Appendix E
Revised Noise Analysis for the Proposed Big Bend Wind Project

Big Bend Wind, LLC
Docket No. IP7013/WS-19-619
September 2021

PUBLIC DOCUMENT - NONPUBLIC DATA HAS BEEN EXCISED

REVISED NOISE ASSESSMENT, BIG BEND WIND PROJECT

September 2021

Big Bend Wind, LLC

Proprietary Information in
Appendix B Included
Not for Public Release

Report Title:

Revised Noise Assessment, Big Bend Wind Project

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1.0 INTRODUCTION

Big Bend Wind, LLC ("Big Bend") has applied for a permit for the Big Bend Wind Project ("Project") in Cottonwood and Watonwan Counties, in southwestern Minnesota. The Project will involve the construction of up to 53 turbines for a total capacity of up to 300 MW. The Project area is located north of Mountain Lake and south of MN Route 30 (MN-30).

Big Bend filed an initial Site Permit Application ("SPA") on November 8, 2020. For the Certificate of Need and SPA, RSG conducted a noise assessment[1] consistent with Minnesota Department of Commerce (MDOC) guidelines for comparison with Minnesota Pollution Control Agency (MPCA) sound level limits. Since that filing, Big Bend has uprated the turbine models under consideration and also modified the layout for consideration. This noise assessment is a revised version of that report that incorporates those changes. No revisions have been made to Sections 3.0 through 5.0 and Appendix A.

This report includes:

- A description of the Project;
- A description of sound level limits and guidelines applicable to the project;
- Some acoustical considerations particular to wind turbines;
- Background sound level monitoring procedures and results;
- Sound propagation modeling procedures and results; and
- Conclusions.

A primer for some of the acoustic-specific terminology is found in Appendix A.

[1] RSG, "Big Bend Wind Project, Noise Assessment," October 28, 2020.

2.0 PROJECT DESCRIPTION

The Project is proposed to be located in Cottonwood and Watonwan Counties, Minnesota. The northern extent of the Project area is MN-30, and the southern extent is MN Route 60 (MN-60) and the rail line that runs parallel to MN-60. The eastern extent of the Project area is 660th Avenue in Watonwan County, just east of Butterfield. The western extent is County Road 2 in Cottonwood County.

The Project is designed to included up to 53 wind turbines although less will be constructed so that the net capacity is up to 300 MW. Nine turbines are proposed for Watonwan County, and the rest would be located in Cottonwood County. There are three turbine models currently under consideration and modeled in this report. A summary of the turbine models and their hub height is provided in Table 1.

TABLE 1: WIND TURBINE MODELS UNDER CONSIDERATION

TURBINE MAKE/MODEL	TURBINE OUTPUT (MW)	HUB HEIGHT (m)	NUMBER OF TURBINES IN LAYOUT
Vestas V162	6.0	119	53
GE-158 LNTE[2]	5.8	117	53
Nordex N163 LNTE	5.94	118	53

The area around the Project is composed primarily of agricultural land uses with rural residences. Terrain in the area is mostly flat.

Butterfield is located at the southeastern corner with the nearest proposed turbine approximately 1.5 miles to the northwest. Mountain Lake is at the southern edge of the Project area with the nearest proposed turbine approximately 0.8 miles to the northeast.

A map of the project area is provided in Figure 1.

[2] Low-Noise Trailing Edge

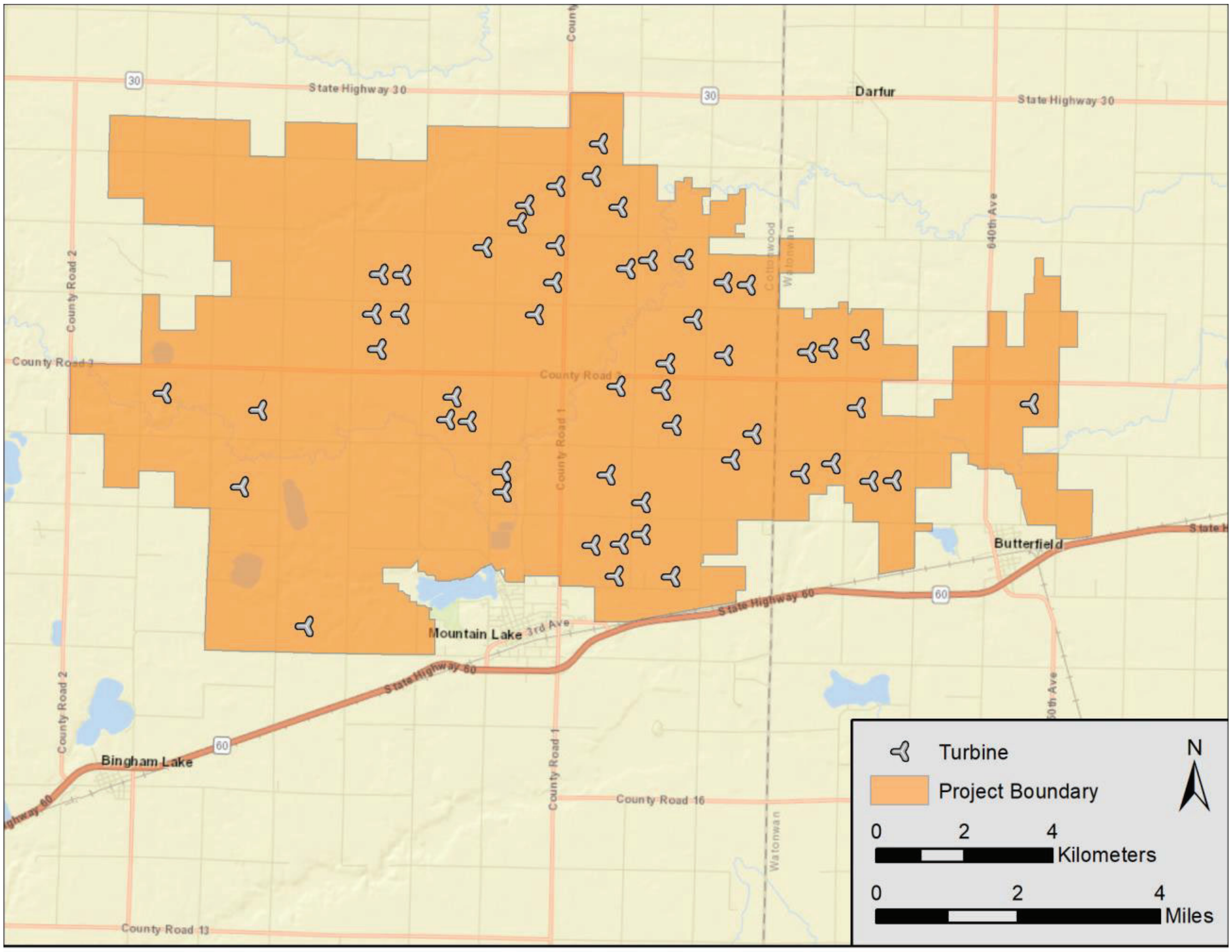

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FIGURE 1: PROJECT SITE MAP

3.0 SOUND LEVEL STANDARDS AND GUIDELINES

3.1 LOCAL STANDARDS

Watonwan County

Information on Watonwan County sound level limits for wind power project are found in Section 12.M.7 of the county's zoning regulation. This section is reproduced below.

> Noise standards are regulated by the Minnesota Pollution Control Agency under Chapter 7030. These rules establish the maximum night and daytime noise levels that effectively limit wind turbine noise to 50-dB (A) at farm residences and are incorporated here by reference. Additional local limits relative to impulsive and pure tone noises may be appropriate and set forth as a condition in the permit.

Cottonwood County

Sound level limits for Cottonwood County are found in Section 25 of the county's zoning regulations and references Chapter 7030 of the MPCA's rules.

3.2 STATE STANDARDS

Minnesota Statute §116.07 charges the Pollution Control Agency with adopting noise standards. These standards are set in Minnesota Rules Chapter 7030, for which a wind power project must demonstrate it will comply with to receive a site permit from the PUC. The rule provides daytime and nighttime[3] sound level limits (Table 2) for a variety of land uses, which are grouped into three categories identified by a Noise Area Classification (NAC). The sensitive land uses around the Project are primarily within NAC 1 which includes residences including farmhouses and contain the most restrictive sound limits.

