

FREEBORN WIND (MN) POST-CONSTRUCTION SOUND MONITORING





Report Title:

Freeborn Wind (MN) Post-Construction Sound Monitoring

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EXECUTIVE SUMMARY

The Freeborn Wind Project (“Project”) is a wind power project located in Freeborn County, Minnesota and extends into Iowa. The Project is composed of 24 wind turbines in Minnesota and 76 wind turbines in Iowa.

In accordance with the Project’s permit, this report provides the results of a post-construction noise assessment for homes located in Minnesota. The turbines in Minnesota use a combination of Vestas V120s and V110s, some of which have serrated trailing edges to reduce sound emissions.

The assessment includes:

- Sound monitoring at four locations within the Project area for a period of approximately 13 days in November 2021;
- Analysis of the post-construction data to determine the total sound levels, background sound levels, and turbine-only sound levels from the Project;
- Comparison of the results with the noise limits in MN Rule 7030, which are the same as set forth in the Project’s permit; and
- Comparison of the monitoring results with modeled sound levels per the Freeborn Wind Post-Construction Sound Monitoring Protocol.

DISCRETE SHUTDOWN RESULTS

The wind turbines were shut down periodically at night throughout the monitoring period to assess background sound levels and to allow for a direct calculation of sound levels attributable to the Project (i.e., turbine-only sound levels). This shutdown analysis, which is presented in detail in Section 6.0, yielded approximately 40 samples at each monitor site under a variety of meteorological conditions. The highest L_{50} (median sound levels) attributed to the wind turbines are shown in Table 1, below.

TABLE 1: SUMMARY OF HIGHEST VALID MONITORED L_{50} AT EACH LOCATION

MONITOR	TOTAL SOUND	BACKGROUND	TURBINE-ONLY
North	50 dBA	31 dBA	50 dBA
Central	48 dBA ¹	26 dBA	48 dBA
West	51 dBA	38 dBA	50 dBA
South	47 dBA	35 dBA	47 dBA

¹ There was one event at 51 dBA at the Central monitor. Our inspection found that this sound level was due to gusty winds and was not attributable to wind turbines.

At the West monitor, one of 44 shutdown evaluation periods (2%) had a Total L_{50} of 51 dBA which exceeded the nighttime limit of 50 dBA and was attributable to the Project. During this time, the sound level attributed to the wind turbines was 50 dBA. At the North, Central, and South monitors, there were no instances where a Total L_{50} was above 50 dBA and attributable to the Project.

Sound levels over 50 dBA at the West monitor observed under the discrete shutdown analysis coincided with high wind shear, with ground gusts at 0 m/s and hub-height wind speed at 10 m/s (24 mph). The combination of zero ground gust and winds at or over 10 m/s (24 mph) occurred approximately 4% of the monitoring period.

BINNING METHOD RESULTS

Because the West monitor had a one-hour period with a Total L_{50} attributable to the Project over 50 dBA, an additional analysis was conducted to evaluate how sound levels change by wind speed and how often these wind speeds occur. This analysis, referred to as “binning” found that:

- The highest sound levels attributed to the wind turbines occurred at 8 m/s wind speeds.
- There were no periods attributable to the Project that exceeded the sound limits using the binning method.
- Above 10 m/s, wind-induced background noise exceeded the turbine-only sound levels.
- The binning method did not allow for the calculation of how frequently the Total L_{50} exceeded 50 dBA due to the Project.

COMPARISON WITH MODELED SOUND LEVELS

We then compared the highest measured sound levels to the those modeled prior to construction. The highest measured turbine-only sound level at each monitor location were 2 to 5 dB greater than the modeled turbine-only sound levels. As discussed in Section 6.3, this is mostly due to the modeling parameters that were used in the Pre-Construction Study.

1.0 INTRODUCTION

This report describes the methodology and results of a sound level monitoring campaign conducted in November 2021 at the Freeborn Wind Project (“Project”) in Freeborn County, Minnesota. The purpose of the monitoring was to assess the Project’s sound levels with the noise limits defined in Minnesota Rules Chapter 7030 and in the Project Permit. While the Project is located in both Minnesota and Iowa, only receptors located in Minnesota are assessed in this study.

The Project received a site permit in December 2018² (“Permit”). Prior to receiving a site permit, Hankard Environmental conducted a pre-construction noise assessment dated June 15, 2017 and August 19, 2019, the latter of which is referred to as the “Pre-Construction Study” in this report.³ Updates to the sound modeling to reflect the as built layout were provided by Xcel Energy (“Xcel”).⁴ This study has been conducted in accordance with the Freeborn Wind Post-Construction Sound Monitoring Protocol⁵ (“Protocol”) that was reviewed and approved by Minnesota Department of Commerce (DOC) Energy Environmental Review and Analysis (EERA) unit and filed to the docket. These documents are referenced in this report.

1.1 PROJECT DESCRIPTION

The Minnesota side of the Project is composed of 24 wind turbines including 9 Vestas V120s, 11 Vestas V120s with STE, a Vestas V110, and 3 Vestas V110s with STE.⁶ There are 76 other Vestas V120s and V120s with STE on the Iowa side of the project. A map of the Project area is provided in Figure 1. In Minnesota, the Project is located between the Iowa border to the south and Interstate 90 to the north. The western extent of the Project area is US Route 65, and it extends as far east as County Road 34.

The area around the Project is composed primarily of agricultural land with farm residences and rural residences interspersed throughout the area. Terrain in the area is relatively flat with some rolling hills.

² Site Permit for a Large Wind Energy Conversion System in Freeborn County, Freeborn Wind Energy, LLC, MN PUC Docket No. 17-410, 19 December 2018. The permit was amended on May 10, 2019.

³ Hankard Environmental, “Pre-Construction Noise Analysis for the Proposed Freeborn Wind Farm,” June 5, 2017 and “Pre-Construction noise Analysis (V120 Turbine) for the proposed Freeborn Wind Farm,” August 19, 2019.

⁴ Xcel Energy updated the model results (7/14/21) to reflect the as-built turbine locations. They used the same model parameters used in the Pre-Construction Study: G=0.5, receptor height of 1.5 meters, and +0 dB uncertainty factor.

⁵ RSG, Freeborn Wind Post-Construction Sound Monitoring Protocol, October 2021.

⁶ STE: Serrated Trailing Edges

Freeborn Wind (MN) Post-Construction Sound Monitoring

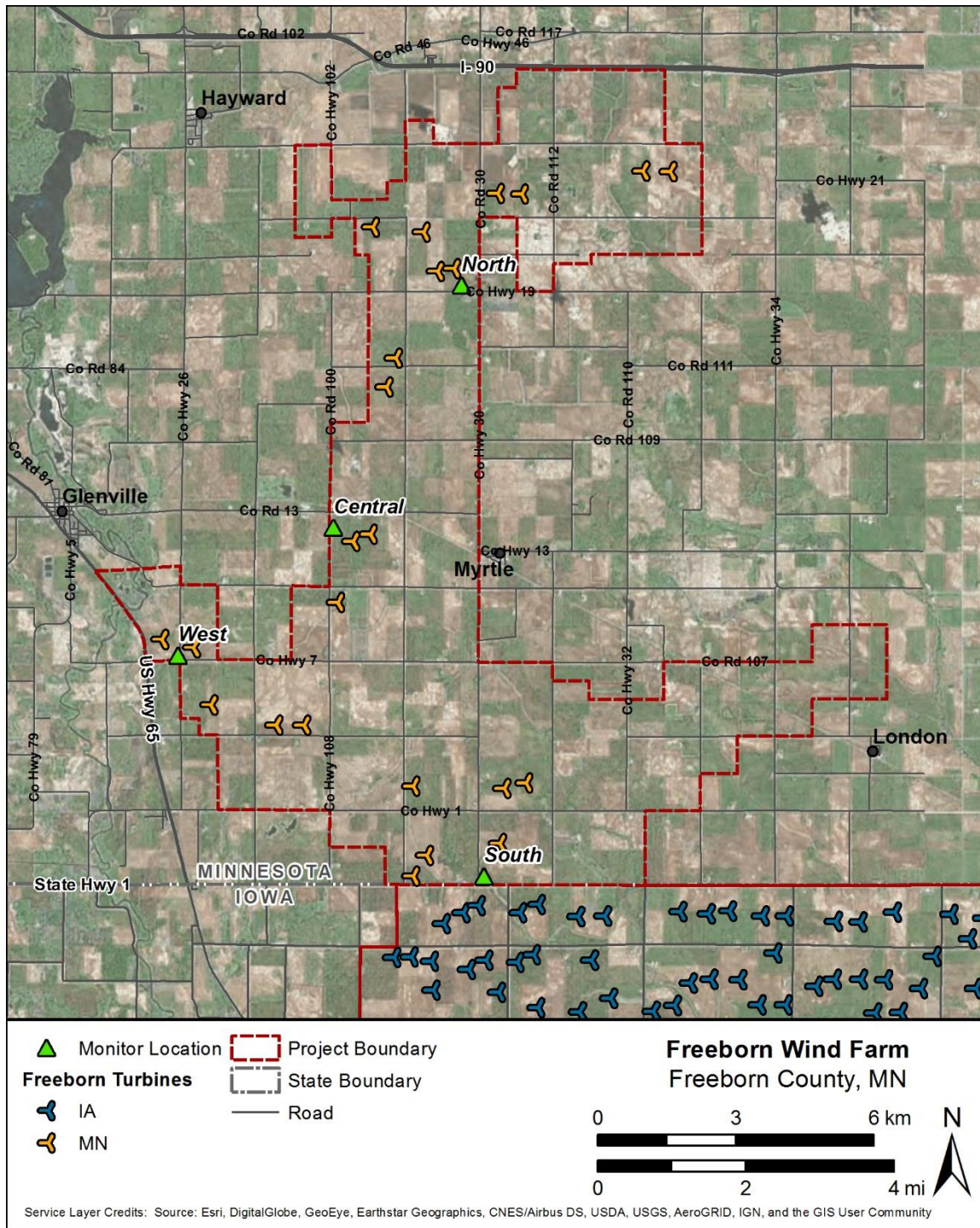


FIGURE 1: MAP OF FREEBORN WIND FARM (MN) AND POST-CONSTRUCTION SOUND MONITOR LOCATIONS

1.2 NOISE STANDARDS

Per the Site Permit,⁷ the Project is required to comply with the noise limits set forth in Minnesota Rules Chapter 7030.

Minnesota Rules Chapter 7030 provides noise limits for a variety of land uses. A residence falls under Noise Area Classification (“NAC”) 1, which is considered the most sensitive land use, and has a median one-hour daytime limit of 60 dBA (L₅₀) and nighttime limit of 50 dBA (L₅₀). The limits for the 90th percentile levels (L₁₀, which is the level exceeded 10% of the time over one hour) are 5 dB higher, as shown in Table 2.

TABLE 2: MINNESOTA NOISE POLLUTION CONTROL 7030.0050 NOISE STANDARDS FOR LIMITING LEVELS OF SOUND OVER A ONE HOUR SURVEY AT A RESIDENCE

	L ₅₀	L ₁₀
Daytime	60 dBA	65 dBA
Nighttime	50 dBA	55 dBA

The noise standards in Minnesota Rules Chapter 7030 “describe the limiting levels of sound,” yet do not explicitly specify if the regulation applies to total sound (source sound level plus background sound level) or just the source in question, which in this case is wind turbines. The relationship between measured total and project sound is included in the amended Site Permit under Special Condition 6.2, as follows:

“6.2 Post-Construction Noise Monitoring

If the Noise Studies conducted under Section 7.4 document an exceedance of the MPCA Noise Standards where turbine-only noise levels produce more than 47 dB(A) L50-one hour at nearby receptors, then the Permittee shall work with the Department of Commerce to develop a plan to minimize and mitigate turbine-only noise impacts.”

In light of the permit conditions, any measured sound level at or below the noise limits in Table 2 would meet the noise standard. If the measured total sound levels are above 50 dBA, then we evaluate the cause of sound levels above the limits to determine if it is due to the Project or background sounds.

⁷ Docket IP-6946/WS-17-410, issued on December 19, 2018, and amended May 10, 2019

2.0 MONITOR LOCATIONS

Continuous sound level monitoring was conducted at four locations identified by the general regions of the Project area they represent: North, Central, West, and South monitors. The location of each monitor relative to the overall Project area is shown in Figure 1. These are the same locations that were identified in the Protocol and represent the highest modeled turbine-only sound levels in their respective regions.

2.1 NORTH MONITOR

The North monitor was located in the yard of an occupied residence along S Shore Drive. A photograph of the monitor is shown in Figure 2, and a map of the location is shown in Figure 3. The monitor was situated in the northern backyard of the property approximately 115 meters (377 feet) from S Shore Drive and 370 meters (1,213 feet) from 850th Ave. Interstate 90 is approximately 4.7 kilometers (2.9 miles) to the north. The closest turbines were T-008 at 430 meters (1,410 feet) to the north and T-007 at 640 meters (2,100 feet) to the northwest.



