



Alliant Energy Corporate Service  
Legal Department  
608.458.0512 – Phone

Arshia Javaherian  
Regulatory Attorney

Wisconsin Power and Light Company  
An Alliant Energy Company

4902 North Biltmore Lane  
Madison, WI 53718

Office: 1.800.822.4348  
[www.alliantenergy.com](http://www.alliantenergy.com)

June 21, 2011

Dr. Burl Haar, Executive Secretary  
Minnesota Public Utilities Commission  
121 7<sup>th</sup> Place East, Suite 350  
St. Paul, MN 55101-2147

RE: Wisconsin Power and Light Company  
Docket No. ET6657/WS-08-573  
Compliance Filing

Dear Dr. Haar:

On March 14, 2011, the Minnesota Public Utilities Commission issued its Order in the above-referenced docket approving Wisconsin Power and Light Company's (WPL) Operational Sound Level Survey Test Protocol for the Bent Tree Wind Project as proposed pursuant to Site Permit Condition III.F.2. with additional data requirements. WPL respectfully submits its completed Survey of Operational Sound Levels for the Bent Tree Wind Project as prepared by Hessler Associates, Inc.

Copies of this submittal have been served on the Minnesota Department of Commerce, Division of Energy Resources by e-filing and the Minnesota Office of Attorney General – Residential and Small Business Utilities Division and the attached service list.

Yours Truly,

By: /s/ Arshia Javaherian  
Arshia Javaherian  
Regulatory Attorney

AJ/tao  
Enclosure

cc: Service List

**STATE OF MINNESOTA**  
**BEFORE THE MINNESOTA PUBLIC UTILITIES COMMISSION**

**Ellen Anderson**  
**David Boyd**  
**J. Dennis O'Brien**  
**Phyllis A. Reha**  
**Betsy Wergin**

**Chair**  
**Commissioner**  
**Commissioner**  
**Commissioner**  
**Commissioner**

**IN THE MATTER OF WISCONSIN  
POWER AND LIGHT COMPANY'S  
SITE PERMIT APPLICATION FOR  
A LARGE WIND ENERGY  
CONVERSION SYSTEM**

**DOCKET NO. ET6657/WS-08-573**

**AFFIDAVIT OF SERVICE**

STATE OF IOWA    )  
                          ) ss.  
COUNTY OF LINN )

Tonya A. O'Rourke, being first duly sworn on oath, deposes and states:

That on the 21<sup>st</sup> day of June, 2011, copies of the foregoing Affidavit of Service, together with Wisconsin Power and Light Company's Compliance Filing, were served upon the parties on the attached service list, by e-filing, overnight delivery, electronic mail, and/or first-class mail, proper postage prepaid from Cedar Rapids, Iowa.

/s/ Tonya A. O'Rourke  
Tonya A. O'Rourke

Subscribed and Sworn to Before Me  
This 21<sup>st</sup> day of June, 2011.

/s/ Kimberly A. Burrows  
Kimberly A. Burrows  
Notary Public  
My Commission expires February 2, 2012

First Name	Last Name	Email	Company Name	Address	Delivery Method	View Trade Secret	Service List Name
Julia	Anderson	Julia.Anderson@state.mn.us	Office of the Attorney General-DOC	1400 BRM Tower 445 Minnesota St St. Paul, MN 551012131	Electronic Service	Yes	OFF_SL_8-573_1
Sharon	Ferguson	sharon.ferguson@state.mn.us	Department of Commerce	85 7th Place E Ste 500  Saint Paul, MN 551012198	Electronic Service	Yes	OFF_SL_8-573_1
Ronald M.	Giteck	ron.giteck@state.mn.us	Office of the Attorney General-RUD	Residential Utilities Division  445 Minnesota Street, BRM Tower St. Paul, MN 55101	Paper Service 900	Yes	OFF_SL_8-573_1
Burl W.	Haar	burl.haar@state.mn.us	Public Utilities Commission	Suite 350 121 7th Place East St. Paul, MN 551012147	Electronic Service	Yes	OFF_SL_8-573_1
Arshia	Javaherian	arshiajavaherian@alliantenergy.com	Interstate Power and Light.	PO Box 351  Cedar Rapids, IA 524060351	Paper Service	No	OFF_SL_8-573_1
Jim	Lepinski	jim.lepinski@psc.state.wi.us	Public Service Commission of Wisconsin	610 North Whitney Way PO Box 7854 Madison, WI 537077854	Paper Service	No	OFF_SL_8-573_1
John	Lindell	agorud.ecf@state.mn.us	Office of the Attorney General-RUD	900 BRM Tower 445 Minnesota St St. Paul, MN 551012130	Electronic Service	Yes	OFF_SL_8-573_1
Katie	Troe	kvtr@juno.com	Safe Wind in Freeborn County	27510 - 775th Avenue  Clarks Grove, MN 56016	Paper Service	No	OFF_SL_8-573_1
Robyn	Woeste	robynwoeste@alliantenergy.com	Interstate Power and Light Company	P.O. Box 351 200 First St SE Cedar Rapids, IA 524060351	Paper Service	No	OFF_SL_8-573_1

**REPORT NO. 1873-052811-A**

REV: A  
DATE OF ISSUE: JUNE 17, 2011

**SURVEY OF OPERATIONAL SOUND LEVELS  
BENT TREE WIND FARM**

HARTLAND, MN

PREPARED FOR:

**Wisconsin Power and Light Company**

Prepared by:

David M. Hessler, P.E., INCE  
Principal Consultant  
Hessler Associates, Inc.





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## 1.0 INTRODUCTION

Hessler Associates, Inc. has been retained by Wisconsin Power and Light Company (WPL) to conduct a field survey of the sound levels produced by its newly operational Bent Tree Wind Farm Project near the Town of Hartland in Freeborn County, Minnesota. The project consists of 122 Vestas V82 wind turbines distributed fairly uniformly over roughly 25 square miles of open, mildly undulating farmland. The survey was conducted over a 15 day period from April 5 to 20, 2011. The principal objective of the study was to evaluate the sound emissions of the project relative to the noise standards imposed on the project by Freeborn County.

The survey was carried out in accordance with a project-specific test procedure (Attachment A) approved by the Minnesota Public Utilities Commission on March 14, 2011. In general, the survey used ten continuously recording sound monitors at key positions throughout the site area and beyond to measure operational sound levels day and night over wide variety of wind and weather conditions. The results were evaluated for compliance with the daytime and nighttime County noise standards, which are expressed as L50 and L10 statistical sound levels. Additional measurements were also recorded to assess the low frequency emissions of the project.

### 1.1 EXECUTIVE SUMMARY

An extensive field survey has been carried out to measure the sound levels produced by the Bent Tree Wind Farm Project in order to evaluate compliance with the Freeborn County noise limits, which derive from the State of Minnesota noise standards and are expressed in terms of daytime and nighttime L10 and L50 statistical levels as tabulated below.

**Table 1.1.1** *Project Sound Level Limits*

Daytime (7 a.m. to 10 p.m.)		Nighttime (10 p.m. to 7 a.m.)	
L10	L50	L10	L50
65 dBA	60 dBA	55 dBA	50 dBA

A total of approximately 2100 10 minute samples were taken on a continuous day and night basis over a 15 day period at each of 10 monitoring stations distributed throughout the project area and beyond. Seven positions were set up at or near residences where maximum project sound levels were anticipated (due to the proximity and number of nearby turbines) and three positions were set-up several miles from the site perimeter in diametrically opposed directions to develop a time history of the background level that would most likely have occurred on the site physically between these positions in the absence of the project at any given time during the survey. This background sound level was subsequently subtracted from the on-site measurements to derive the likely project-only sound level – the quantity actually limited by the County noise standards.

The survey was carried out from April 5 to 20, 2011 during early spring conditions. A wide variety of high wind periods, wind directions and atmospheric conditions were captured during the survey.

In general, it was found that the sound levels produced exclusively by the project (after correction for background, local contamination, rain and turbine operation) were lower than the permissible noise limits the vast majority of the time; however, there were occasions when the project sound level apparently exceeded the limits either momentarily or for more extended periods of time at all positions in very high wind conditions. These excursions were rare and infrequent, however, generally occurring for a cumulative total of between 1 and 2% of time; i.e. over the observed survey period of 15 days. The specific results for the seven on-site receptor locations are tabulated below.

**Table 1.1.2** *Summary of Results at On-Site Receptor Positions*

Position	Percent of Time in Compliance with Applicable Limits	
	L10	L50
1	99.3%	98.3%
2	100.0%	98.8%
3	95.0%	92.5%
4	99.0%	98.5%
5	99.9%	98.2%
6	99.7%	98.5%
7	99.1%	98.4%
<b>Site-Wide Average</b>	<b>98.9%</b>	<b>97.6%</b>

As illustrated in the table, the results are highly consistent from one location to another, except at Position 3 where the monitor position was considerably closer to the nearest turbine than the residence it was intended to represent and where the meter happened to be directly downwind of the turbine during the period of the survey when the maximum winds were experienced. Thus, the result there is considered anomalous and higher than it should be. On average, however, still accepting the Position 3 result at face value, site-wide compliance with the County/State noise limits was found to be 98.9% for the L10 statistical measure and 97.6% for the L50 level. As stated in Section 7.0 of the Test Protocol, a compliance rate of 95% or greater is considered satisfactory evidence of compliance with the applicable noise standards. Consequently, it can be concluded that the sound emissions from the project are compliant with the Freeborn County noise standards.

Additional analyses of the L90 statistical sound level, which generally yields a more accurate value for project-only sound than the L10 and L50 measures due to its higher signal-to-noise ratio, were carried out for each monitoring site and compared to model predictions at those locations. Good agreement was generally observed between the measured and modeled levels at low to moderate wind speeds but during very high wind conditions (>11 m/s) the actual project sound levels appear to significantly exceed the predicted levels. It is generally under these elevated wind conditions that the project was found to exceed the County noise standards.

Although the regulatory noise limits place no restriction on the frequency content of the project's sound emissions or on low frequency sound levels, a frequency analysis was carried out to evaluate the potential for low frequency noise emissions. Measurements of the 1/3 octave band frequency spectrum, measured down to 6.3 Hz, taken both on the site and miles away from the site show that the low frequency sound levels are generally the same and that both are driven by wind-induced, false-signal noise rather than by any actual source of low frequency noise.

The C-weighted sound levels measured at all on-site positions were also compared to the C-weighted levels measured at the three off-site background locations. C-weighted sound levels generally reflect and quantify a signal's low frequency content and, in this case, merely measure the degree of microphone distortion due to local wind effects. These comparisons show that the off-site levels of ostensible low frequency noise were often higher than or similar to the on-site levels demonstrating that the turbines are not producing any significant low frequency sound emissions.



## **2.0 SURVEY METHODOLOGY**

### **2.1 GENERAL APPROACH**

The principal technical challenge in carrying out a survey of wind turbine sound emissions centers around separating the project-only sound level due exclusively to the turbines from the concurrent background noise level associated with such things as trees rustling, cars passing by, planes flying over, etc. At typical setback distances project and non-project sounds are often of similar in both a qualitative and quantitative sense, meaning that the total measured sound level is usually strongly influenced by background noise and cannot be taken at face value as reflecting only project noise. In the pre-construction background sound level survey carried out in March of 2010 [2] L50 and L10 sound levels in excess of the County limits were measured in the obvious absence of any turbines simply due to natural wind-induced sounds.

The quantity sought in this study is the project-only sound level since that is the value limited by regulations. Since under most circumstances the background sound level is too high to directly measure project-only noise, the only practical way of determining the project's actual sound level is to measure the total sound; measure, estimate, or otherwise deduce the background level occurring under identical wind and atmospheric conditions; and then subtract the background level from the total to derive the project-only level.

For this survey the total sound level was measured by continuously recording sound level monitors at 7 points within the site area at or near residences with the greatest potential exposure to project noise and, importantly, at 3 additional monitoring stations roughly 2 miles or more beyond the project perimeter in diametrically opposed directions to record the background level that probably would have existed within the project area between these positions at any given time throughout the survey. This proxy background level is then used to correct the total levels measured at the on-site positions – yielding the project-only sound level.

### **2.2 SITE DESCRIPTION AND MEASUREMENT POSITIONS**

The Bent Tree site area is rural and can be characterized as consisting essentially of farms on relatively large tracts of land irregularly interspersed with scattered farmhouses and other residences on smaller parcels. The site topography is largely flat with only minor undulations that would have no real bearing on sound propagation. In terms of vegetation, the area consists of open fields but most of the residences have some trees immediately around the house.

Seven measurement locations were chosen to be at or near residences with the maximum exposure to potential project sound emissions due to the proximity and number of nearby turbines. These are the same positions used in the pre-construction background survey [2], which were selected at that time with this post-construction survey in mind. The specific positions are shown in **Graphic A** and described below along with photographs of each location. As will be noted from the pictures, most of the monitors were located on utility poles in the public right of way but two, Positions 5 and 7, were set up on private property with the permission of the landowners.





**Position 1 – 68595 300<sup>th</sup> St. (CR 31)**

The monitor was located on a utility pole opposite a residence (68595) on the north side of 300<sup>th</sup> Street and just east of another house on the same road.



**Figure 2.2.1A** *Position 1 Looking S Towards 68595*



**Figure 2.2.1B** *Position 1 Looking W toward T392*



**Position 2 – 70435 290<sup>th</sup> St. (CR 95)**

This position was intended to be conservatively representative of two residences on CR 95, 70286 and 70435, in the sense that the measurement point was considerably closer (300 to 400 ft.) to the nearest turbine (T132) than the houses themselves. Two instruments (for redundancy) were placed on a utility pole on the north side of the road opposite the driveway to 70435.



**Figure 2.2.2A** *Position 2 Looking S Towards 70435 290<sup>th</sup> St. and T397*



**Figure 2.2.2B** *Position 2 Looking NE Towards T132*



**Position 3 – 28281 690<sup>th</sup> Ave. (T335)**

Two monitors (again for redundancy) were located on a utility pole on the east side of 690<sup>th</sup> Ave. roughly 500 ft. south of 28281. This position is conservative in that it is substantially closer to the nearest turbine (T423) than any of the other homes in the area. Specifically, the monitor was 830 ft. west of T423 whereas the nearest house (28281) is 1130 ft. to the WNW. Consequently, the measurement point was well within the minimum set back distance to residences.



**Figure 2.2.3A** *Position 3 Looking NW Towards 28281 690<sup>th</sup> Ave.*



**Figure 2.2.3B** *Position 3 Looking ESE Towards T423 and Other Units*



**Position 4 – 72047 290<sup>th</sup> St. (CR 95)**

The monitor was located on a utility pole on the north side of 290<sup>th</sup> St. across the street from and about 400 ft. west of 72047 - making the measurement point considerably closer to the nearest turbine (T360) than the residence.



**Figure 2.2.4A** *Position 4 Looking E Towards 72047 290<sup>th</sup> St.*



**Figure 2.2.4B** *Position 4 Looking W*



**Position 5 – 71255 275<sup>th</sup> St.**

This position near the center of the project site is surrounded on all sides by a number of units and is one the several residences with essentially maximum exposure to project sound emissions. Two sound monitors (A-weighted and a 1/3 octave band frequency analyzer) were set up on posts about 100 ft. from the house. As illustrated in the figures, a temporary weather station was also set up at this position because of its central location within the project area. The anemometer was set at the typical microphone elevation of about 3 ft. and was exposed to the wind from all directions, although a thin stand of trees to the south and west may have provided some shielding from winds coming from those directions.



**Figure 2.2.5A** *Position 5 Looking S, Weather Station and Monitors*



**Figure 2.2.5B** *Position 5 Looking ENE, Weather Station and Monitors*

## **Position 6 – 29271 690<sup>th</sup> Ave.**

The monitor was located on a utility pole near a residence at the intersection of 690<sup>th</sup> Avenue and 260<sup>th</sup> Street. This house was in the process of being rebuilt after suffering severe tornado damage and distant hammering and sawing sounds were audible at the time the instrument was set up. Note that the evergreen trees that previously existed in front of house (Figure 2.2.6B) were completely obliterated by the storm.



**Figure 2.2.6A** *Position 6 Looking W Towards Residence – Current Survey*



**Figure 2.2.6B** *Position 6 Looking W Towards Residence – March 2010 Survey Prior to Tornado Damage*

**Position 7 – 71610 263<sup>rd</sup> St.**

The monitor was located on a tree in the front yard of a home on 263<sup>rd</sup> Street.



**Figure 2.2.7A** *Position 7 Looking NNE Towards Residence*



**Figure 2.2.7B** *Position 7 Looking SSW Towards T368 (on Right)*

In addition to these on-site locations three off-site monitoring stations were established at locations surrounding the project area that were similar in character to the principal measurement points but removed from any significant exposure to turbine noise.



## **Remote East – Near the Intersection of 290<sup>th</sup> St. and 750<sup>th</sup> Ave.**

Two monitors (A-weighted and a 1/3 octave band frequency analyzer) were located on a utility pole on the east side of 750<sup>th</sup> Ave. in an open field over 2 miles (10,890 ft.) from the nearest turbine (T173). This area is very quiet and removed from any homes or substantial traffic noise. 750<sup>th</sup> Ave. is a little-used dirt road and experiences only occasional vehicles.



**Figure 2.2.8** *Position Remote East Looking W towards the Project Area*

## **Remote North – Near 33116 715<sup>th</sup> Ave.**

The monitor was located on a utility pole on the east side of 715<sup>th</sup> Ave. in an open field nearly 3 miles (14,600 ft.) from the nearest turbine (T463). This area is quiet and isolated. The farm structures at this address have collapsed and the property is unoccupied.



**Figure 2.2.9** *Position Remote North Looking SE towards the Project Area*



**Remote South – Near the Intersection of 245<sup>th</sup> St. and 650<sup>th</sup> Ave.**

The monitor was located on a utility pole on the east side of 650<sup>th</sup> Ave. in an open field at the top of a slight rise 3.3 miles (17,400 ft.) from the nearest turbine (T312) in the southwestern corner of the site. This position (on lightly traveled local roads) is 1 mile east of CR 6 and 3 miles north of I-90.



**Figure 2.2.10** *Position Remote South Looking NE towards the Project Area*

## 2.3 INSTRUMENTATION AND MEASUREMENT QUANTITIES

Rion NL Series sound level meters (NL-32, and NL-22) ANSI Type 1 and 2 (respectively) sound level meters were used at all positions and Norsonic 140, ANSI Type 1, 1/3 octave band analyzers were used at Position 5 near the center of the site and at the Remote East position. Each meter was enclosed in a watertight case fitted with a 12" microphone boom.

The microphones on all instruments were protected from wind-induced self-noise by oversized 180 mm (7 in.) diameter foam windscreens (ACO Model WS7-80T) and were situated at a fairly low elevation of about 1 m above grade to minimize their exposure to wind. Wind speed normally diminishes rapidly close to the ground, theoretically going to zero at the surface. Wind tunnel experiments [3] for this type of windscreen demonstrate that self-generated wind noise affects only the lower frequencies and, except in extremely high wind conditions, has little or no influence on the measured A-weighted level (the principal quantity sought in the survey), since A-weighting, just like the human ear, is relatively insensitive to low frequency sound. The wind speed at microphone height was measured during the survey using an Onset Microstation anemometer at Position 5.

All equipment was field calibrated at the beginning of the survey and again at the end of the survey. The observed calibration drift of all the instruments was a positive value between 0 and +0.5 dB, meaning that some of the instruments recorded slightly higher sound levels than were actually present for some portion of the survey – but none recorded lower levels.

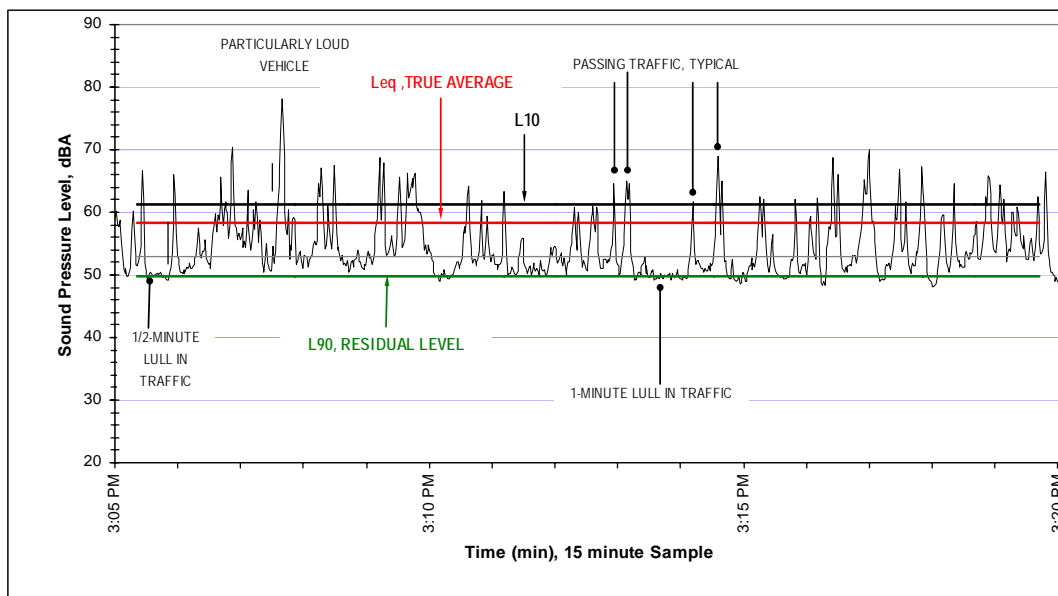
Because the County/State noise standards are expressed as L10 and L50 statistical sound levels these measures were recorded in 10 minute increments by all instruments to correspond to the wind speed data collection frequency of the met towers. In addition, the more commonly used "residual", or L90, statistical level was also measured along with the average C-weighted level (LCeq) for each 10 minute period.