TABLE 2: NOISE LIMITS (dBA) FROM MN RULES 7030.0040

NOISE AREA CLASSIFICATION	DAYTIME		NIGHTTIME	
	L_{50}	L_{10}	L_{50}	L_{10}
1	60	65	50	55
2	65	70	65	70
3	75	80	75	80

[3] MN Rules 7030.0020 define daytime as 7:00 a.m. to 10:00 p.m. and nighttime as 10:00 p.m. to 7:00 a.m.

The Rule says that the limits are for the "…preservation of public health and welfare" and that they are "…consistent with speech, sleep, annoyance, and hearing conservation requirements…", but that they "…do not, by themselves, identify the limiting levels of impulsive noise[4] needed for the preservation of public health and welfare."

[4] Impulsive noise is defined in Minnesota Rules Chapter 7030.0020. Typical, wind turbine sound at the distance of a residential receiver is not considered impulsive.

4.0 WIND TURBINE ACOUSTICS – SPECIAL CONSIDERATIONS

4.1 SOURCES OF SOUND GENERATION BY WIND TURBINES

Wind turbines generate two principle types of sound: aerodynamic, produced from the flow of air around the blades, and mechanical, produced from mechanical and electrical components within the nacelle.

Aerodynamic sound is the primary source of sound associated with wind turbines. These acoustic emissions can be either tonal or broadband. Tonal sound occurs at discrete frequencies, whereas broadband sound is distributed with little peaking across the frequency spectrum. While unusual, tonal sound can originate from unstable air flows over holes, slits, or blunt trailing edges on blades. The majority of audible aerodynamic sound from wind turbines is broadband at the middle frequencies, roughly between 200 Hz and 1,000 Hz.

Wind turbines emit aerodynamic broadband sound as the rotating blades interact with atmospheric turbulence and as air flows along their surfaces. This produces a characteristic “whooshing” sound through several mechanisms (Figure 2):

- Inflow turbulence sound occurs when the rotor blades encounter atmospheric turbulence as they pass through the air. Uneven pressure on a rotor blade causes variations in the local angle of attack, which affects the lift and drag forces, causing aerodynamic loading fluctuations. This generates sound that varies across a wide range of frequencies but is most significant at frequencies below 500 Hz.
- Trailing edge sound is produced as boundary-layer turbulence as the air passes into the wake, or trailing edge, of the blade. This sound is distributed across a wide frequency range but is most notable at high frequencies between 700 Hz and 2 kHz.
- Tip vortex sound occurs when tip turbulence interacts with the surface of the blade tip. While this is audible near the turbine, it tends to be a small component of the overall sound further away.
- Stall or separation sound occurs due to the interaction of turbulence with the blade surface.

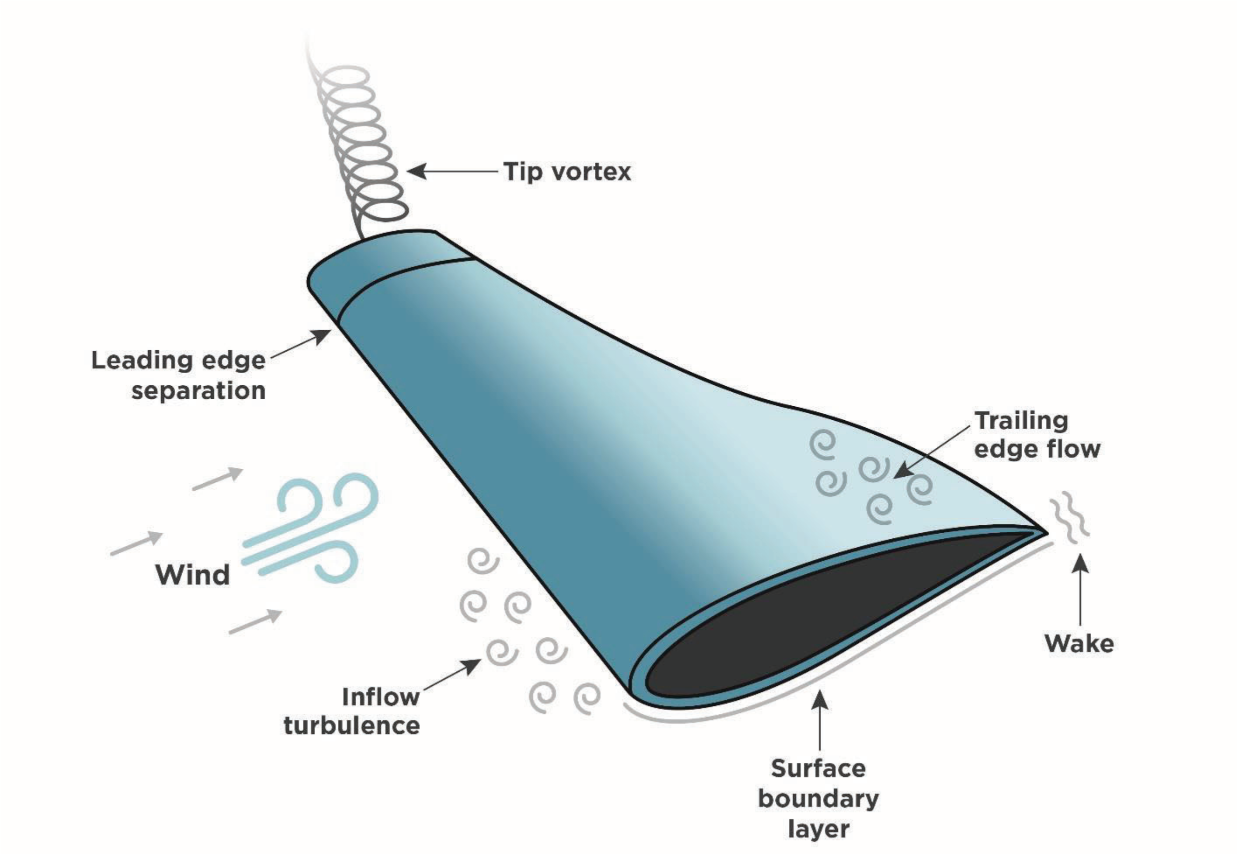


FIGURE 2: AIRFLOW AROUND A ROTOR BLADE

Mechanical sound from machinery inside the nacelle tends to be tonal in nature but can also have a broadband component. Potential sources of mechanical sound include the gearbox, generator, yaw drives, cooling fans, and auxiliary equipment. These components are housed within the nacelle, whose surfaces, if untreated, radiate the resulting sound. However modern wind turbines have nacelles that are designed to reduce the transmission of internal sound, and rarely is this a significant portion of the total wind turbine sound.

4.2 AMPLITUDE MODULATION

Amplitude modulation (AM) is a fluctuation in sound level that occurs at the blade passage frequency. There is no consistent definition how much of a sound level fluctuation is necessary for blade swish to be considered AM. Fluctuations can sometimes synchronize and desynchronize over periods, leading to increases and decreases in magnitude of the AM.[5] Most

[5] McCunney, Robert, et al. "Wind Turbines and Health: A Critical Review of the Scientific Literature." *Journal of Occupational and Environmental Medicine.* 56(11) November 2014: pp. e108-e130.

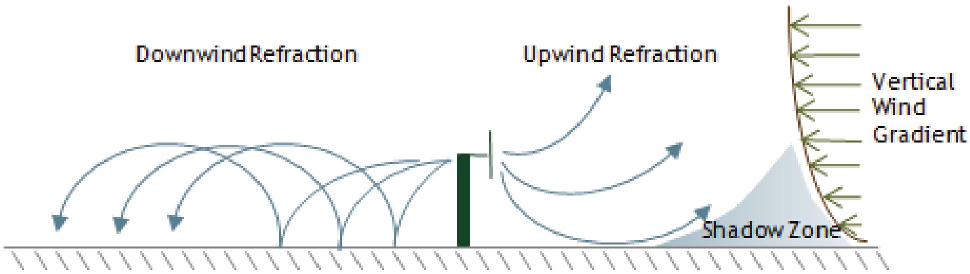
amplitude modulation is in the mid-frequencies and most overall A-weighted AM is less than 4.5 dB in depth.[6]

There are many confirmed and hypothesized causes of amplitude modulation including: blade passage in front of the tower, blade tip sound emission directivity, wind shear, inflow turbulence, transient blade stall, and turbine blade yaw error. It has recently been noted that although wind shear can contribute to the extent of amplitude modulation, wind shear does not contribute to the existence of amplitude modulation in and of itself. Instead, there needs to be detachment of airflow from the blades for wind shear to contribute to amplitude modulation.[7] While factors like the blade passing in front of the tower are intrinsic to wind turbine design, other factors vary with turbine design, local meteorology, topography, and turbine layout. Mountainous areas, for example, are more likely to have turbulent airflow, less likely to have high wind shear, and less likely to have turbine layouts that allow for blade passage synchronization for multiple turbines. Amplitude modulation extent varies with the relative location of a receptor to the turbine. Amplitude Modulation is usually experienced most when the receptor is between 45 and 60 degrees from the downwind or upwind position and is experienced least directly with the receptor directly upwind or downwind of the turbines.