FIGURE 2: PHOTOGRAPH OF THE NORTH MONITOR FACING NORTH

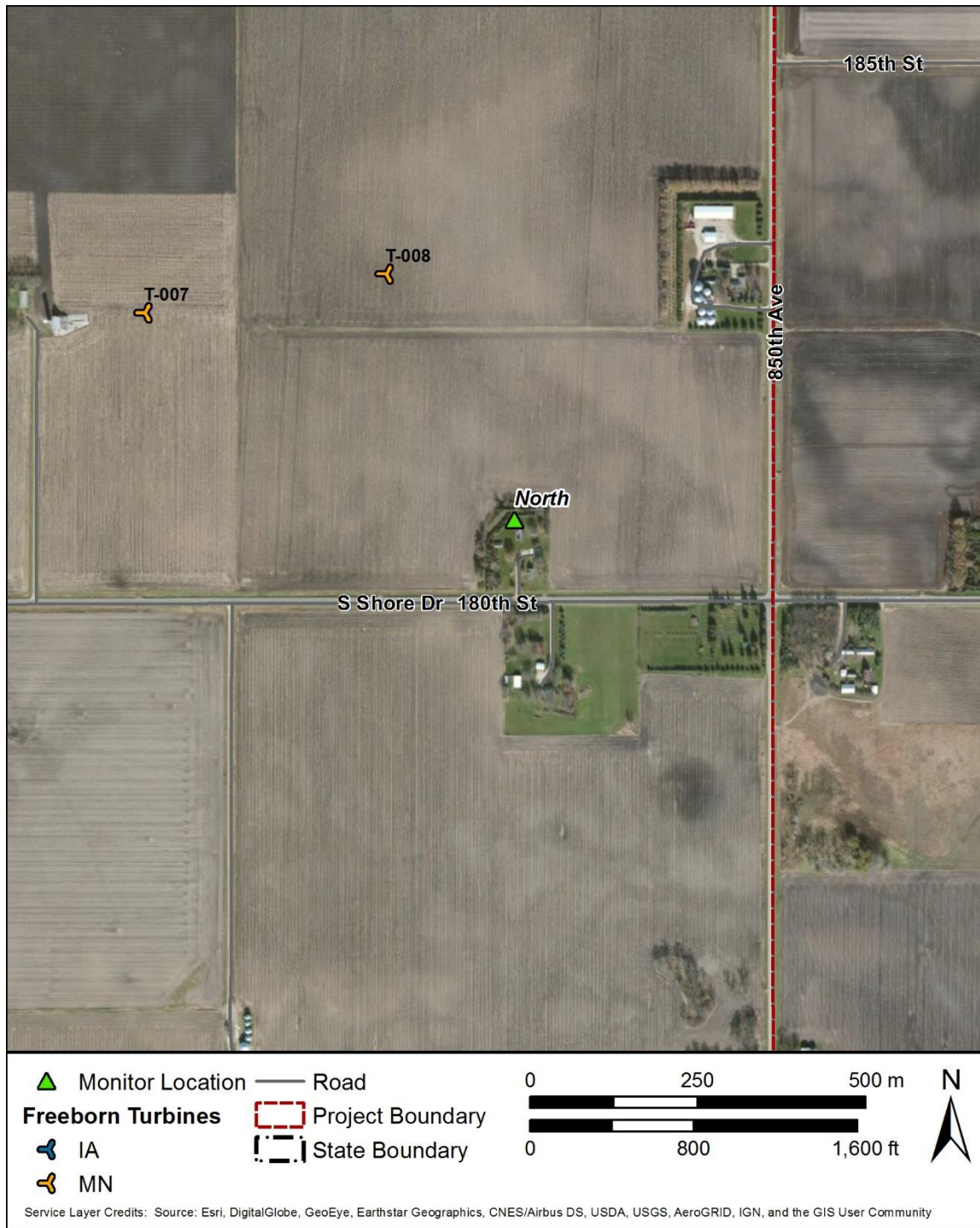


FIGURE 3: MAP OF THE NORTH MONITOR

2.2 CENTRAL MONITOR

The Central monitor was located in the yard of an occupied residence along 830th Ave. A photograph of the monitor is shown in Figure 4, and a map of the location is shown in Figure 5. The monitor was situated in the southeast corner of the property approximately 75 meters (246 feet) from 830th Ave and 350 meters (1,148 feet) from 150th Ave. The town of Glenville is approximately 5.5 kilometers (3.4 miles) to the west. The closest turbines were T-011 at 485 meters (1,591 feet) to the southeast and T-012 at 780 meters (2,559 feet) to the east.



FIGURE 4: PHOTOGRAPH OF THE CENTRAL MONITOR FACING WEST



FIGURE 5: MAP OF THE CENTRAL MONITOR

2.3 WEST MONITOR

The West monitor was located in the yard of an occupied residence and farming operation along 810th Ave. A photograph of the monitor is shown in Figure 6, and a map of the location is shown in Figure 7. The monitor was situated in the southern yard of the property approximately 30 meters (2,296 feet) from 810th Ave and 90 meters (295 feet) from 130th Ave. State Route 65 is approximately 700 meters (2,296 feet) to the west. The closest turbines were T-014 at 340 meters (1115 feet) to the northeast and T-013 at 520 meters (1,706 feet) to the northwest.



FIGURE 6: PHOTOGRAPH OF THE WEST MONITOR FACING SOUTH



FIGURE 7: MAP OF THE WEST MONITOR

2.4 SOUTH MONITOR

The South monitor was located in the yard of an occupied residence along 850th Ave. A photograph of the monitor is shown in Figure 8, and a map of the location is shown in Figure 9. The monitor was situated in the backyard of the property approximately 124 meters (407 feet) from 850th Ave and 170 meters (558 feet) from 510th Ave and the Iowa state boundary. The closest Minnesota turbines were T-024 at 800 meters (2,624 feet) to the north and T-023 at 1,400 meters (4,593 feet) to the northwest. The closest turbine to the site however is T-027 approximately 645 meters (2,116 feet) to the south in Iowa.



FIGURE 8: PHOTOGRAPH OF THE SOUTH MONITOR

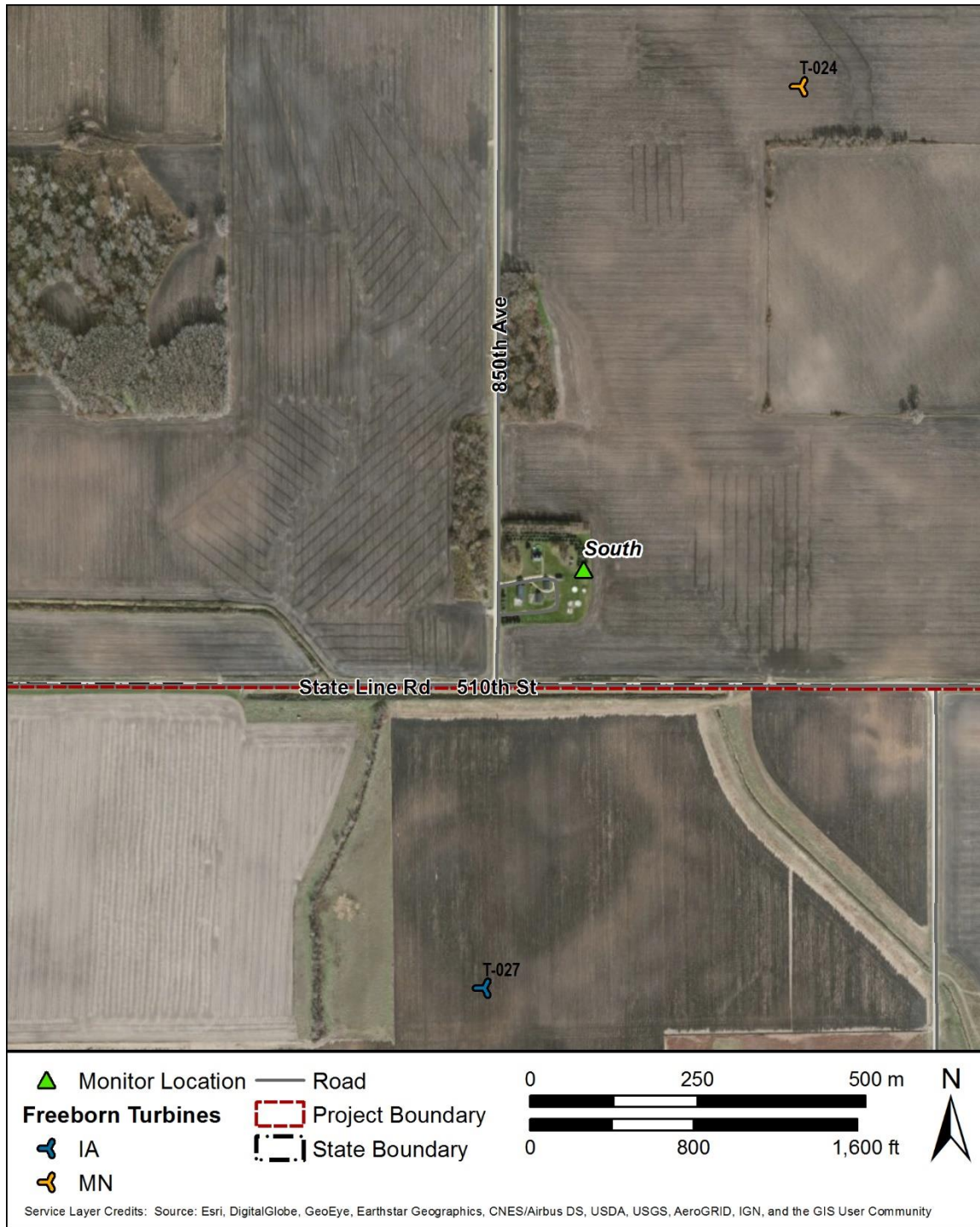


FIGURE 9: MAP OF THE SOUTH MONITOR

2.5 PRE-CONSTRUCTION MODELED SOUND LEVELS

As discussed above, the preconstruction sound levels were modeled by Hankard Environmental in 2019 and updated by Xcel Energy for the as-built layout in 2021. Both used the same parameters: $G=0.5$, 1.5-meter receptor height, and no added uncertainty.

Table 3 provides the predicted wind turbine-only sound levels⁴ at the residences represented by each monitor. We note that the Hankard and Xcel modeling results were with 0.2 dB of each other for the monitored locations.

TABLE 3: MODELED TURBINE-SOUND LEVEL AT THE RESIDENCE CLOSEST TO EACH MONITOR LOCATION

Monitor	Receptor ID	Project Participation Status	Modeled Turbine-only Sound Level
North	129	Participating	45 dBA
Central	401	Non-Participating	44 dBA
West	227	Participating	45 dBA
South	190	Non-Participating	45 dBA

3.0 DATA COLLECTION

3.1 MONITORING PERIOD

RSG visited the Project and installed the sound monitors on November 2, 2021. RSG conducted an equipment maintenance site visit to replace batteries and download data on November 9. The monitors continued to collect continuous data until they were uninstalled on November 15. All monitors collected approximately 13 days of data.

3.2 EQUIPMENT AND DATA TYPES

Sound Level Meters

Sound level data were collected using ANSI/IEC Type 1 Svantek SV979 and SV977 sound level meters (“SLM”). The SLMs continuously logged overall and 1/3-octave band sound levels once each second. The Svantek sound level meters internally recorded continuous audio files in 24-bit *.wav format at a 12 kHz sample rate.

The microphone of each SLM was mounted on a wooden stake at a height of approximately 1.2 m (4 ft) and protected by an ACO-Pacific hydrophobic windscreen 17 cm (7 in) in diameter. Before and after measurement periods, sound level meters were field-calibrated with an acoustic calibrator. In addition, each sound level meter was calibrated in a NIST-traceable lab within one year of the measurement campaign.

The specific equipment that was used at each monitor location is listed in Table 4.

TABLE 4: SOUND LEVEL METER SPECIFICATIONS

Monitor	Manufacturer	Model	SN	1/3 Octave Band Frequency Range		
North	Svantek	SV979	34091	5 Hz	to	20 kHz
Central	Svantek	SV979	35869	5 Hz	to	20 kHz
West	Svantek	SV977	97503	5 Hz	to	20 kHz
South	Svantek	SV977	97548	5 Hz	to	20 kHz

Meteorological & Turbine Operation Data

At each monitor site, an Onset HOBO anemometer was deployed in conjunction with the sound level monitoring equipment. The average wind speed and maximum gust speed was logged once per minute. Additionally, a wind vane that measured ground-level wind direction was placed at the Central monitor.

In addition to site-specific wind data, the Automated Surface Observation Station (“ASOS”) at the Albert Lea Municipal Airport (KAEL) in Albert Lea, MN provided regional meteorological data. Regional precipitation rates obtained from these data are used throughout the time history

results in this report. The Kael ASOS station is located about 17.5 km (10.9 mi) west-northwest of the North monitor.

Wind Turbine Operation Data

Xcel Energy provided SCADA data that included 10-minute hub-height wind speed, nacelle direction, RPM, and power production by turbine at ten-minute intervals. This study utilizes the hub-height wind speed and direction data from all project wind turbines. For each monitor, only turbines within 2.4 kilometers (1.5 miles) from the monitoring location are associated with the monitor in the time-history graphs and shutdown analysis tables.

3.3 DATA PROCESSING

All logged sound levels, in one-second L_{eq} intervals, were processed and analyzed using the R software.⁸ The outputs from this analysis are provided as plots and tables throughout this report.

Statistical levels and equivalent continuous levels in A-, C-, and Z-weightings over one-hour intervals were computed from the valid (non-excluded) data from the measured one-second sound level data. If a one-hour interval did not include at least 30 minutes of valid data, the L_{50} results for that hourly interval are not reported.⁹

Note that daylight savings time occurred on November 8, toward the end of the first week of monitoring. To maintain linear time on all plots, the first week of monitoring is presented in daylight savings time (CDT = GMT-5) and the second week of monitoring is presented in standard time (CST = GMT-6).

Data Exclusions

For each monitoring location, pre-processing of the data was carried out to exclude periods during which any of the following occurred:

- “Wind” – ground-level wind gust speeds above 5 m/s (11.2 mph).
- “Precipitation” – Rain and thunderstorm events identified through regional data and pinpointed through inspection of acoustic data, including digital audio recordings.¹⁰
- “Anomaly” – The presence of short-term contaminating sound caused by human or other activity, which includes site setup and microphone calibration.

Excluded data for a given location were verified using one or more of the following methods:

⁸ <https://www.r-project.org/about.html>

⁹ As per the requirements of ANSI S12.9 Part 3: Quantities and Procedures for Description and Measurement of Environmental Sound - Part 3: Short-Term Measurements with an Observer Present

¹⁰ Note that data are excluded for any period of precipitation, regardless of the rain rate, because of the self-noise induced on the microphone windscreen by droplets or hailstones.

- High ground-level wind periods were removed according to the measurements of ground-level wind gust speed collected by an anemometer present at each monitoring location.
- Precipitation events were identified by regional meteorological data and pinpointed with spectrograms representatives of the sound level data and/or continuous audio recordings at each monitor.
- Anomalous sounds such as site setup, microphone calibration, and extraneous anthropogenic sources in some¹¹ shutdown periods were identified by 1/3 octave band spectrograms and audio files.

A summary of data exclusion periods is provided in Table 5. Note that a particular hour may have more than one exclusion type, such that the total exclusion hours are less than the sum of rain, wind, and anomaly exclusion hours.

TABLE 5: SUMMARY OF EXCLUSION PERIODS AT EACH MONITOR

Monitor	Runtime	Rain		Wind		Anomalies		Total	
	(hr)	(hr)	(%)	(hr)	(%)	(hr)	(%)	(hr)	(%)
North	309	14	5	3	1	2	1	19	6
Central	310	15	5	43	14	4	1	60	19
West	312	14	4	15	5	2	1	31	10
South	314	14	4	19	6	1	0	33	10

Other Anomalies

High levels of humidity adversely affected the measured sound levels on November 6 from 11 AM to 2:10 PM and from 11 AM on November 8 until monitor checkup on November 9. The humidity introduced signal distortion that manifested itself as high frequency static. The issue resolved itself upon redeployment following the checkup. The introduced anomalous signal was

¹¹ Shutdown periods with anomalous events excluded are indicated in The following tables show the valid shutdowns for each monitor. Shutdowns without valid sound levels are not included.

