0.07	0.979181
	0.002	0.0079	0.5	0.015822785	0.07	0.958796
	0.001	0.0040	0.8	0.00494462	0.07	0.986937
	0.0012	0.0047	0.8	0.005933544	0.07	0.984345
	0.0027	0.0107	0.9	0.011867089	0.07	0.968935
Pasture/Hay	0.0019	0.0075	0.7	0.01073689	0.08	0.973246
Row Crops	0.0017	0.0067	0.8	0.008405854	0.08	0.978993
	0.0009	0.0036	0.1	0.035601266	0.1	0.921295
Row Crops	0.001	0.0040	0.2	0.019778481	0.1	0.95548
	0.0025	0.0099	0.3	0.032964135	0.1	0.926906
	0.0009	0.0036	0.3	0.011867089	0.1	0.973045
	0.0024	0.0095	0.7	0.013562387	0.1	0.969254
	0.0011	0.0044	0.9	0.00483474	0.1	0.988929
Woody Wetlands	0.0033	0.0131	0.9	0.014504219	0.7	0.99484
Transportation	0.0037	0.0146	0.2	0.07318038	0.1	0.844928
Deciduous Forest	0.001	0.0040	0.1	0.039556962	1	1
	0.0009	0.0036	0.2	0.017800633	1	1
	0.2073	0.8200	0.6	1.366693038	1	1
Evergreen Forest	0.0038	0.0150	0.4	0.037579114	1.3	1.009908
	0.0007	0.0028	0.7	0.003955696	1.3	1.001038
	0.0032	0.0127	0.8	0.015822785	1.3	1.00416
TOTAL	0.2528	1.0000		1.837491524		0.401321
Roughness Calculation sz (m)		0.608432				

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (3 of 6)

Sector Number 7						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0227	0.0866	0.9	0.096194593	0.001	0.514537
Urban/Recreational Grasses	0.003	0.0114	0.2	0.057208238	0.01	0.768393
Shrubland	0.001	0.0038	0.1	0.038138825	0.07	0.903553
	0.002	0.0076	0.4	0.019069413	0.07	0.950554
	0.0095	0.0362	0.7	0.051759834	0.07	0.87141
	0.004	0.0153	0.7	0.021793614	0.07	0.943693
	0.0093	0.0355	0.8	0.044336384	0.07	0.888783
	0.0018	0.0069	0.8	0.008581236	0.07	0.977439
Pasture/Hay	0.001	0.0038	0.8	0.004767353	0.07	0.987402
	0.0018	0.0069	0.9	0.007627765	0.07	0.97992
Row Crops	0.0008	0.0031	0.6	0.005085177	0.08	0.987238
	0.0007	0.0027	0.6	0.00444953	0.08	0.988825
Woody Wetlands	0.0028	0.0107	0.2	0.053394355	0.1	0.884312
	0.0051	0.0195	0.3	0.064836003	0.1	0.861319
Transportation	0.001	0.0038	0.6	0.006356471	0.7	0.997735
	0.001	0.0038	0.7	0.005448404	0.7	0.998059
	0.0015	0.0057	0.7	0.008172605	0.7	0.997089
	0.009	0.0343	0.8	0.042906178	0.7	0.984813
Deciduous Forest	0.003	0.0114	0.2	0.057208238	0.1	0.87658
	0.0017	0.0065	0.1	0.064836003	1	1
Evergreen Forest	0.0021	0.0080	0.3	0.026697178	1	1
	0.1624	0.6194	0.6	1.032290872	1	1
	0.0008	0.0031	0.5	0.006102212	1.3	1.001602
TOTAL	0.2622	1.0000		1.804627813		0.149834
Roughness Calculation sz (m)		0.349285				

Sector Number 8						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Urban/Recreational Grasses	0.0037	0.0145	0.2	0.07254902	0.01	0.715982
	0.0091	0.0357	0.3	0.118954248	0.01	0.578218
	0.0013	0.0051	0.9	0.005664488	0.01	0.974251
Shrubland	0.0008	0.0031	0.1	0.031372549	0.07	0.919958
	0.0017	0.0067	0.6	0.011111111	0.07	0.970885
Pasture/Hay	0.0009	0.0035	0.8	0.004411765	0.07	0.988337
	0.003	0.0118	0.6	0.019607843	0.08	0.951682
Row Crops	0.002	0.0078	0.2	0.039215686	0.1	0.913659
	0.0008	0.0031	0.4	0.007843137	0.1	0.982103
Transportation	0.0008	0.0031	0.2	0.015686275	0.1	0.964526
	0.0084	0.0329	0.3	0.109803922	0.1	0.776598
	0.0093	0.0365	0.4	0.091176471	0.1	0.810632
Deciduous Forest	0.0033	0.0129	0.1	0.129411765	1	1
	0.0028	0.0110	0.2	0.054901961	1	1
	0.2071	0.8122	0.6	1.353594771	1	1
TOTAL	0.255	1.0000		2.065305011		0.184617
Roughness Calculation sz (m)		0.441302				