These statistical levels represent the sound level that is exceeded a certain percentage of the measurement period. For example, the L90 level is the sound level that is exceeded for 90% of each 10 minute measurement period; meaning that the actual sound level was *louder* than the L90 level for a cumulative total of 9 minutes out of every 10. This particular metric is commonly used as a conservative measure of environmental background levels since it captures the momentary, quiet lulls between sporadic noise events, such as cars passing by, wind gusts, or planes flying over, and quantifies the near-minimum level that is consistently present and available to potentially mask noise from a new source. Because contaminating events are largely excluded by the L90, this measure is also useful for measuring sound levels from operational wind projects because it normally has a higher signal to noise ratio; i.e. it is least affected by contamination and has a greater tendency to record the more or less constant sound level associated with the project.

The L10 level, on the other hand, captures the near-maximum level, since the actual sound level is only higher than this measure 10% of the time (and quieter 90% of the time). This statistical tends to be dominated by and reflect the sound level of sporadic noise events rather than project noise.

The L50 statistical measure lies in between the L10 and L90 in the sense that it captures the median sound level that is exceeded 50% of the time. It is similar to but technically slightly different than the actual average sound level (Leq).

The L90, L10 and Leq levels are illustrated graphically in Figure 2.3.1.



**Figure 2.3.1** Sample 15 minute Measurement Showing L90, L10 and Leq Sound Levels

The designation “LA90” or “LA50” is sometimes used to indicate that the level represents the A-weighted sound level. Unless otherwise noted all sound levels presented in this report are A-weighted levels.

The only exception to this is the average C-weighted sound level, or LCeq, that was also recorded for informational purposes. A-weighted sound levels re-shape the frequency spectrum to make the sound qualitatively correspond with the sensitivity of the human ear, which is highly insensitive to low frequency sounds. The C-weighted level, on the other hand, is only very slightly re-shaped in the lower frequencies so that its value is heavily dependent on and, in fact, dominated by the low



frequency content of the sound. Consequently, C-weighted sound levels are used exclusively in applications where the low frequency sound emissions of a source are of concern; principally, in the specification and testing of simple cycle combustion turbines.

The C-weighted sound levels measured in this survey are considered “informational” because, except for a small percentage of the measurements recorded during perfectly calm wind conditions, they are not a true indication of the low frequency sound present in the environment. Wind blowing through the windscreen and over the microphone tip creates a substantial amount of false signal noise in the low end of the frequency spectrum that is essentially unavoidable in long-term monitoring applications, even with the over-sized windscreens employed in this survey. Because the C-weighted sound level is dominated by the lower frequencies this distortion resulting from windy conditions dramatically skews the C-weighted levels upwards - usually to the point where it is purely a quantification of this measurement error rather than the actual sound level. Wind tunnel testing [3] indicates that this error does not affect the A-weighted sound level, which is highly insensitive to the lower frequencies, to any significant extent at the wind speeds of relevance to wind turbine field surveys (generally less than about 8 m/s at microphone elevation).

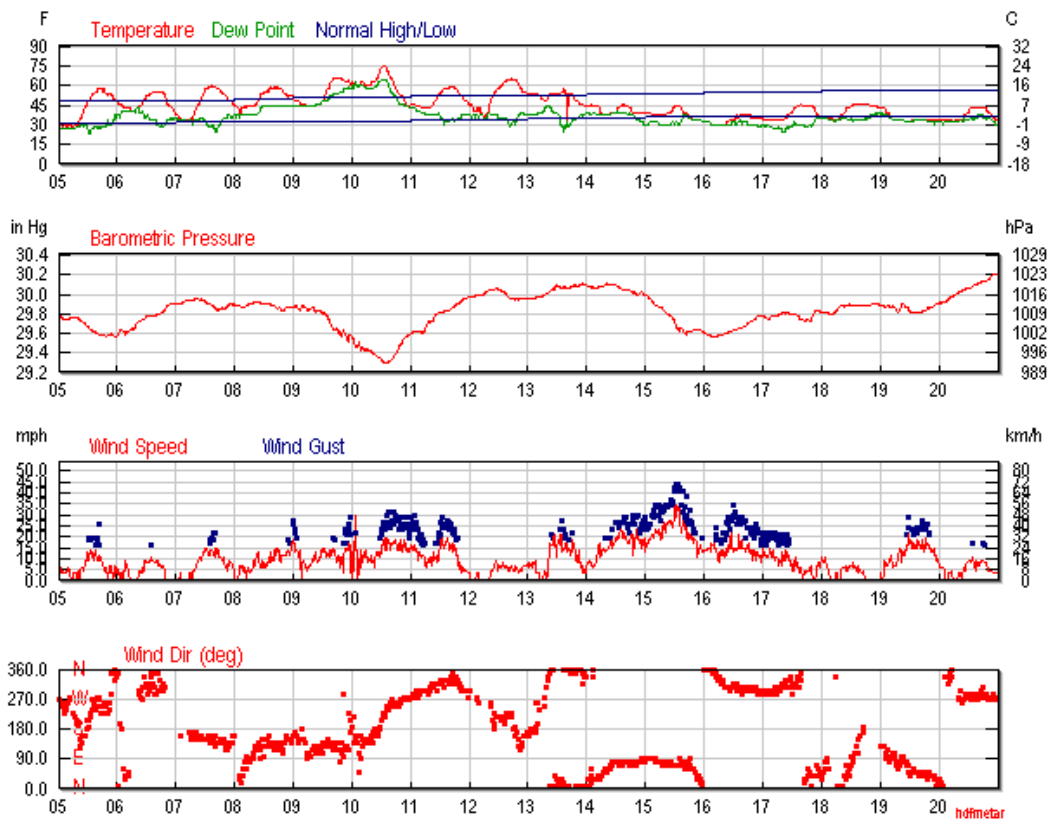
Consequently, as discussed more fully in Section 3.5, the recorded C-weighted sound levels in this survey cannot and should not be construed as a quantification of the low frequency emissions from the turbines.

Moreover, the L10 and L50 levels called out in the County/State noise standards are prone to contamination from sources unrelated to the project and they also cannot be taken at face value as being a pure reflection of project noise.

In order to quantitatively evaluate these drawbacks, recordings of all A and C-weighted measures were taken both on the site and several miles away from the site at the three remote positions to help sort out and identify how much of the measured signal can be reasonably attributed to the project.

## 2.4 SURVEY WEATHER CONDITIONS

A variety of weather conditions occurred during the survey period including several periods of very high wind, light snow, rain, at least one major thunderstorm and a wide array of wind directions and temperatures (ranging from 29 to 75 deg. F). The general weather parameters during the survey period as observed in Albert Lea, several miles south of the project area, are shown below.



**Figure 2.4.1** General Survey Weather Conditions as Observed in Albert Lea, MN.

The specific wind and weather conditions at the site itself were measured by two on-site met towers – 712 near Position 6 in the southern part of the site and 1712 not far from the Remote North measurement position - and by an additional weather station set up at Position 5 in the center of the site.

For analysis purposes the wind speed at a standard elevation of 10 m above ground level is of interest because turbine sound levels are normally expressed as a function of the 10 m speed per IEC 61400-11 [1]. The average wind speeds recorded by the 58 m anemometers on the north and south met towers are normalized to 10 m per Ref. 1 in the plot below.

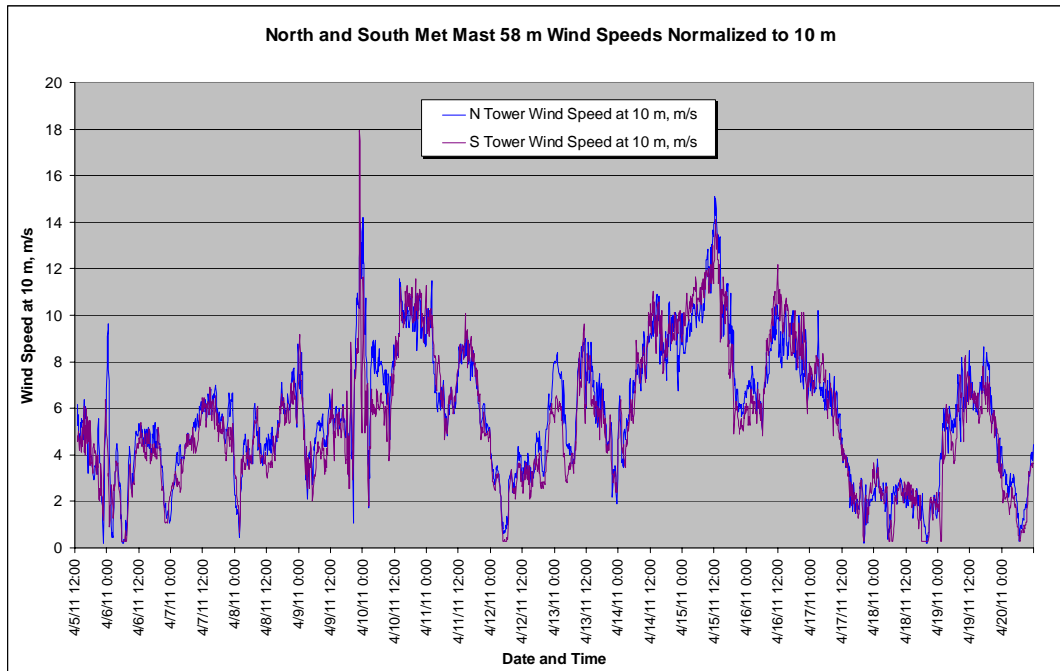


Figure 2.4.2

This figure shows that the wind speeds measured by both towers were not identical at all times - as would be expected since the two towers are nearly 6 miles apart - but are still remarkably uniform suggesting that the wind speed at any point within the site area at any given time was similar in value to what was measured by the met towers. Consequently, the average of the two can be taken as the site-wide design wind speed.

This average 10 m wind speed is compared to the wind speed measured at 1 m above grade (microphone height) at Position 5 in Figure 2.4.3. Periods of rainfall are also shown in this graphic.

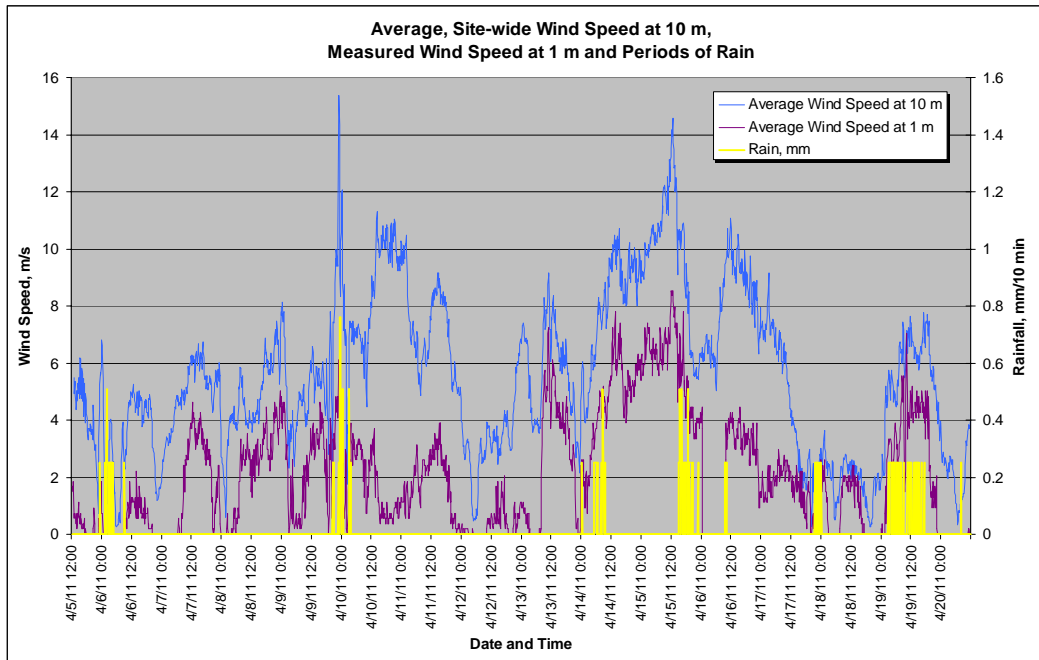


Figure 2.4.3

Wind direction, as measured by the 57 m vane on the north met tower, is plotted below.

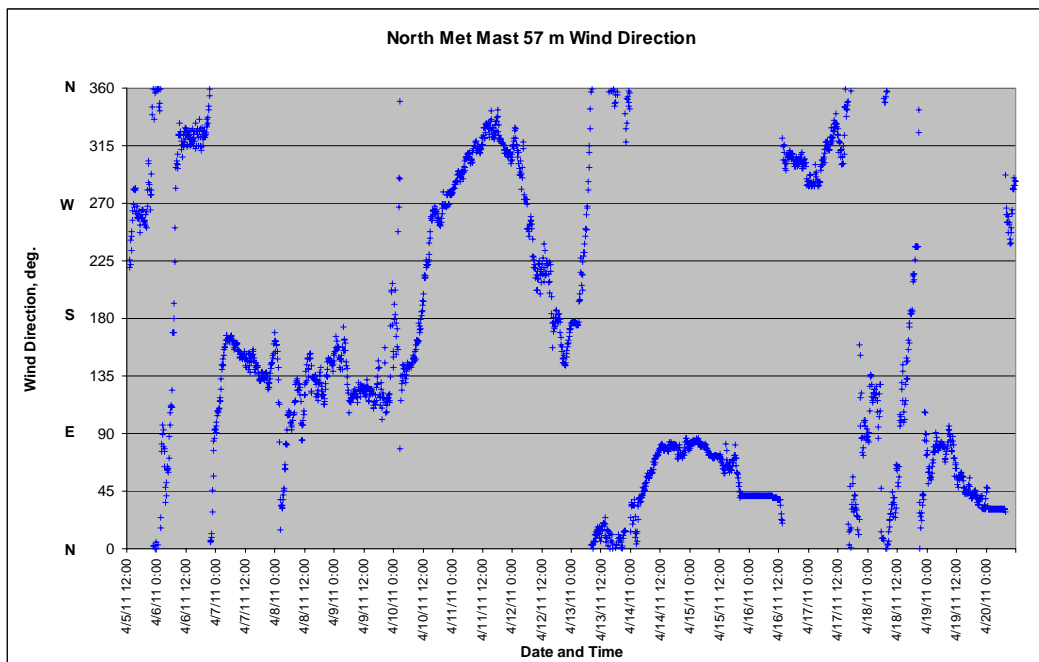


Figure 2.4.4



### 3.0 SURVEY RESULTS

#### 3.1 REGULATORY NOISE LIMITS

Freeborn County has adopted the Minnesota State noise standard (Minnesota Noise Pollution Statute and Rule 7030-0040), which for a Zone 1 Noise Area Classification (NAC) limits sound levels exclusively from the project to the following values at residential land uses:

**Table 3.1.1** *Project Sound Level Limits*

Daytime (7 a.m. to 10 p.m.)		Nighttime (10 p.m. to 7 a.m.)	
L10	L50	L10	L50
65 dBA	60 dBA	55 dBA	50 dBA

It is important to note that these limits apply exclusively to sound levels produced by the project and do not include any background noise from unrelated sources, such as cars passing by, trees rustling in the wind, planes flying over, etc. Consequently, the aim of the survey is to quantify the project-only sound level, which will involve subtracting the concurrent background sound level from the total measured level at measurement locations within the project area and making other corrections for contamination. In general, the as-measured sound level at any given moment is sum total of all sounds present in the environment and cannot be ascribed to the project without further analysis.

#### 3.2 MONITOR RESULTS – OFF-SITE BACKGROUND SOUND LEVELS

During windy conditions background noise can become very significant and was even observed to exceed the regulatory limits at times during the 2010 pre-construction survey. Consequently, in order to reasonably determine the project-only sound level – the quantity of interest with respect to the regulatory limit - it is necessary to quantify the background sound level and then subtract it (logarithmically) from the total measured level with the project in operation to determine the project-only sound level.

For wind projects, where the facility sound level is a function of highly variable wind and atmospheric conditions and where it is impractical to shutdown the project to directly obtain meaningful background data for a variety of conditions, the only methodology for measuring the background level is to monitor for an extended period of time at positions outside of the site area in settings and surroundings that are substantially similar to those within the project area but removed from any project noise. This provides a time history of sound levels throughout the survey that can be used to correct concurrent, on-site measurements. Background levels in rural areas are highly variable and usually highly dependent on the specific wind and atmospheric conditions occurring at a particular moment. Consequently, it is not typically possible to measure one day, for instance, and assume similar levels of background sound would occur the next day. It is for this reason that the background data collected in 2010 cannot be relied on to provide accurate correction factors for the operational measurements made in 2011.

The technique used to reasonably determine the background sound level during this survey was to set up monitoring positions at three diametrically opposite locations 2 to 3 miles from the edge of the project area to the north, east and southwest as illustrated in **Graphic B**.

The L10(10 min) levels recorded at these three positions are plotted below.

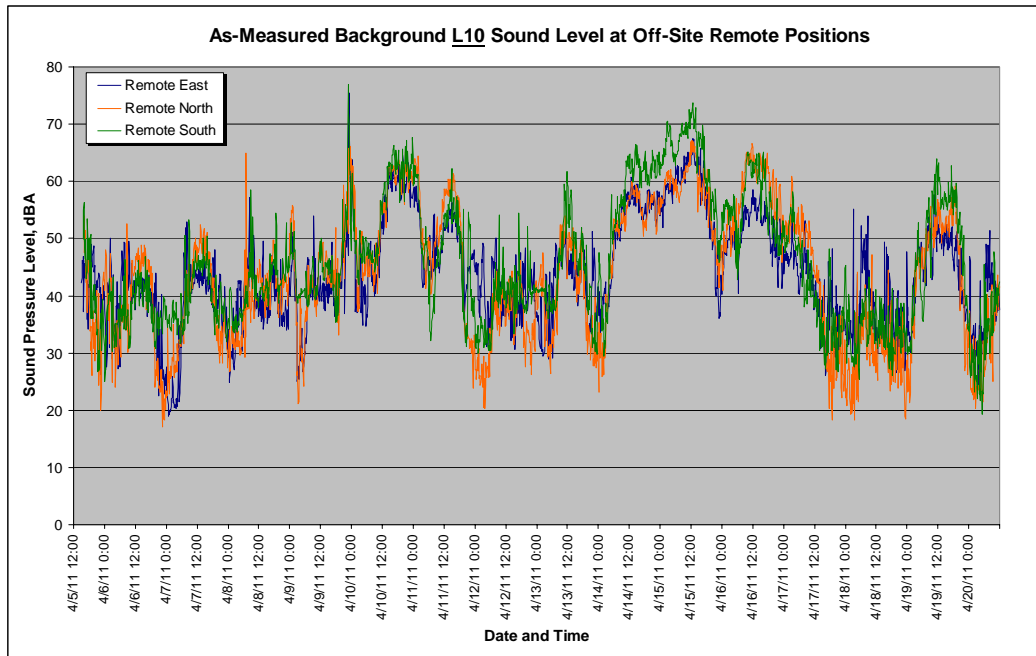


Figure 3.2.1

This plot shows that the L10 background sound levels are highly variable over a large dynamic range, from about 20 to 70 dBA, and that the levels are generally consistent in the sense that their values at any given time are similar and they all follow the same temporal trends, which, as will be seen in a moment, are driven almost entirely by wind speed. The tendency for the Remote South levels tend to be somewhat higher during peak noise periods can probably be ascribed to the relatively exposed setting of the monitor on an open rise. Nevertheless, because the South position levels are not always higher than the others and sound levels at all three locations are generally similar most of the time, the arithmetic average can be considered a reasonably good approximation of the background sound level that would have existed in the absence of the project within the site area, which lies between the three monitoring points. This average, or design level is plotted below relative to the average, site-wide wind speed normalized to a 10 m elevation.