Turbine-only sound levels were calculated on a 1/3 octave band basis, then A-weighted and summed, as noted in Section 6.1, following the procedures of ANSI S12.9 Part 3 Section 6.9. Where turbine-only sound levels are below background (at all 1/3 octaves), “n/a” is indicated.

Note that all times prior to midday on November 9 are in GMT-5 (first monitoring period), while all times after midday on November 9 are in GMT-6 (monitoring period 2). Local time was discontinuous due to daylight savings on November 7 at 2 AM local (Central) time. through Table 12 in Appendix D

not enough to affect the ability of the Project to meet sound standards and was thus not excluded from the analysis

4.0 METEOROLOGICAL SUMMARY

Regional meteorological conditions over the course of the monitoring period are plotted in Figure 10 (Week 1) and Figure 11 (Week 2). The charts of data for each monitoring period are presented with three panes of approximately hourly data from the ASOS meteorological station at the Albert Lea Airport (KAEL) in Albert Lea, MN. The top pane displays temperature (in red); the second pane displays relative humidity (in purple) and rain rate in centimeters per hour (green). The third pane shows average wind speed (in meters per second) and direction measured at 10 meters (33 feet) above ground level. The convention in the figures is that the arrow at the mean wind speed points in the direction that the wind was blowing, (e.g., ">" would represent winds out of the west blowing to the east).

The maximum temperature in Albert Lea during the monitoring period was 21°C (70°F) and the minimum temperature was -6°C (21°F).

There was no notable precipitation logged at the ASOS station during the first week. However, the second week of monitoring saw a precipitation event on the afternoon of November 10 into the morning of November 11. Some precipitation was also measured in the early morning hours of November 12.

With the exception of the strong winds on November 5, winds in the second week were consistently stronger than winds in the first week.

Freeborn Wind (MN) Post-Construction Sound Monitoring

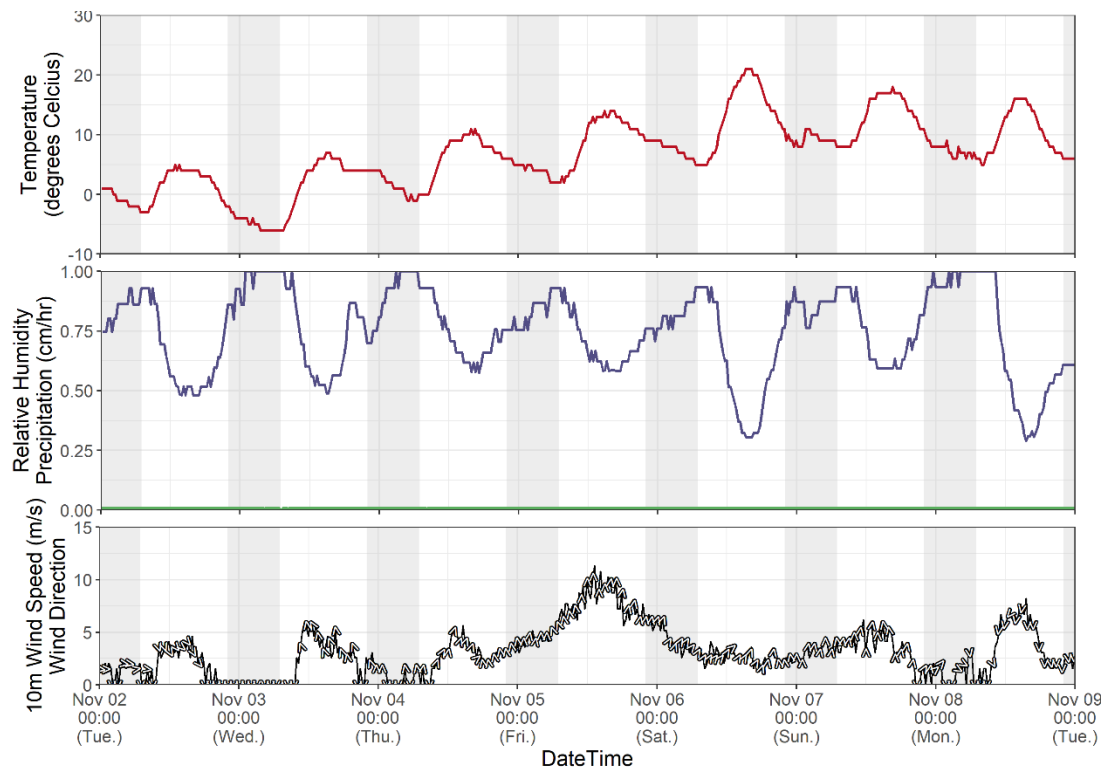


FIGURE 10: REGIONAL METEOROLOGY DURING WEEK 1 OF THE MONITORING PERIOD

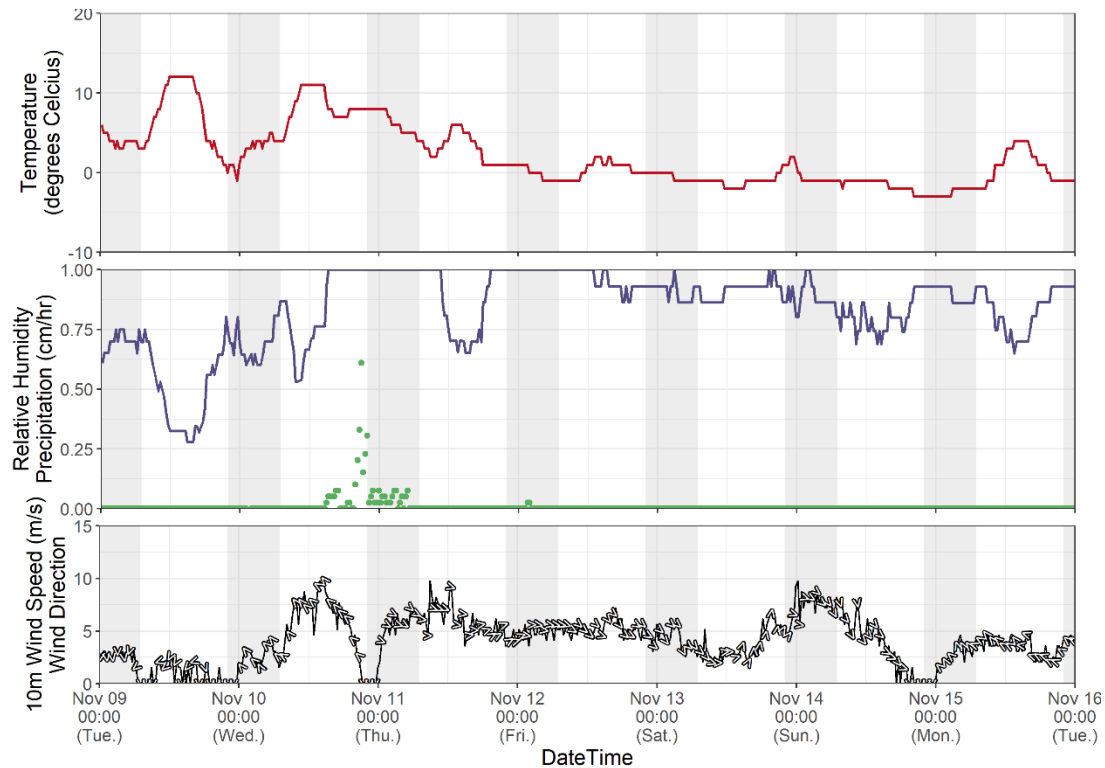


FIGURE 11: REGIONAL METEOROLOGY DURING WEEK 2 OF THE MONITORING PERIOD

5.0 SOUND LEVEL DATA

Sound levels for acoustically valid periods were aggregated in one-hour periods for each monitoring period in accordance with Minnesota Rules Chapter 7030 methods and related guidance from the MN Department of Commerce. This section provides a summary of the overall sound levels at each monitor location by daytime and nighttime over the entire period followed by time history graphs at each monitor site. The measured sound levels for each on-site monitor are assessed for turbine-only contributions in Section 6.0.

5.1 OVERALL SOUND LEVEL SUMMARY

The overall results from all valid acoustic periods are provided in Table 6. The North monitor had the highest overall daytime L_{10} due to its closer proximity to the more well-traveled S Shore Drive. At all monitors, sound levels were higher during the day compared to night due primarily to other anthropogenic sounds.

TABLE 6: OVERALL A-WEIGHTED SOUND LEVEL RESULTS FOR EACH MONITOR

MONITOR LOCATION	DAYTIME				NIGHTTIME			
	L_{EQ}	L_{10}	L_{50}	L_{90}	L_{EQ}	L_{10}	L_{50}	L_{90}
North	51	54	45	36	49	51	41	28
Central	52	50	45	36	44	48	42	31
West	49	50	44	36	45	48	40	29
South	49	51	44	35	46	48	42	30

5.2 DESCRIPTION OF SOUND LEVEL PLOTS

For the time history plots in this section (Figures 13, 14, 16, 17, 19, 20, 22, and 23) time runs consecutively along the x-axis (from left to right). The labeled dates represent the beginning of each day; dotted vertical lines through each plot delineate midnight and noon. Nighttime periods (10 PM to 7 AM) are indicated in each pane by vertical grey shading.

The top pane shows the average hourly wind turbine power production in kilowatts (kW). Production from the closest turbine is displayed in red, while the range, median, and mean of other nearby turbines are identified by color in the legend. The shaded area between the green lines (min/max) represents the operating range of other nearby turbines.

The middle pane provides the aggregated sound level data results as hourly values for L_{10} (in orange) and the L_{50} (in dark grey). The orange shading represents the range of statistical sound levels for each hourly period (L_{10} to L_{90}). Periods when the L_{10} and L_{50} lines are blank are excluded periods. The cause of the exclusion is denoted by the colored points (yellow, red, and blue) corresponding to the type of exclusion (anomaly, wind gust, and precipitation). Note that the L_{10} and L_{90} range are still plotted during excluded periods for context and continuity. The

daytime and nighttime sound level limits for the L_{10} and L_{50} metrics are also provided as orange and black lines, respectively. If the raw uncorrected data exceeds one of these sound limits, then a dot in the corresponding color is placed on the limit line.

The third pane provides microphone-height gust speed, hub-height wind speed, and precipitation. To match the aggregation period of sound levels, the maximum microphone-level wind gust speed for each hour is plotted in red, while the average wind speed over the hour is displayed in pink. Hub-height wind speed (in green) and direction (arrows) are averaged over the hour for all nearby turbines; light green shading provides the range of hourly windspeeds at all nearby turbines. The horizontal red dotted line corresponds to wind speed exclusion threshold of 11.2 mph (5 m/s), while the horizontal green dotted line at 20 mph (9 m/s) represents the hub height wind speed at which the wind turbines reach their full rated sound power output. The blue shading shows the rate of precipitation, with darker shading indicating a higher precipitation rate.

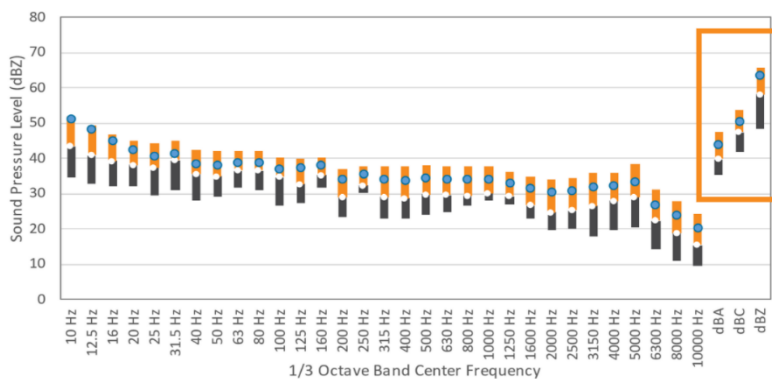
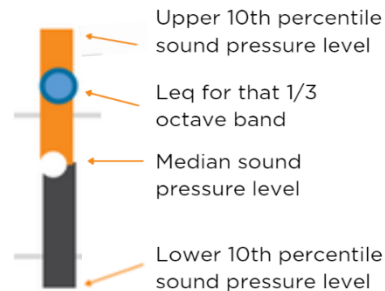
Similar time history plots that provide the L_{eq} and statistical sound levels for A- and C-weighted data are provided in Appendix C.

Description of Sound Level Summary Plots at the Representative Wind Speed

The Protocol calls for the reporting of sound levels by 1/3 octave band for a representative wind speed per LWECS Guidance.¹² Post-construction wind speed data were analyzed using SCADA data from nearby wind turbines. To calculate sound levels at representative windspeeds, all acoustically valid one-second data with average hub-height wind speeds (as reported by all nearby turbines) in the stated range were collected and summarized. These data were aggregated into L₁₀, L₅₀, L₉₀, and L_{eq} on an overall (i.e., dBA, dBC, and dBZ) and 1/3 octave band basis.

An illustration of the data that is represented in the representative wind speed plots (Figures 15, 18, 21, and 24) is provided in Figure 12.

Each vertical orange and dark-grey bar show the Lower 10th, median, and Upper 10th percentile (L₉₀, L₅₀, and L₁₀) sound level for a single 1/3 octave band. The entire length of the bar indicates the middle 80th percentile of sound pressure levels.



At the far right of the chart are the A-, C-, and Z-weighted overall levels.

FIGURE 12: ILLUSTRATION EXPLAINING THE DATA IN THE SOUND LEVEL SUMMARY PLOTS AT THE REPRESENTATIVE WIND SPEED

¹² Minnesota Department of Commerce, Energy Facilities Permitting, "LWECS Guidance for Noise Study Protocol and Report," July 2019.

5.3 NORTH MONITOR RESULTS

Time History Results (North)

The three-paned time history results for the first week of monitoring (11/2 to 11/9) is provided in Figure 13. There was no rain during the first week. Ground level wind speeds above 5 m/s were only measured for most of the day on November 5. Thus, nearly all nighttime periods during the first week were acoustically valid at the North monitor. The closest wind turbine to the North monitor (T-08) did not operate for a 24-hour period starting midday on November 5. Planned shutdowns for background sound measurements are visible in the time history data on all nights of the first week except for the first night (11/2 to 11/3). Background sound levels were generally between 29 and 36 dBA during shutdowns; the one-hour L_{50} during operation periods was observed to be between 44 and 50 dBA.