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (4 of 6)

Sector Number 9						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Urban/Recreational Grasses	0.0061	0.0245	0.2	0.122588424	0.01	0.568621
	0.0274	0.1101	0.8	0.137660772	0.01	0.530492
Shrubland	0.0018	0.0072	0.2	0.036173633	0.07	0.908287
Row Crops	0.0009	0.0036	0.6	0.006028939	0.1	0.986214
	0.002	0.0080	0.7	0.011483693	0.1	0.973904
	0.0325	0.1306	0.8	0.163283762	0.1	0.68662
Transportation	0.0025	0.0100	0.8	0.012560289	0.1	0.971493
	0.0016	0.0064	0.1	0.064308682	0.1	0.862365
	0.0132	0.0531	0.3	0.176848875	0.1	0.665505
Deciduous Forest	0.0148	0.0595	0.6	0.099142551	0.1	0.795898
	0.0861	0.3461	0.3	1.153536977	1	1
	0.0272	0.1093	0.7	0.156178227	1	1
	0.0046	0.0185	0.7	0.026412494	1	1
	0.026	0.1045	0.9	0.116112897	1	1
	0.0021	0.0084	0.9	0.009378349	1	1
TOTAL	0.2488	1.0000		2.291698566		0.08018
Roughness Calculation sz (m)	0.332492					

Sector Number 10						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Shrubland	0.0086	0.0349	0.4	0.087221095	0.07	0.792991
	0.007	0.0284	0.6	0.047329277	0.07	0.881738
	0.0019	0.0077	0.9	0.008564345	0.07	0.977483
	0.001	0.0041	0.9	0.00450755	0.07	0.988085
	0.0011	0.0045	0.9	0.004958305	0.07	0.986901
Row Crops	0.0017	0.0069	0.2	0.034482759	0.1	0.923671
	0.0008	0.0032	0.6	0.00540906	0.1	0.987622
	0.0186	0.0755	0.7	0.107794842	0.1	0.780199
Transportation	0.0012	0.0049	0.6	0.00811359	0.1	0.981491
Deciduous Forest	0.0635	0.2576	0.5	0.515212982	1	1
	0.0303	0.1229	0.7	0.175601275	1	1
	0.088	0.3570	0.7	0.509997102	1	1
	0.0054	0.0219	0.7	0.031295277	1	1
Evergreen Forest	0.0079	0.0320	0.4	0.080121704	1.3	1.021244
	0.0095	0.0385	0.6	0.06423259	1.3	1.016995
TOTAL	0.2465	1.0000		1.684841753		0.48354
Roughness Calculation sz (m)	0.649684					

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (5 of 6)

Sector Number 11						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Shrubland	0.0082	0.0336	0.2	0.168170632	0.07	0.63941
	0.0046	0.0189	0.4	0.047169811	0.07	0.882112
Pasture/Hay	0.0022	0.0090	0.7	0.012891129	0.08	0.967965
Row Crops	0.0254	0.1042	0.6	0.173639595	0.1	0.670441
Transitional Barren	0.001	0.0041	0.6	0.006836205	0.2	0.989058
Deciduous Forest	0.0109	0.0447	0.2	0.223543888	1	1
	0.1906	0.7818	0.6	1.302980585	1	1
Evergreen Forest	0.0009	0.0037	0.4	0.009228876	1.3	1.002424
TOTAL	0.2438	1.0000		1.944460721		0.362908
Roughness Calculation sz (m)	0.593761					