4.3 METEOROLOGY

Meteorological conditions can significantly affect sound propagation. The two most important conditions to consider are wind shear and temperature lapse. Wind shear is the difference in wind speeds by elevation and temperature lapse rate is the temperature gradient by elevation. In conditions with high wind shear (large wind speed gradient), sound levels upwind from the source tend to decrease and sound levels downwind tend to increase due to the refraction, or bending, of the sound (Figure 3).

[6] RSG, et al., "Massachusetts Study on Wind Turbine Acoustics," Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, 2016
[7] "Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect." *RenewableUK.* December 2013.



Not to scale

FIGURE 3: SCHEMATIC OF THE REFRACTION OF SOUND DUE TO VERTICAL WIND GRADIENT (WIND SHEAR)

With temperature lapse, when ground surface temperatures are higher than those aloft, sound will tend to refract upwards, leading to lower sound levels near the ground. The opposite is true when ground temperatures are lower than those aloft (an inversion condition).

High winds and/or high solar radiation can create turbulence which tends to break up and dissipate sound energy. Highly stable atmospheres, which tend to occur on clear nights with low ground-level wind speeds, tend to minimize atmospheric turbulence and are generally more favorable to downwind propagation.

In general terms, sound propagates along the ground best under stable conditions with a strong temperature inversion. This tends to occur during the night and is characterized by low ground level winds. As a result, worst-case conditions for wind turbines tend to occur downwind under moderate nighttime temperature inversions. Therefore, this is the default condition for modeling wind turbine sound.

4.4 MASKING

As mentioned above, sound levels from wind turbines are a function of wind speed. Background sound is also a function of wind speed, i.e., the stronger the winds, the louder the resulting background sound. This effect is amplified in areas covered by trees and other vegetation.

The sound from a wind turbine can often be masked by wind sound at downwind receptors because the frequency spectrum from wind is very similar to the frequency spectrum from a wind turbine. Figure 4 compares the shape of the sound spectrum measured during a 5 m/s wind event at the Project site to that of a wind turbine models under consideration. As shown, the shapes of the spectra are very similar. The masking of turbine sound occurs at higher wind speeds for some meteorological conditions. Masking will occur most, when ground wind speeds are relatively high, creating wind-caused sound such as wind blowing through the trees and interaction of wind with structures.

It is important to note that while winds may be blowing at turbine height, there may be little to no wind at ground level. This is especially true during strong wind gradients (high wind shear), which mostly occur at night. This can also occur on the leeward side of ridges where the ridge blocks the wind.

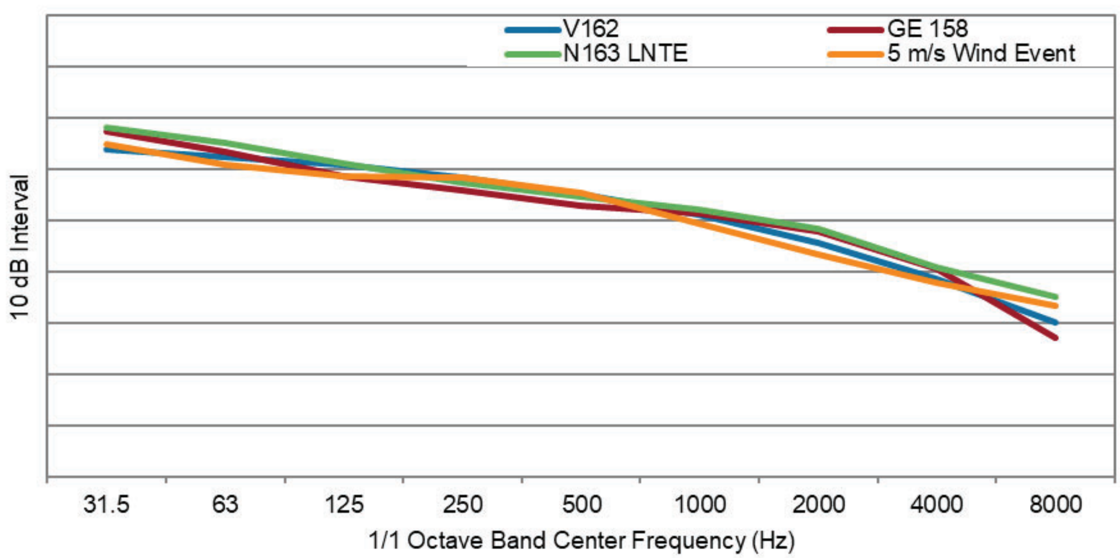


FIGURE 4: COMPARISON OF NORMALIZED FREQUENCY SPECTRA FROM THE WIND AND THE GE 158, V162, AND N163 LNTE[8]

4.5 INFRASOUND AND LOW FREQUENCY SOUND

Infrasound is sound pressure fluctuations at frequencies below about 20 Hz. Sound below this frequency is only audible at very high magnitudes. Low frequency sound is in the audible range of human hearing, that is, above 20 Hz, but below 100 to 200 Hz depending on the definition.

Low frequency aerodynamic tonal sound is typically associated with downwind rotors on horizontal axis wind turbines. In this configuration, the rotor plane is behind the tower relative to the oncoming wind. As the turbine blades rotate, each blade crosses behind the tower's aerodynamic wake and experiences brief load fluctuations. This causes short, low-frequency pulses or thumping sounds. Large modern wind turbines are "upwind", where the rotor plane is upwind of the tower. As a result, this type of low frequency sound is at a much lower magnitude with upwind turbines than downwind turbines, well below established infrasonic hearing thresholds.

[8] The purpose of this Figure is to show the shapes to two spectra relative to one another and not the actual sound level of the two sources of sound. The level of each source was normalized independently.

As an example of this, Figure 5 shows the sound levels 350 meters (1,148 feet) from a wind turbine when the wind turbine was operating (T-on) and shut down (T-off) for wind speeds at hub height greater than 9 m/s from a recent research study.[9] Measurements were made over approximately two weeks. The red 90 dBG line is shown here as the ISO 7196:1995 perceptibility threshold. As shown, the wind turbines generated measurable infrasound, but at least 20 dB below audibility thresholds.

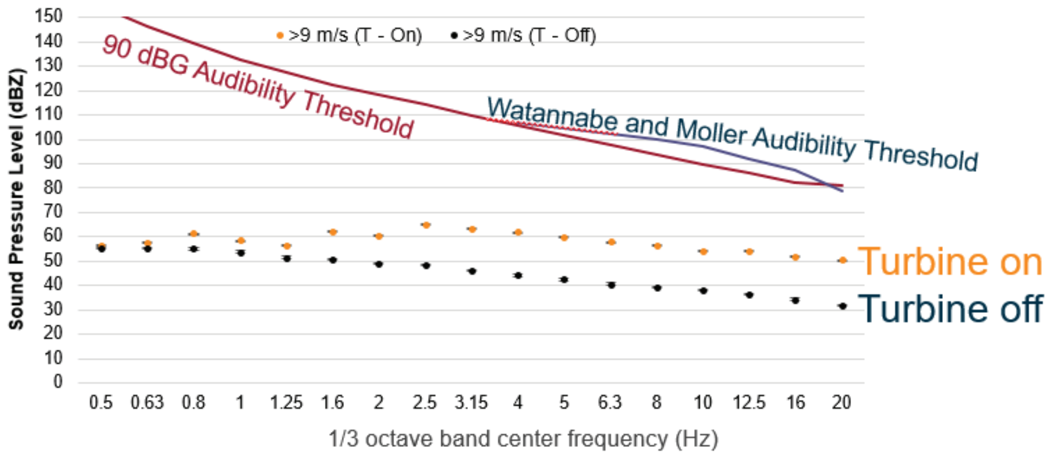


FIGURE 5: INFRASOUND FROM A WIND TURBINE AT 350 METERS (1,148 FEET) COMPARED WITH PERCEPTION THRESHOLDS

Low frequency sound is primarily generated by the generator and mechanical components. Much of the mechanical sound has been reduced in modern wind turbines through improved sound insulation at the hub. Low frequency sound can also be generated by the blades at higher wind speeds when the inflow air is very turbulent. However, at these wind speeds, low frequency sound from the wind turbine blades is often masked by wind sound at the downwind receptors.