The time history plot for the second week of monitoring at the North monitor is provided in Figure 14. Compared to the first week of monitoring, variable weather and strong winds were more common during the second week, with strong winds and periods of precipitation on November 10, 11, and 12. The only shutdown visible in the time history data was on the first night of monitoring, with background sound levels below 30 dBA and total one-hour L_{50} during turbine operation of about 45 dBA.

The night ending on November 12 had three hours above the 50 dBA one-hour L_{50} limit after a precipitation event. For the first two hours over the nighttime L_{50} limit, wind turbines were shut down. As evidenced by Shutdown #36 (Figure 47 in Appendix E), background sound levels of 50 dBA resulting from gusty winds aloft led to subsequent turbine operation periods of 51 dBA. As confirmed by audio recordings, these periods over the nighttime L_{50} limit were attributable to strong winds, not the Project.

Overall sound levels are notably correlated with both wind turbine operation and hub-height wind speeds. Particularly above 11 m/s (25 mph) hub-height wind speeds, winds aloft drove sound level on the ground, as exemplified on the night ending on November 14, which resulted in elevated sound levels for the entire night. The hourly L_{50} remained above 55 dBA all night. Wind turbine shutdowns were not discernible in the overall A-weighted data. Often, sound levels were higher during wind turbine shutdowns than during operation due to the gusty winds in the trees. The protection offered by the wind break at the North monitor kept microphone-height wind speeds below 5 m/s for more than half of the night. Therefore, the periods were not excluded, but it is clear from the data during the shutdown periods that background sound levels were driven by winds through foliage and the periods over the nighttime noise limits are not attributable to the Project.

Freeborn Wind (MN) Post-Construction Sound Monitoring

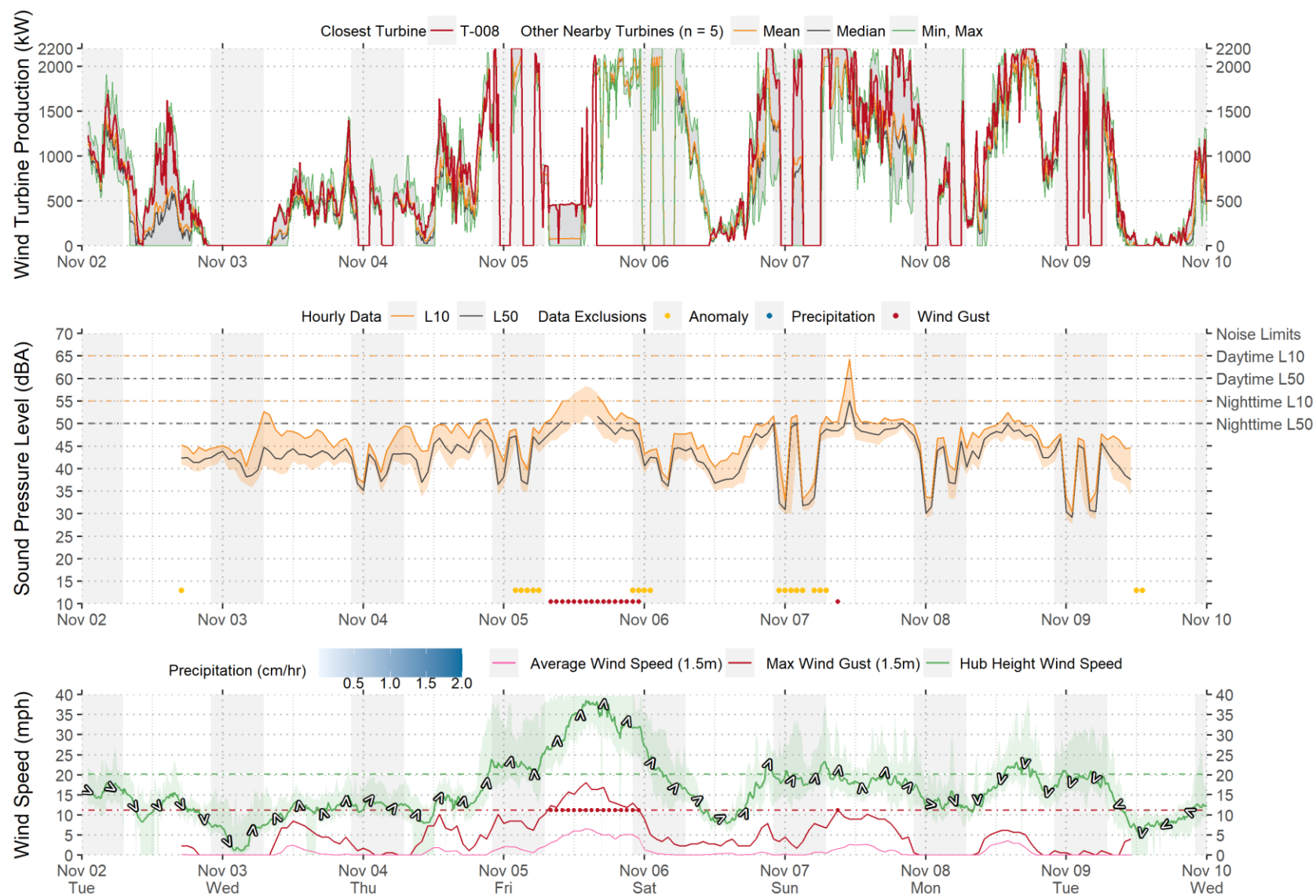


FIGURE 13: NORTH MONITOR, WEEK 1, TIME HISTORY PLOT

Freeborn Wind (MN) Post-Construction Sound Monitoring

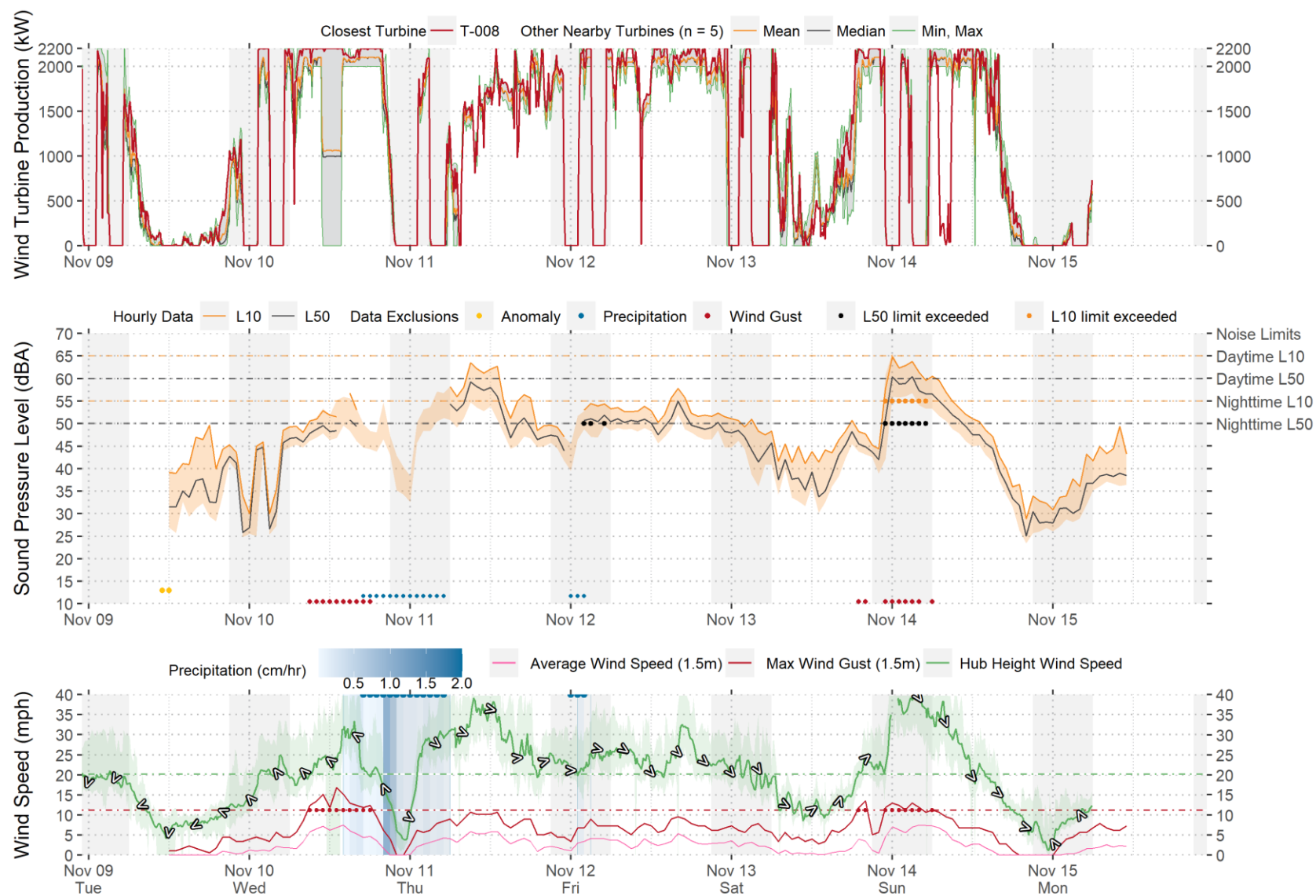


FIGURE 14: NORTH MONITOR, WEEK 2, TIME HISTORY PLOT

Sound Level Summary Plot at the Representative Wind Speed (North)

Figure 15 depicts statistical sound levels during post-construction monitoring at the North monitor within the representative hub-height wind speeds range. Data represented in the plot only includes periods when wind turbines were operating (i.e., not during the prescribed wind-turbine shutdowns). At the representative wind speed and wind turbines operating, the overall A-weighted L_{50} at the North monitor during post-construction monitoring was 47 dBA.

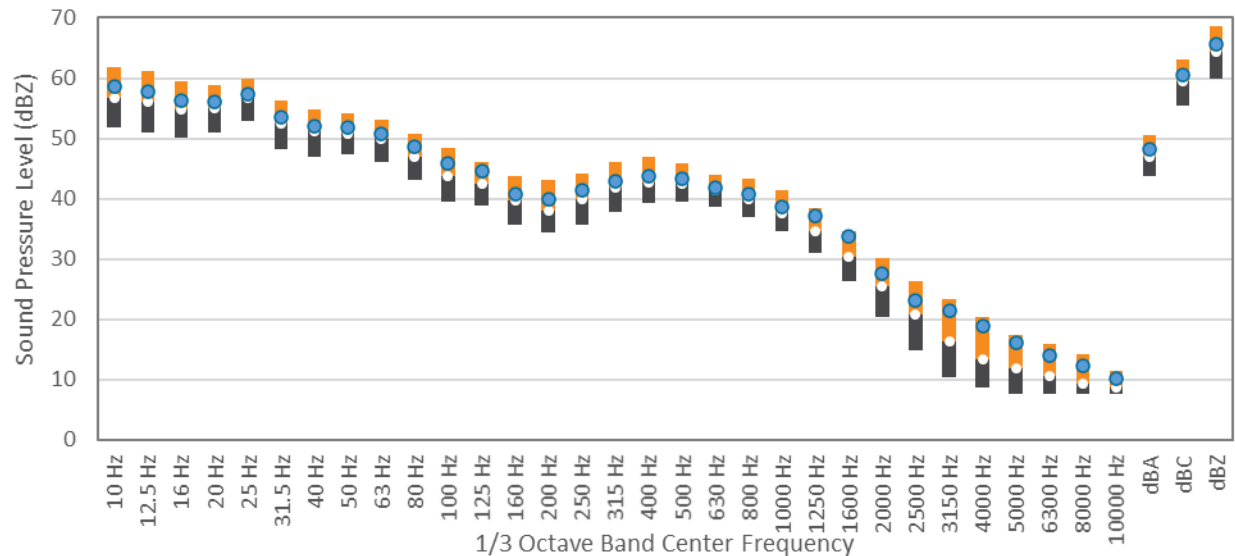


FIGURE 15: STATISTICAL SUMMARY OF POST-CONSTRUCTION 1/3 OCTAVE BAND SOUND LEVELS DURING PERIODS OF HUB HEIGHT WIND SPEED OF 9 M/S (20 MPH), NORTH MONITOR

5.4 CENTRAL MONITOR RESULTS

Time History Results (Central)

The results from the first week of monitoring at the Central monitor are provided in Figure 16. Shutdowns on most nights are visible in the time history data during the first week, with particularly clear traces visible on nights ending on November 5, 7, 8, and 9. Background sound levels during wind turbine shutdowns were between 25 and 30 dBA, with sound levels during wind turbine operations between about 40 and 45 dBA.

On the night ending on November 6 in the first week, a single nighttime one-hour L_{50} was over 50 dBA (10 PM to 11 PM on 11/5). Notably, sound levels throughout the day on November 5 were more than 50 dBA because of excessive winds aloft. Overall sound levels from about 5 AM on November 5 to the start of November 6 were correlated with excessive wind speeds at hub height; T-11 (the closest wind turbine to the Central monitor) was shut down for most of this period. Shutdown #9, approximately corresponding to this one-hour period, is discussed in further detail in Section 6.2.

As noted in Section 3.3, high levels of humidity adversely affected the measured sound levels on November 6 from 11 AM to 2:10 PM and from 11 AM on November 8 until monitor checkup on November 9. This raised the apparent sound levels during these periods.

The time history results for the second week of monitoring are shown in Figure 17. Substantial periods of rain and high winds were observed during the second period. The only shutdown visible in the sound level data trace was on the night ending on November 10, with background sound levels below 30 dBA and total sound levels up to 48 dBA while turbines were operating.