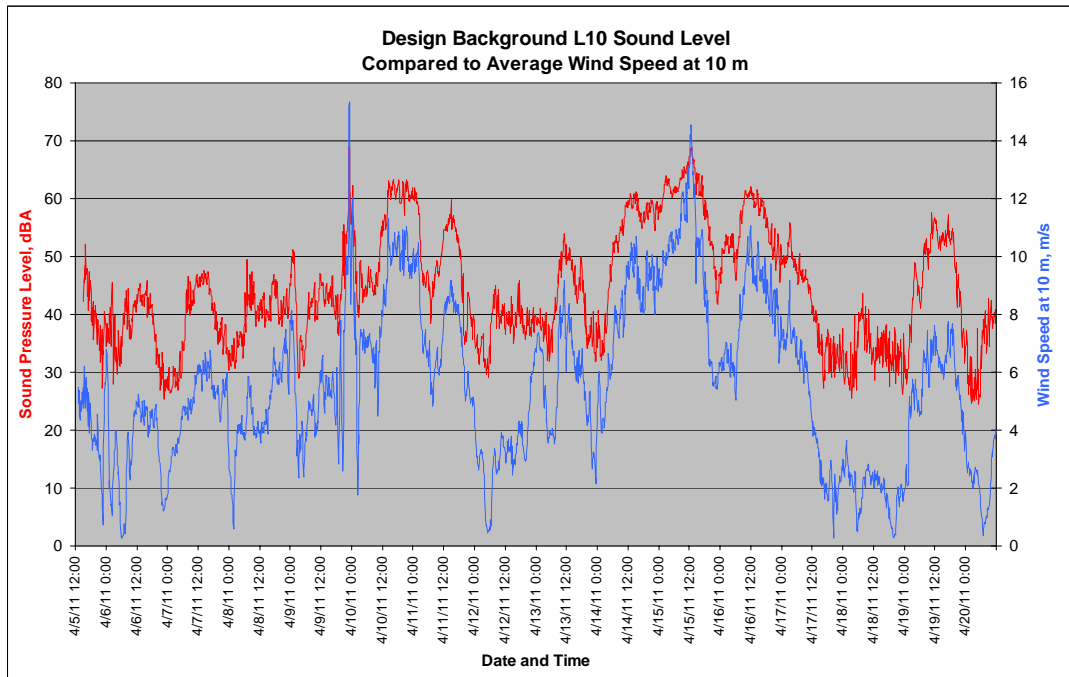


Figure 3.2.2

The fact that the sound levels closely follow the wind speed supports the validity of this design approach, since the principal driver of environmental sound levels in rural areas is wind-induced sounds, at least during cool season conditions in the absence nocturnal insects.

The L50 sound levels measured at the three off-site background positions are shown below.

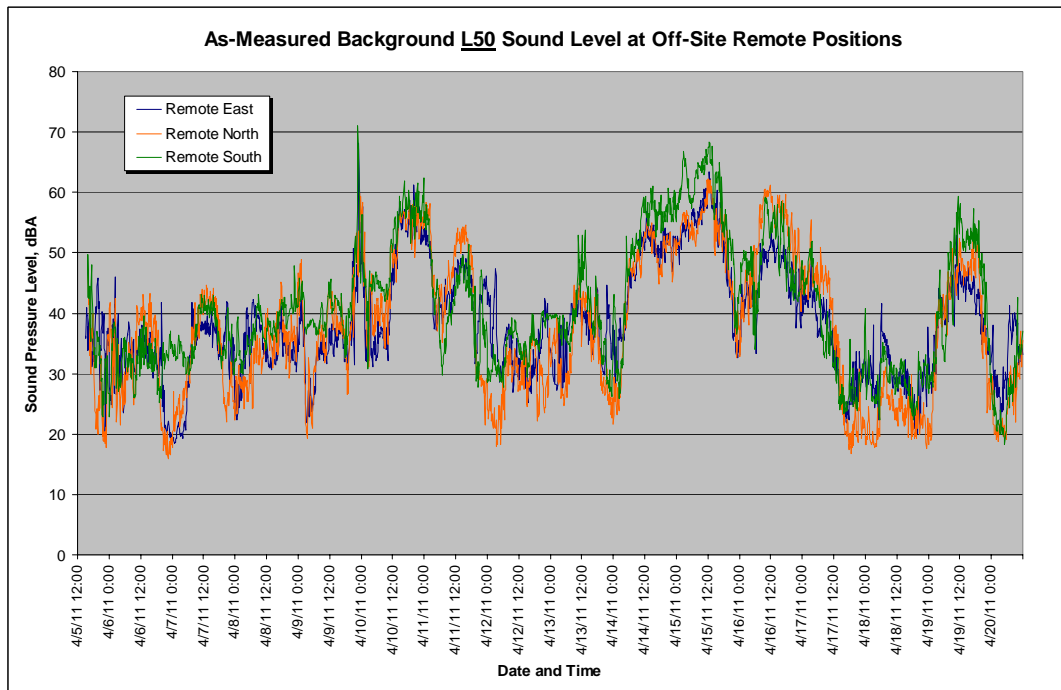


Figure 3.2.3

The figure is similar in appearance to the L10 results in Figure 3.2.1 but the levels are generally lower in magnitude. The average/design L50 level is plotted relative to the 10 m wind speed in Figure 3.2.4.

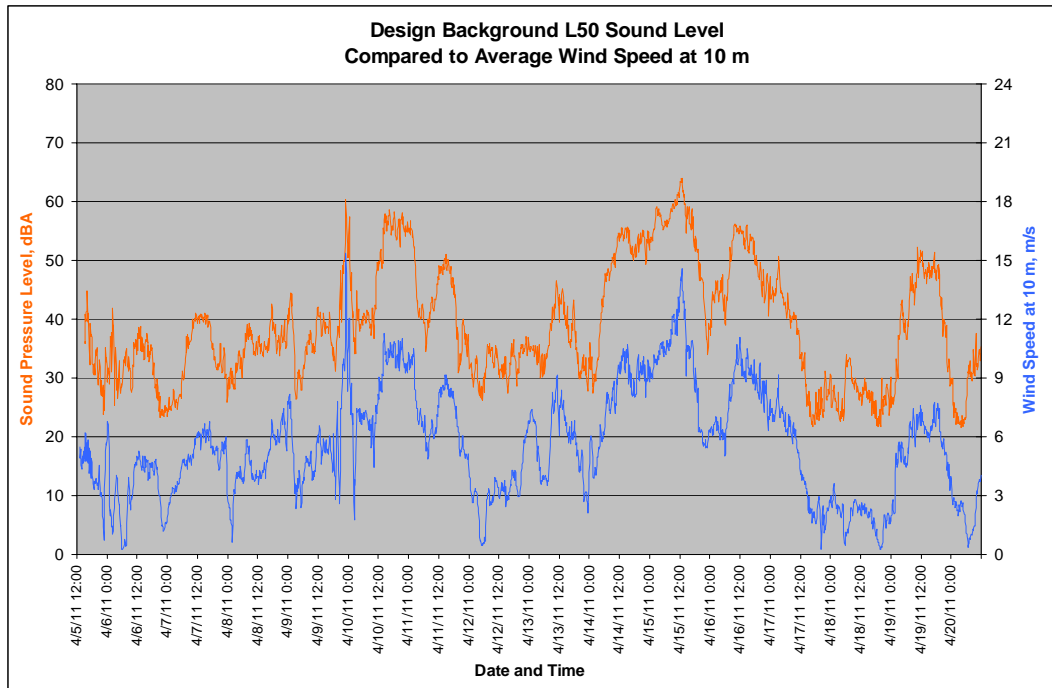


Figure 3.2.3

The L90 background was derived in the same manner. All three background levels are plotted in Figure 3.2.4 for comparison.

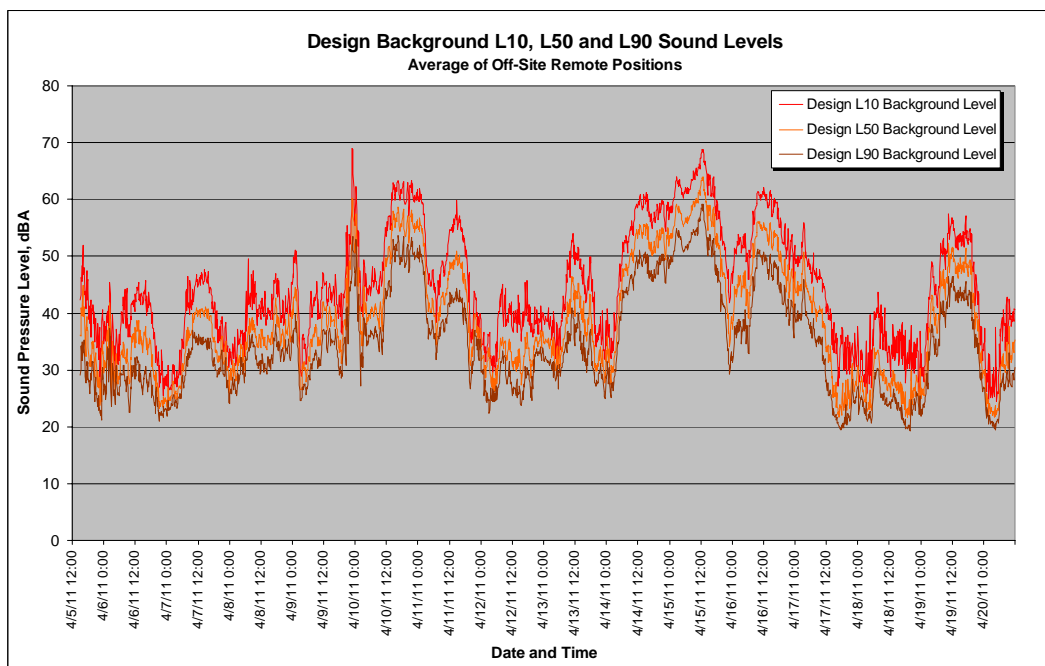


Figure 3.2.4



In general, the background levels determined in this survey are significantly higher than those measured during the 2010 pre-construction survey. The L10 and L50 results from both surveys are shown below as a function of wind speed (rather than time).

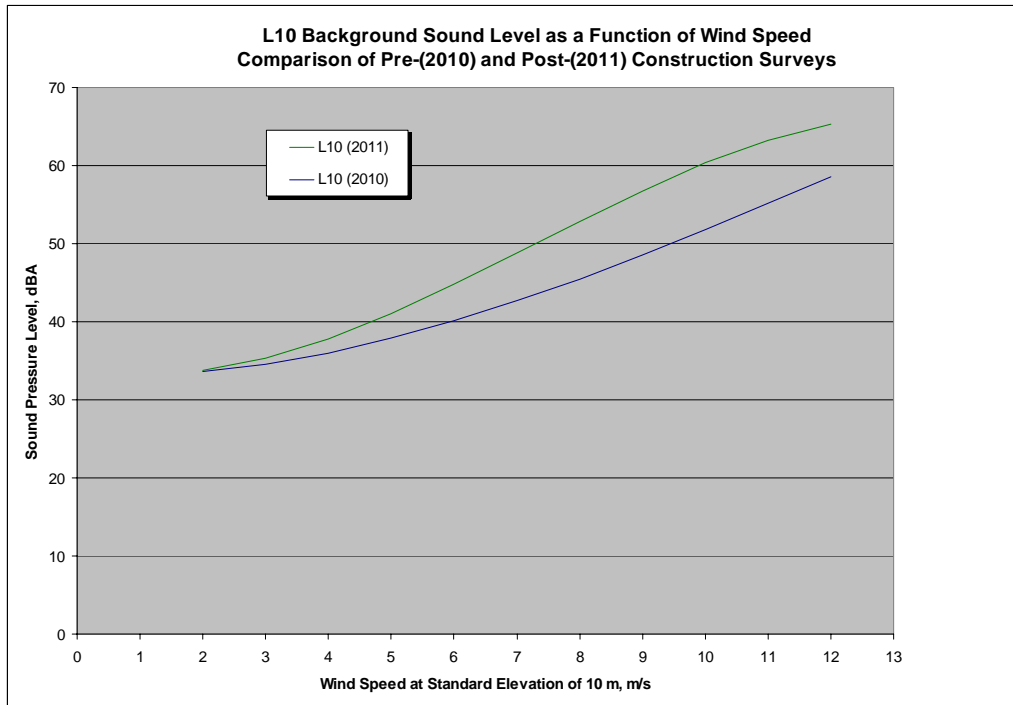


Figure 3.2.5

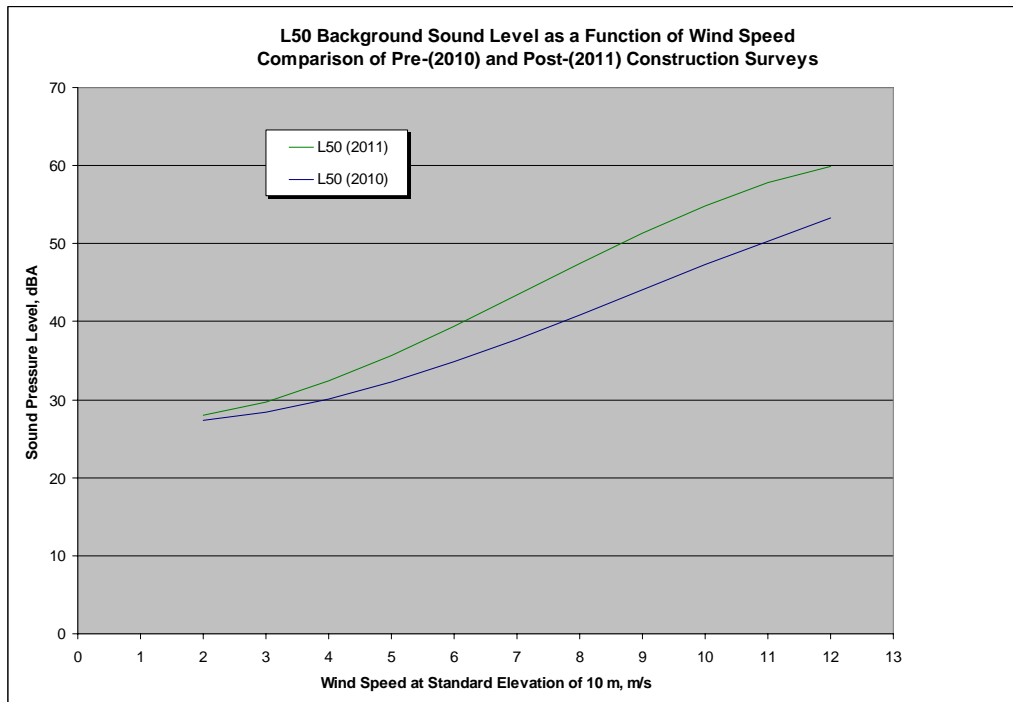


Figure 3.2.6



This differential, among a number of other things, illustrates why the results from another time period cannot be relied on to accurately represent the background level during an operational survey. In essence, only the simultaneous background sound level, when all wind and atmospheric conditions are the same, can be used to derive the project-only sound level.

### 3.3 DATA ANALYSIS METHODOLOGY

The design L10, L50 and L90 background levels discussed above were used to derive the project-only sound level at the on-site measurement positions. However, this is not the only factor that must be considered in order to quantify the sound emissions due exclusively to the project at each location. The following adjustments, discussed below, were made to the raw data:

- The deletion of apparent local contamination
- The deletion of all data measured during periods of rain
- A correction for background noise
- A correction for wind-induced self-noise
- The consideration of sound levels only during project operation

#### *Local Contamination*

At most positions noise spikes or extended periods of relatively high sound levels were observed that were clearly not associated with the project because there was no concurrent increase in wind speed that might cause turbine noise to increase. All significant or obvious noise spikes that appear at only one location in the absence of any related spike in wind speed have been deleted. Minor spikes or other perturbations without any clear explanation were allowed to remain in on the chance that they were somehow related to project operation.

#### *Rain*

Rain impacting the windscreen and falling on surrounding vegetation can significantly elevate the measured sound level giving the appearance that project noise may have increased if there is a simultaneous increase in wind speed. However, a review of audio recordings during rainy periods from this and other projects clearly indicates that the sound level is being driven by the rain itself. Consequently, all data at all positions that was recorded during the periods of rain measured by the weather station at Position 5 (illustrated in Figure 2.4.3) were omitted from the analysis. Measurements immediately before or after 10 minute periods with measurable rain were retained to be conservative even though they probably contain contamination from such things as dripping trees or elevated tire noise on wet roads.

#### *Background Correction*

Background sound was logarithmically subtracted from the total measured sound level when the on-site level exceeded the design background level for that time period by more than 3 dB. While the calculation of the project-only sound is mathematically possible when the background level is below but within 3 dB of the total level, doing so tends to create spurious mathematical artifacts where the project level can be estimated at unrealistically low and obviously incorrect sound levels. A separation of 3 dB or more is mandated in most ISO standards and in IEC 61400 before a legitimate subtraction can be made. Whenever the background level was greater than the on-site level or within 3 dB of it, the project sound level was considered indeterminate and those data points were discarded. All subtractions were performed on a like-to-like basis; for example, the L10 background level was used to correct the L10 on-site levels, etc.



### Microphone Error Correction

The level of wind-induced self-noise for the type of windscreen used for this survey (ACO Model WS7-80T) is known from wind tunnel experiments [3] where the measured frequency spectra were correlated to known perpendicular incidence wind velocities. The specific relationship for the overall A-weighted sound level is:

$$L_{p,self} = 28.692 \ln(v) - 17.447, \text{ dBA} \quad \text{for } v > 3 \text{ m/s}$$

Where  $v$  is the average wind speed measured at the microphone in m/s.

For this type of oversize (7 inch diameter) windscreen the empirical evidence indicates that the A-weighted sound level is essentially unaffected by this error at the wind speeds normally observed at 1 m above grade during such surveys. In other words, the level of self-generated A-weighted noise is usually substantially below the level actually measured - to the extent that little or no correction is typically warranted. The graphic below shows the near-minimum (L90) background level measured at the off-site receptors compared to the level of calculated A-weighted self-noise based on the wind speed measured at microphone height. There are only a few instances when the level of self-generated noise approaches this minimal background level and the nominal correction is very small and, in fact, can be safely neglected at this and all other positions.

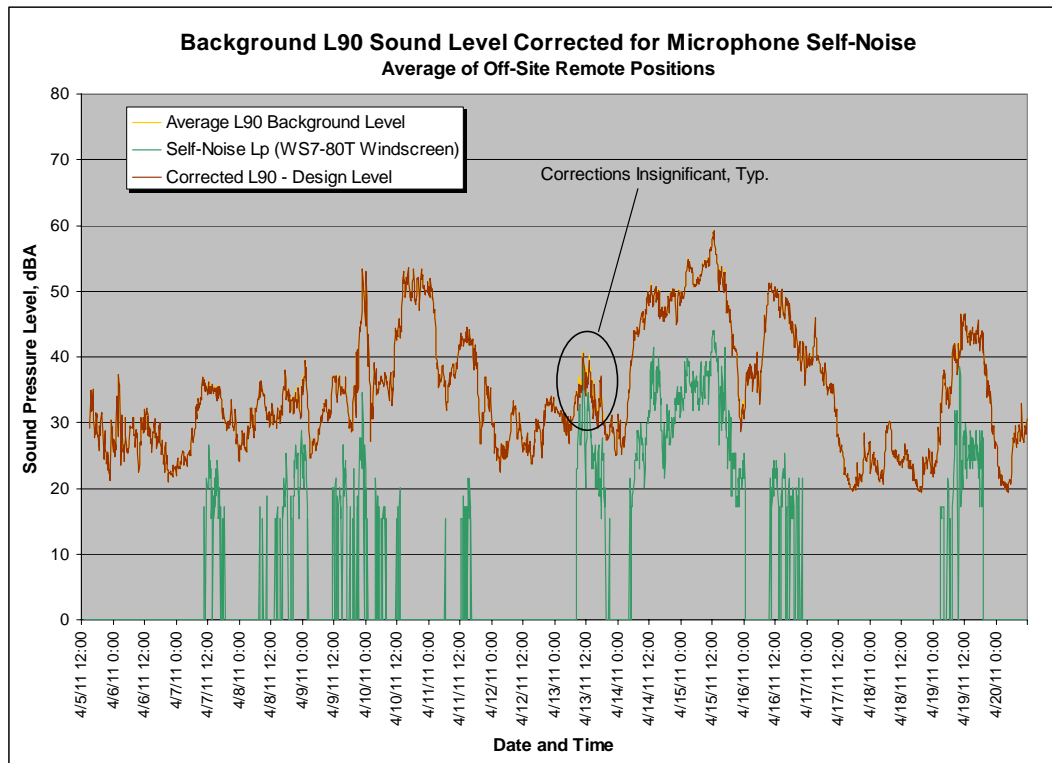


Figure 3.3.1

While this wind-induced distortion is of no real consequence to the A-weighted sound level it is still strongly affecting the low frequencies and the C-weighted sound level, as will be discussed later.



### *Project Operation*

There are many instances when the design background level is lower than the measured level at an on-site receptor but this difference is not always or necessarily due to operational noise from the project; particularly during low wind conditions when the turbines are substantially or completely idle. In an effort to filter out these periods of apparent but not actual project noise the sound measurements at each position are compared to the electrical output of the two nearest units. The data point is considered valid if either of these units was operational at that time but discarded if both units were down. While more distant units could well be operating, it is highly unlikely that the noise from these far away units would reach or exceed the regulatory noise limits.

## 3.4 MONITOR RESULTS – ON-SITE POSITIONS

The survey results are summarized by seven principal graphics, described below, for each of the seven on-site measurement positions. However, in the interest of brevity, only Position 1 is discussed in detail in the text and only the final results are given for the other positions. Complete sets of plots for the other six monitoring stations are appended to the end of the report (Appendix B).