Finally, low frequency sound is absorbed less by the atmosphere and ground than higher frequency sound. Our modeling takes into account frequency-specific ground attenuation and atmospheric absorption factors that takes this into account.

4.6 USE OF SOUND LEVEL WEIGHTING NETWORKS FOR WIND TURBINE SOUND

The human ear is not equally sensitive to sound pressure levels at all frequencies and magnitudes. Some frequencies, despite being the same decibel level (that is, magnitude), seem

[9] RSG, et al., "Massachusetts Study on Wind Turbine Acoustics," Massachusetts Clean Energy Center and Massachusetts Department of Environmental Protection, 2016 – Graphic from RSG presentation to MassDEP WNTAG, March, 2016

louder than others. For example, a 500 Hz tone at 80 dB will sound louder than a 63 Hz tone at the same level. In addition, the relative loudness of these tones will change with magnitude. For example, the perceived difference in loudness between those two tones is less when both are at 110 dB than when they are at 40 dB.

To account for the difference in the perceived loudness of a sound by frequency and magnitude, acousticians apply frequency weightings to sound levels. The most common weighting scale used in environmental noise analysis is the “A-weighting”, which represents the sensitivity of the human ear at lower sound pressure levels. The A-weighting is the most appropriate weighting when overall sound pressure levels are relatively low (up to about 70 dBA). The A-weighting de-emphasizes sounds at lower and very high frequencies, since the human ear is insensitive to sound at these frequencies at low magnitude. The A-weighting is indicated by “dBA” or “dB(A)”.

At higher sound pressure levels (greater than approximately 70 dBA), a different weighting must be used since human hearing sensitivity does not change as much with frequency. The “C-weighting” mimics the sensitivity of the human ear for these moderate to higher sound levels (greater than approximately 70 dBA, which is higher ground-based sound levels produced by wind power projects). C-weighted sound levels are indicated by “dBC” or “dB(C)”.

The “Z-weighting” does not emphasize or de-emphasize sound at any frequency. “Z” weighted sound levels are sometimes labeled as “Flat” or “Linear”. The difference is that the “Z-weighting” is defined as being unweighted in a specific range, whereas “Flat” or “Linear” indicate that no weighting has been used. Z-weighting or unweighted levels are typically used when reporting sound levels at individual octave bands.

The most appropriate weighting for wind turbine sound is A-weighting, for two reasons. The first is that sound pressure levels due to wind turbine sound are typically in the appropriate range for the A-weighting at typical receiver distances (50 dBA or less). The second is that various studies of wind turbine acoustics have shown that the potential effects of wind turbine noise on people are correlated with A-weighted sound level (i.e. Pedersen et al, 2008[10]) as well as to the perceived loudness of wind turbine sound.[11,12] Other researchers found that 51% of the energy making up a C-weighted measurement of wind turbine sound is not audible. Thus, it is more difficult to relate the level of C-weighted sound to human perception. That is, two sounds may be perceived exactly alike, but there could be significant variations in the C-weighted sound level depending on the content of inaudible sound in each.[6]

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[10] Pedersen, Eja and Waye, Kerstin. “Perception and annoyance due to wind turbine noise - a dose-response relation.” Journal of the Acoustical Society of America. 116(6). pp. 3460-3470.
[11] Yokoyama S., et al. “Perception of low frequency components in wind turbine noise.” Noise Control Engr. J. 62(5) 2014
[12] Yokoyama et al. “Loudness evaluation of general environmental noise containing low frequency components.” Proceedings of InterNoise2013, 2013

5.0 SOUND LEVEL MONITORING

5.1 MONITORING PROCEDURES

Background sound level monitoring was conducted from November 12 to November 21, 2019 throughout the Project area to quantify the existing sound levels, including the nighttime L_{50}, and to identify existing sources of sound. Monitoring locations were selected per the guidance provided in the Department of Commerce's "Guidance for Large Wind Energy Conversion System Noise Study Protocol and Report," July 2019. The guidance recommends a minimum of three locations within the Project area. For this Project there were a total of five onsite locations and one offsite monitor. The guidance also recommends that one monitor location be in proximity to the worst-case modeled receptor. Monitors 2 and 3 are representative of the worst-case Project sound levels. A map of all the monitor locations is provided in Figure 6, and each monitor location is described further in Section 5.2.

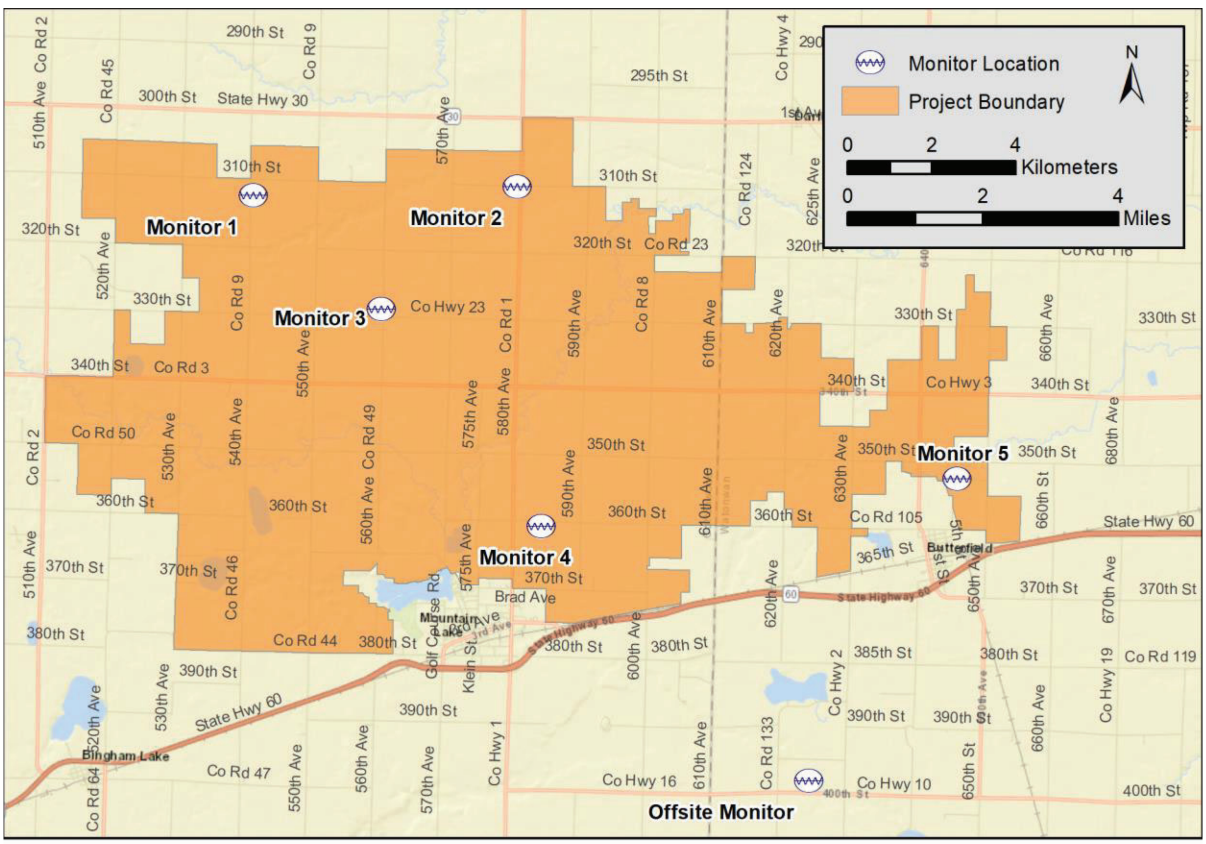

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FIGURE 6: MAP OF BACKGROUND SOUND MONITOR LOCATIONS

Equipment

Background sound level monitoring was performed with ANSI/IEC Class 1 Cesva SC310, Cirrus CR:171B, and Svantek 979 sound level meters with a minimum frequency range of 20 Hz to 10 kHz. Meters were set to log, at a minimum, 1/3 octave band sound levels once each second for the entire measurement period. Sound level meter microphones were mounted on wooden stakes at a height of approximately 1.5 meters (5 feet) and covered with 180 mm (7 inch) windscreens to minimize the impact of wind-caused distortion on measurements. The sound level meters either had internal audio recording or were connected to Edirol audio recorders, recording audio data at a minimum resolution of 96 kbps in .mp3 format. Before and after the measurement periods, the meters were calibrated with a B&K 4231 calibrator. The monitoring equipment meets LWECS Guidance.