Freeborn Wind (MN) Post-Construction Sound Monitoring

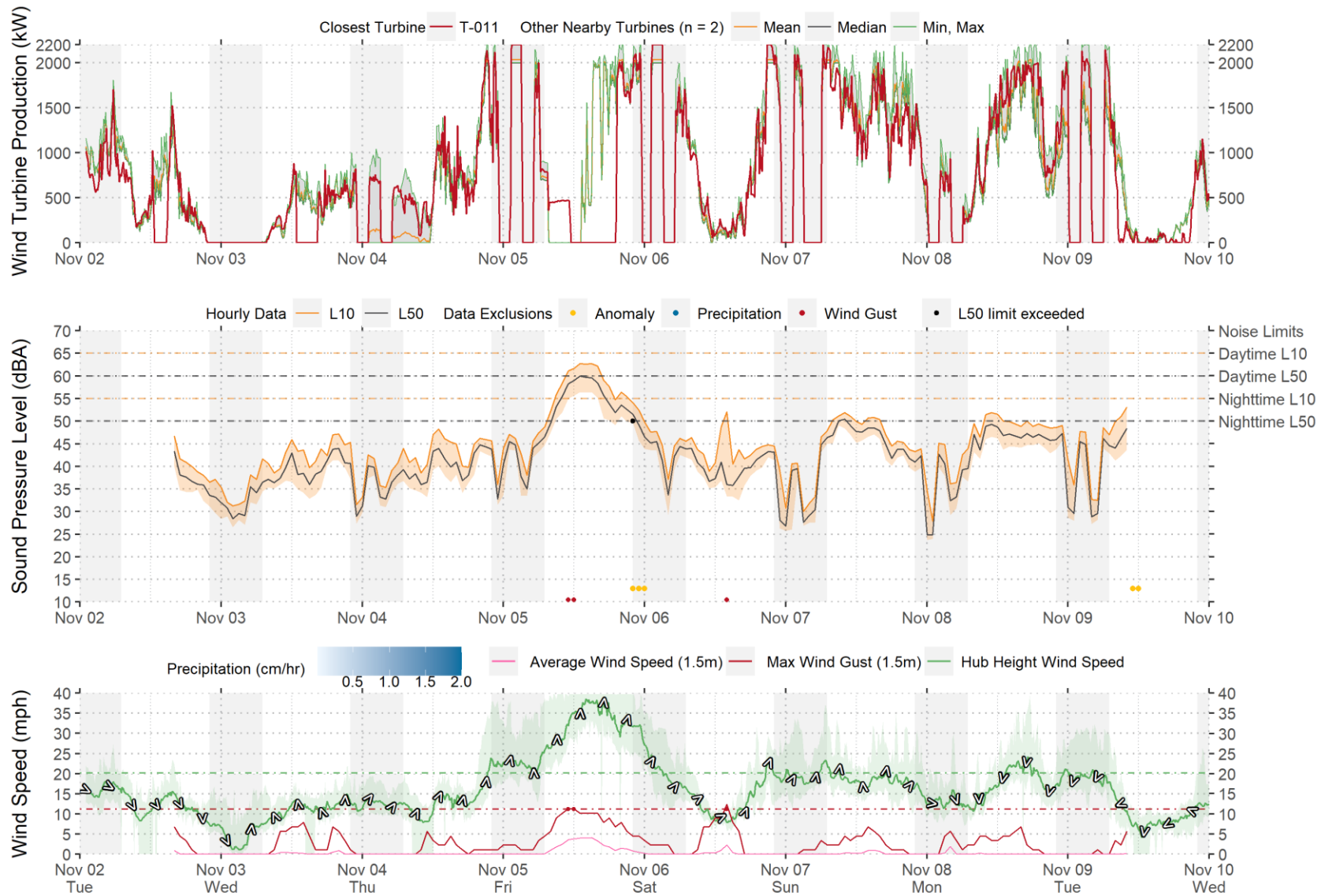


FIGURE 16: CENTRAL MONITOR, WEEK 1, TIME HISTORY PLOT

Freeborn Wind (MN) Post-Construction Sound Monitoring

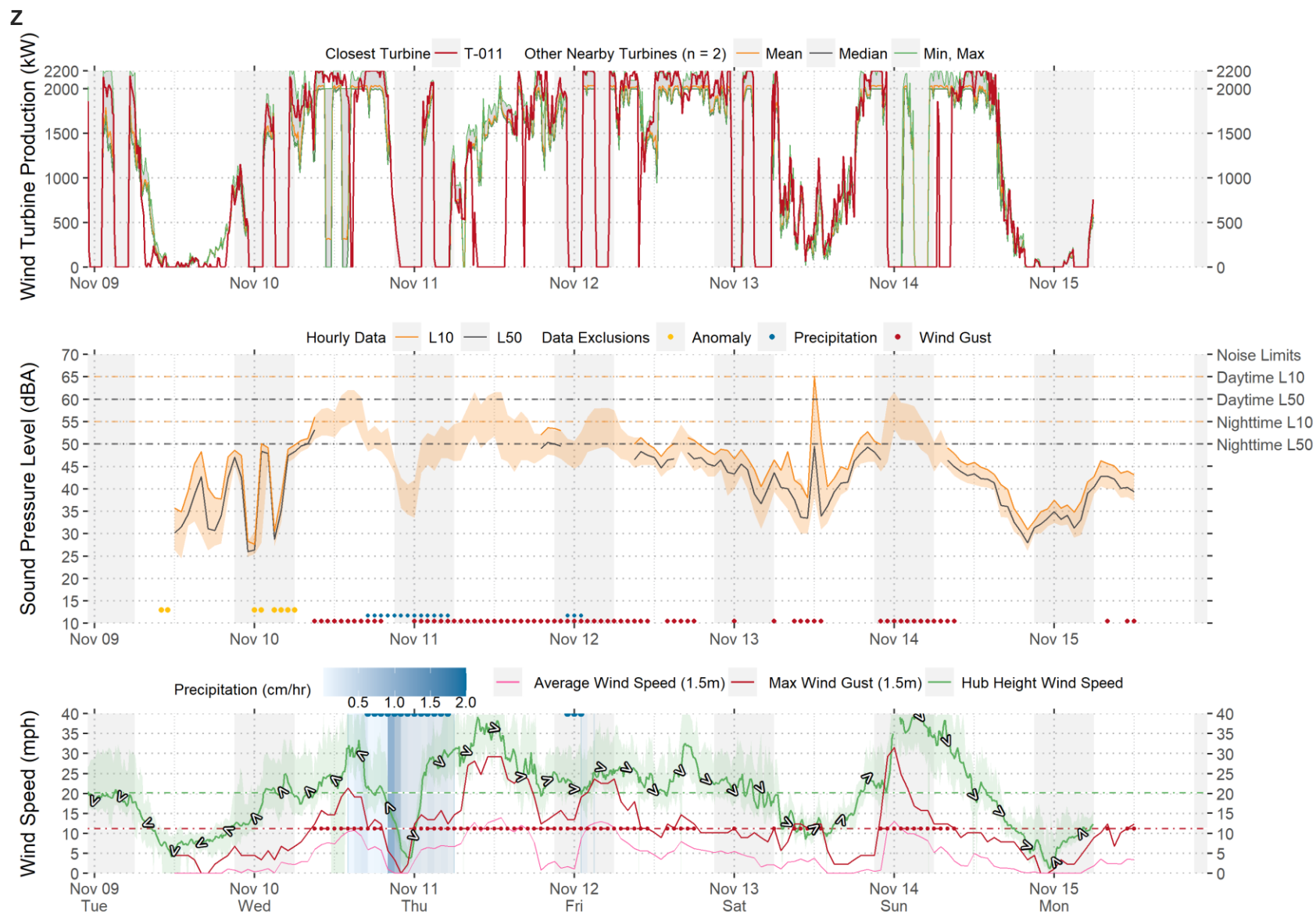


FIGURE 17: CENTRAL MONITOR, WEEK 2, TIME HISTORY PLOT

Sound Level Summary Plot at the Representative Wind Speed (Central)

Figure 18 shows the statistical sound levels during post-construction monitoring at the Central monitor within the representative hub-height wind speeds range. Data represented in the plot only includes periods when wind turbines were operating (i.e., data during prescribed wind-turbine shutdowns was not included). At the representative wind speed with wind turbines operating, the overall A-weighted L_{50} at the Central monitor during post-construction monitoring was 46 dBA.

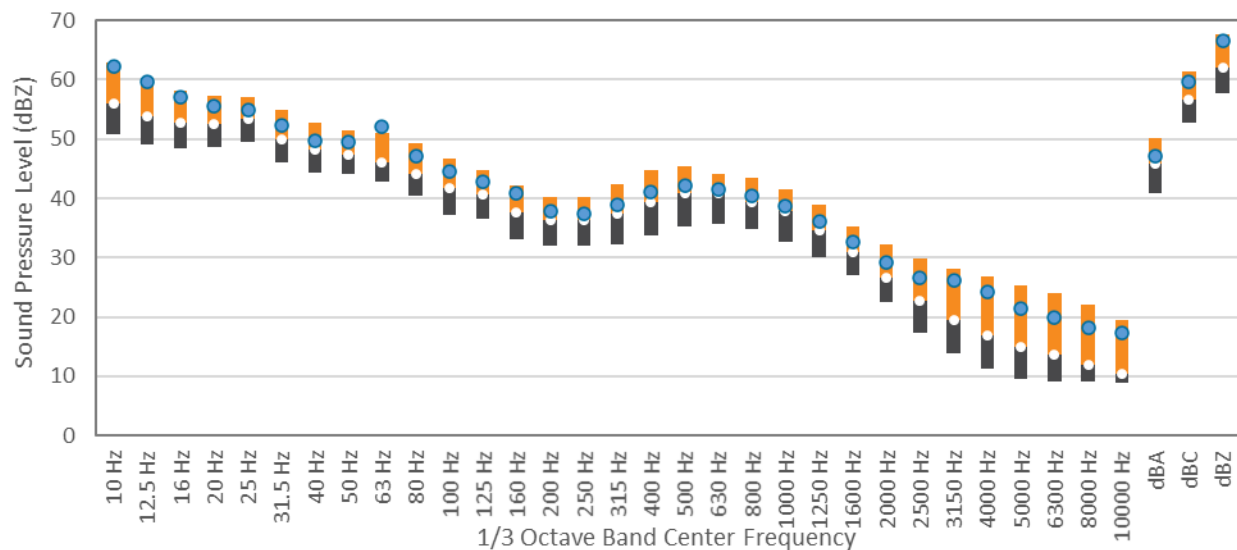


FIGURE 18: STATISTICAL SUMMARY OF POST-CONSTRUCTION 1/3 OCTAVE BAND SOUND LEVELS DURING PERIODS OF HUB HEIGHT WIND SPEED OF 9 M/S (20 MPH), CENTRAL MONITOR

5.5 WEST MONITOR RESULTS

Time History Results (West)

Time history results for the first week of monitoring at the West monitor are plotted in Figure 19. High ground level wind speeds were recorded at the site during the days of November 5 and November 8. All nighttime periods during the first week were acoustically valid. Wind turbine shutdowns are visible in the time history traces of one-hour sound levels on the nights ending on November 5 to November 9. Background sound levels at night with the wind turbine shutdown were often between 40 and 45 dBA from a nearby fan or grain dryer. The final night of the first week provided the greatest difference between background sound levels (about 30 dBA) and wind turbine operation (about 47 dBA).

The results from the second week of monitoring at the West monitor are provided in Figure 20. Although winds aloft were strong and variable, ground level wind speeds were lower at the West monitor during the second week; gust wind speeds remained below 5 m/s (11.2 mph) during the second week. Nighttime wind turbine shutdowns are visible in the sound level traces on the nights ending on November 10 and November 13.

Although it is not shown explicitly in Figure 20, during the early morning of November 13, a one-hour L_{50} adjacent to turbine Shutdown #37 exceeded 50 dBA. This hour is further evaluated for turbine-only sound levels in Section 6.2. The one-hour exceedance attributable to the Project does not show up in Figure 20 because Project wind turbines were shut down for over half of the one-hour period beginning at 11 PM.

In the early morning hours of November 14, a one-hour period exceeded 50 dBA. A rapid increase in hub-height wind speeds (from 20 mph to 40 mph in one hour) occurred when Project wind turbines were shut down (see Shutdown ID 42 in Figure 48 in Appendix E). With project turbines shut down, the change in wind conditions raised background sound levels from about 40 to 49 dBA. The one-hour period recorded over the nighttime L_{50} limit nearly corresponds to Shutdown ID 43 (Figure 49 in Appendix E), where background one-hour median sound levels with wind turbines shutdown were 49 dBA and corresponding total sound levels were 51 dBA. When subtracting Background sound from Total sound, the Turbine-only L_{50} associated with Shutdown ID 43 was 41 dBA (Table 11).¹³ This indicates that the Total L_{50} above the nighttime sound level limit was not attributed to the Project.

¹³ While the difference between the A-weighted L_{50} for the Total and Background periods was less than 3 dB, we calculated the Turbine-only sound level using 1/3 octave bands where the difference on a third-octave band basis was greater than or equal to 3 dBA. This follows the methodology of ANSI S12.9 Part 3 Section 6.9. Caution should be used when interpreting A-weighted turbine-only sound levels below the background sound level.