### **Raw Results**

The first plot shows the as-measured L10(10 min) sound level (containing both project and background noise) as a function of time over the 15 day survey period compared to the design L10 background level as measured by the off-site monitors and the concurrent wind speed as measured by the on-site met towers and normalized to 10 m. Project noise is apparent wherever the total sound level significantly exceeds the background level and, at the same time, parallels the wind speed curve. If the total level exceeds the background without a simultaneous rise in wind speed, the noise is unlikely to be associated with the turbines and can be ascribed to some local noise event. These noise spikes have generally been deleted from subsequent analyses.

### **Apparent Project Sound Level**

The second graphic shows the nominal project-only L10 sound level vs. time where the background sound level has been logarithmically subtracted and all local contamination and rainy periods have been deleted. This is the apparent project sound level over the survey before the data have been further filtered to limit the results to times when at least one of the two nearest units was operating.

### **Compliance**

The third graphic shows the remaining ostensibly valid data points representing the project-only L10 sound level relative to the daytime and nighttime L10 noise limits. Compliance is expressed by the percentage of time the project-only sound level is within the prescribed limits relative to the total survey period, which consisted of approximately 2100 measurements at each location.

The 4<sup>th</sup> through 6<sup>th</sup> graphics show the same three plots for the L50 statistical measure.

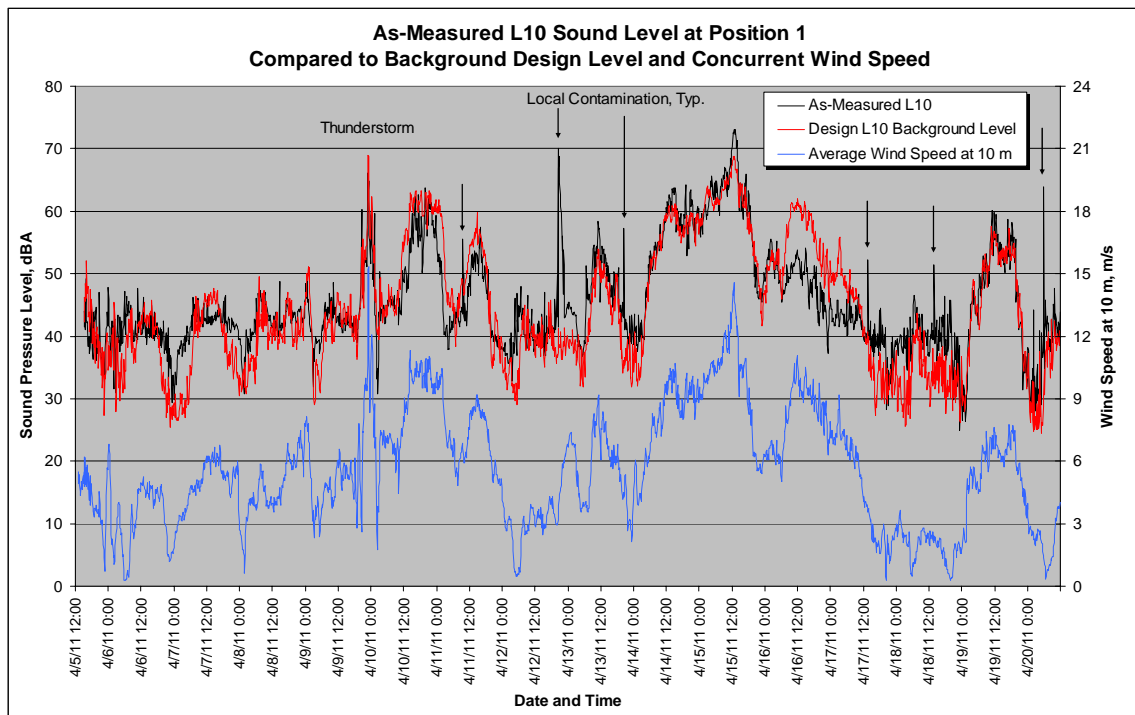
### **Project Sound Level as a Function of Wind Speed**

The final plot shows the L90 project-only sound level plotted as a function of wind speed rather than time. The L90 project-only levels are derived in the same way as the L10 and L50 values using the same filters; however, the L90 measure is much less susceptible to contamination from unrelated short-duration noise sources and best captures the long-term, steady project sound level with a substantially higher signal-to-noise ratio; i.e. many more data points survive the filters and appear to represent the actual project sound level, whereas the L50 and particularly the L10 measures are more likely to contain influences from traffic, birds, tractors, planes, etc. inflating the apparent project sound level.



### 3.4.1 Position 1 – 68595 300<sup>th</sup> St. (CR 31)

The total L10 sound level measured at Position 1 is plotted in Figure 3.4.1.1 along with the design background level and 10 m wind speed.



**Figure 3.4.1.1**

This plot shows the not unexpected result that the on-site L10 level is similar to, and sometimes lower than, the off-site L10 level measured miles from any turbines. This result is unsurprising because the L10 statistical measure is normally driven by and dominated by short-duration, extraneous noises that are mostly unrelated to the project, such as cars passes, wind gusts, birds, planes, etc.; hence the apparently low signal-to-noise ratio where any sound from the project is minor and largely inconsequential compared to other environmental sounds. In general, the L10 statistical measure is unsuited to the meaningful measurement of wind turbine noise because the project signal is usually subtle at normal set back distances and can often only be clearly discerned during quiet lulls in the background level whereas the L10 tends to capture and quantify noise peaks rather than valleys (see Figure 2.3.1).

Figure 3.4.1.2 below shows the apparent project-only sound level for this location, where values could be determined (only about 1/3 of the time), after the deletion of obvious contamination.

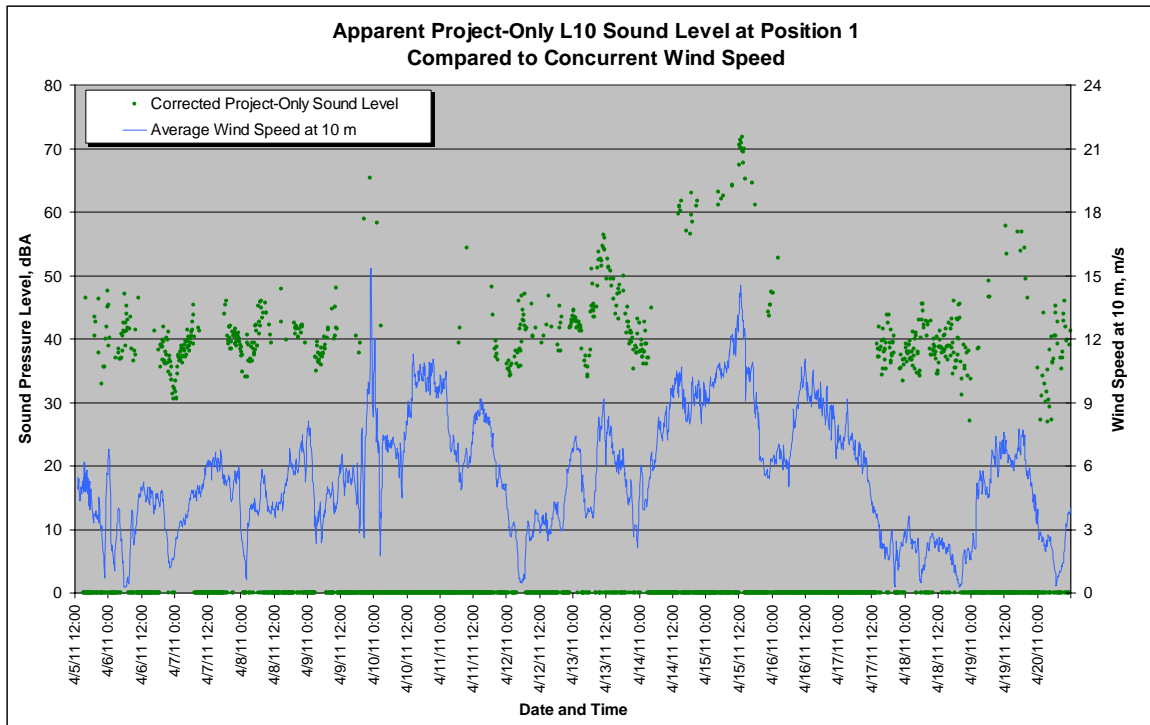


Figure 3.4.1.2

If these values are filtered further to limit the results only to times when one of the two nearest turbines was operating the following plot results in which the final results are compared to the permissible daytime and nighttime limits.

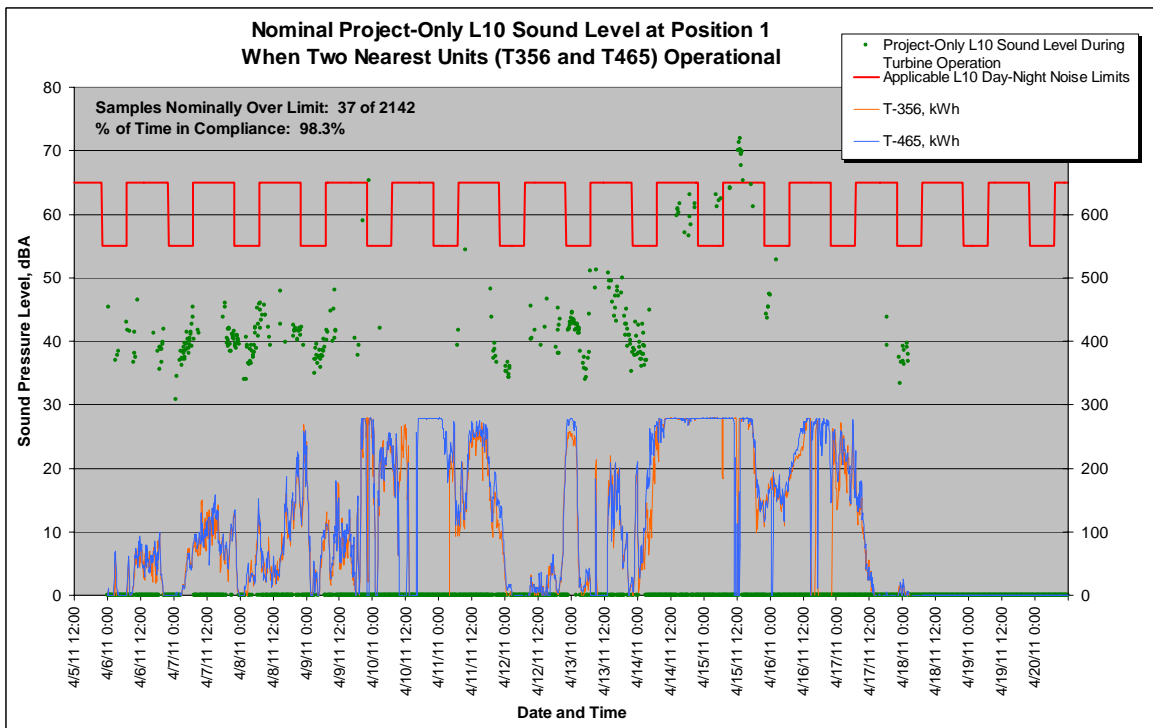


Figure 3.4.1.3





As indicated in the graphic there are 37 apparently valid data points out of a total of 2142 samples with values in excess of the 65 dBA daytime and 55 dBA nighttime limits. This suggests that the project produced a sound level above the L10 limits 1.7% of the time during this 15 day sample period and, conversely, that the project was in compliance 98.3% of the time. However, it is important to note that the L10 statistical measure has a tendency to capture contaminating noise events rather than the fairly steady sound signal produced by the project, so it is unlikely that all of these overages are actually due to the project.

Nevertheless, this is a fairly common result for wind projects in the sense that almost all projects are subject to brief periods when the project's sound level significantly exceeds the average or typical level for a given wind speed due to a confluence of unstable wind and atmospheric conditions favoring the production and propagation of sound. For example, in Figure 3.4.1.3 immediately above the period of peak noise around 1 p.m. on 4/15 when L10 levels as high as 72 dBA were observed is preceded by a nearly continuous stretch of 30 hours when the project was essentially operating at full capacity and during most of that period project noise was either indeterminate relative to the off-site background level or below the permissible limits. The only thing that apparently changed at 1 p.m. on 15<sup>th</sup> was the behavior of the wind (its stability in terms of speed and direction and/or its vertical velocity gradient) and the atmospheric conditions. Because such environmental conditions are as inevitable as they are uncontrollable by the wind farm operator, it is largely impossible for any wind project to maintain a specific noise emission limit at all times unless the level is extremely high or the distance to any receptors is extremely large. Consequently, a compliance rate in the vicinity of 98 to 99% is actually remarkably good and can reasonably be regarded as constituting compliance with the intent of the regulations.

The L50 test results for this position are shown below.

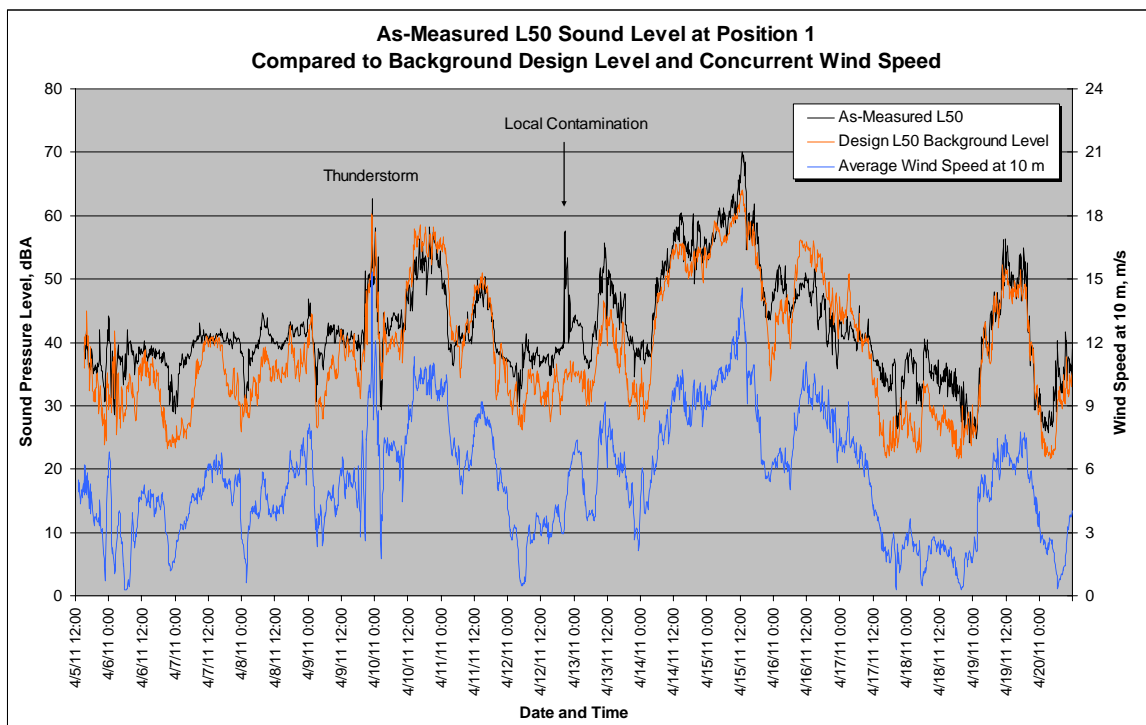


Figure 3.4.1.4

While there are fewer contaminating noise spikes (usually associated with short-duration noise events picked up the L10 measure) in the L50 data, the overall magnitude of the on-site and off-site levels remains similar indicating that noise from the project is not particularly prominent above the background level most of the time.

After correcting for background noise, rain and contamination the apparent L50 sound level over the survey period is plotted below.

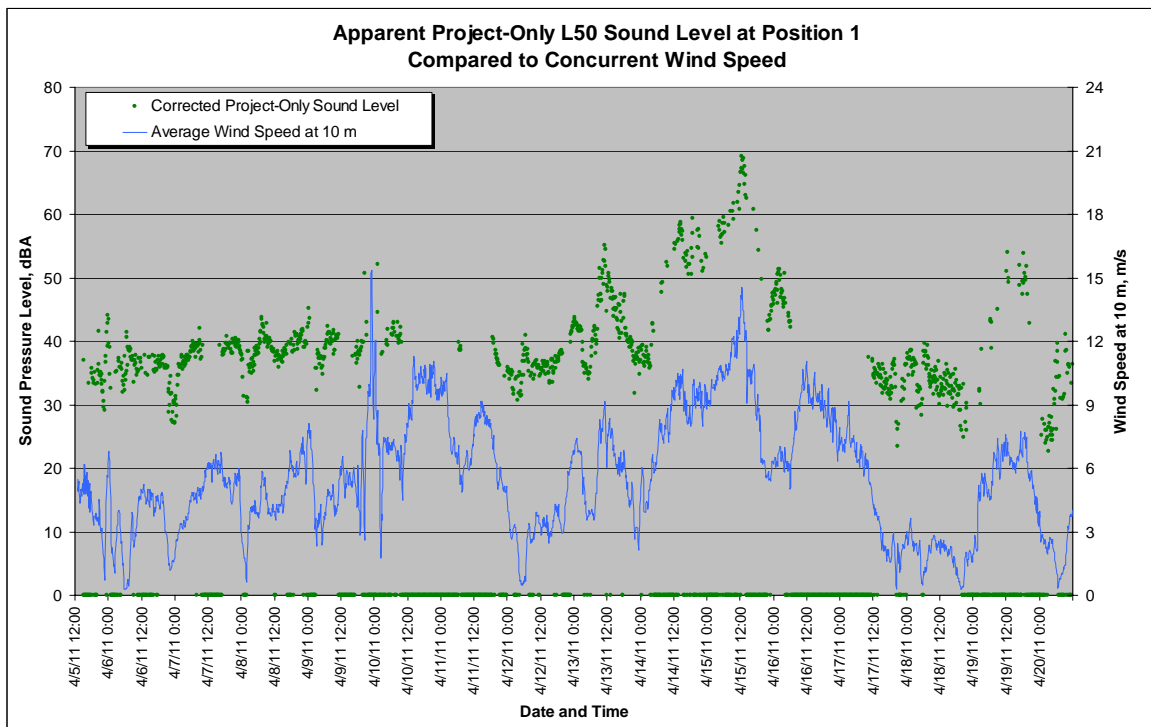


Figure 3.4.1.5

Figure 3.4.1.6 further filters the data so that only values measured during the operation of nearby turbines are retained.