A list of the equipment used at each monitor is shown in Table 3. At each site, an ONSET anemometer was located at microphone height. At Monitor 5, a wind direction sensor was also included in the setup. Monitor 3 also logged temperature and relative humidity. Wind data was logged at a rate of once each minute. Regional precipitation periods were collected from the FAA automated weather station KMWM in Windom, MN, about 12 miles to the southwest.

TABLE 3: SOUND MONITOR EQUIPMENT SPECIFICATIONS BY SITE

Monitor Location	Sound Level Meter	1/3 Octave Band Frequency Range	Audio Recorder	Weather Station
Monitor 1	Cesva SC310	10 Hz – 20 kHz	Edirol R-05	ONSET HOBO Wind Speed Sensor
Monitor 2	Cesva SC310	20 Hz – 10 kHz	Edirol R-05	ONSET HOBO Wind Speed Sensor
Monitor 3	Svantek 979	0.8 Hz – 20 kHz	Internal	ONSET HOBO Wind Speed and Temperature Sensors
Monitor 4	Cirrus CR: 171B	6.3 Hz – 20 kHz	Edirol R-05	ONSET HOBO Wind Speed Sensor
Monitor 5	Cirrus CR: 171B	6.3 Hz – 20 kHz	Edirol R-05	ONSET HOBO Wind Speed and Direction Sensors
Offsite	Cesva SC310	10 Hz – 20 kHz	Edirol R-05	ONSET HOBO Wind Speed Sensor

Data Processing

For each period A-, C-, and Z-weighted equivalent average sound levels (L_{eq}) were calculated. For A- and C-weighted sound levels, the L_{10}, L_{50}, and L_{90} statistical sound levels were also calculated.

A second set of data was also generated with periods removed from the data that either contained anomalous sound events or periods with conditions that could lead to false sound level readings.

Periods that were removed from the sound level data included:

- Wind speeds above 11 mph (5 m/s),
- Precipitation and thunderstorm events, and
- Personnel and animal interaction with equipment.

5.2 MONITOR LOCATION DESCRIPTIONS

Monitor 1

Monitor 1 was located at the edge of a field in the northwest corner of the Project area. The monitor was located 250 feet east of County Road 9 (540th Ave.), and 1,360 feet south of 310th Street. The nearest residence was a farm approximately 700 feet south of the monitor. The area around the monitor is largely agricultural with scattered farm residences, although little farming was being done at the time of the monitoring. A photograph of the monitor setup is provided in Figure 7, and a map of the surrounding area is shown in Figure 8.

FIGURE 7: PHOTOGRAPH OF MONITOR 1 LOOKING TO THE SOUTH

FIGURE 8: AERIAL VIEW OF MONITOR 1 AND THE SURROUNDING AREA

Monitor 2

Monitor 2 was located at a farm residence in the northern portion of the Project area. The monitor was located approximately 115 feet south of 310th Street, and 300 feet west of County Road 1 (580th Ave.). The area around the monitor is largely agricultural with scattered farm residences. The monitor was placed just west of a wind break. A photograph of the monitor setup is provided in Figure 9, and a map of the surrounding area is shown in Figure 10.

FIGURE 9: PHOTOGRAPH OF MONITOR 2 LOOKING TO THE NORTH

FIGURE 10: AERIAL VIEW OF MONITOR 2 AND THE SURROUNDING AREA

Monitor 3

Monitor 3 was located at a farm residence in the middle of the Project area. The monitor was located approximately 150 feet west of County Road 49, and 545 feet north of County Highway 23 (330th St.). The area around the monitor is largely agricultural with scattered farm residences. The monitor was located approximately 100 feet north-northeast of a large outbuilding and 320 feet north of the farm residence. A photograph of the monitor setup is provided in Figure 11, and a map of the surrounding area is shown in Figure 12.

FIGURE 11: PHOTOGRAPH OF MONITOR 3 LOOKING TO THE SOUTH

FIGURE 12: AERIAL VIEW OF MONITOR 3 AND THE SURROUNDING AREA

Monitor 4

Monitor 4 was located at a farm residence in the southern portion of the Project area. The monitor was located approximately 460 feet south of 360th Street and 2,200 feet east of Country Road 1. The area around the monitor is largely agricultural with scattered farm residences. Mountain Lake is located approximately 1.25 miles southwest of the monitor location. The monitor was located approximately 70 feet north-northeast of an outbuilding, and 170 feet north of a larger outbuilding. A photograph of the monitor setup is provided in Figure 13, and a map of the surrounding area is shown in Figure 14.

FIGURE 13: PHOTOGRAPH OF MONITOR 4 LOOKING TO THE SOUTH

FIGURE 14: AERIAL VIEW OF MONITOR 4 AND THE SURROUNDING AREA

Monitor 5

Monitor 5 was located in the southeastern portion of the Project area slightly less than a mile north-northeast of Butterfield. The monitor was located just under half a mile west of 650th Avenue and 0.75 miles north of Township Road 105. The area around the monitor is agricultural with scattered farm residences. There was a water treatment facility about a half a mile to west of the monitor. The monitor was located approximately 160 feet south of an outbuilding and 200 feet southeast of another outbuilding. A photograph of the monitor setup is provided in Figure 15, and a map of the surrounding area is shown in Figure 16.

FIGURE 15: PHOTOGRAPH OF MONITOR 5 LOOKING TO THE NORTH

FIGURE 16: AERIAL VIEW OF MONITOR 5 AND THE SURROUNDING AREA

Offsite Monitor

The offsite monitor was located at the edge of a field south-southeast of the Project area, over 4 miles from the nearest proposed turbine. The monitor was located just approximately 865 feet north of County Highway 10 (400^{th} Street) and about half a mile east of County Road 133 (620^{th} Ave.) The area around the monitor is primarily agricultural with scattered farm residences. The closest residence was approximately 760 feet south-southwest of the monitor. A photograph of the monitor setup is provided in Figure 17, and a map of the surrounding area is shown in Figure 18.

FIGURE 17: PHOTOGRAPH OF THE OFFSITE MONITOR LOOKING TO THE SOUTHEAST

FIGURE 18: AERIAL VIEW OF THE OFFSITE MONITOR AND THE SURROUNDING AREA

5.3 MONITORING RESULTS

For each monitor site, sound level time-history monitoring results are presented in a single chart in this report section. Each chart contains hourly sound levels, gust wind speed measured adjacent to each microphone, "hub height" average wind speed, precipitation events, and indications of data exclusions in conformance with LWECS Guidance. Points on the sound level graph represent data summarized for a single one-hour interval. The top portion of the chart displays A-weighted sound levels, the middle portion presents C-weighted levels, and the bottom portion shows wind speeds and times when there were data exclusions. All portions of the chart indicate day/night by shading: night is defined as 22:00 to 07:00 and shaded in grey.

The specific sound level metrics reported are L_{eq}, L_{90}, L_{50}, and L_{10}. Equivalent continuous sound levels (L_{eq}) are the energy-average level over one hour. Tenth-percentile sound levels (L_{90}) are the statistical value above which 90% of the sound levels occurred during one hour. Fiftieth-percentile sound levels (L_{50}) represent the median sound level of that one-hour period. Ninetieth-percentile sound levels (L_{10}) are the statistical value above which 10% of the sound levels occurred during one hour. Data that were excluded from processing (e.g., due to high wind and rain periods) are included in the graphs but shown in lighter colors. Furthermore, rectangular markers on the lower portion of the chart indicate periods for which data was excluded and designate if the period was eliminated as a result of rain, wind gusts over 11 mph, or anomalous events.

Sound level data and wind gust data presented in the charts are those measured at each corresponding site. Wind data from the monitoring location, measured at the microphone height of 1.5 meters (5 feet), are presented as the maximum gust speed occurring at any time over a 10-minute interval; they are not averaged. The average 10-minute hub height wind speed extrapolated from the Project met-tower closest to the monitoring location is also displayed on the chart. Lastly, regional one-hour precipitation totals, as reported by KMWM in Windom, MN, are plotted with respect to the secondary axis on the right-hand side of the chart. Note that the precipitation may not line up exactly with precipitation exclusions because the airport is approximately 12 miles southwest of the project site and some localized rain events were not registered at the airport.