Freeborn Wind (MN) Post-Construction Sound Monitoring

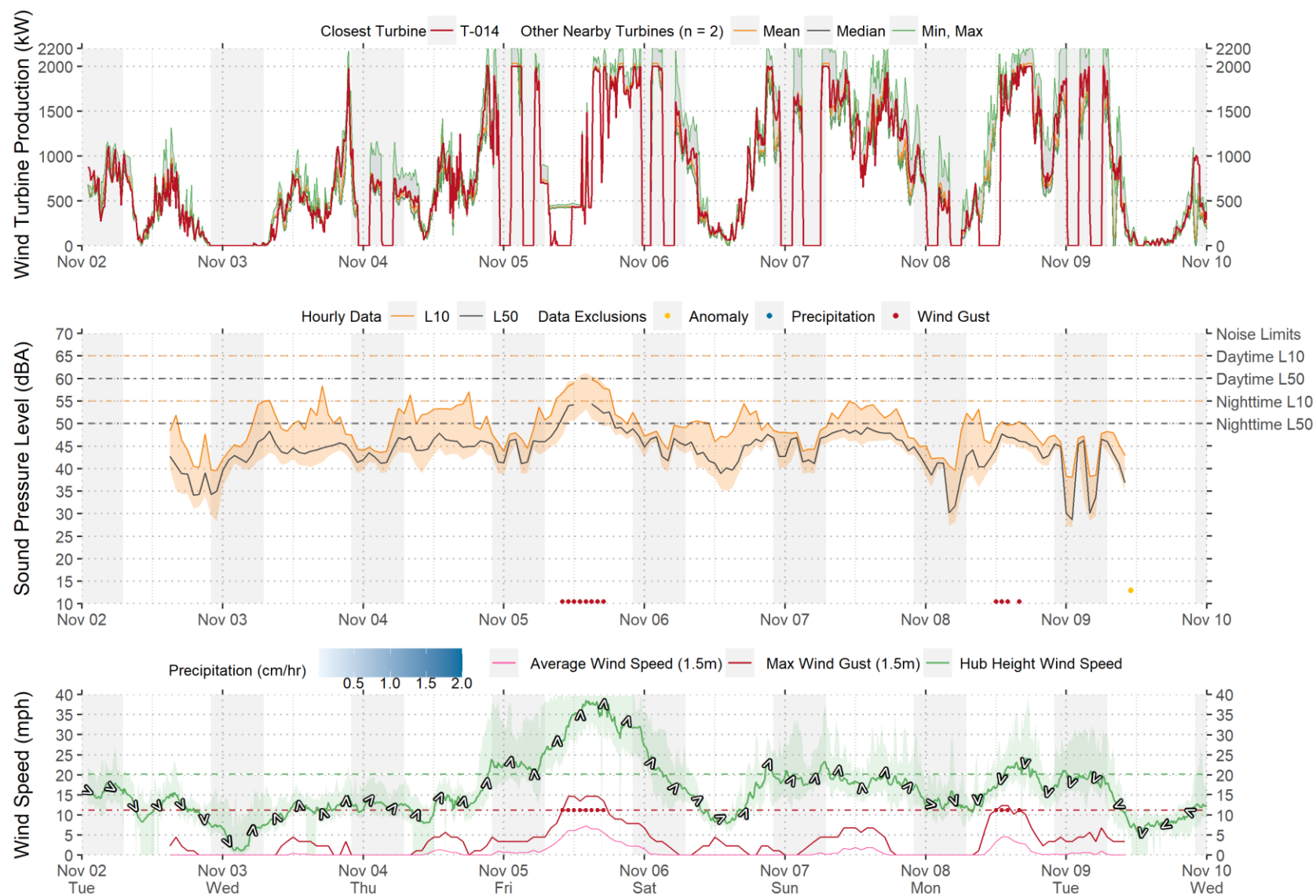


FIGURE 19: WEST MONITOR, WEEK 1, TIME HISTORY PLOT

Freeborn Wind (MN) Post-Construction Sound Monitoring

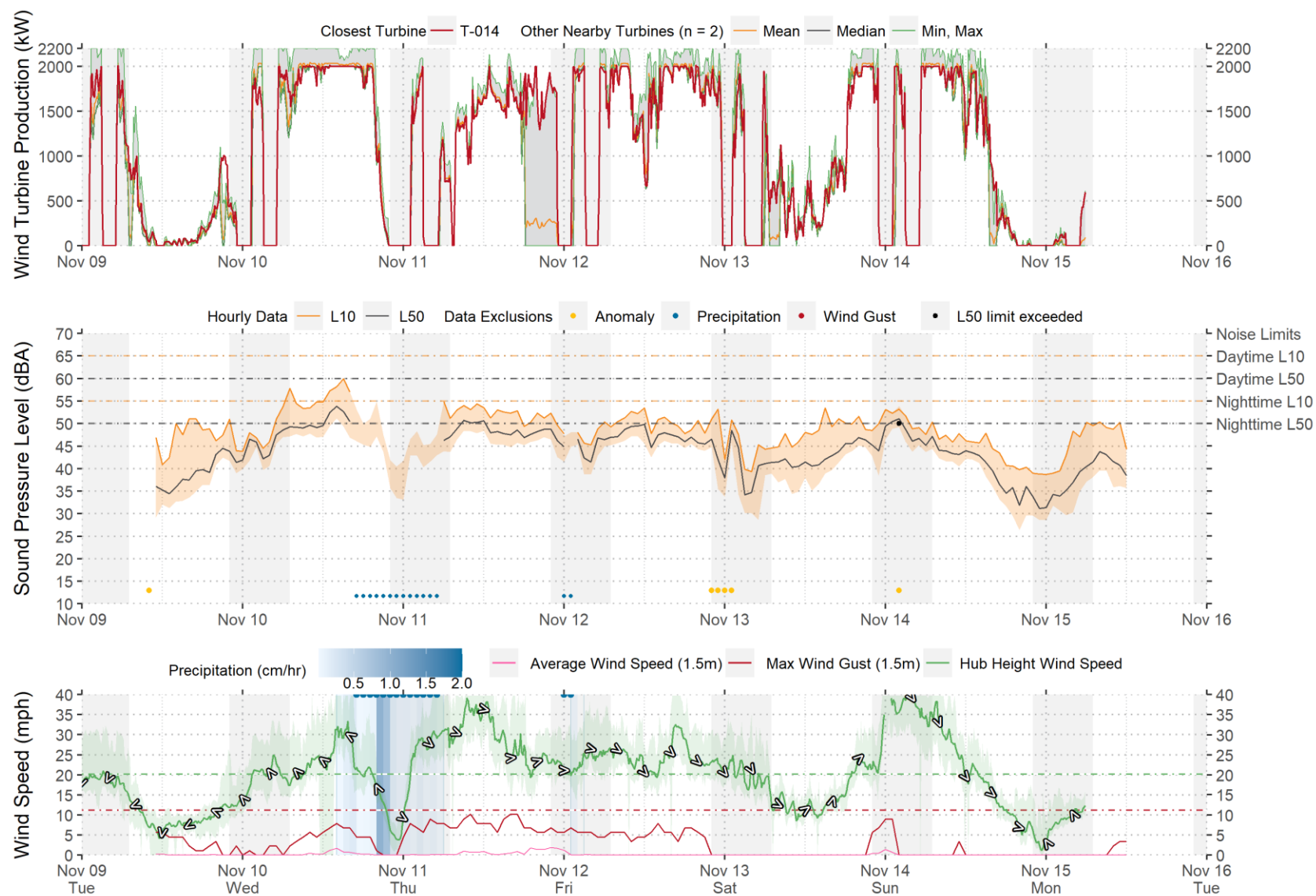


FIGURE 20: WEST MONITOR, WEEK 2, TIME HISTORY PLOT

Sound Level Summary Plot at the Representative Wind Speed (West)

Figure 21 presents the statistical sound levels during post-construction monitoring at the West monitor within the representative hub-height wind speeds range. Data represented in the plot only includes periods when wind turbines were operating. At the representative wind speed with wind turbines operating, the overall A-weighted L_{50} at the West monitor during post-construction monitoring was 47 dBA.

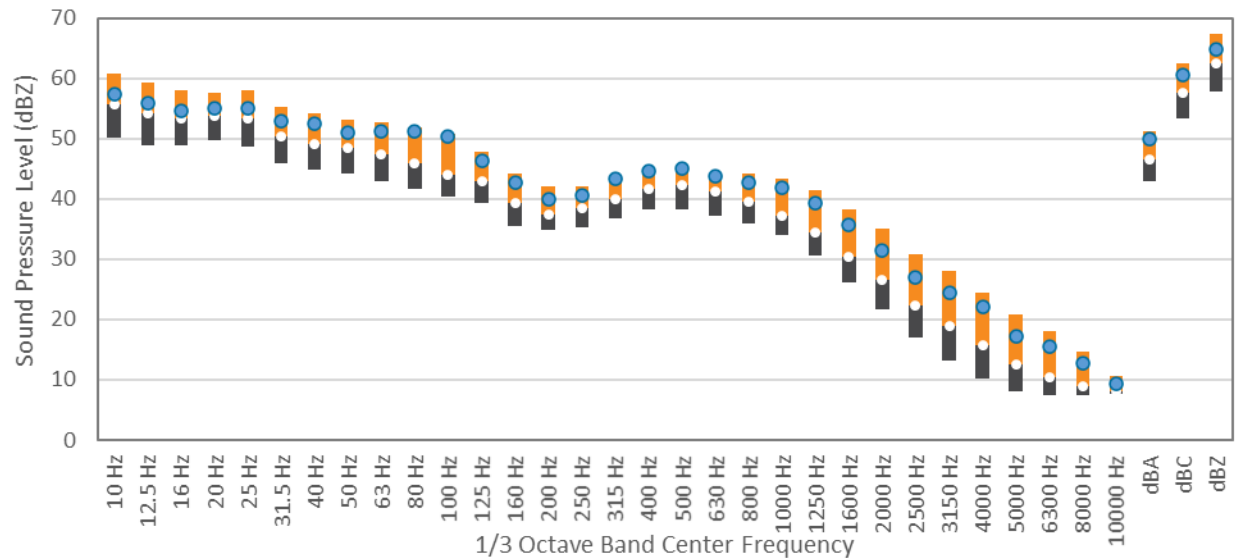


FIGURE 21: STATISTICAL SUMMARY OF POST-CONSTRUCTION 1/3 OCTAVE BAND SOUND LEVELS DURING PERIODS OF HUB HEIGHT WIND SPEED OF 9 M/S (20 MPH), WEST MONITOR

5.6 SOUTH MONITOR RESULTS

Time History Results (South)

Results at the South monitor from the first week of monitoring are provided in Figure 22. With the exception of the first and last days of monitoring, all days experienced some periods of ground-level wind speeds above 5 m/s (11.2 mph) that necessitated exclusion; most of these periods were during the daytime hours. Shutdowns are visible in the data on most nights, particularly the nights ending on November 7 and November 9. On those nights, background sound levels during shutdown periods were between about 30 and 35 dBA and sound levels during turbine operation periods were between 45 and 47 dBA.

Figure 23 provides the time history results at the South monitor for the second week of monitoring. Shutdowns are visible in the sound level traces on the nights ending November 10 and November 13. On those nights, background sound levels were between 30 and 35 dBA and turbine operation periods had total one-hour L_{50} values between about 40 and 46 dBA.