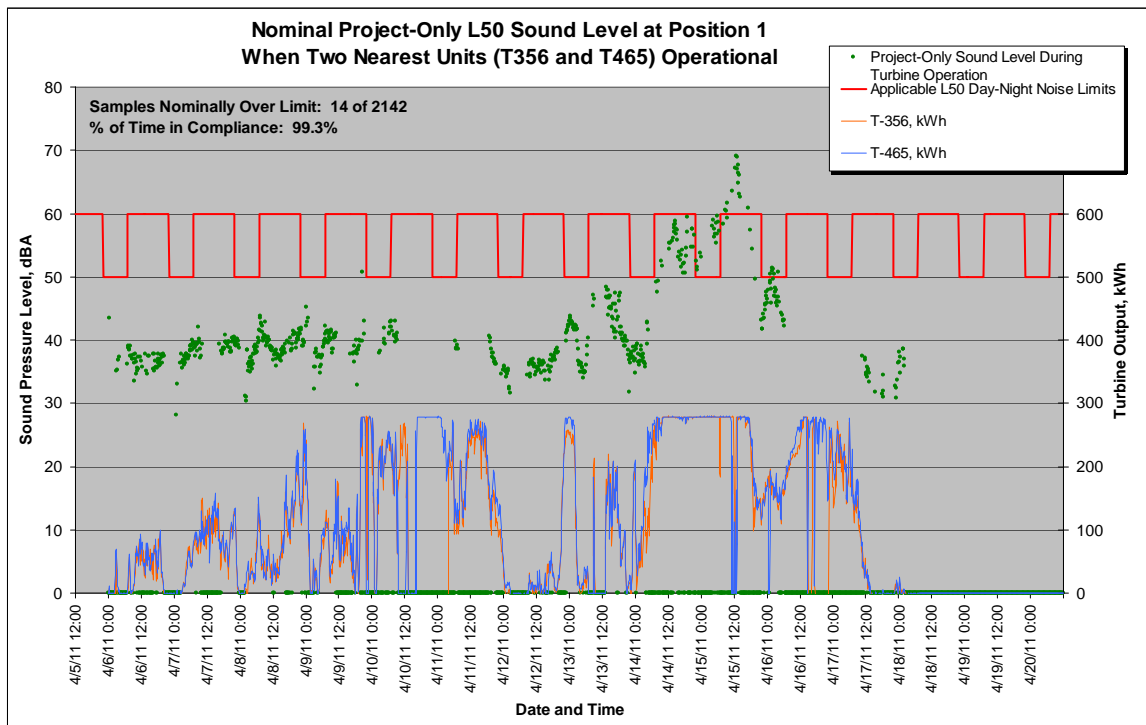
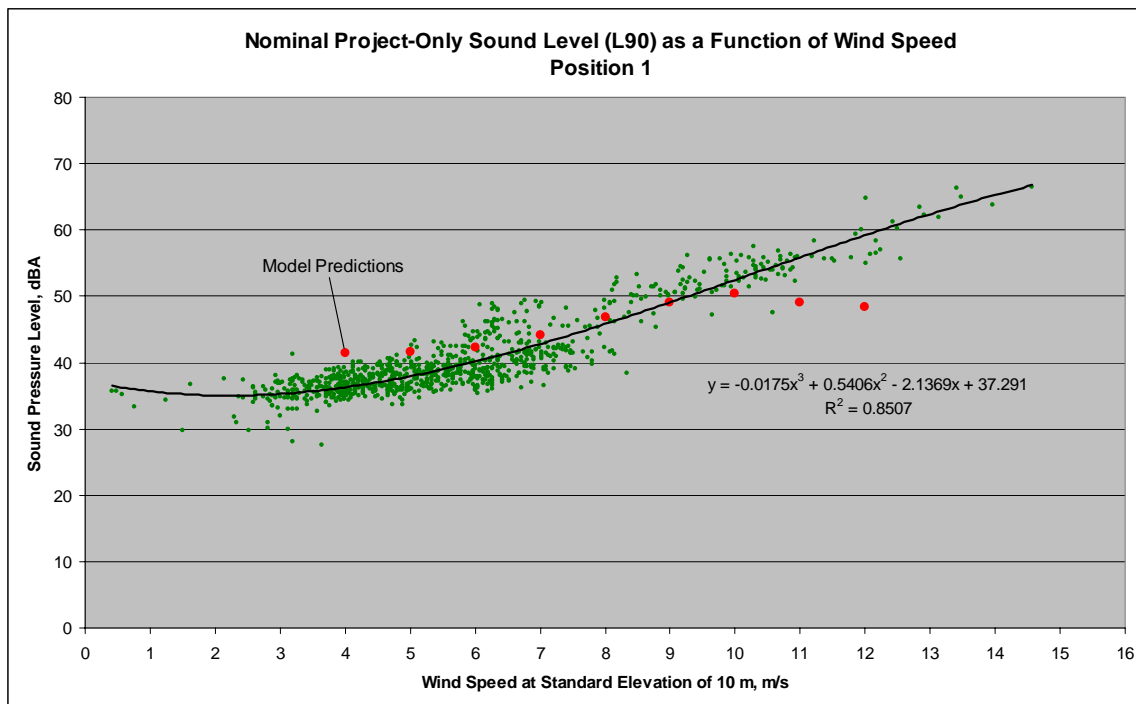


Figure 3.4.1.6

These results indicate that the project sound level was well below the permissible L50 limits most of the time (in fact, 99.3% of the time over the survey period) but apparently exceeded the limits at times on 4/15 evidently as a result of the wind conditions that existed that day. The fact that the turbine electrical output fluctuated rapidly between full power and zero output during the period (around noon on 4/15) when the maximum sound levels were observed suggests a highly unstable or turbulent wind condition possibly associated with a storm front.

Although not directly relevant to the compliance assessment with the County/State noise standards, the L90 statistical sound levels were also analyzed for this and all other positions to quantify the actual steady-state project sound level as a function of wind speed. As previously mentioned, the L90 level tends to cut through the clutter of contaminating noises and yield the clearest signal with respect to the project-only sound level. The L90 data were filtered in exactly the same way as the L10 and L50 measurements above and then plotted as a function of wind speed (at 10 m) rather than time (Figure 3.4.1.7).



**Figure 3.4.1.7**

This figure shows that for this particular sampling period the project operated predominately in low to moderate wind conditions (3 to 7 m/s); i.e. most of the data points fall in this range – and sound levels were mostly in the 35 to 42 dBA range. Operation at higher wind speeds was much less common but when it did occur it was accompanied by sound levels generally in the 50 to 60 dBA range.

For informational purposes the sound emissions of the project were modeled over a range of wind speeds from 4 to 12 m/s per ISO 9613-2 [7] at the seven on-site monitoring points for comparison the mean L90 field measurements. The input sound power levels for the analysis were taken from a brief warranty statement from Vestas for the V82-1.65MW from 2005. The turbines are modeled as point sources 80 m in the air. A mid-range ground absorption coefficient of 0.5 was assumed.

The results plotted for Position 1 in Figure 3.4.1.7 are typical of what was found at all seven locations in that the modeled levels are somewhat higher the mean measured level at low wind speeds, generally equivalent to measurements around 8 or 9 m/s then below the measured level at all higher wind speeds.



### 3.4.2 Position 2 – 70435 290<sup>th</sup> St. (CR 95)

The L10 and L50 sound levels measured at Position 2 are shown in Figures 3.4.2.1 and 3.4.2.2. In the first instance, only one measurement was found to be over the permissible L10 limits and that point occurred during the thunderstorm on the 4/9 and can probably be disregarded. The L50 levels were found to be within the County standard 98.8% of the time.

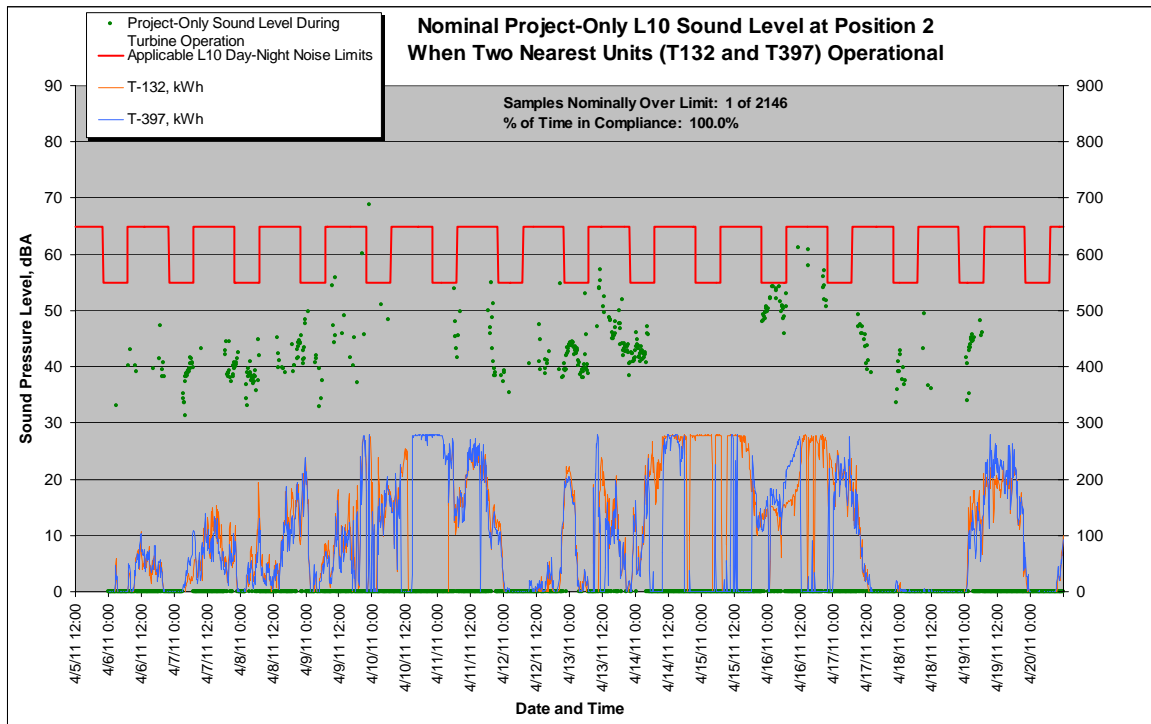


Figure 3.4.2.1

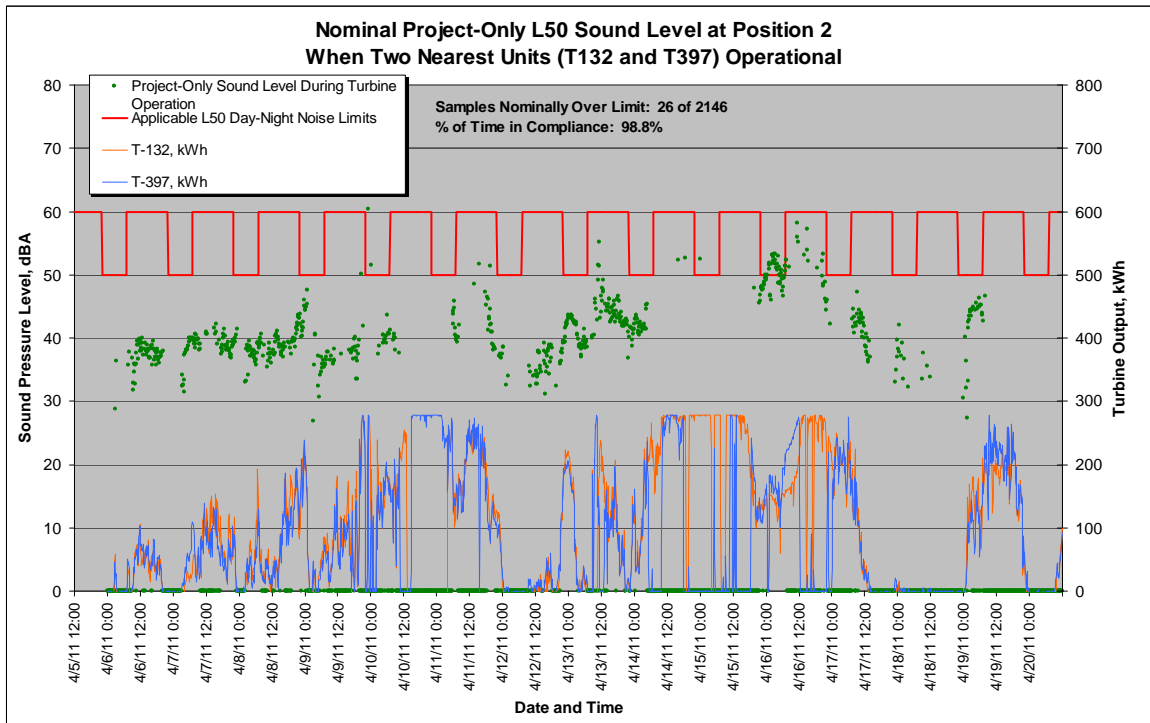


Figure 3.4.2.2

### 3.4.3 Position 3 – 28281 690<sup>th</sup> Ave. (T335)

The behavior of the project-only sound levels at Position 3 (Figures 3.4.3.1 and 3.4.3.2) was generally similar to that at the other positions except during the period of very high winds on 4/14 and 4/15 when a relatively large number of measurements above the L10 and L50 limits were measured. The reason for these high sound levels appears to be two-fold:

- The monitor was located considerably closer to the nearest turbine than the house. Specifically, the monitor was 830 ft. west of T423 whereas the nearest house (28281) is 1130 ft. WNW.
- The wind direction during this period was from the ENE, or more or less directly from T423 towards the measurement position.

The observed rate of compliance at this position was 95.0 and 92.5% for L10 and L50 limits, respectively. The change in distance from 830 to 1130 ft. would nominally lead to a reduction of 2.8 dBA ( $20\log(D1/D2)$ ), which would bring many of the overage points down below the permissible thresholds and significantly increase the percent of time in compliance figures. In fact, the numerical change would be to 96.8% (L10) and 94.8% (L50) compliance.

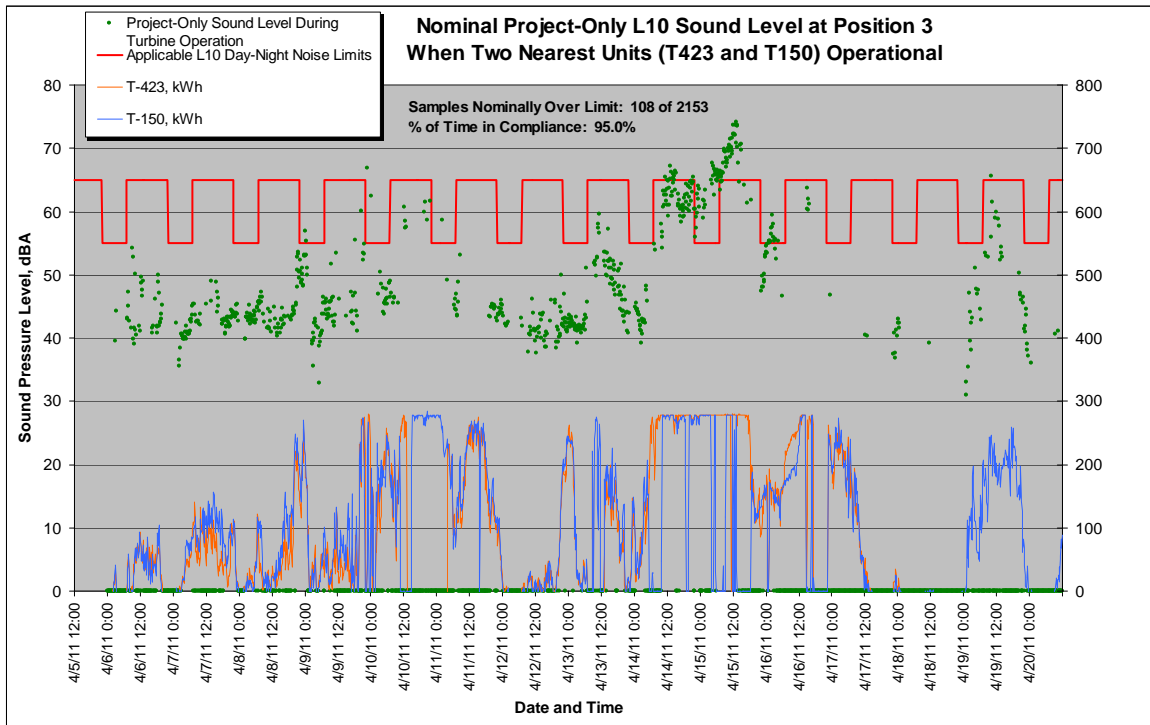


Figure 3.4.3.1

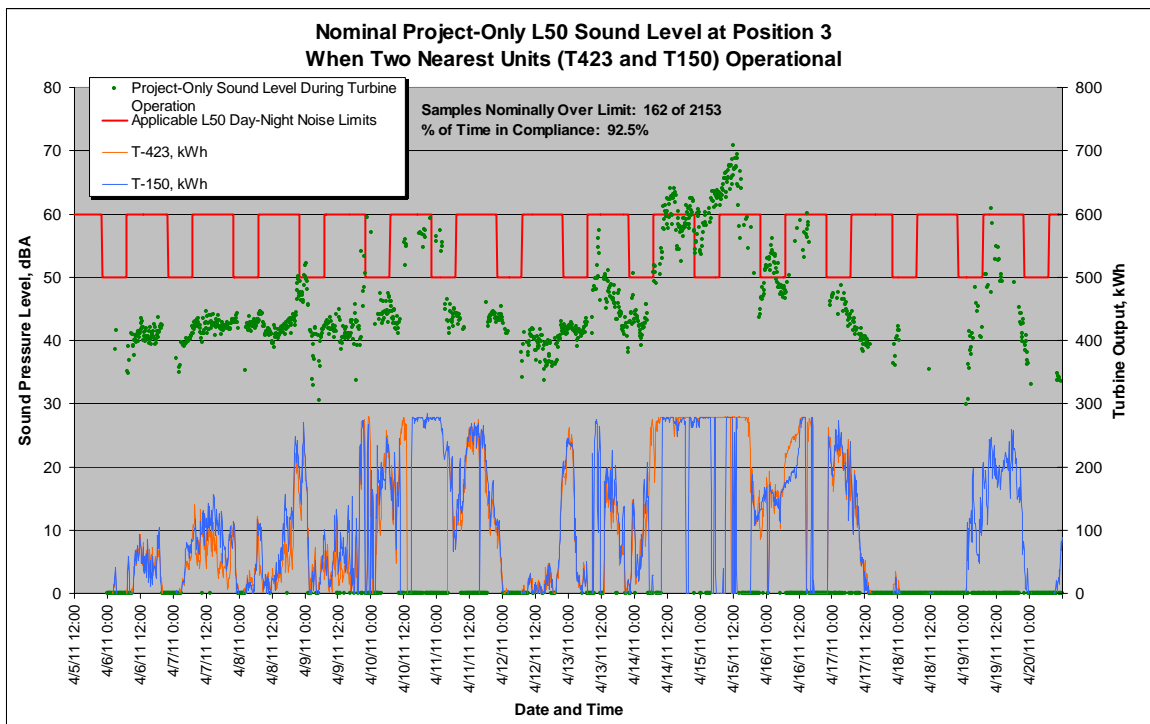


Figure 3.4.3.2



### 3.4.4 Position 4 – 72047 290<sup>th</sup> St. (CR 95)

The results at Position 4 (Figure 3.4.4.1 and 3.4.4.2) are more keeping with the norm for the survey in the sense that the derived project-only sound levels were found to be below the applicable limits 99.0% (L10) and 98.5% (L50) of the time.

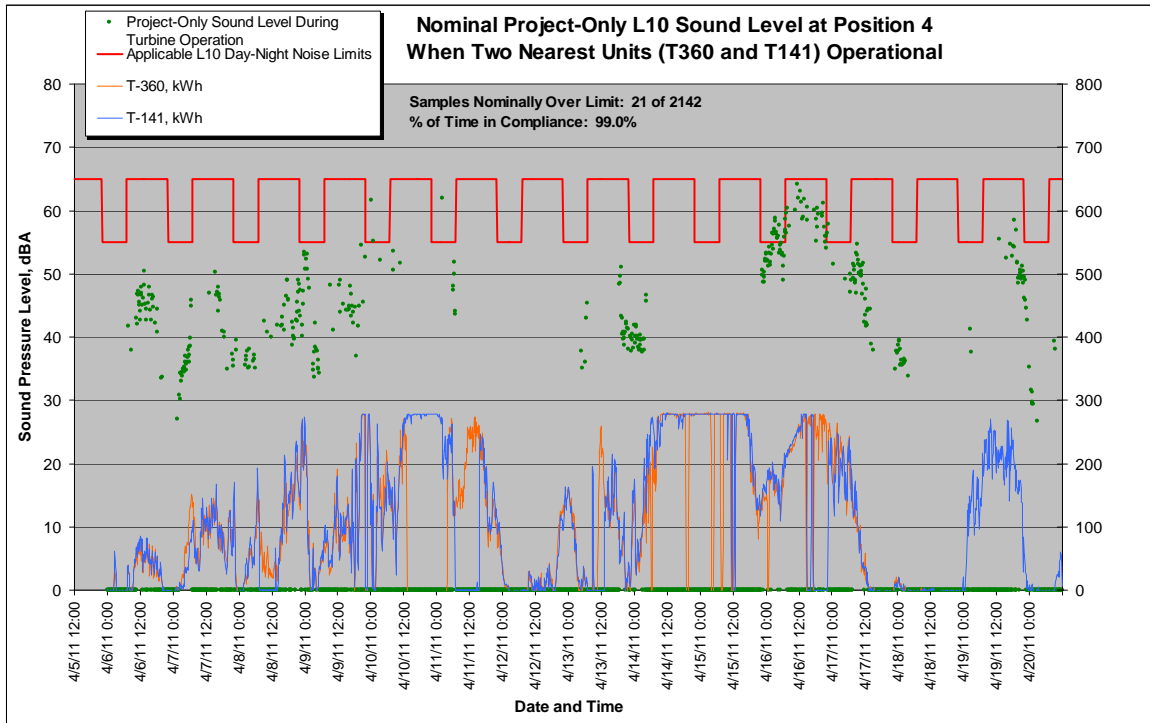


Figure 3.4.4.1



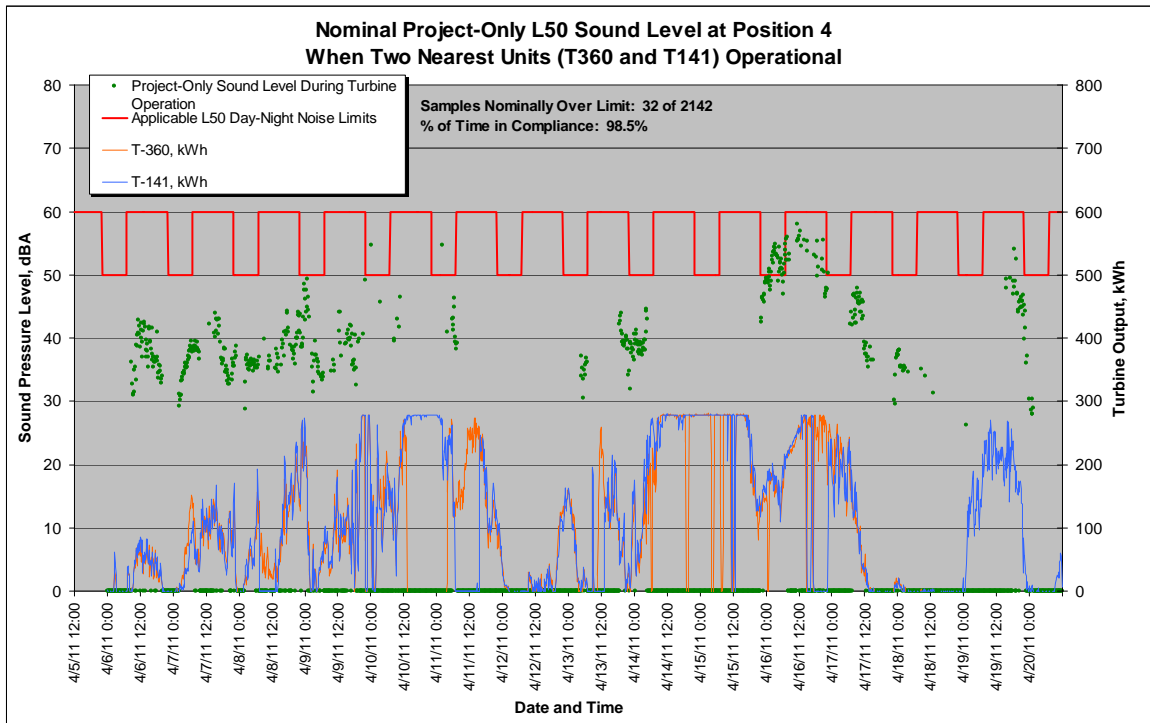


Figure 3.4.4.2

### 3.4.5 Position 5 – 71255 275<sup>th</sup> St.

The results for Position 5 are plotted in Figures 3.4.5.1 and 3.4.5.2 and show that the project sound level was below the L10 and L50 limits 99.9% and 98.2% of the time. These very high compliance rates are significant in that this position near the center of the site is closely surrounded by four units with quite a few others only a short distance further away. In essence, this position represents one of the most exposed residential locations to turbine noise yet the project sound level was found to be within the permissible limits almost all of the time.