Lastly, one-third octave band statistical sound level results are also presented for periods when a representative wind speed (9 m/s) existed at a height of 109 meters (358 feet). This condition reflects the wind conditions that would result in turbines producing near maximum sound power (9 m/s wind speed or greater at hub height). Only periods with this representative wind speed were used for the unweighted statistical one-third octave band metrics in the figures, providing a baseline for direct comparison with post-construction measurements. Each vertical orange and grey bar shows the lower 10th, median, and upper 10th percentile (L_{90}, L_{50}, and L_{10}) sound level for a single 1/3 octave band. The top of the orange bar is the upper 10th percentile sound pressure level, the white dot is the median, and the bottom of the grey bar is the lower 10th percentile sound level. The entire length of the bar indicates the middle 80th percentile of sound pressure levels. The blue dots indicate the equivalent continuous sound pressure level (L_{eq}) for that 1/3 octave band. At the far right of the chart are the A-, C-, and Z-weighted overall levels.

Results Summary

Exclusion Periods

Periods were excluded at each monitor through both manual identification and automated processing. Manual processing included the review of spectrograms created from the measured one-second one-third octave band data, accompanied by audio recordings made through the sound level meter's microphone. In this way, typical sources and anomalous events were identified.

Exact rain periods were manually identified from the spectrogram to ensure that data during rain events at each monitor were excluded. Automated processing of wind speed permitted the identification of gusts above 5 m/s (11.2 mph) on a one-minute basis. That is, if a gust within a specific one-minute period was measured above 5 m/s (11.2 mph), then that whole minute was eliminated.

A summary of each monitor's total runtime and the amount of time excluded from the reported sound levels for rain, wind, and anomalous events are shown in Table 4.

TABLE 4: SUMMARY OF EXCLUSION PERIODS AT EACH MONITOR

Location	Run-Time	Exclusion Statistics							
		Rain		Wind		Anomalies		Total	
	(hr)	(hr)	(%)	(hr)	(%)	(hr)	(%)	(hr)	(%)
1	210	27.4	13.1	54.6	26.0	11.4	5.4	87.3	41.6
2	210	27.4	13.1	34.7	16.5	7.8	3.7	64.8	30.9
3	210	27.4	13.1	25.8	12.3	0.2	0.1	50.8	24.2
4	210	27.4	13.1	68.4	32.6	8.9	4.3	95.3	45.4
5	215	26.3	12.2	25.8	12.0	0.4	0.2	53.1	24.7
Offsite	214	26.3	12.3	46.1	21.5	0.4	0.2	71.5	33.4

Overall Sound Levels

The A-weighted sound levels are listed for all seven sites in Table 5, and the C-weighted sound levels are listed Table 6. The reported levels represent all valid periods, that is, all periods that were not excluded due to weather or anomalous activity, as discussed in the previous section. In both tables, the equivalent continuous levels (L_{eq}) at night are less than (or equal to) daytime levels at all sites except at Monitor 1, which is typical and indicate the influence of human activity on the measured sound levels during the day.

As shown in Table 5, the average nighttime L_{50} across all the onsite monitors was 33 dBA with more rural locations (Monitors 1, 2, and 3) resulting in slightly lower levels and less rural locations (Monitors 4 and 5) having slightly higher levels.

TABLE 5: PRECONSTRUCTION MONITORING SUMMARY (A-WEIGHTED RESULTS)

Location	Sound Levels (dBA)											
	Overall				Day				Night			
	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}
Monitor 1	48	25	35	46	44	27	36	45	50	23	32	55
Monitor 2	50	26	37	53	51	31	40	54	47	23	31	50
Monitor 3	46	25	34	48	48	27	36	51	39	23	31	42
Monitor 4	42	28	39	46	43	32	40	46	42	26	36	46
Monitor 5	42	31	38	46	43	31	39	47	41	31	36	42
Onsite Average	*46*	*27*	*36*	*48*	*46*	*29*	*38*	*48*	*44*	*25*	*33*	*47*
Offsite	41	28	35	42	42	30	36	42	38	26	33	41

TABLE 6: PRECONSTRUCTION MONITORING SUMMARY (C-WEIGHTED RESULTS)

Location	Sound Levels (dBC)											
	Overall				Day				Night			
	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}
Monitor 1	57	44	52	61	57	45	53	61	57	44	51	61
Monitor 2	59	40	49	60	61	44	51	62	55	38	45	56
Monitor 3	62	41	50	59	63	44	51	62	52	39	46	55
Monitor 4	57	45	54	60	57	48	55	60	56	43	52	59
Monitor 5	56	44	52	59	57	46	54	60	54	42	50	57
Onsite Average	*58*	*43*	*52*	*60*	*59*	*45*	*53*	*61*	*55*	*41*	*49*	*58*
Offsite	58	45	53	58	60	46	53	59	55	44	52	58

Meteorology

As discussed above, local meteorological data was collected from anemometers alongside the monitors, Project met towers, and the Windom Airport ASOS station (KMWM). According to the temperature sensor at Monitor 3, local temperatures ranged from -8.9°C to 11.0°C (16°F to 52°F) during the monitoring period. According to KMWM, precipitation events took place on November 18th and 20th. Based on review of the spectrograms, a precipitation event was also identified on November 16th that lasted into the 17 h. All of the monitor sites had a light layer of snow on the ground during the monitor setup, but the snow had melted by the end of the monitoring period.

A summary of the 1.5-meter (5-foot) wind speeds measured at each monitoring location over the deployment period at each site is provided in Table 7.

TABLE 7: SUMMARY OF MEASURED 1.5-METER (5-FOOT) WIND SPEEDS

Location	Measured 1.5-meter Wind (mph)			
	10-min Wind Speed		10-min Gust Speed	
	Average	Maximum	Average	Maximum
1	4.3	11.0	9.0	22.5
2	3.0	19.4	5.7	31.5
3	2.9	14.8	6.6	24.8
4	5.7	18.6	10.2	29.9
5	2.9	14.8	6.6	24.8
Offsite	5.0	16.8	9.2	28.7

Monitor 1

Monitoring results for Monitor 1 are presented in Figure 19. The primary noise sources at this location were occasional car passbys, biogenic sounds (birds especially), aircraft overflights, occasional distant agricultural equipment, and wind rustling through trees. The location's sound levels generally exhibited a diurnal pattern. It also had the second greatest amount of wind exclusions during the monitoring period. The quietest nighttime periods were between 20 and 25 dBA, and some higher nighttime periods were between 40 and 45 dBA. The highest nighttime hourly L_{50} at this site was 60 dBA which occurred for several hours during one night (11/13/19) due to sound from nearby agricultural activity. Nighttime hourly L_{50}s were less than 50 dBA at all other times. Over the entire monitoring period, the daytime L_{50} at this site was 36 dBA and the nighttime L_{50} was 32 dBA.