Sector Number 12						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Shrubland	0.0059	0.0243	0.2	0.121749897	0.07	0.72342
	0.0044	0.0182	0.5	0.036318613	0.07	0.907937
	0.0009	0.0037	0.7	0.005306291	0.07	0.985988
	0.0059	0.0243	0.8	0.030437474	0.07	0.922248
Pasture/Hay	0.001	0.0041	0.4	0.010317788	0.08	0.974277
	0.0008	0.0033	0.6	0.00550282	0.08	0.986198
	0.0037	0.0153	0.7	0.021814751	0.08	0.946392
Row Crops	0.005	0.0206	0.4	0.051588939	0.1	0.887996
	0.0017	0.0070	0.6	0.011693493	0.1	0.973434
	0.0053	0.0219	0.7	0.031248158	0.1	0.930576
Woody Wetlands	0.0069	0.0285	0.8	0.035596368	0.7	0.987384
Deciduous Forest	0.007	0.0289	0.1	0.28889806	1	1
	0.0354	0.1461	0.3	0.486999587	1	1
	0.154	0.6356	0.6	1.059292888	1	1
Evergreen Forest	0.002	0.0083	0.2	0.041271151	1.3	1.010887
	0.0024	0.0099	0.5	0.019810153	1.3	1.005211
TOTAL	0.2423	1.0000		2.257846432		0.438327
Roughness Calculation sz (m)	0.693989					

Figure C.2.1. ADEC Land Classifications, Area, and Weighting for 1992 NLCD. (6 of 6)

Sector Number 1						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0445	0.1926	0.8	0.240800866	0.001	0.189494846
	0.0037	0.0160	0.7	0.02288188	0.001	0.85379648
Grassland	0.0117	0.0506	0.2	0.253246753	0.1	0.558152979
	0.007	0.0303	0.3	0.101010101	0.1	0.792482898
Deciduous Forest	0.102	0.4416	0.5	0.883116883	1	1
	0.0526	0.2277	0.8	0.284632035	1	1
	0.0095	0.0411	0.9	0.045695046	1	1
TOTAL	0.231	1.0000		1.831383564		0.07156405
Roughness Calculation sz (m)	0.236932					

Sector Number 2						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0185	0.0783	0.9	0.087026061	0.001	0.548178272
Grassland	0.0138	0.0584	0.2	0.292125318	0.1	0.510357713
	0.0034	0.0144	0.2	0.071972904	0.1	0.847280274
	0.004	0.0169	0.2	0.084674005	0.1	0.822860083
	0.0175	0.0741	0.4	0.185224386	0.1	0.652793188
Deciduous Forest	0.0182	0.0771	0.2	0.385266723	1	1
	0.0043	0.0182	0.4	0.045512278	1	1
	0.1565	0.6626	0.7	0.946534414	1	1
TOTAL	0.2362	1.0000		2.098336089		0.127328377
Roughness Calculation sz (m)	0.374486					

Sector Number 3						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0333	0.1369	0.9	0.152075627	0.001	0.349762399
Grassland	0.1338	0.5499	0.5	1.099876695	0.1	0.079455379
Deciduous Forest	0.0762	0.3132	0.6	0.521989314	1	1
TOTAL	0.2433	1.0000		1.773941636		0.027790504
Roughness Calculation sz (m)	0.132678					

Sector Number 4						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Grassland	0.2514	1.0000	0.6	1.666666667	0.1	0.021544347
TOTAL	0.2514	1.0000		1.666666667		0.021544347
Roughness Calculation sz (m)	0.1					

Figure C.2.2. ADEC Land Classifications, Area, and Weighting for 2008 Google Earth Image. (1 of 3)

Sector Number 5						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Grassland	0.1274	0.4969	0.5	0.99375975	0.1	0.101447243
	0.0115	0.0449	0.8	0.056064743	0.1	0.878891486
	0.0125	0.0488	0.9	0.054168833	0.1	0.882736667
Deciduous Forest	0.105	0.4095	0.7	0.585023401	1	1
TOTAL	0.2564	1.0000		1.689016727		0.078705788
Roughness Calculation sz (m)		0.222008				

Sector Number 6						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0087	0.0340	0.9	0.037760417	0.001	0.770404392
Grassland	0.0663	0.2590	0.3	0.86328125	0.1	0.136999427
	0.0058	0.0227	0.6	0.037760417	0.1	0.916726073
Deciduous Forest	0.1752	0.6844	0.8	0.85546875	1	1
TOTAL	0.256	1.0000		1.794270833		0.096755817
Roughness Calculation sz (m)		0.272075				