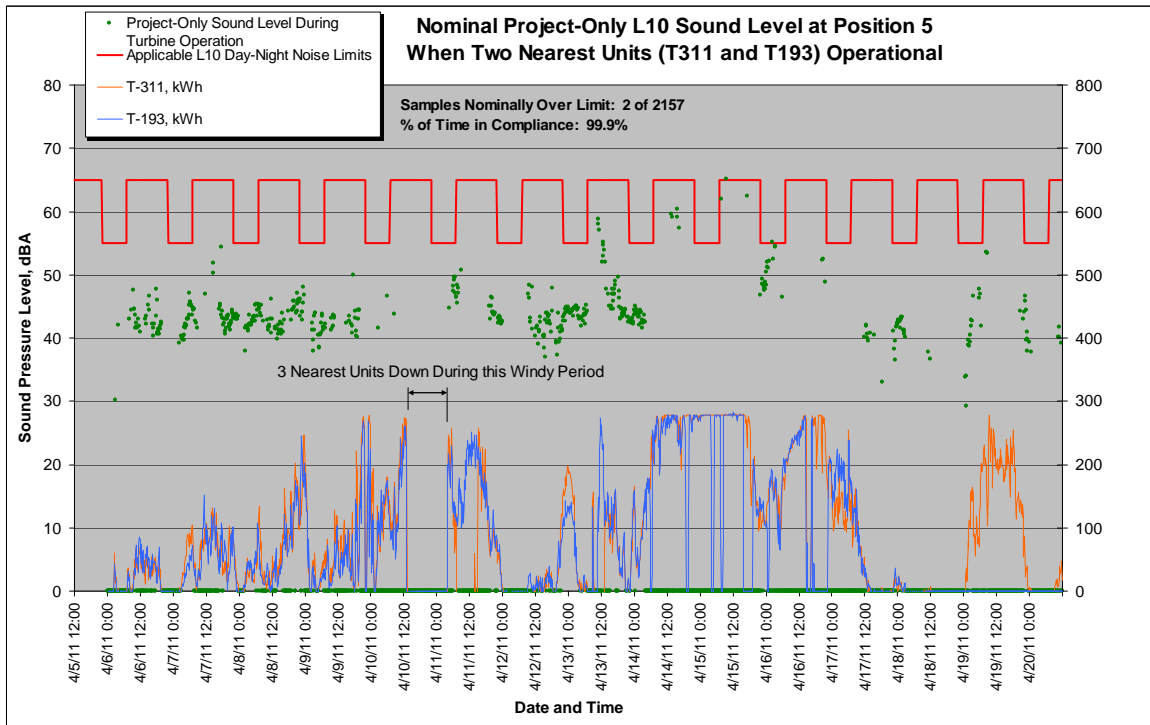


Figure 3.4.5.1

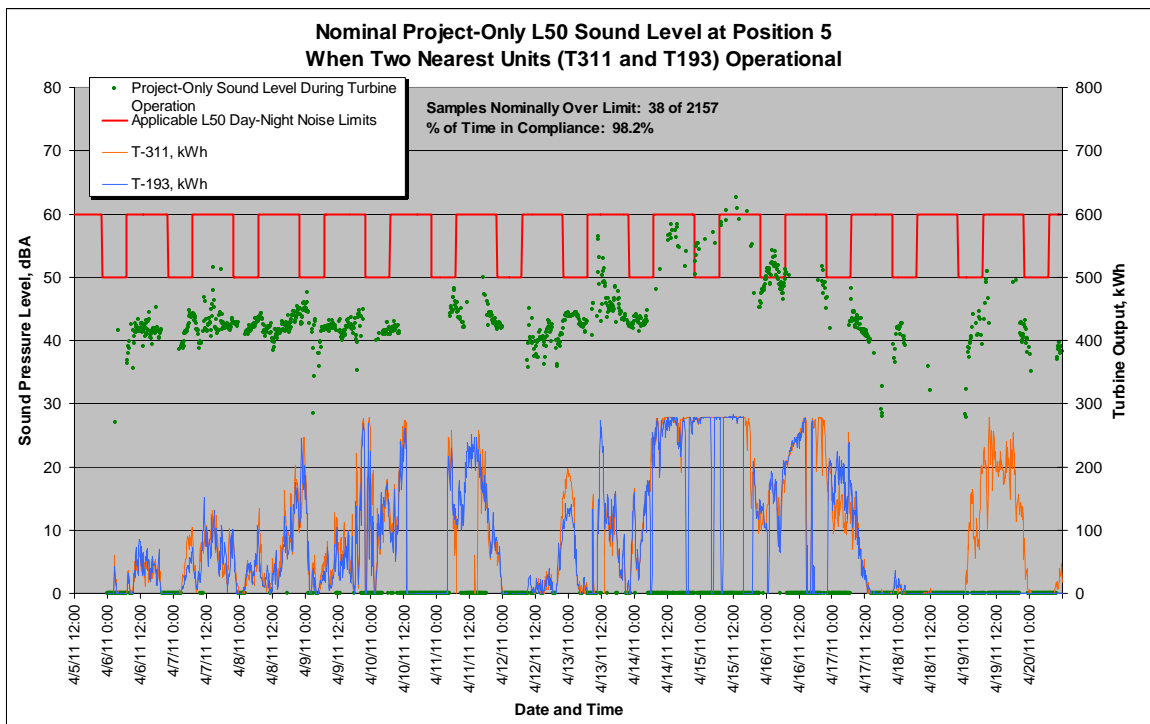


Figure 3.4.5.2



### 3.4.6 Position 6 – 29271 690<sup>th</sup> Ave.

The results at Position 6, also surrounded closely by 3 or 4 units, are almost identical to Position 5: 99.7% compliance L10 and 98.5% L50.

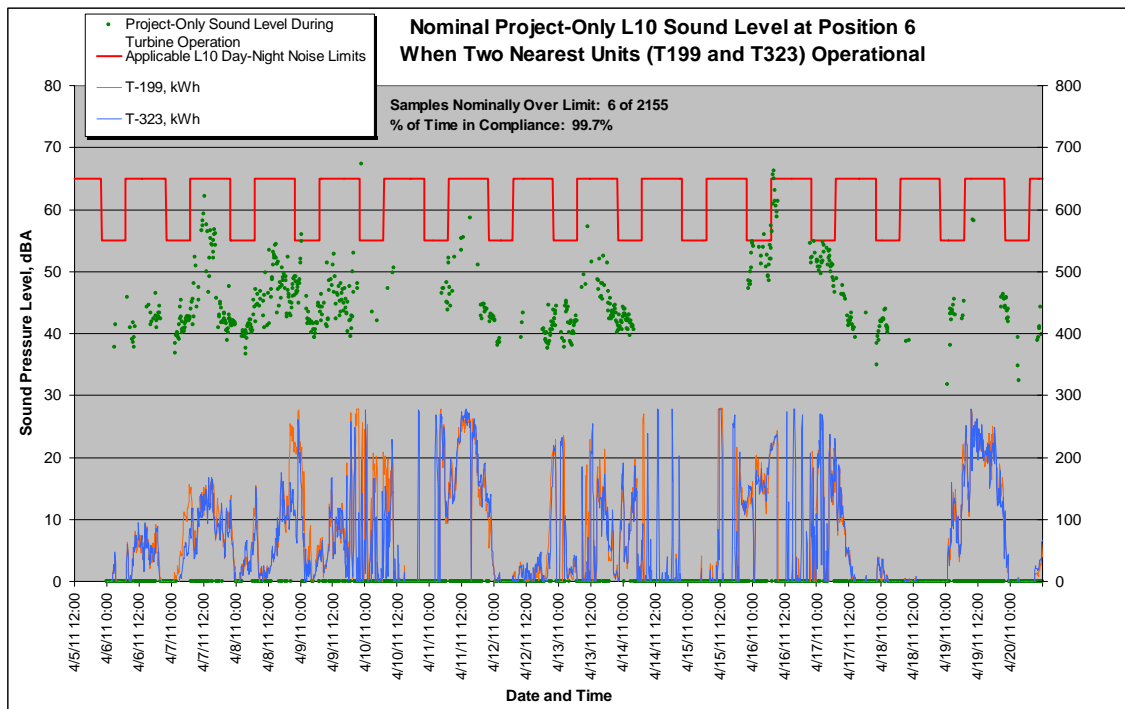


Figure 3.4.6.1

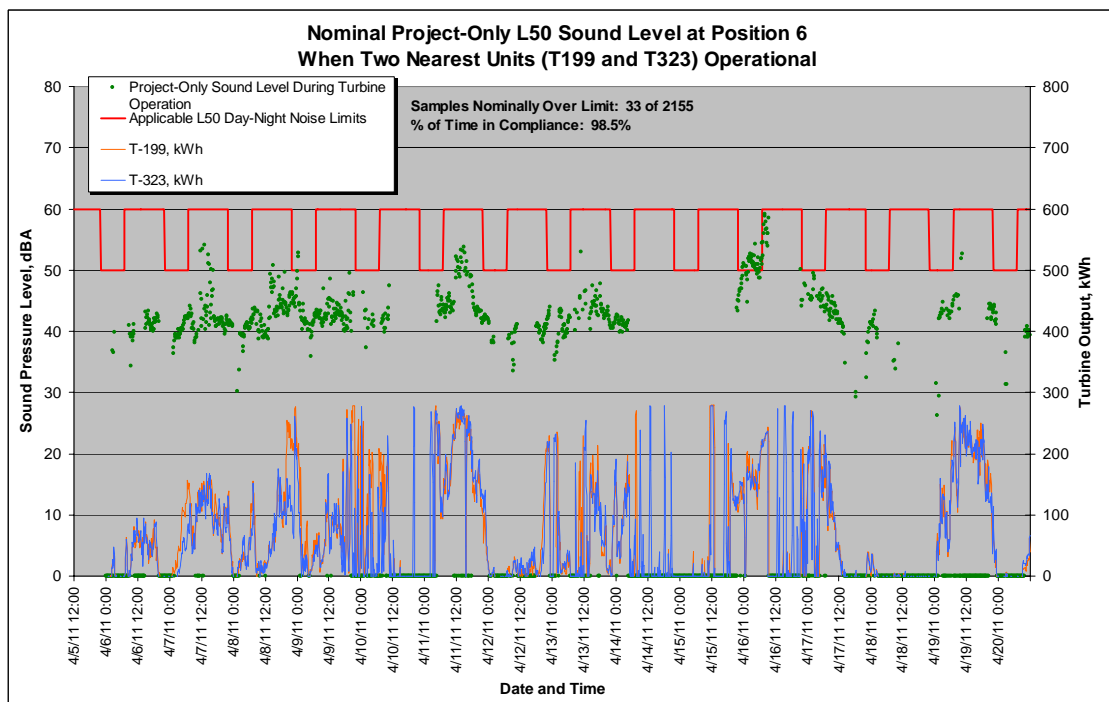


Figure 3.4.6.2



### 3.4.7 Position 7 – 71610 263<sup>rd</sup> St.

Lastly, at Position 7 (Figure 3.4.7.1 and 3.4.7.2) similar results were also found: 99.1% compliance L10 and 98.4% L50.

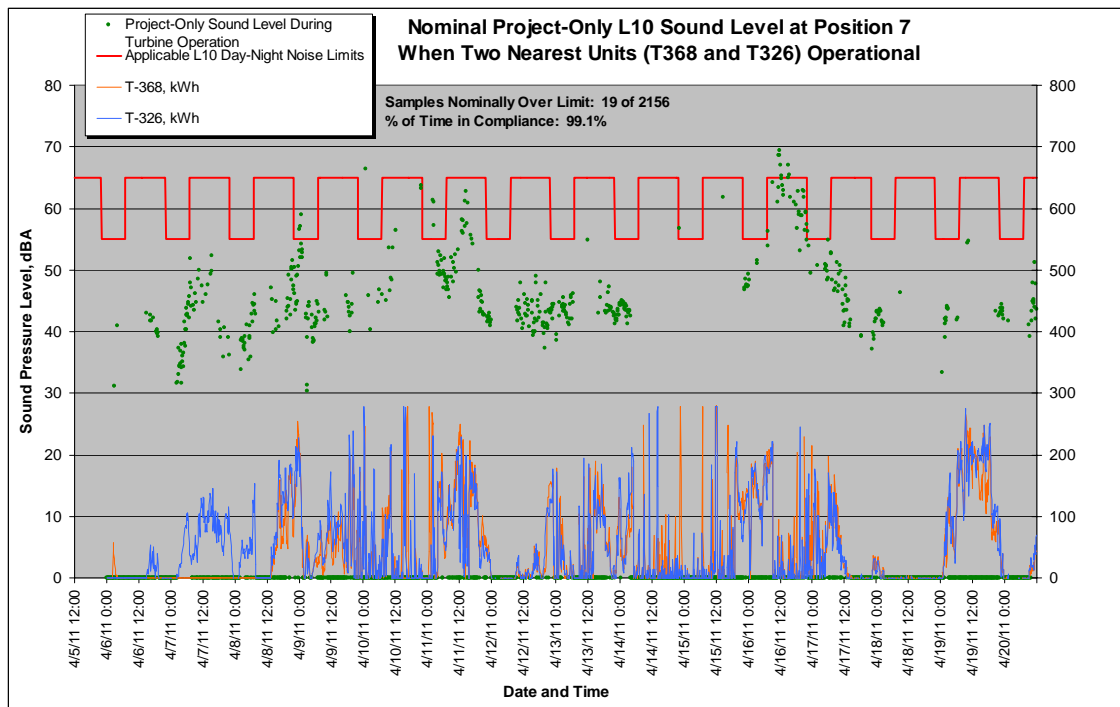


Figure 3.4.7.1

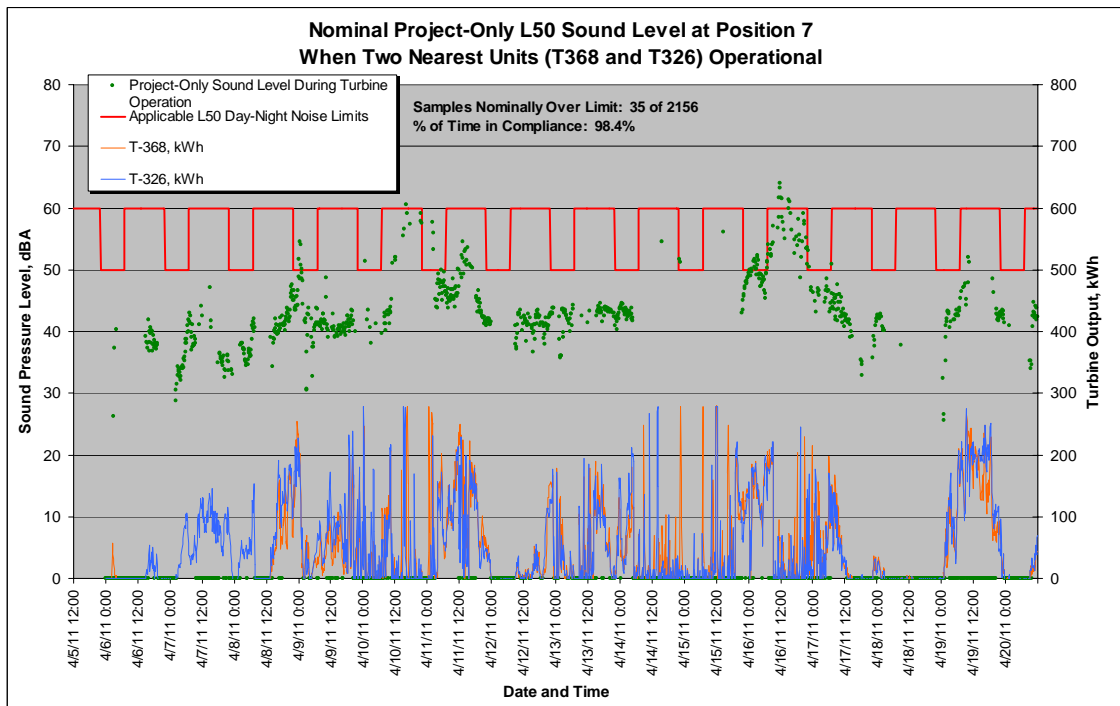


Figure 3.4.7.2



### 3.4.8 Results Summary – A-weighted On-Site Sound Levels

Table 3.4.8 summarizes the survey results at all of the on-site positions.

**Table 3.4.8.1** *Summary of Compliance Results*

Position	Percent of Time in Compliance with Applicable Limits	
	L10	L50
1	99.3%	98.3%
2	100.0%	98.8%
3	95.0%	92.5%
4	99.0%	98.5%
5	99.9%	98.2%
6	99.7%	98.5%
7	99.1%	98.4%
<b>Site-Wide Average</b>	<b>98.9%</b>	<b>97.6%</b>

As can be seen, the results are highly consistent from one location to another, except at Position 3 where the measurement location was considerably closer to the nearest turbine than the residence it was intended to represent and where the meter happened to be directly downwind of the turbine during the period of maximum wind and apparently unsettled weather on April 14 and 15. Thus the result there is considered anomalous and higher than it should be. On average, however, still accepting the Position 3 result at face value, site-wide compliance with the County/State noise limits was found to be 98.9% for the L10 statistical measure and 97.6% for the L50 level. As stated in Section 7.0 of the Test Protocol, a compliance rate of 95% or greater is considered satisfactory evidence of the compliance with the applicable noise standards. Consequently, it can be concluded that the sound emissions from the project are compliant with the Freeborn County noise standards.

### 3.5 FREQUENCY ANALYSIS AND LOW FREQUENCY NOISE

The County/State noise standards are expressed as A-weighted sound levels and no reference is made to the frequency spectrum or, specifically, to the low frequency content of the project's sound emissions. Consequently, there is no compliance threshold that limits low frequency noise emissions; however, concerns about low frequency noise from wind projects commonly arise warranting their consideration in this study.

In general, the widespread belief that wind turbines emit high or even harmful levels of low frequency or infrasonic sound appears to be based on a mixture of misinformation and misunderstanding and has no substantive basis in fact, as discussed, for example, by Leventhall [5] and Sondergaard [6]. Our own first-hand measurements of numerous turbine models clearly indicate that the low frequency sound energy produced by wind turbines is inconsequential and often comparable to the natural background sound level in rural areas – and certainly not high enough to be associated with any kind of health issue or even to exceed minimal perception thresholds.

One of the primary reasons that low frequency noise from wind turbines is mistakenly believed to be excessive is probably the measurement error resulting from wind-induced false-signal noise touched on in Section 2.3 above. In essence, any sound measurement made in a windy field will exhibit rather high levels of low frequency sound – whether a wind turbine is present or not. Wind blowing through any windscreen (particularly a standard 3" diameter size) and over the



microphone tip will cause the low end of the frequency spectrum to rise substantially, but no actual low frequency noise is present. Consequently, without any knowledge of this pitfall it is extremely easy to measure the frequency spectrum of wind turbine noise incorrectly and quite difficult to measure it accurately and correctly [4]. Meaningful measurements of low frequency sound can essentially only be made when there is little or no air movement at the microphone, which is why most ISO and ANSI standards relating to field measurements of conventional power stations and other industrial noise sources prohibit measurements above certain fairly low wind speeds. Wind turbines are unique in the sense that, almost by definition, any sound measurements of them must be taken during windy conditions; however, there are really only two methodologies for accurately measuring low frequency sound in the presence of wind: one, stemming from IEC 61400-11 [1], is to place the microphone flat on a reflective ground plate where the wind speed is theoretically zero and the other is to measure at an above ground position that is shielded from the wind but exposed to the turbine(s) of interest taking into account possible reflections from the obstruction blocking the wind. Both of these methods are impractical for use during an extended field survey over days or weeks because, in the first case, the microphone on the ground would be exposed to rain damage or snow and, in the second case, it is not practical to shield the microphone from varying wind directions and, in any case, one can only measure the upwind sound emissions from the turbine with this approach. Consequently, any long term survey can only really measure the A-weighted sound level, which is largely unaffected by self-generated noise (see Section 3.3), and cannot meaningfully measure either the frequency spectrum or the C-weighted sound level, which is essentially a measurement of the low frequency content of the signal.