Freeborn Wind (MN) Post-Construction Sound Monitoring

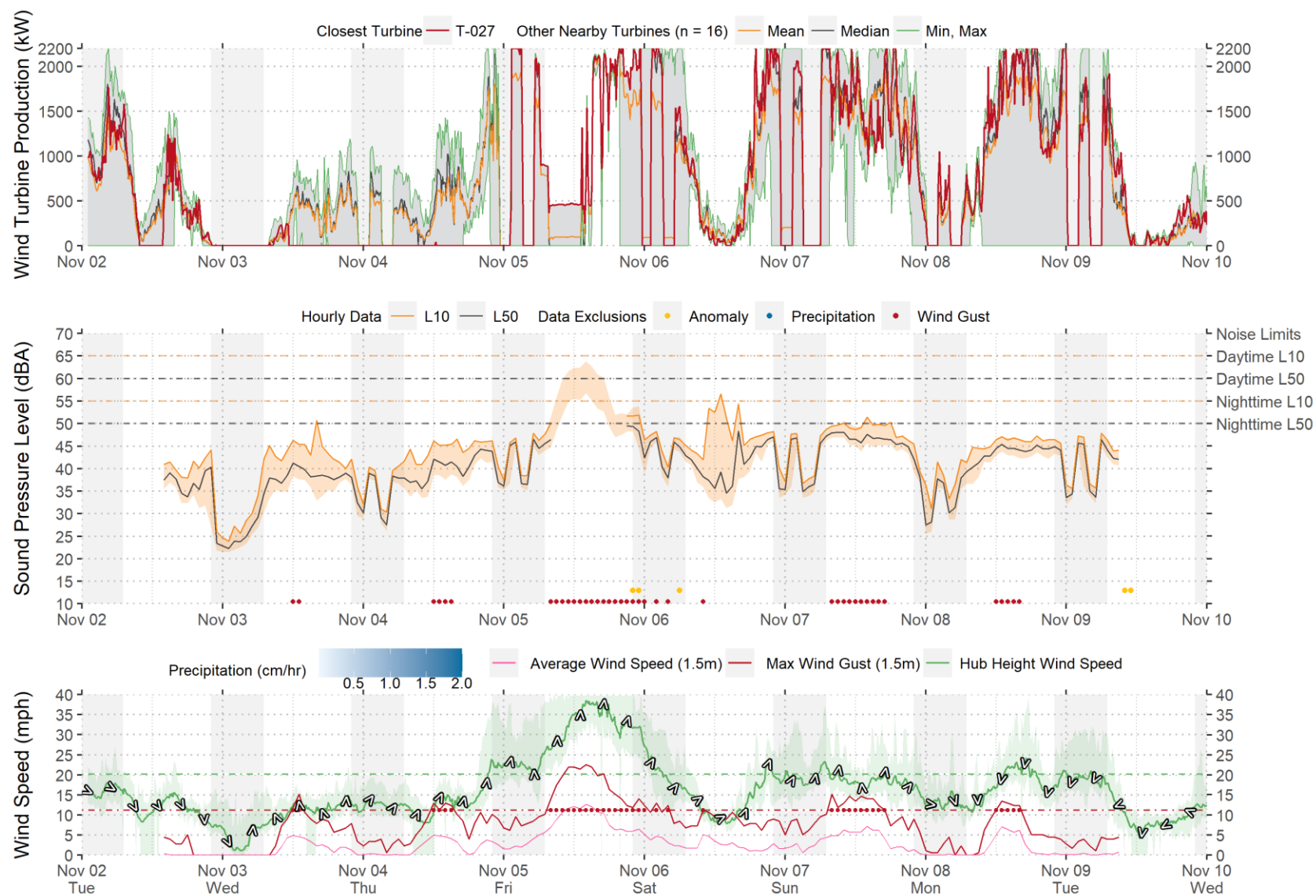


FIGURE 22: SOUTH MONITOR, WEEK 1, TIME HISTORY PLOT

Freeborn Wind (MN) Post-Construction Sound Monitoring

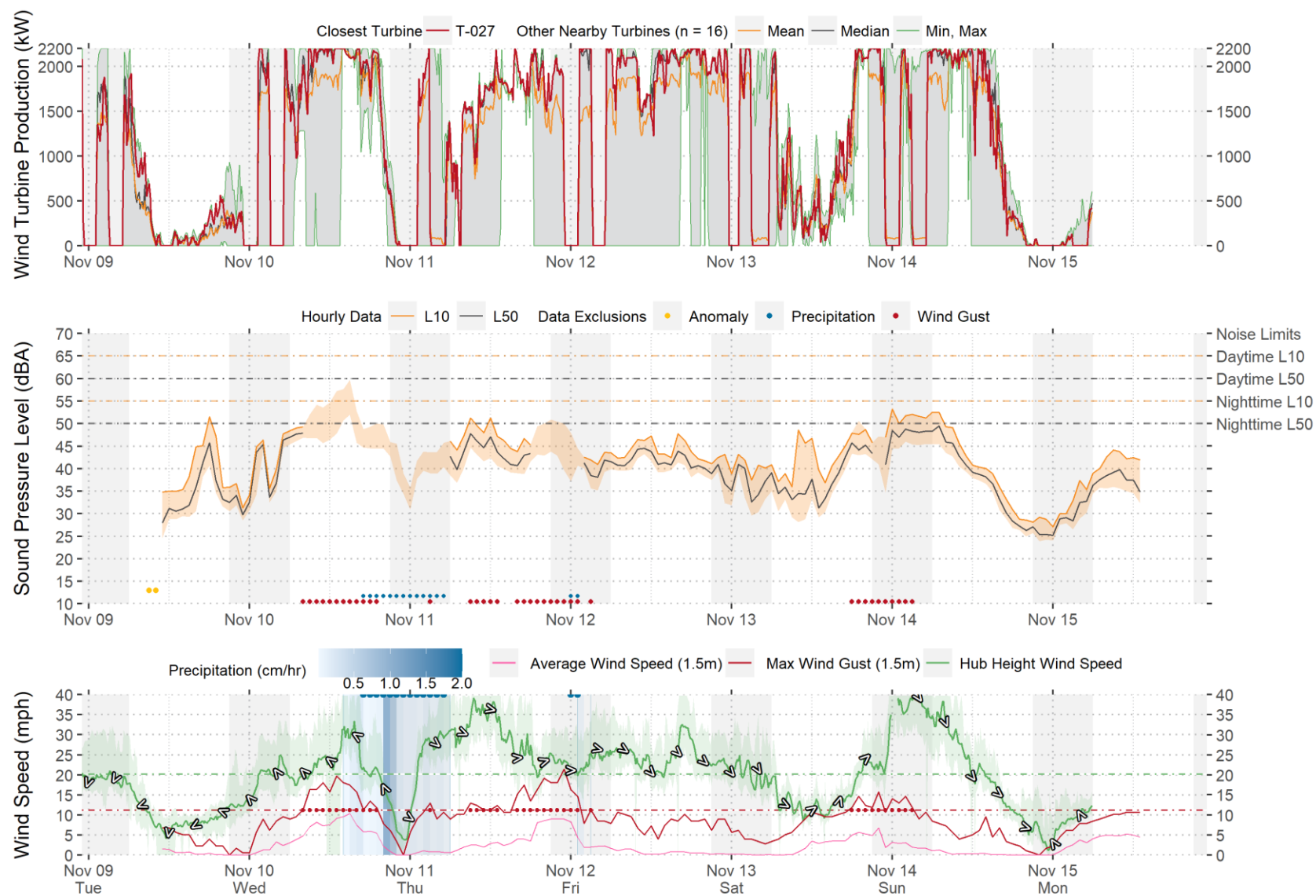


FIGURE 23: SOUTH MONITOR, WEEK 2, TIME HISTORY PLOT

Sound Level Summary Plot at the Representative Wind Speed (South)

Figure 24 provides the statistical sound levels during post-construction monitoring at the South monitor at the representative hub-height wind speed. Data represented in the plot only includes periods when wind turbines were operating; periods when wind turbines were shut down were excluded from the aggregation. At the representative wind speed with wind turbines operating, the overall A-weighted L_{50} at the South monitor during post-construction monitoring was 45 dBA.

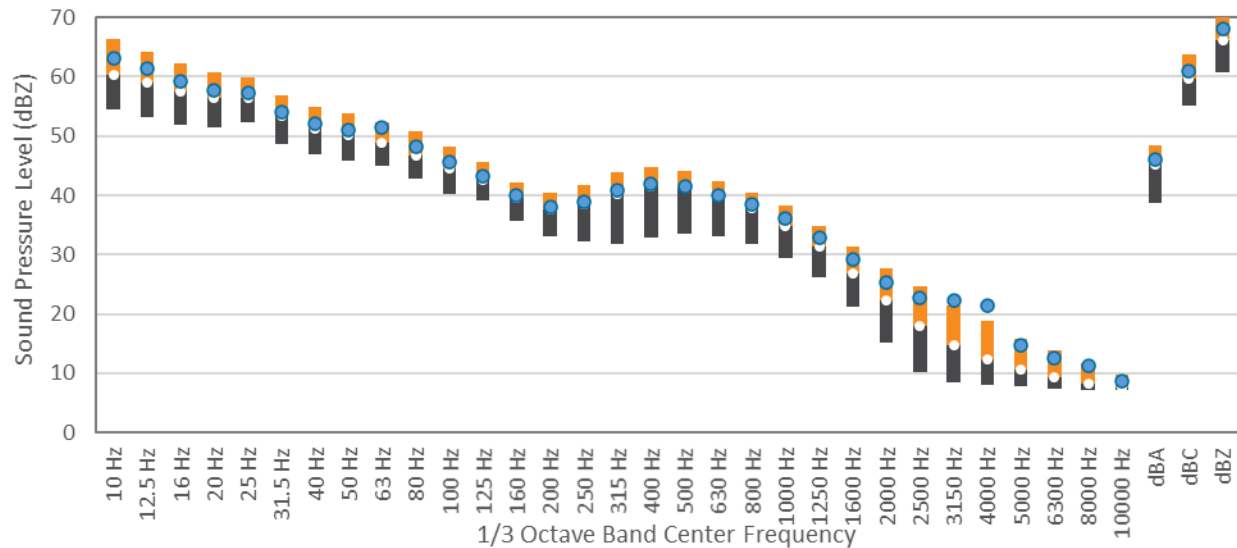


FIGURE 24: STATISTICAL SUMMARY OF POST-CONSTRUCTION 1/3 OCTAVE BAND SOUND LEVELS DURING PERIODS OF HUB HEIGHT WIND SPEED OF 9 M/S (20 MPH), SOUTH MONITOR

6.0 ASSESSMENT OF PROJECT-ONLY SOUND LEVELS

The Protocol and 2019 Guidance recommend implementing an operational shutdown-based method that permits the measurement of background sound levels in-situ to separate “Total” sound (wind turbine + background) into its constituent components (“Turbine-only” sound and “Background” sound). This discrete shutdown method allows for a more precise assessment of background sound levels at each monitor location and determination of the sound level attributable to the wind turbines.

An alternative method for determining wind turbine only sound levels utilizes the grouping, or “binning,” of data based on periods with sufficiently similar conditions. As outlined in the Protocol, this additional analysis is triggered at monitors that register Total sound levels above the limit and are attributable to the Project. In this report, the binning method was triggered for the West monitor.

6.1 ANALYSIS METHODOLOGY

Discrete Shutdowns

Wind turbine shutdowns are the most effective method at our disposal to determine the contribution of wind turbines to total sound.¹⁴ They provide an in-situ measurement of background sound that allows for the turbine-only sound to be calculated from the total (turbine + background) sound by quantifying the background sound immediately before or after a period of turbine operation at the same location. The background sound level measured during a turbine shutdown is utilized to represent the background sound level of all other sources of sound during turbine operation.

The target periods for evaluation include one hour of normal wind turbine operation temporally adjacent to a one-hour shutdown period. The one-hour operation period provides a direct measurement of the total sound at the monitor (turbine + background) pursuant to Minnesota Rule 7030 that regulates total sound in one-hour periods. Shutdowns were performed at night because nighttime periods typically have lower background sound levels, favorable conditions for sound propagation, and the most stringent noise limits. Shutdowns were scheduled during the monitoring period to evenly divide the nighttime hours into background and turbine operating conditions in case further extrapolated analyses of the data would be necessary.

During the monitoring period, all Project turbines were shut down (so that the blades ceased rotating) twice each night for about two hours. The nightly shutdowns typically began around

¹⁴ Duncan, E., et.al., Methods for assessing background sound levels during post-construction compliance monitoring within a community, Proceedings of the 6th International Meeting on Wind Turbine Noise, April 2015.

11:00 PM and 3:00 AM; the turbines were subsequently restarted around 1:00 AM and 5:00 AM, respectively. The shutdown and restart times are not precise for every shutdown period but are approximate. The operational and shutdown periods and how they make up a turbine-only assessment period is illustrated in Figure 25.

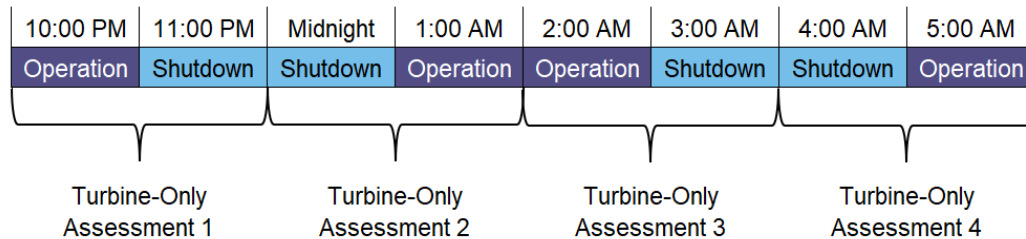


FIGURE 25: ILLUSTRATION OF TURBINE-ONLY ASSESSMENT PERIODS

For each shutdown, SCADA-reported wind turbine production and sound level data were leveraged to identify precise time intervals for shutdowns and turbine operations. As such, wind turbine shutdown and operation periods were assigned according to the observable sound level and production data.

Within each identified time interval, each measured one-second L_{eq} was aggregated for acoustically valid periods (i.e., no precipitation, ground level windspeeds below 5 m/s, etc.) and the L_{50} is reported. One-hour periods on both sides of each shutdown were analyzed independently to determine the one-hour L_{50} for each discrete turbine operation period. To determine the Turbine-only sound level for each turbine operation period, the Background L_{50} was logarithmically subtracted the corresponding turbine operation (“Total”) period L_{50} on a 1/3 octave band basis.¹³

Binning Method

Under the Protocol, a binning method is used if sound levels are over prescribed levels. In this method, the Background L_{50} is subtracted from the Total L_{50} for each hub-height wind speed bin rather than for each shutdown event. Wind speed bins rounded to the nearest integer in meters per second are used for the analysis.

The distribution of discrete shutdowns described in Section 6.1 provides equal lengths of time for turbine operation and background periods at night (10:00 PM to 7:00 AM). Raw one-second sound level data are grouped with SCADA-derived wind speed data to compute the aggregated L_{50} in each wind speed bin.

Hub-height wind speeds were computed using the method outlined in IEC 61400-11, in which SCADA-reported power production is used to determine hub height wind speed within the allowed range of the power curve when the turbines are operating. Transition periods between turbine operation and turbine shutdown were excluded from the binning analysis.

The L_{50} in each wind speed bin is calculated by

1. Grouping each valid one-second L_{eq} into a wind speed bin based on the 10-minute SCADA wind speed of the closest wind turbine, within which that second occurred.
2. Categorizing data by turbine operation (i.e., Total or Background sound),
3. Computing the Total and Background L_{50} on a 1/3 octave band basis for each wind speed bin,
4. Calculating the 1/3 octave-band wind turbine-only L_{50} (Total minus Background L_{50}),
5. Summing the A-weighted 1/3 octave bands to calculate the respective A-weighted wind turbine-only L_{50} for each bin.
6. Calculating the percentage of time that each wind speed occurs for the total nighttime measurement period.

The protocol requires this analysis for sites which may have one or more hours over specified levels. These results are provided for the West monitor in Section 6.2.

Sound levels are only aggregated if each wind speed bins has at least one-hour of valid data in each category. Turbine-only sound levels for wind speed bins with background sound levels within 3 dB of the corresponding total sound levels are not reported due to the poor signal-to-noise ratio inherent in the comparison. Extraneous noise sources (e.g., vehicular traffic and trains) have not been excluded from a majority of the data included in the binning analysis. Anomalous anthropogenic noise was only removed from discrete shutdown periods associated with wind-turbine only sound levels of 47 dBA and above.

6.2 TURBINE-ONLY RESULTS

North Monitor

Discrete Shutdowns

A total of 39 valid periods were assessed at the North monitor. A table with the results for each valid period is provided in Table 9 in Appendix D.

Shutdown ID 14

The worst-case period occurred on the morning of November 7 (Shutdown ID 14). The measured L_{50} while the nearest turbine was in operation with production between 1.6 and 2.0 MW was 50 dBA. The measured L_{50} during the shutdown was 30 dBA, resulting in a turbine-only sound level of 50 dBA.

A time history graph of the worst-case assessment period for the North monitor is provided in Figure 26. As shown in the figure, winds were out of the southwest, putting T-08 and T-07 crosswind from the receptor. Ground-level wind gusts were not a dominant source of sound during the assessment period. Hub height wind speeds hovered around 20 mph (9 m/s). Anomalies related to traffic and train activity were excluded from the results. Note that results from the surrounding assessment periods on the same night (Shutdown ID 13 and Shutdown ID 15) were nearly equivalent (background within 2 dB, total sound with turbine operation the same).