Sector Number 7						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Open Water	0.0264	0.1020	0.9	0.11338745	0.001	0.45691735
Grassland	0.104	0.4020	0.4	1.005025126	0.1	0.09884959
	0.0968	0.3742	0.7	0.534540836	1	1
Deciduous Forest	0.0315	0.1218	0.7	0.173946656	1	1
TOTAL	0.2587	1.0000		1.826900068		0.045166093
Roughness Calculation sz (m)		0.183518				

Sector Number 8						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Grassland	0.1586	0.6266	0.5	1.253259581	0.1	0.055813649
Deciduous Forest	0.0945	0.3734	0.7	0.533386013	1	1
TOTAL	0.2531	1.0000		1.786645595		0.055813649
Roughness Calculation sz (m)		0.198857				

Sector Number 9						
Land Cover Category	Area (km2)	Fraction		Weighting (Frac/Dist)	zo (m)	AVG sz (m)
		of Total Area	Distance (km)			
Grassland	0.2472	1.0000	0.6	1.666666667	0.1	0.021544347
TOTAL	0.2472	1.0000		1.666666667		0.021544347
Roughness Calculation sz (m)		0.1				

Figure C.2.2. ADEC Land Classifications, Area, and Weighting for 2008 Google Earth Image. (2 of 3)

Sector Number 10						
Land Cover Category	Area (km ²)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	z ₀ (m)	AVG sz (m)
Grassland	0.1559	0.6493	0.5	1.298625573	0.1	0.050277587
Deciduous Forest	0.0842	0.3507	0.8	0.438359017	1	1
TOTAL	0.2401	1.0000		1.73698459		0.050277587
Roughness Calculation sz (m)	0.1788					

Sector Number 11						
Land Cover Category	Area (km ²)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	z ₀ (m)	AVG sz (m)
Grassland	0.0258	0.1096	0.2	0.547770701	0.1	0.283288731
	0.0376	0.1597	0.6	0.266100495	0.1	0.541875486
Deciduous Forest	0.0513	0.2178	0.4	0.544585987	1	1
	0.1208	0.5130	0.8	0.64118896	1	1
TOTAL	0.2355	1.0000		1.999646143		0.153507219
Roughness Calculation sz (m)	0.391735					

Sector Number 12						
Land Cover Category	Area (km ²)	Fraction of Total Area	Distance (km)	Weighting (Frac/Dist)	z ₀ (m)	AVG sz (m)
Grassland	0.0136	0.0528	0.2	0.263770365	0.1	0.544790637
	0.0094	0.0365	0.5	0.072924748	0.1	0.845425323
Deciduous Forest	0.0785	0.3045	0.5	0.608999224	1	1
	0.0354	0.1373	0.3	0.457719162	1	1
	0.1209	0.4690	0.7	0.669954561	1	1
TOTAL	0.2578	1.0000		2.073368059		0.460579801
Roughness Calculation sz (m)	0.688033					

Figure C.2.2. ADEC Land Classifications, Area, and Weighting for 2008 Google Earth Image. (3 of 3)

**APPENDIX D: Base and Attainment Year Emission Inventories for the Oneida County
Nonattainment Area**

Oneida County SO₂ emissions from nonpoint sources

SCC	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four	Annual emissions (tons)				
					2011 whole county	2011 partial county (NAA)	2018 whole county	2018 partial county (NAA)	2017 partial county (NAA)
2103004001	Stationary source fuel combustion	Commercial/institutional	Distillate oil	Boilers	0.6289	0.3149	0.6289	0.3115	0.3120
2104002000	Stationary source fuel combustion	Residential	Bituminous/subbituminous coal	Total: all combustor types	1.1365	0.5691	1.1365	0.5629	0.5638
2810060100	Miscellaneous area sources	Other combustion	Cremation	Humans	0.0182	0.0091	0.0182	0.0090	0.0090
2103002000	Stationary source fuel combustion	Commercial/institutional	Bituminous/subbituminous coal	Total: all boiler types	2.2738	1.1385	2.2738	1.1261	1.1279
2102011000	Stationary source fuel combustion	Industrial	Kerosene	Total: all boiler types	0.0002	0.0001	0.0002	0.0001	0.0001
2104006000	Stationary source fuel combustion	Residential	Natural gas	Total: all combustor types	0.2630	0.1317	0.2630	0.1302	0.1304
2102006000	Stationary source fuel combustion	Industrial	Natural gas	Total: boilers and IC engines	0.0190	0.0095	0.0190	0.0094	0.0094
2103006000	Stationary source fuel combustion	Commercial/institutional	Natural gas	Total: boilers and IC engines	0.1394	0.0698	0.1394	0.0691	0.0692
2102005000	Stationary source fuel combustion	Industrial	Residual oil	Total: all boiler types	0.0631	0.0316	0.0631	0.0313	0.0313
2103005000	Stationary source fuel combustion	Commercial/institutional	Residual oil	Total: all boiler types	0.0000	0.0000	0.0000	0.0000	0.0000
2104001000	Stationary source fuel combustion	Residential	Anthracite coal	Total: all combustor types	0.0116	0.0058	0.0116	0.0057	0.0057
2610004000	Waste disposal, treatment, and recovery	Open burning	All categories	Yard waste - brush species unspecified	0.1018	0.0510	0.1018	0.0504	0.0505
2102004001	Stationary source fuel combustion	Industrial	Distillate oil	All boiler types	0.1276	0.0639	0.1276	0.0632	0.0633