Figure 3.5.1 below may help to illustrate this situation. Frequency content was measured during the survey by 1/3 octave band analyzers at Position 5 near the center of the site closely surrounded by numerous turbines and at the Remote East position miles away from the perimeter of the project. The graph below shows the L50 frequency spectra measured simultaneously at both of these positions during a randomly selected period of fairly high wind just after midnight (12:10 a.m.) on April 6. The wind speed at 10 m, normalized from the met tower anemometers, was 6.8 m/s, indicating that the project was fully operational, and the wind speed measured by the 1 m anemometer at Position 5 was 3.5 m/s.

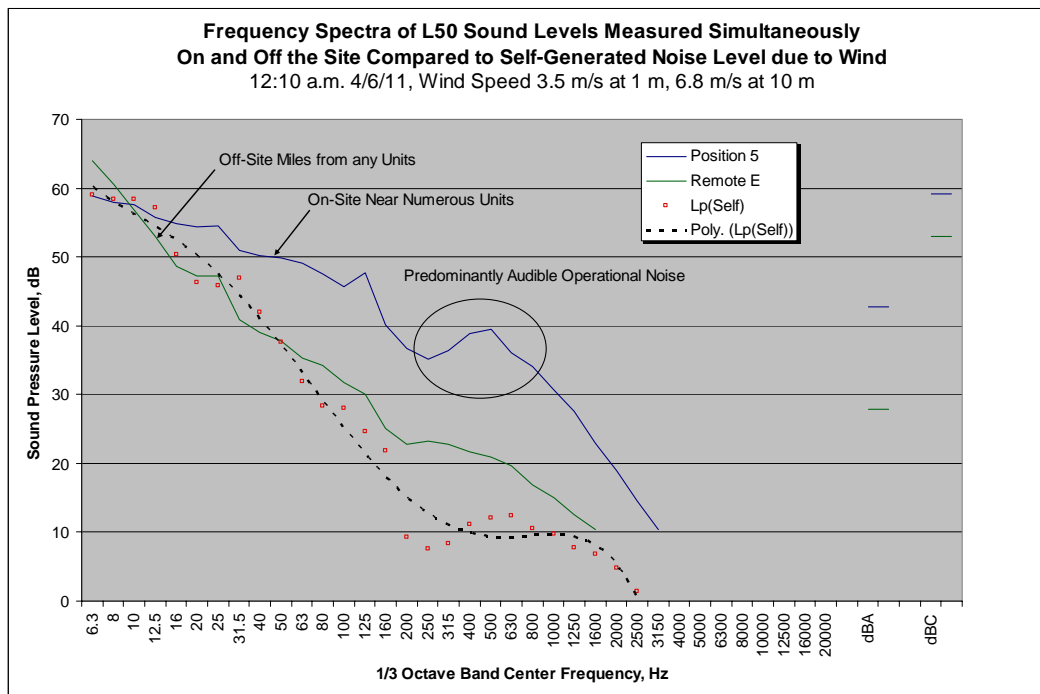


Figure 3.5.1

As might be expected, the A-weighted sound levels at each position are vastly different: 42.8 dBA at Position 5 and 27.8 dBA at the off-site background position, meaning that turbine noise was probably very clearly audible and dominant at Position 5 while the environment was virtually silent at Remote East. This qualitative difference is evident in the plot in the mid-frequencies, around 500 Hz, since this is the part of the frequency spectrum that the human ear is most sensitive to and which drives the A-weighted sound level (the purpose of A-weighting is to modify the actual frequency spectrum, substantially suppressing the low frequencies, so that it conforms to the way the sound is qualitatively perceived by the ear).

What is most significant about this plot, however, is the behavior of the lower frequencies at both positions. At the extreme low end, 6.3 Hz, the magnitude of the off-site sound level is actually higher than at Position 5. There was almost certainly no source of low frequency noise just after midnight on 4/6 anywhere around the Remote East location, which is in an open field along a seldom-used dirt road far away from any homes, farms or significant roads. All that was “measured” below about 50 Hz at both locations was false-signal noise due to the wind. The red dots are the levels of self-noise for this type of the wind screen in a 3.5 m/s perpendicular wind that were empirically determined in the wind tunnel experiment described in Reference 3. In short, both the on- and off-site measurements are meaningless in the lower frequencies. At around 63 Hz the sound level at Position 5 is sufficiently higher than the self-noise level that it is beginning to reflect actual turbine sound; however, a low level of 50 dB at 63 Hz is basically imperceptible, insignificant and of no concern whatsoever. Dramatically higher sound levels at and below 63 Hz are experienced, without apparent ill-effect, every day by millions when driving in a car [8].

C-weighting is used to evaluate sources with significant low frequency content - most commonly simple cycle combustion turbines - because the lower frequencies are not substantially suppressed as they are in A-weighting (again, to shape the sound to match the way it is subjectively perceived). In other words, the C-weighted frequency spectrum remains somewhat similar in appearance to the un-weighted spectra plotted in Figure 3.5.2. An overall C-weighted sound level



is the logarithmic sum of the frequency spectrum, which means that it is driven almost entirely by what is happening in the low end of the spectrum. Note that the overall C-weighted sound levels in Figure 3.5.2 are both in the 50's dBC because both spectra are being dominated by the same false-signal noise in the lower frequencies.

This example is actually somewhat unusual in that the overall C-weighted sound level measured on-site is higher than the simultaneous off-site level; 59 and 53 dBC, respectively. In most cases, there was no discernable difference between the C-weighted sound levels,  $L_{Ceq}(10 \text{ min})$ , measured at the seven on-site monitoring stations and the average C-weighted sound level measured at the three off-site locations. In fact, the off-site level is frequently higher than the on-site level or about the same, but there is no general tendency for the on-site C-weighted levels to be higher, which would suggest that significant low frequency noise from the project was being produced and detected. The on-site C-weighted sound levels are compared to the off-site C-weighted levels in the following seven graphics. Any differences between the two levels are largely due to differences in the local wind speed at microphone height, which is less uniform over the site area due to surface friction and obstructions than the high elevation wind speed. Additional discrepancies are due to the presence of local contamination from such things as farming activity or vehicles – events that were not edited from the C-weighted data.

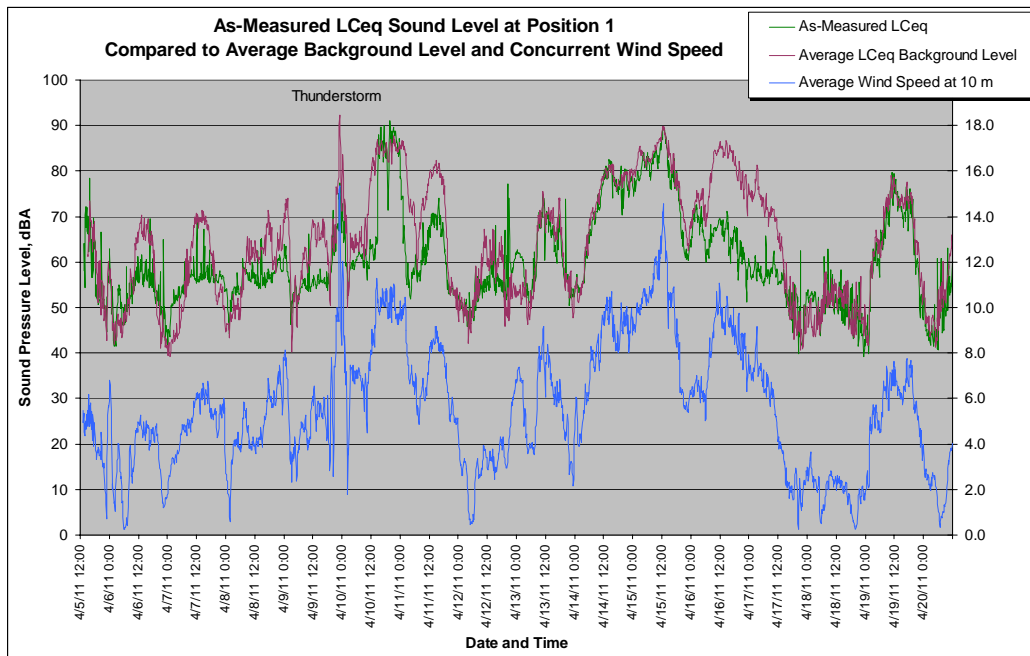


Figure 3.5.2

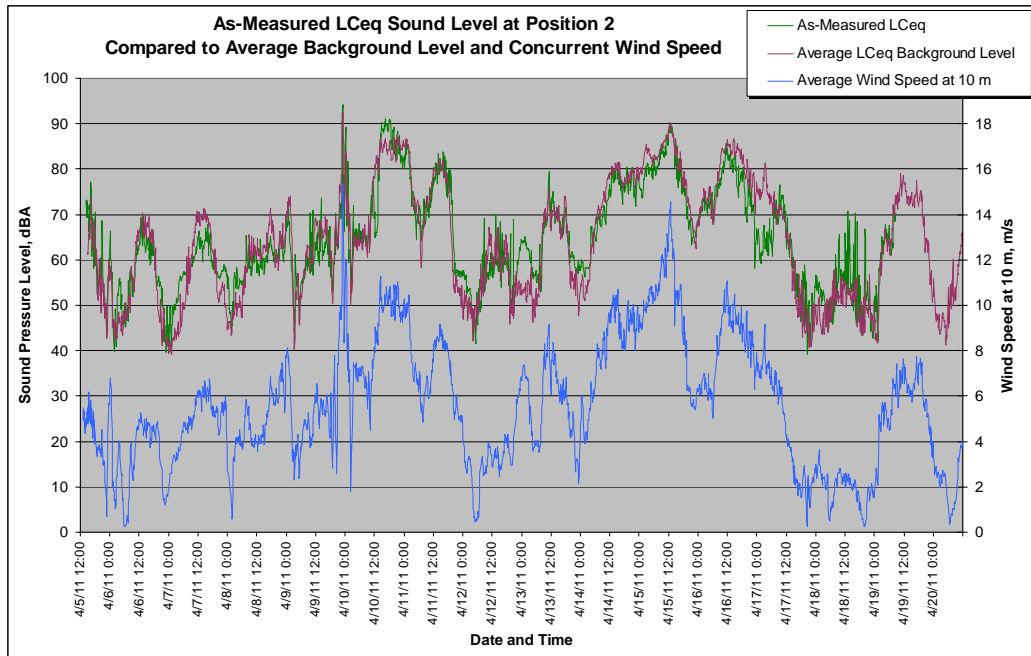


Figure 3.5.3

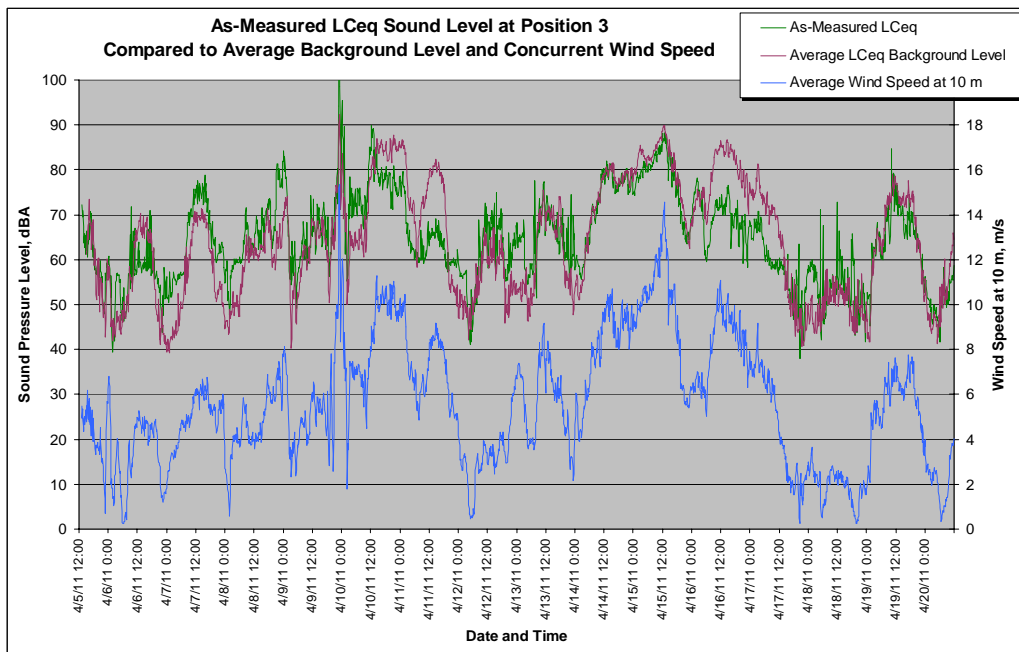


Figure 3.5.4

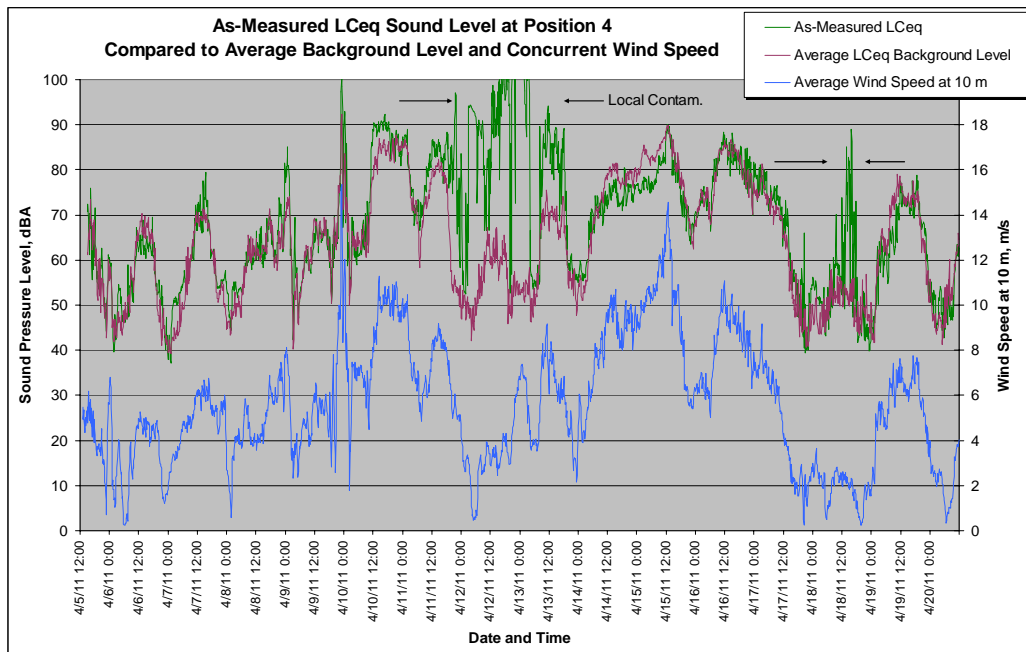


Figure 3.5.5

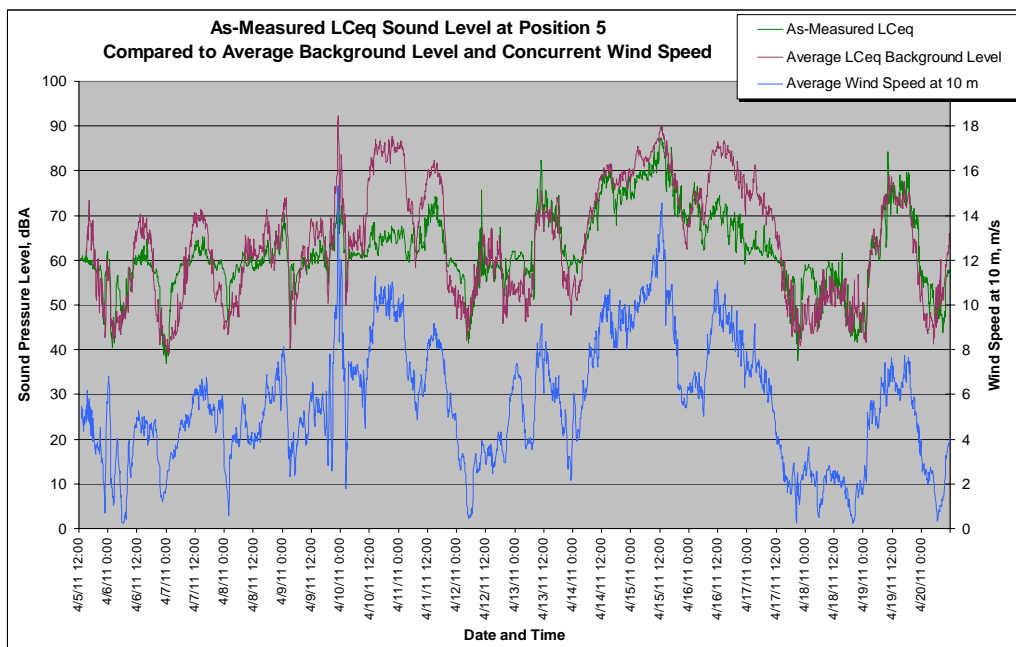


Figure 3.5.6

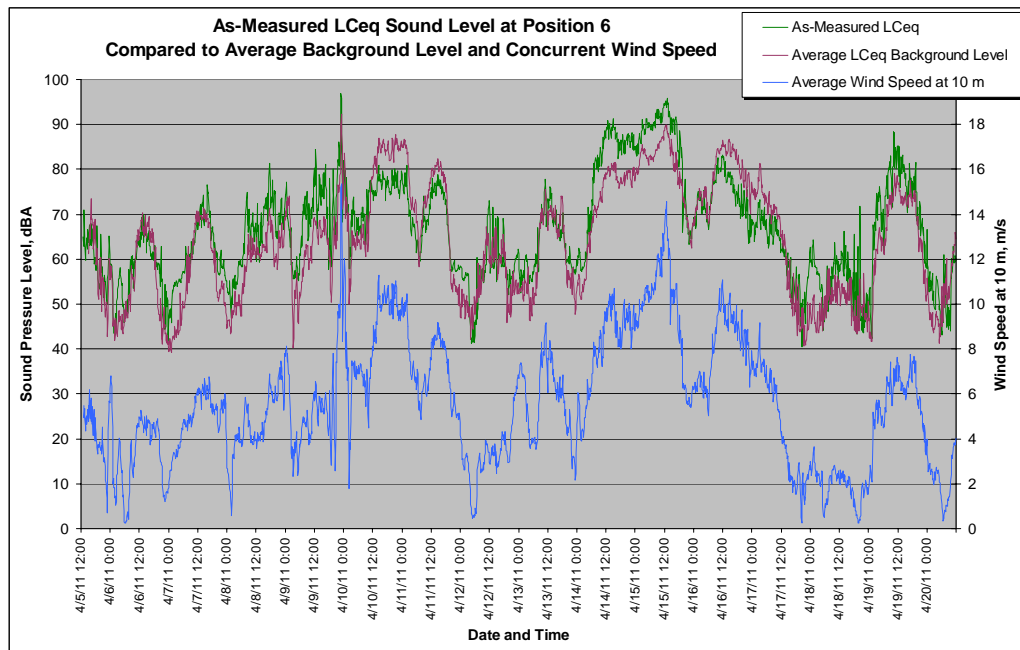


Figure 3.5.7

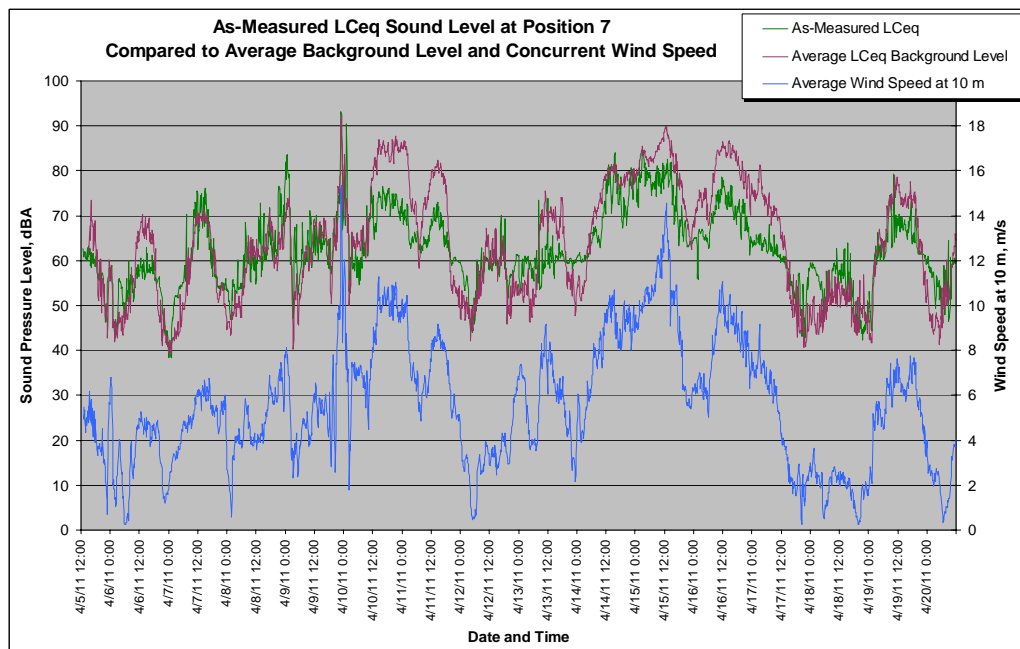


Figure 3.5.8

In summary, the survey measurements, carried out continuously day and night for over two weeks in a variety of wind and weather conditions, indicate that there is no evidence whatsoever of any significant low frequency noise emissions from the project.