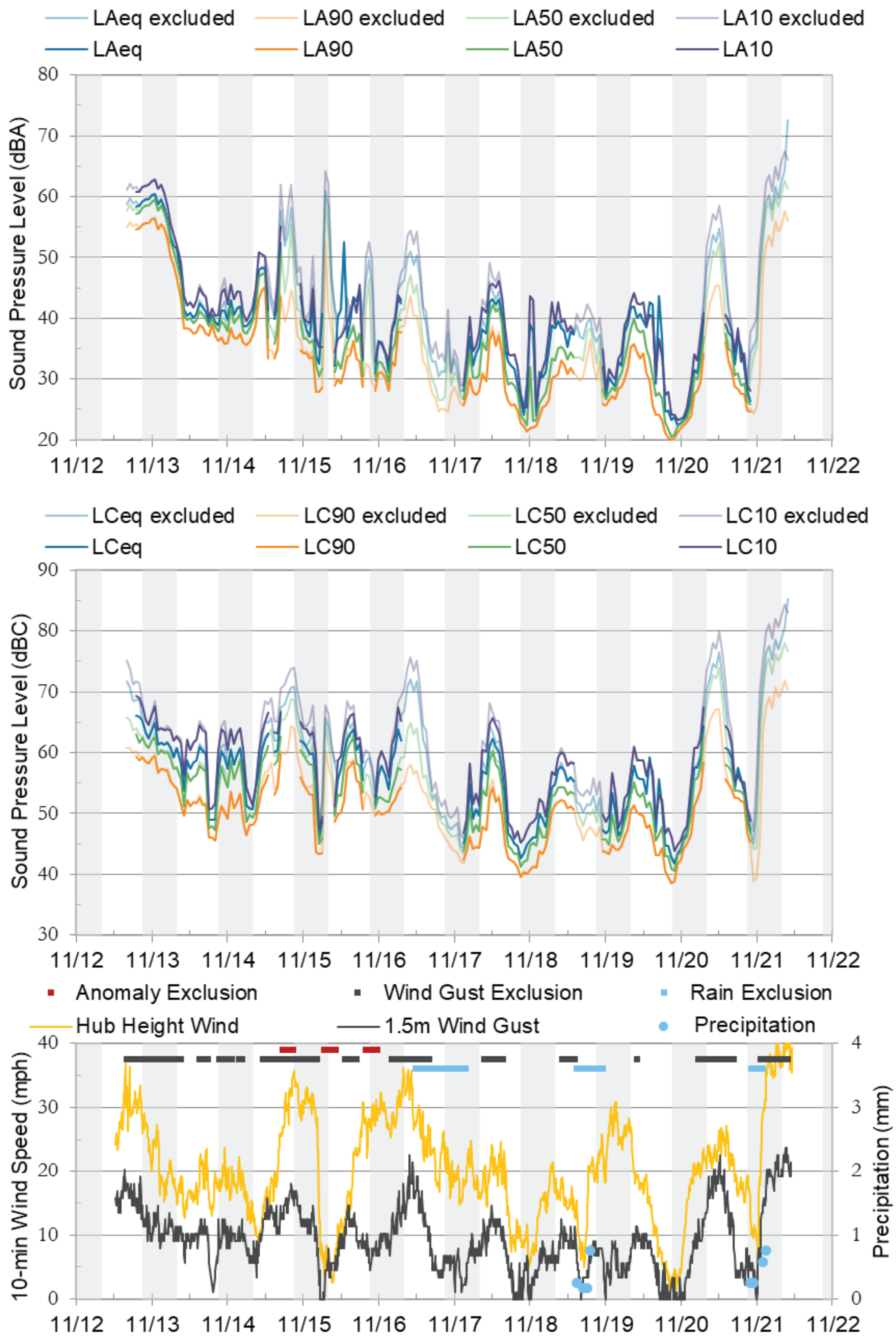

FIGURE 19: PRE-CONSTRUCTION MONITORING RESULTS AT MONITOR 1

Monitor 2

Results for Monitor 2 are presented in Figure 20. The primary noise sources at this location were car and truck passbys, biogenic sounds (birds especially), occasional aircraft overflights, distant agricultural equipment, local agricultural operations, and wind rustling through trees. The location generally exhibited a diurnal pattern. The quietest nighttime periods were between 20 and 25 dBA, and some higher nighttime periods were between 40 and 45 dBA. The highest nighttime hourly L_{50} at this site was 58 dBA which occurred for a few hours during one early morning (11/21/19) due to sound from nearby agricultural activity. Nighttime hourly L_{50}s were less than 50 dBA at all other times. Over the entire monitoring period, the daytime L_{50} at this site was 40 dBA and the nighttime L_{50} was 31 dBA.

Monitor 2 represents one of the areas with the highest projected sound levels by the pre-construction sound propagation model, so the statistical spectral levels for a representative wind speed (9 m/s) at a representative hub height (109 meters) are presented in Figure 21.

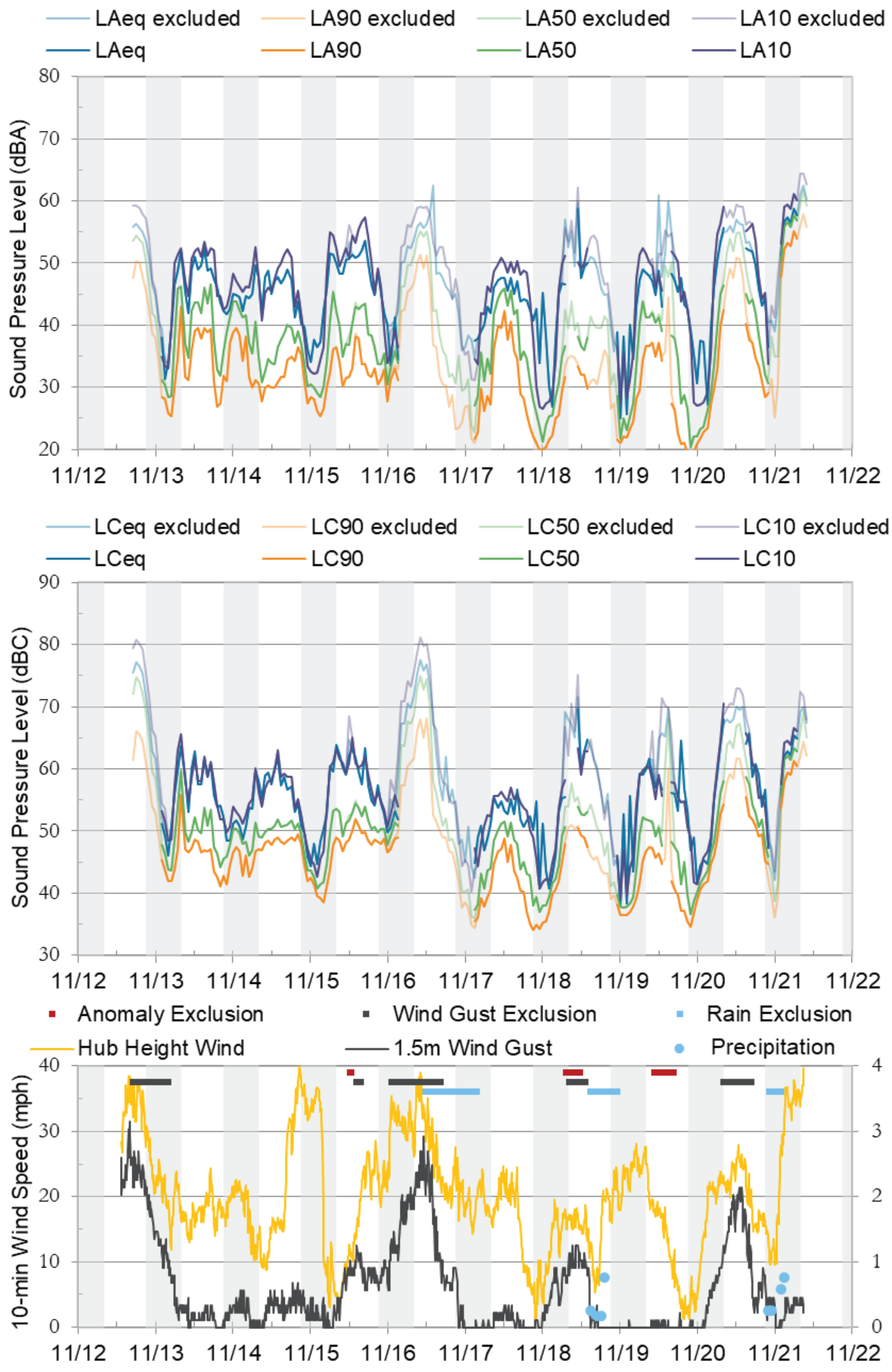

FIGURE 20: PRE-CONSTRUCTION MONITORING RESULTS AT MONITOR 2

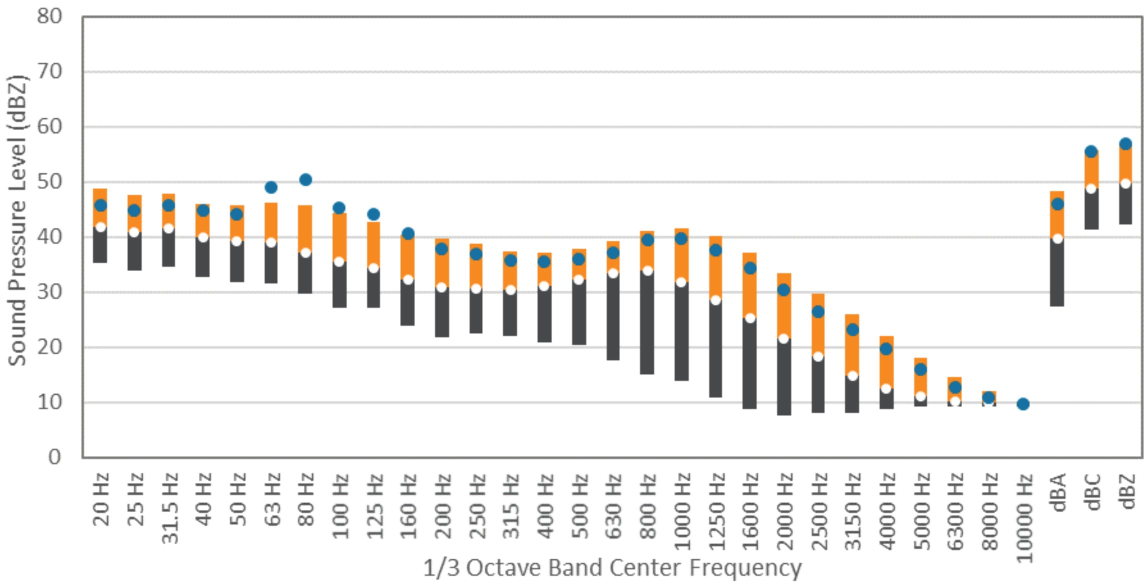

FIGURE 21: 1/3 OCTAVE BAND AND OVERALL STATISTICAL SOUND LEVELS AT MONITOR 2 (FOR PERIODS WITH 9 m/s WIND SPEED AT HUB HEIGHT)