SCC	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four	Annual emissions (tons)				
					2011 whole county	2011 partial county (NAA)	2018 whole county	2018 partial county (NAA)	2017 partial county (NAA)
2102008000	Stationary source fuel combustion	Industrial	Wood	Total: all boiler types	0.0000	0.0000	0.0000	0.0000	0.0000
2103011000	Stationary source fuel combustion	Commercial/institutional	Kerosene	Total: all combustor types	0.0000	0.0000	0.0000	0.0000	0.0000
2103008000	Stationary source fuel combustion	Commercial/institutional	Wood	Total: all boiler types	0.0018	0.0009	0.0018	0.0009	0.0009
2104011000	Stationary source fuel combustion	Residential	Kerosene	Total: all heater types	0.0855	0.0428	0.0855	0.0423	0.0424
2104004000	Stationary source fuel combustion	Residential	Distillate oil	Total: all combustor types	4.1441	2.0750	4.1441	2.0524	2.0557
2610000100	Waste disposal, treatment, and recovery	Open burning	All categories	Yard waste - leaf species unspecified	0.0466	0.0233	0.0466	0.0231	0.0231
2102007000	Stationary source fuel combustion	Industrial	Liquefied petroleum gas (LPG)	Total: all boiler types	0.0000	0.0000	0.0000	0.0000	0.0000
2102002000	Stationary source fuel combustion	Industrial	Bituminous/subbituminous coal	Total: all boiler types	0.0000	0.0000	0.0000	0.0000	0.0000
2104007000	Stationary source fuel combustion	Residential	Liquefied petroleum gas (LPG)	Total: all combustor types	0.1203	0.0602	0.1203	0.0596	0.0597
2610030000	Waste disposal, treatment, and recovery	Open burning	Residential	Household waste (use 26-10-000-xxx for yard wastes)	1.3401	0.6710	1.3401	0.6637	0.6648
2103007000	Stationary source fuel combustion	Commercial/institutional	Liquefied petroleum gas (LPG)	Total: all combustor types	0.0080	0.0040	0.0080	0.0040	0.0040
2104008230	Stationary source fuel combustion	Residential	Wood	Woodstove: fireplace inserts, EPA certified, catalytic	0.0212	0.0106	0.0250	0.0124	0.0122
2104008330	Stationary source fuel combustion	Residential	Wood	Woodstove: freestanding, EPA certified, catalytic	0.2384	0.1194	0.2816	0.1394	0.1366
2104008310	Stationary source fuel combustion	Residential	Wood	Woodstove: freestanding, non-EPA certified	0.6822	0.3416	0.6685	0.3311	0.3326

SCC	SCC Level One	SCC Level Two	SCC Level Three	SCC Level Four	Annual emissions (tons)				
					2011 whole county	2011 partial county (NAA)	2018 whole county	2018 partial county (NAA)	2017 partial county (NAA)
2104008400	Stationary source fuel combustion	Residential	Wood	Woodstove: pellet-fired, general (freestanding or FP insert)	0.0417	0.0209	0.0685	0.0339	0.0321
2104008610	Stationary source fuel combustion	Residential	Wood	Hydronic heater: outdoor	9.3825	4.6978	11.6061	5.7482	5.5981
2104008210	Stationary source fuel combustion	Residential	Wood	Woodstove: fireplace inserts, non-EPA certified	0.1555	0.0779	0.1395	0.0691	0.0703
2104008100	Stationary source fuel combustion	Residential	Wood	Fireplace: general	0.2507	0.1255	0.2688	0.1331	0.1320
2104008220	Stationary source fuel combustion	Residential	Wood	Woodstove: fireplace inserts, EPA certified, non-catalytic	0.0661	0.0331	0.0781	0.0387	0.0379
2104008510	Stationary source fuel combustion	Residential	Wood	Furnace: Indoor, cordwood-fired, non-EPA certified	3.5563	1.7806	3.9226	1.9427	1.9196
2104008320	Stationary source fuel combustion	Residential	Wood	Woodstove: freestanding, EPA certified, non-catalytic	0.2159	0.1081	0.2550	0.1263	0.1237
2104008700	Stationary source fuel combustion	Residential	Wood	Outdoor wood burning device, NEC (fire-pits, chimneys, etc.)	0.4202	0.2104	0.4505	0.2231	0.2213
Total annual emissions (tons):					25.5601	12.7980	28.2936	14.0130	13.8395

