Appendix D – Crocker Wind Farm Noise Compliance Report (proprietary information excluded)

NOISE COMPLIANCE REPORT

CROCKER WIND FARM

the science of insight

7.21.2017

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PROPRIETARY INFORMATION IN APPENDIX B EXCLUDED

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1.0 INTRODUCTION

Crocker Wind Farm, LLC is submitting a permit application to the South Dakota Public Utilities Commission (PUC) to build a Wind Energy System (WES) facility in Clark County, South Dakota. The facility will involve the construction of up to 200 wind turbines for a project rating of up to 400 MW. The turbines would be installed in an area northwest, west, southwest, south, and southeast of Crocker and is bisected by South Dakota Route 20 (SD 20). For the application, RSG has performed a noise compliance assessment of the project based on the current turbine layout. Included in this report are:

- A description of the project;
- A discussion of sound level standards;
- Background sound level monitoring procedure and results;
- Sound propagation modeling procedures and results; and
- Conclusions.

Appendix A includes a primer on the science of sound, including descriptions of some of the acoustical terms used in this report.

The information presented in this report leads us to conclude that the proposed Crocker Wind Farm can be constructed and operated in such a way as to comply with the Clark County and PUC noise limits for wind energy systems at all non-participating residences.

2.0 PROJECT DESCRIPTION

Crocker Wind Farm is proposed to be located in Clark County, South Dakota. The project area is generally to the northwest, west, southwest, south, and southeast of Crocker, just south of the Day/Clark County Line and 3 miles east of the Spink/Clark County Line. The southern extent of the project area is approximately 7 miles north of US Route 212 and the county seat, Clark. The roads and borders that envelope the project area are the Day/Clark County Line to the north, 415th Avenue to the west, 166th Street to the south, and 426th Avenue to the east.

The wind project is designed to include up to 200 turbines, with hub heights between 80 and 95 meters (262 and 312 feet), depending on the final turbine selection. A substation will be located in the middle of the project, just off of 419th Avenue. A table showing the proposed turbine model options and the number of turbines proposed for each option are shown in Table 1.

The area around the project is composed primarily of agricultural land uses with farm residences and undeveloped lands. Terrain in the area is mostly flat with some rolling elevation variations of approximately 100 feet, and a typical overall elevation of 1,800 feet (550 meters) above sea level.

A map of the site for all turbine configuration is provided in Figures 1 to 4.

TABLE 1: PROPOSED TURBINE MODELS

Turbine Make/Model	Turbine Output (MW)	Proposed Turbine Count
Vestas V136 3.45 MW	3.45	116
Vestas V110 STE 2.0 MW	2.0	200
GE 2.5-116 LNTE	2.5	160
Gamesa G126 2.625 MW	2.625	152