## 4.0 SUMMARY AND CONCLUSIONS

An extensive field survey has been carried out to measure the sound levels produced by the Bent Tree Wind Farm Project in order to evaluate compliance with the Freeborn County noise limits, which derive from the State of Minnesota noise standards and are expressed in terms of daytime and nighttime L10 and L50 statistical levels as tabulated below.

**Table 4.0.1** *Project Sound Level Limits*

Daytime (7 a.m. to 10 p.m.)		Nighttime (10 p.m. to 7 a.m.)	
L10	L50	L10	L50
65 dBA	60 dBA	55 dBA	50 dBA

A total of approximately 2100 10 minute samples were taken on a continuous day and night basis over a 15 day period at each of 10 monitoring stations distributed throughout the project area and beyond. Seven positions were set up at or near residences where maximum project sound levels were anticipated (due to the proximity and number of nearby turbines) and three positions were set-up several miles from the site perimeter in diametrically opposed directions to develop a time history of the background level that would most likely have occurred on the site physically between these positions in the absence of the project at any given time during the survey. This background sound level was subsequently subtracted from the on-site measurements to derive the likely project-only sound level – the quantity actually limited by the County noise standards.

The survey was carried out from April 5 to 20, 2011 during early spring conditions. A wide variety of high wind periods, wind directions and atmospheric conditions were captured during the survey.

In general, it was found that the sound levels produced exclusively by the project (after correction for background, local contamination, rain and turbine operation) were lower than the permissible noise limits the vast majority of the time; however, there were occasions when the project sound level apparently exceeded the limits either momentarily or for more extended periods of time at all positions in very high wind conditions. These excursions were rare and infrequent, however, generally occurring for a cumulative total of between 1 and 2% of time; i.e. over the observed survey period of 15 days. The specific results for the seven on-site receptor locations are tabulated below.

**Table 4.0.2** *Summary of Results at On-Site Receptor Positions*

Position	Percent of Time in Compliance with Applicable Limits	
	L10	L50
1	99.3%	98.3%
2	100.0%	98.8%
3	95.0%	92.5%
4	99.0%	98.5%
5	99.9%	98.2%
6	99.7%	98.5%
7	99.1%	98.4%
<b>Site-Wide Average</b>	<b>98.9%</b>	<b>97.6%</b>

As illustrated in the table, the results are highly consistent from one location to another, except at Position 3 where the monitor position was considerably closer to the nearest turbine than the



residence it was intended to represent and where the meter happened to be directly downwind of the turbine the period of maximum wind and apparently unsettled weather on April 14 and 15. Thus, the result there is considered anomalous and higher than it should be. On average, however, still accepting the Position 3 result at face value, site-wide compliance with the County/State noise limits was found to be 98.9% for the L10 statistical measure and 97.6% for the L50 level. As stated in Section 7.0 of the Test Protocol, a compliance rate of 95% or greater is considered satisfactory evidence of compliance with the applicable noise standards. Consequently, it can be concluded that the sound emissions from the project are compliant with the Freeborn County noise standards.

Additional analyses of the L90 statistical sound level, which generally yields a more accurate value for project-only sound than the L10 and L50 measures due to its higher signal-to-noise ratio, were carried out for each monitoring site and compared to model predictions at those locations calculated using simple assumptions and ISO 9613-2. Good agreement was generally observed between the measured and modeled levels at low to moderate wind speeds but during very high wind conditions (>11 m/s) the actual project sound levels appear to significantly exceed the predicted levels. It is generally under these elevated wind conditions that the project was found to exceed the County noise standards.

Although the regulatory noise limits place no restriction on the frequency content of the project's sound emissions or on low frequency sound levels, a frequency analysis was carried out to evaluate the potential for low frequency noise emissions. Measurements of the 1/3 octave band frequency spectrum, measured down to 6.3 Hz, taken both on the site and miles away from the site show that the low frequency sound levels are generally the same and that both are driven by wind-induced, false-signal noise rather than by any actual source of low frequency noise.

The C-weighted sound levels measured at all on-site positions were also compared to the C-weighted levels measured at the three off-site background locations. C-weighted sound levels generally reflect and quantify a signal's low frequency content and, in this case, merely measure the degree of microphone distortion due to local wind effects. These comparisons show that the off-site levels of ostensible low frequency noise were often higher than or similar to the on-site levels demonstrating that the turbines are not producing any significant low frequency sound emissions.

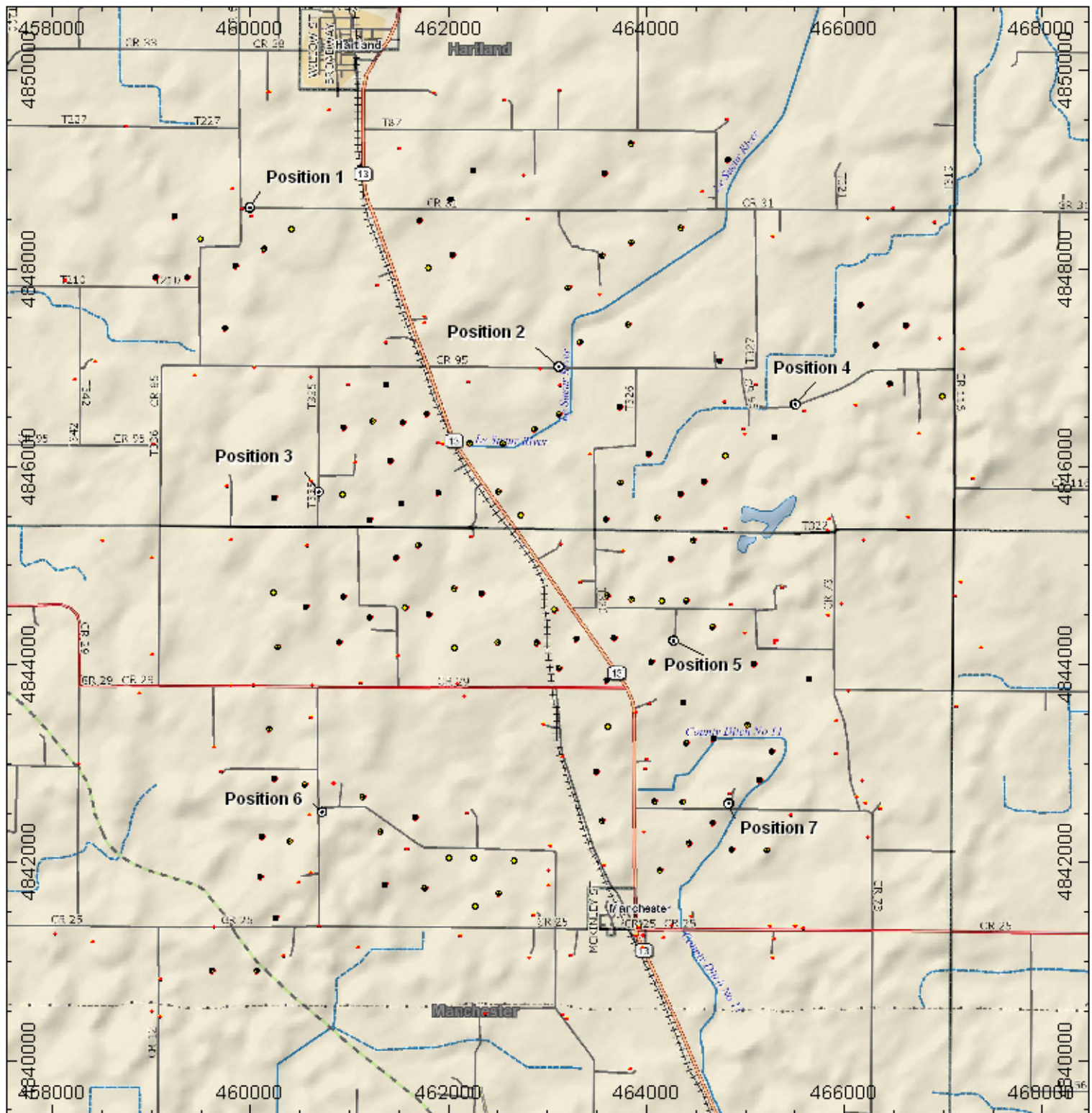
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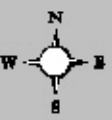
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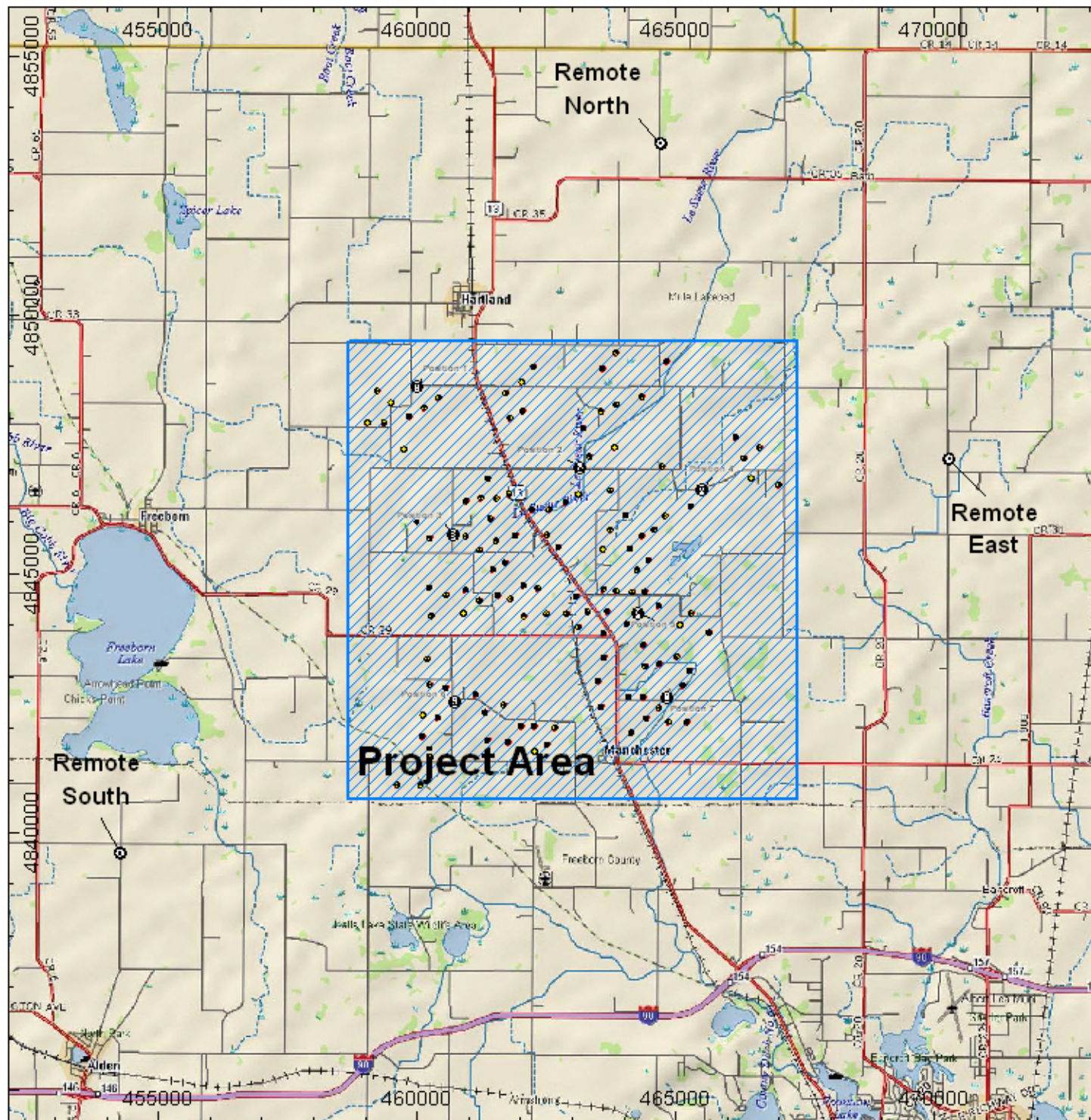


Scale in meters - Units are UTM NAD83 coordinates

<b>Project:</b> <b>Bent Tree Wind Park</b>	<b>Description:</b> <b>Graphic A</b>	<b>Legend:</b>  Sound Monitoring Location
<b>Prepared for:</b> <b>Wisconsin Power &amp; Light Co.</b>	<b>On-Site Sound Monitoring Positions</b>	 Turbine Location
<b>Date:</b> April 12, 2010		 Nearby Residence
<b>Drawing #:</b> AA-Rev-A-1-1	<b>Hessler Associates, Inc.</b> Consultants in Engineering Acoustics Since 1976	3862 Clifton Manor Place, Suite B Haymarket VA, 20169 www.hesslernoise.com (703) 753-2291 (703) 753-1602







Description:

## Graphic B

### Project Area and Remote Background Measurement Location Areas

Project:

**Bent Tree Wind Park**

Drawing Number:

ABT-Rev-B-1B-1




Date:

December 6, 2010

Prepared for:

**Wisconsin Power & Light Co.**

Legend:

-  Measurement Position
-  Turbine Location
-  Project Area

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Border Scale in meters, units are UTM NAD83 coordinates



## **Appendix A**

### Test Protocol

## TECHNICAL MEMORANDUM

**Title:** Operational Sound Level Survey Test Protocol

**Project:** Bent Tree Wind Farm

**Location:** Hartland, MN

**Prepared For:** Wisconsin Power and Light

**Prepared By:** David M. Hessler, P.E.

**Revision:** A

**Issue Date:** December 6, 2010

**Reference No:** TM-110810-A

**Attachments:** Graphic A – On-Site Sound Monitoring Positions  
Graphic B – Off-Site Background Sound Monitoring Positions

### 1.0 Introduction

This protocol summarizes the field test procedures to be used in evaluating the sound emissions from the Wisconsin Power and Light (WPL) Bent Tree Wind Farm relative to applicable regulatory noise limits once the project is fully operational.

Freeborn County (the project location) has adopted the Minnesota State noise standard (Minnesota Noise Pollution Statute and Rule 7030-0040), which for a Zone 1 Noise Area Classification (residential, including farm houses) limits sound levels exclusively from the project to the following values:

**Table 1.0.1** *Project Sound Level Limits*

Daytime (7 a.m. to 10 p.m.)		Nighttime (10 p.m. to 7 a.m.)	
L10	L50	L10	L50
65 dBA	60 dBA	55 dBA	50 dBA

The terms L10 and L50 are the statistical sound levels exceeded 10% and 50% of the time over the course of the measurement period. As such, the L10 generally captures near maximum or peak levels and the L50 is usually similar to the “average” sound level - although the actual average is a slightly different quantity, Leq, or the equivalent energy sound level.

It is important to note that these limits apply exclusively to sound levels produced by the project and do not include any background noise from unrelated sources, such as cars passing by, trees rustling in the wind, planes flying over, etc. Consequently, the aim of the survey is to quantify the project-only sound



level, which will generally involve subtracting the likely concurrent background sound level from the total measured level at measurement locations within the project area.

In general, it is also important to note that many customary techniques that have long been successfully used to test, say, a conventional fossil fueled power plant either cannot be applied to wind turbine projects or must be modified in recognition of the fact that the sound emissions from the project are wholly dependent on, rather than independent of, the wind, weather and general atmospheric conditions. For instance, the usual approach of taking sound measurements during quiet, low wind conditions to avoid contamination from wind-induced background sounds cannot be employed because the project is likely to be idle during such circumstances. Almost by definition one is required to measure during windy condition so a number of special measurement techniques are needed that are applicable only to the unique circumstances of wind turbine projects.

The general concept of the test is to measure continuously over a roughly two week period with automated monitors at a number of key test points both on and off the site to record sound levels during a range of wind and atmospheric conditions. The off-site measurements will be used to estimate the background level during any given measurement interval so the on-site measurements can be corrected. It is essential in wind turbine surveys to use the background level recorded at the same time as the operational sound measurement so that all the weather parameters - such as wind speed, wind direction, wind gradient, thermal gradient, turbulence, cloud cover, precipitation, etc. - are the same. Both wind turbine and background sound levels are highly variable with time and the specific atmospheric conditions occurring at that instant and it is not practical to generalize about the background sound level based solely on wind speed and correct a measurement of operational sound with a background level measured at some other time.

## **2.0 Instrumentation and Set up**

The instruments used shall be Type 2 or better per ANSI S1.4-1983 (R2006) *American National Standard for Sound Level Meters* and shall be capable of integrating and storing the A-weighted L10, L50, and L90 statistical sound levels in 10 minute increments over a 14 day survey period. The instruments shall be field calibrated at the beginning of the survey and checked at the end of the survey for possible drift. Any variance from the original pre-survey reading shall be recorded and noted in the survey report. All instruments shall be synchronized to local time or control room SCADA system time, if significantly different.

The meters shall be protected from the elements inside weather-proof cases and the microphones shall be fitted with hydrophobically treated windscreens with a minimum diameter of 7" (ACO Pacific WS7-80T, or similar). Standard 3" windscreens are unacceptable.

Each meter shall be mounted on a post or tripod such that, where possible, the microphone is located at 3 ft. above local grade. This is to minimize the wind speed incident on the microphone. Wind speed diminishes rapidly close to surface, theoretically going to zero at the ground or boundary layer. Care should be taken that the instrument is positioned no closer than about 20 ft. from any large reflective surface or building to avoid reflections.

The selected measurement position should be representative of the sound environment experienced at and around nearby houses and away from any sources of local contaminating noise, such as HVAC systems, farm equipment, on-going human activity, etc.



In addition to the sound measurement equipment a temporary weather station shall be set up at at least one measurement position to record in 10 minute increments the wind speed at 3 ft. above ground level (microphone height), wind direction and rainfall during the survey. This selected location(s) shall be at measurement stations that are fairly open and exposed to the wind.

Arrangements shall be made to obtain, once the survey is completed, the wind speed and direction data (in 10 minute increments) from all on-site met towers for the survey period. In addition, a time history of the operating parameters of the project as a whole and each turbine shall be recorded by the SCADA system and made available after the survey for correlation to the measured sound levels.

### **3.0 Measurement Quantities and Duration**

The instruments shall be set up to store at least the L10, L50, L90 and Leq A-weighted statistical measures in concurrent 10 minute increments over the survey, which shall run for approximately 14 days. The survey may be carried out at any time under cold season conditions when no insect noise is present and all deciduous trees are bare (minimizing background noise contamination). Replication of the pre-construction survey dates (the last two weeks in March) is desirable but not imperative, since the background sound levels used to correct the operational survey results will be measured simultaneously with the operational sound levels. The background levels measured in the pre-construction survey shall be generally compared to the new background data to help validate the results.

### **4.0 On-Site Measurement Locations**

The 7 measurement positions selected for the background survey were generally chosen because they were representative of the residences in closest proximity to turbines, or where the highest project sound levels at residences were expected to occur. Consequently, the 7 original survey positions, illustrated in **Graphic A**, shall be replicated to the extent practicable in the operational survey. In addition, up to three other measurement positions may be used representing locations where homes are in relatively close proximity to turbines and/or where concerns about project noise have been expressed by homeowners.

The data measured at each location shall be evaluated and corrected for spurious noise events, which typically manifest themselves as short-duration noise spikes that are not evident at any other location. Any such isolated spikes that are not accompanied by a simultaneous spike in wind speed (as measured by the on-site met tower(s)) shall be disregarded. Any measurements obtained during periods of precipitation shall be neglected.

### **5.0 Off-Site Measurement Locations and Background Noise Correction**

In addition to the on-site measurement locations, 4 background monitor stations shall be established at off-site locations North, South, East and West of the project area that are at least 1.5 miles from the nearest turbine but no more than 2.5 miles. The selected locations shall be similar in setting and general circumstances to typical on-site positions, the objective being to record the “proxy” background sound level that would have probably existed at the on-site locations at any given time during the survey.

The levels measured at these four off-site positions shall be plotted together to evaluate their consistency over the survey. Based on the homogeneous nature of the site area and its surroundings it is anticipated that the sound levels will be similar in the sense that they intertwine with one another and no one position is consistently higher or lower than the others. If that turns out to be the case the arithmetic average of all four shall be used as the design background level for the survey after any spurious noise spikes occurring