2011 Oneida County SO₂ emissions from mobile sources

Sector	Emissions (tons per year)	Source
On road	5.179	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2011emissions/onroad_by_state/
Commercial marine	0.000	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2011emissions/nonpoint_by_state/
Aircraft	3.378	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2011emissions/point_by_state/
Railroad	0.062	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2011emissions/nonpoint_by_state/
All other nonroad	1.442	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2011emissions/nonroad_by_state/
Total	10.061	

Note: Emissions were estimated using U.S. EPA's emissions modeling platform (2011v6/v1platform).

2018 Oneida County SO₂ emissions from mobile sources

Sector	Emissions (tons per year)	Source
On road	2.053	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2018emissions/onroad_by_state/
Commercial marine	0.000	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2018emissions/nonpoint_by_state/
Aircraft	3.673	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2018emissions/point_by_state/
Railroad	0.002	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2018emissions/nonpoint_by_state/
All other nonroad	0.663	ftp://ftp.epa.gov/EmisInventory/2011v6/v1platform/2018emissions/nonroad_by_state/
Total	6.392	

Note: Emissions were estimated using U.S. EPA's emissions modeling platform (2011v6/v1platform).

APPENDIX E: WDNR Response to Comments on the Oneida County 2010 SO₂ NAAQS SIP

Comment #	Commenter	Date of Comment	Comment	Response
1	Forest County Potawatomi Community (FCPC)	December 15, 2015	FCPC believes SO ₂ design values for FCPC monitor are valid and not due to possible equipment issues as suggested by WDNR. FCPC requests the statement regarding FCPC design values are removed from Appendix A: Air Quality Analysis, July 25, 215, page 25.	<p>WDNR removes, “The increase in measured values at Forest County may be due to equipment issues as data from January 2015 have decreased to long term values” from Appendix A, Air Quality Analysis, July 25, page 25.</p> <p>WDNR adds, “Horicon is centrally located within Wisconsin, and measured values are representative of SO₂ background values for a large area of the state. In addition, the Horicon monitoring station uses high sensitivity SO₂ monitoring equipment that is designed to measure low concentrations. The Horicon monitoring data will be used as background concentration for many types of future SO₂ analyses, including those associated with designations related to EPA’s Final Data Requirements Rule” to Appendix A, Air Quality Analysis, July 25, page 25.</p> <p>Regarding the FCPC monitor, WDNR acknowledges that all quarters from 2012-2014 do meet 75% data completeness criteria as shown in AQS, though some quarters are close to that threshold.</p>
2	FCPC	December 15, 2015	FCPC notes that typographical error on page 9, recommends 3.20 pounds per hour be revised to mmBtu. FCPC also recommends that including enforcement for the 3.00 pound per mmBtu – 24 average.	WDNR revises sentence to read, “An emission rate limit of 3.00 pounds per mmBtu on a 24-hour basis based on modeling the emission rate of 3.2 pounds per mmBtu.

3	FCPC	December 15, 2015	FCPC supports measures to bring the Rhinelander area into attainment of the SO ₂ NAAQS and the back-up plan requiring implementation of a Continuous Emissions Monitor (CEM) if SO ₂ concentrations exceed the rate of 75 ppb on an hourly basis during four or more individual days over any twelve month rolling period. FCPC is also pleased to see the goal for reaching attainment has been set at one year.	No response necessary.
4	FCPC	December 15, 2015	FCPC is concerned that the result of increasing the stack height could potentially increase SO ₂ ambient concentrations and deposition levels on Tribal lands. They will have the opportunity to observe any changes as they operate monitors and collectors.	No response necessary.