Monitor 3

Results for Monitor 3 are presented in Figure 22. The primary noise sources at this location were occasional vehicle passbys, biogenic sounds (birds especially), occasional aircraft overflights, distant agricultural equipment, distant train horn, and wind rustling through trees. The location generally exhibited a diurnal pattern. The quietest nighttime periods were between 20 and 25 dBA, and some higher nighttime periods were around 40 dBA. The highest nighttime hourly L_{50} at this site was 49 dBA. Over the entire monitoring period, the daytime L_{50} at this site was 36 dBA and the nighttime L_{50} was 31 dBA.

Monitor 3 represents one of the areas with the highest projected sound levels by the pre-construction sound propagation model, so the statistical spectral levels for a representative wind speed (9 m/s) at a representative hub height (109 meters) are presented in Figure 23.

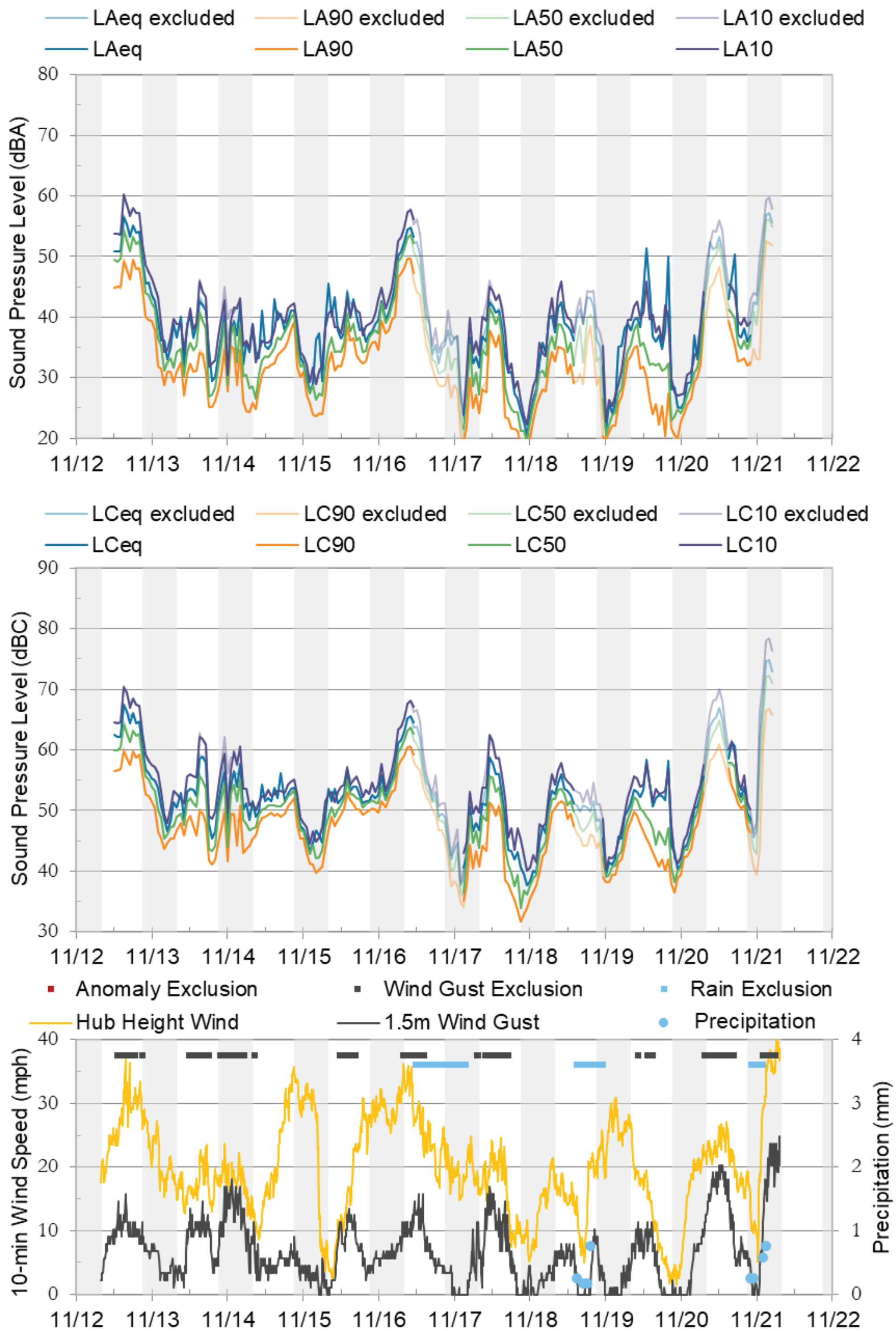

FIGURE 22: PRE-CONSTRUCTION MONITORING RESULTS AT MONITOR 3

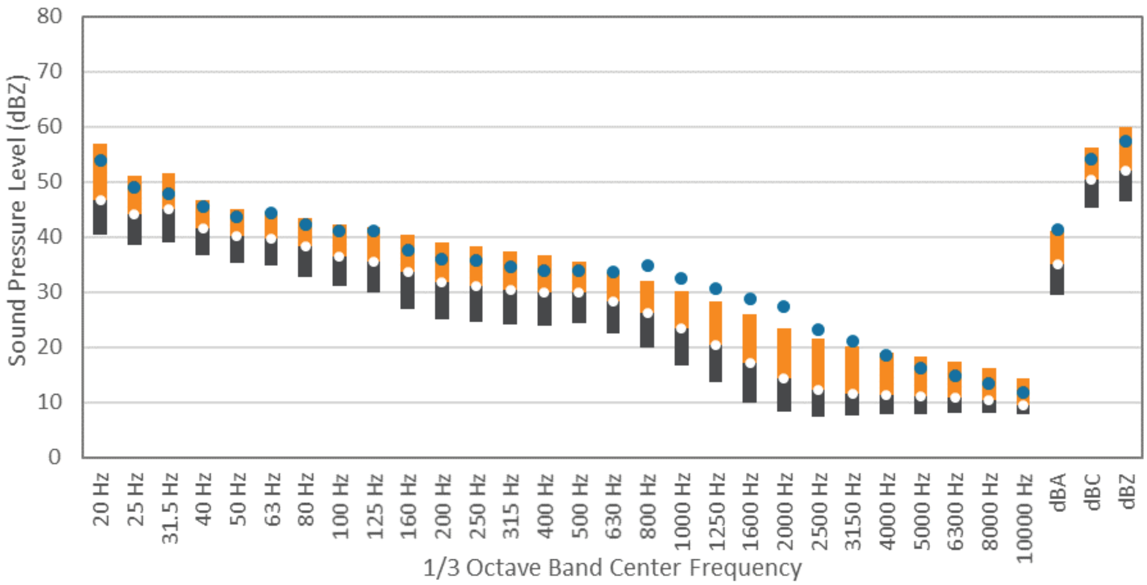

FIGURE 23: 1/3 OCTAVE BAND AND OVERALL STATISTICAL SOUND LEVELS AT MONITOR 3 (FOR PERIODS WITH 9 m/s WIND SPEED AT HUB HEIGHT)

Monitor 4

Results for Monitor 4 are presented in Figure 24. The primary noise sources at this location were occasional vehicle passbys, distant traffic, biogenic sounds, occasional aircraft overflights, local agricultural operations, and distant train passbys. The location generally exhibited a diurnal pattern, and had the highest number of exclusions due to wind speed. The quietest nighttime periods were between 25 and 30 dBA, and some higher nighttime periods were between 40 and 50 dBA. The highest nighttime hourly L_{50} at this site was 47 dBA. Over the entire monitoring period, the daytime L_{50} at this site was 40 dBA and the nighttime L_{50} was 36 dBA.