Freeborn Wind (MN) Post-Construction Sound Monitoring

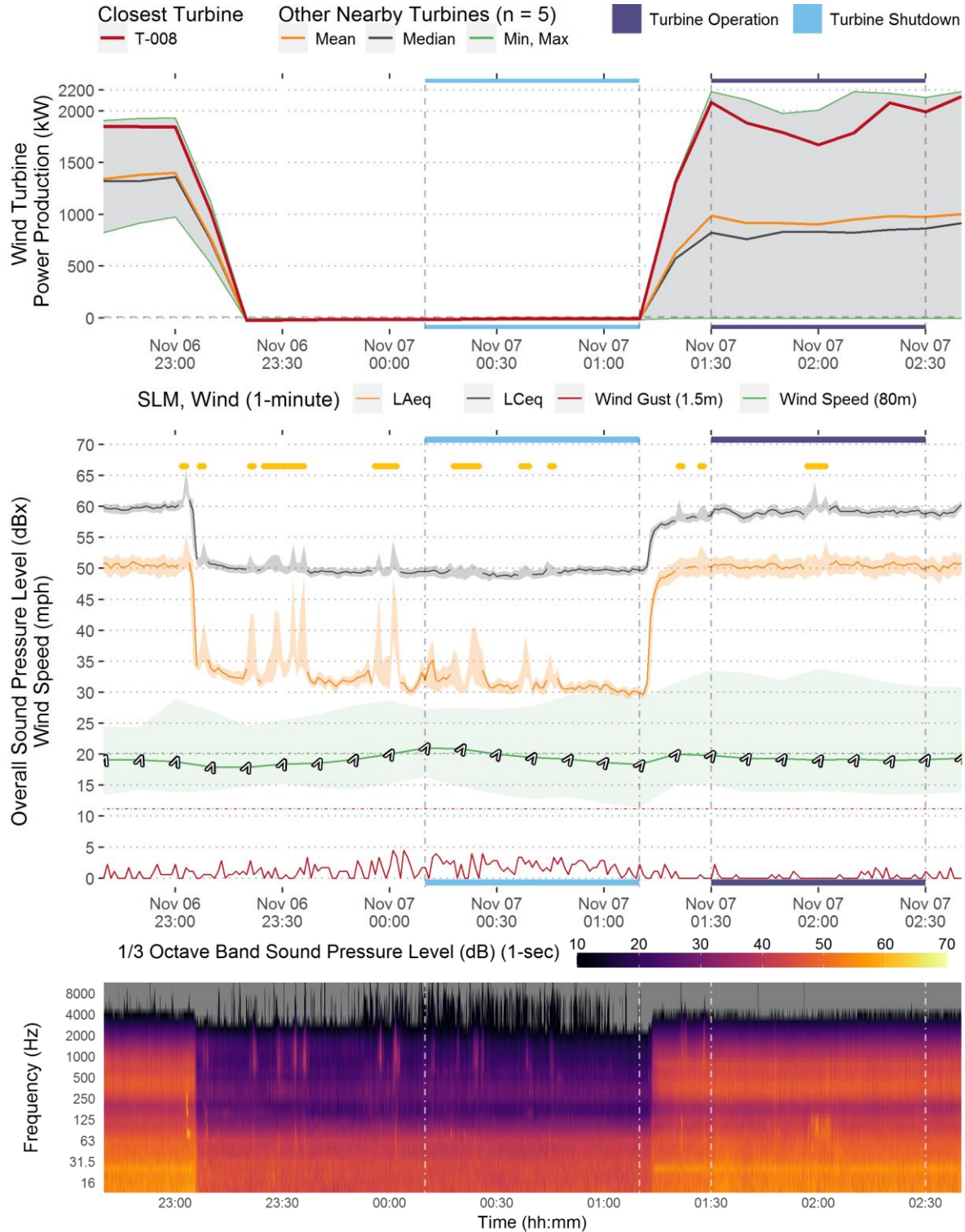


FIGURE 26: GRAPHICAL RESULTS OF SHUTDOWN ID 14 AT THE NORTH MONITOR

The yellow points above 65 dBA indicate periods removed due to extraneous anthropogenic noise (i.e., anomalies)

Central Monitor

Discrete Shutdowns

A total of 32 valid shutdown periods were assessed at the Central monitor. A table of with the results for each valid assessment period is provided in Table 10 in Appendix D. The highest total sound level and calculated wind turbine level were observed with respect to Shutdown #9. The conditions during the background period and turbine operation periods for Shutdown #9 were not sufficiently similar to provide an accurate accounting of background sound during the turbine operation periods. Specifically, there was a clear shift in wind conditions during the background period, such that it was not similar to the wind conditions during the turbine operation period. Nonetheless, the results are presented herein. Shutdown #26 is more representative of wind turbine sound as it provided a better signal-to-noise ratio.

Shutdown ID 9

The detailed results surrounding Shutdown ID 9 at the Central monitor are provided in Figure 27. The turbine operation period associated with Shutdown ID 9 was defined by strong and gusty winds aloft, averaging 14 m/s (32 mph). The total sound level during the turbine operation period was 51 dBA.

Coinciding with the wind turbine shutdowns, hub-height wind speeds began to decrease, dropping almost 2 m/s (5 mph) by the beginning of the defined shutdown period and 4 m/s (10 mph) by the end of the shutdown period. The background period, with an average hub-height wind speed of 12 m/s (27 mph), registered a one-hour L_{50} of 47 dBA, resulting in a calculated turbine-only sound level of 49 dBA.

The wind turbine operation period following the shutdown (Shutdown ID 10) continued the trend of moderating hub-height wind speeds to an average of 10 m/s (22 mph) and had a total one-hour L_{50} of 45 dBA, which is 2 dB less than the associated background L_{50} during the turbine shutdown of 47 dBA. Although not explicitly denoted in the figure, the turbine operation period associated with Shutdown ID 10 is observable in Figure 27 (1 AM to 2 AM). The anomalous anthropogenic noises excluded during the shutdown included a passing train and other railroad activity.

The average hub height wind during the turbine operation period was a consistent 14 m/s (32 mph) and the average during the background period dropped to 12 m/s (27 mph). Thus, this leads to the conclusion that the drop in sound level from the turbine-on to background period is a primarily due to the drop in wind-induced noise, and not from turbine operations.

To confirm that the change in wind speed was a meteorological phenomenon and not an artifact of the SCADA data when shutting down the wind turbines, we investigated SCADA data from other wind turbines in the project that were not shut down during this period. T-10 is located about 3.3 km (2 miles) north of the Central monitor and T-18 is located about 4.3 km (2.7 miles)

south of the Central monitor. These turbines were not shut down for the post-construction noise assessment because they were farther than 1.5 miles from a monitoring location.

A time history plot of SCADA-reported wind speeds at T-10, T-11, T-12, and T-18 for the period surrounding Shutdown ID 9 is provided in Figure 28. Although the wind speed reported by the nacelle anemometer at T-11 is reading relatively high, the overall behavior of wind speeds dropping precipitously after 11:00 PM, as shown in Figure 27, is confirmed. We therefore conclude that the drop in wind speed coincident with the start of Shutdown ID 9 is real and not an artifact of the turbine shutdown.

Finally, we conducted a detailed review of the audio recordings around Shutdown ID 9. These audio recordings confirmed that the wind turbines were not readily discernible during the turbine-on period. Rather, gusty wind winds dominated the recordings during both turbine-on and background periods. As a result, we conclude that the sound levels recorded around Shutdown ID 9 were not substantially influenced by or attributed to the wind turbines. That is, the 4 dB drop between Turbine-on and Background periods was due to a drop in wind-induced noise related to a coincident drop in wind speed. Given this, the calculated wind turbine-only sound level cannot be accurately assessed for Shutdown ID 9 and therefore cannot be attributed to the Project.

Freeborn Wind (MN) Post-Construction Sound Monitoring

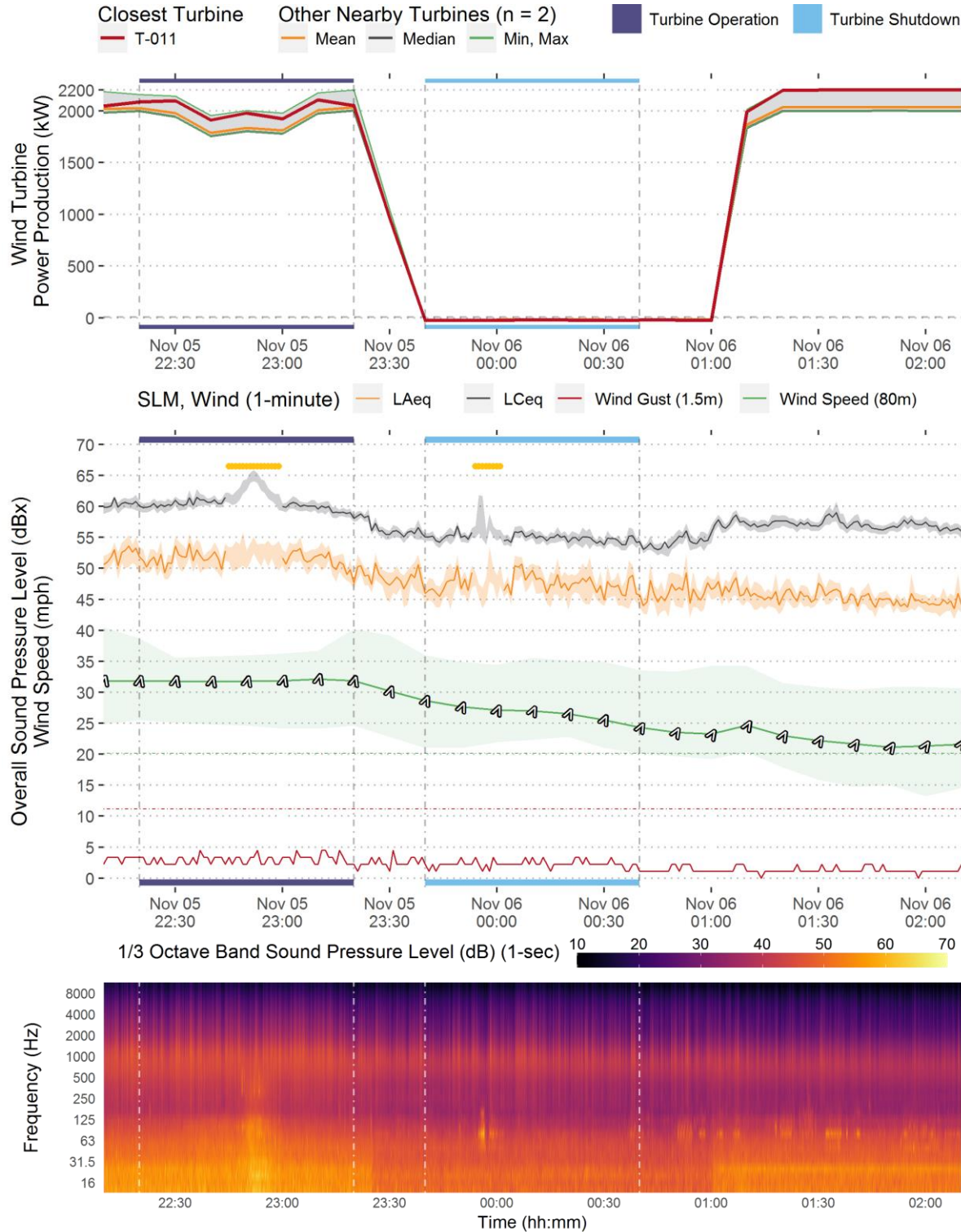


FIGURE 27: GRAPHICAL RESULTS OF SHUTDOWN ID 9 AT THE CENTRAL MONITOR

The yellow points above 65 dBA indicate periods removed due to extraneous anthropogenic noise (i.e., anomalies)

Freeborn Wind (MN) Post-Construction Sound Monitoring

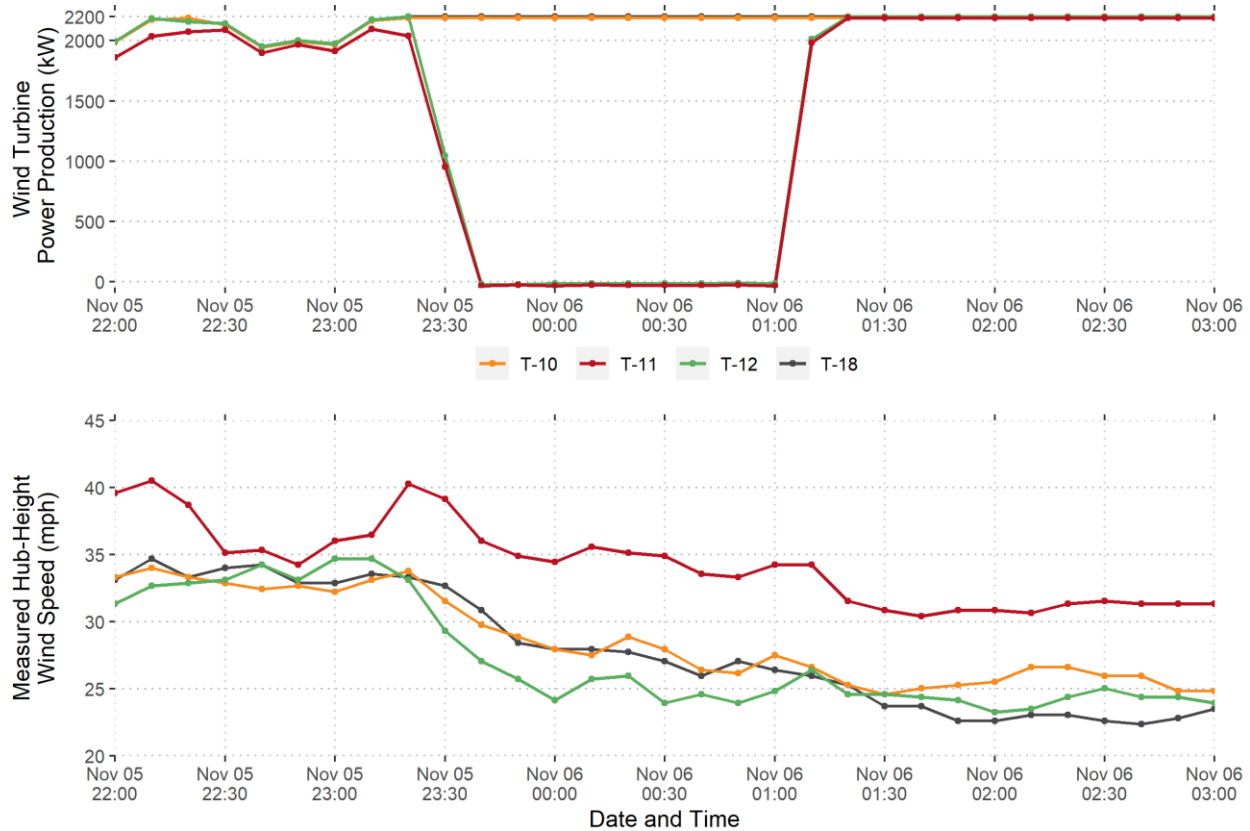


FIGURE 28: TIME HISTORY COMPARING HUB-HEIGHT WIND SPEEDS REPORTED BY T-11 AND T-12 (CLOSEST TURBINES TO THE CENTRAL MONITOR), WITH T-10 T-18 FOR SHUTDOWN ID 9. T-10 AND T-18 WERE NOT SHUT DOWN FOR THE POST-CONSTRUCTION STUDY.

Shutdown ID 26

Results for Shutdown ID 26 are provided in Figure 29. Similar to Shutdown ID 9, the hub-height wind conditions changed between the background shutdown period. However, the winds aloft were distinctly consistent (and not gusty), leading to more consistent sound levels typical of wind turbine operation. Winds out of the southeast during Shutdown ID 26, on the morning of November 10, placed the Central monitor downwind from the closest turbine (T-011). The one-hour L_{50} while the Project was shutdown was 26 dBA while the total one-hour L_{50} level during turbine operation was one-hour L_{50} of 48 dBA. The anthropogenic anomaly removed was a passing train.