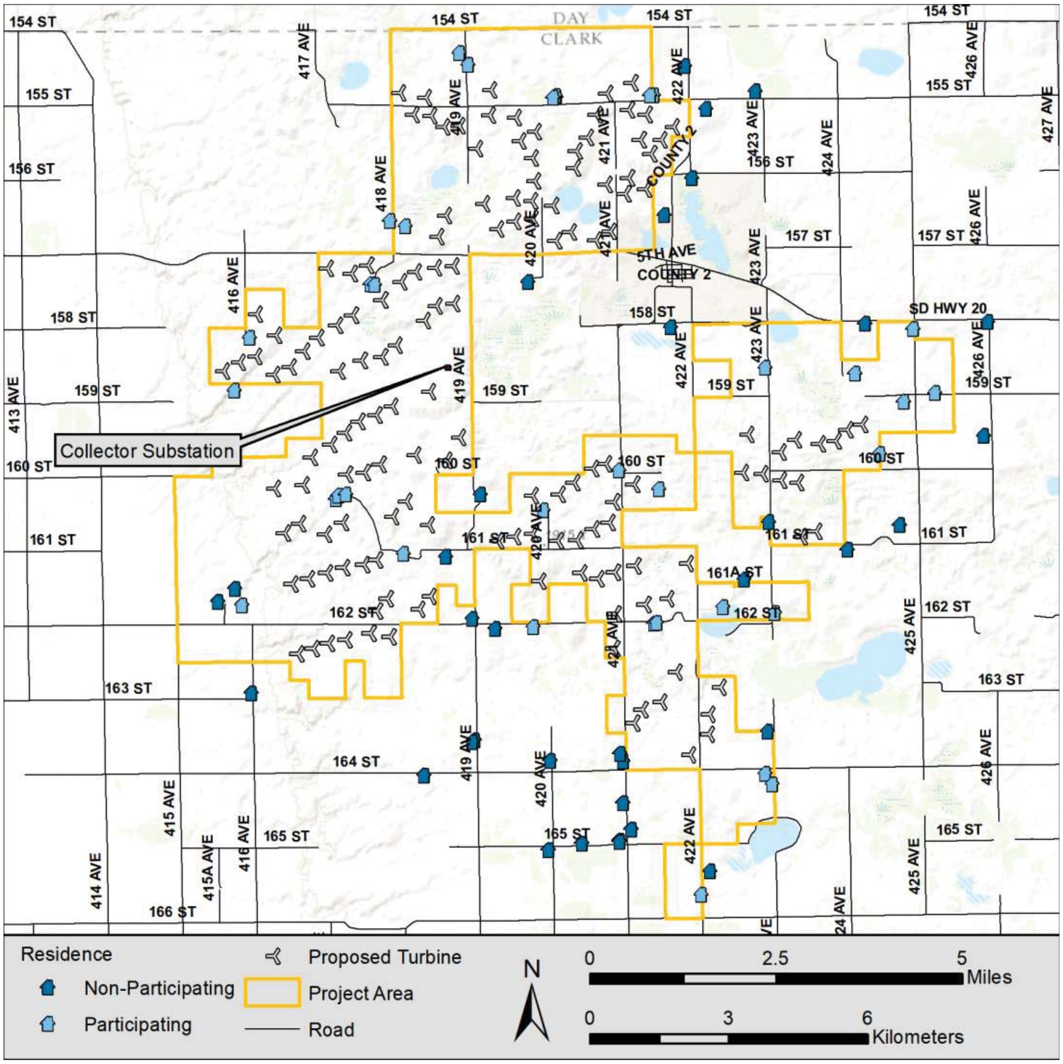

FIGURE 1: CROCKER WIND FARM AREA MAP - GAMESA G126 2.625 MW LAYOUT

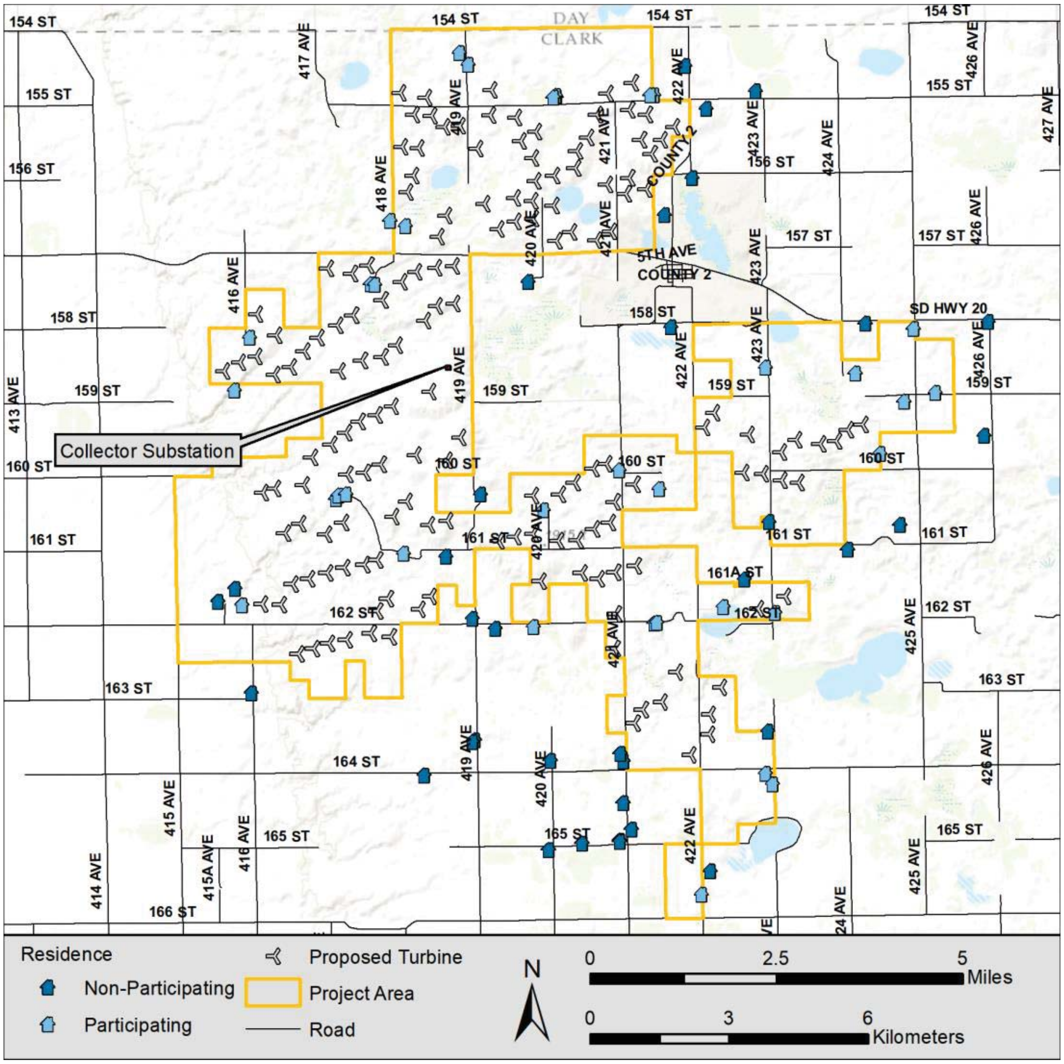

FIGURE 2: CROCKER WIND FARM AREA MAP - GE 2.5-116 LNTE LAYOUT

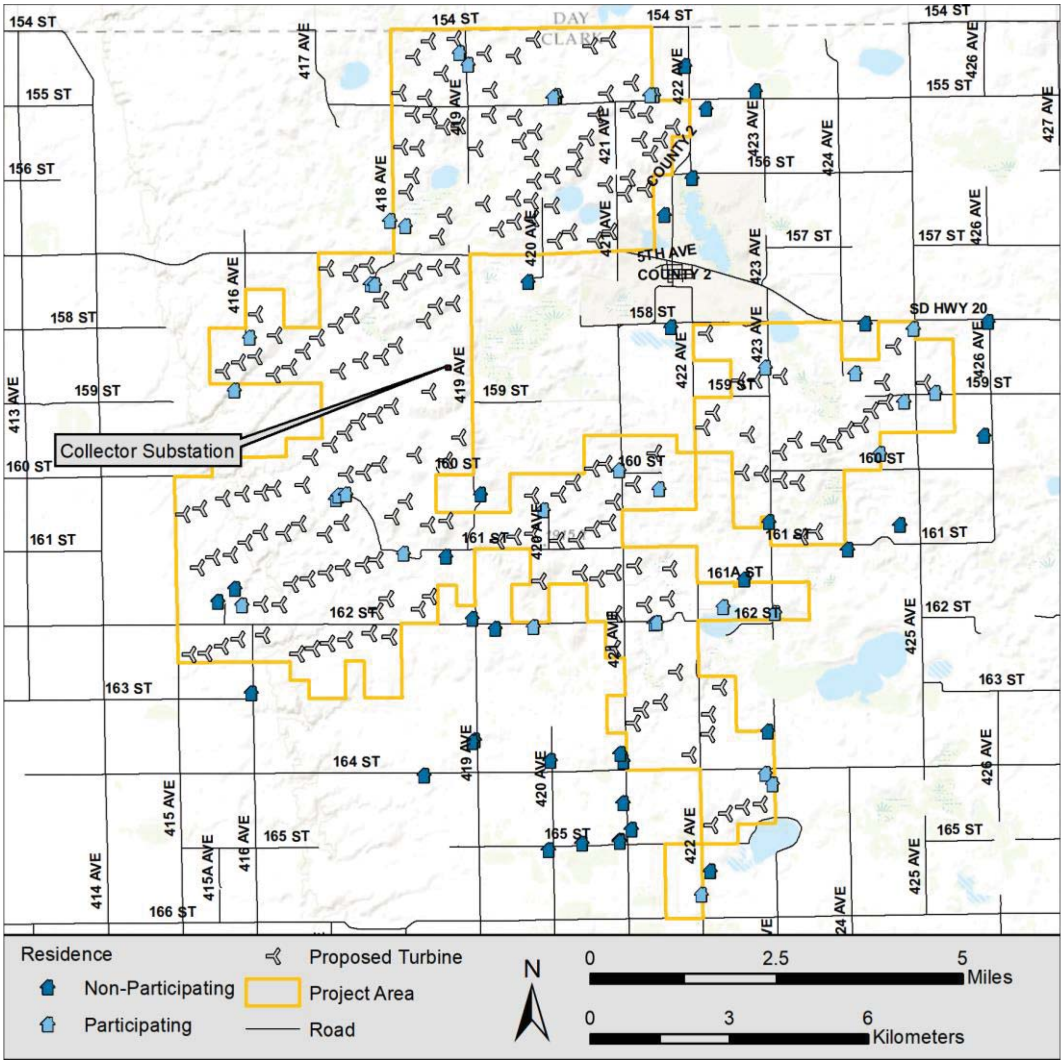

FIGURE 3: CROCKER WIND FARM AREA MAP - VESTAS V110 STE 2.0 MW LAYOUT

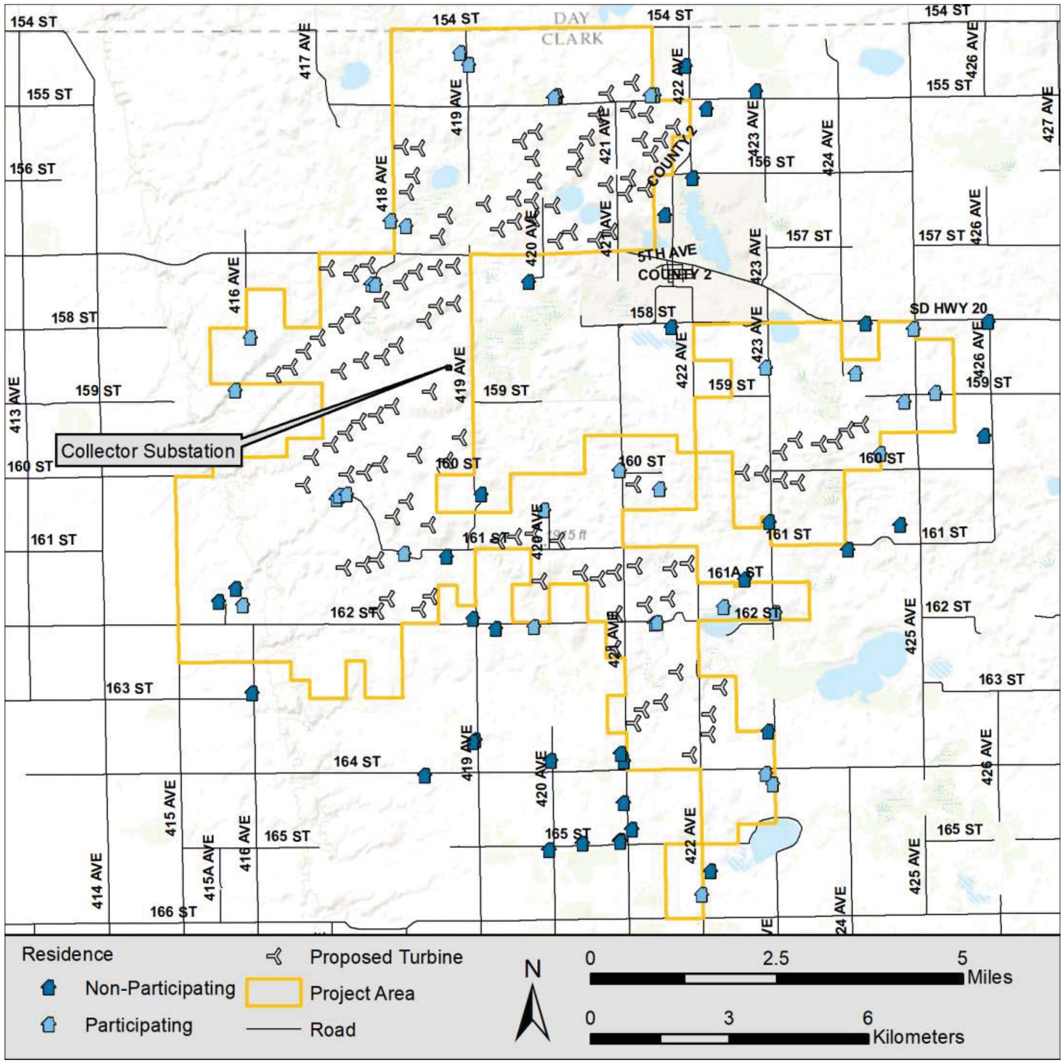

FIGURE 4: CROCKER WIND FARM AREA MAP - VESTAS V136 3.45 MW LAYOUT

3.0 SOUND LEVEL STANDARDS & GUIDELINES

3.1 | LOCAL STANDARDS

Locally, the Clark County Zoning Ordinance regulates noise from wind energy systems in Section 4.21.03:

> "13. Noise. Noise shall not exceed 50 dBA, average A-weighted Sound pressure including constructive interference effects at the perimeter of the principal and accessory structures of existing off-site residences, businesses, and buildings owned and/or maintained by a governmental entity."

3.2 | STATE STANDARDS

The South Dakota PUC does not have a quantified or codified standard or rule regarding noise from WES facilities. They have, however, developed a "Model Ordinance for Siting of Wind Energy Systems"[1] (Model Ordinance). The PUC encourages local governments to use the model ordinance for their specific needs. For large WES facilities the model ordinance states that noise, "[…] shall not exceed 55 dBA, average A-weighted sound pressure at the perimeter of occupied residences existing at the time the permit application is filed, unless a signed waiver or easement is obtained from the owner of the residence."

It is our understanding that since developing the Model Ordinance, the PUC has reduced their recommended noise limit to 50 dBA at the perimeter of an existing occupied residence, unless a signed waiver or easement is obtained from the owner of the residence. This is consistent with the sound limits in the Clark County Zoning Ordinance.

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[1] SD PUC, "Draft Model Ordinance for Siting of Wind Energy Systems (WES)", October 2008

4.0 SOUND LEVEL MONITORING PROCEDURES

Background sound level monitoring was conducted throughout the area to quantify the existing sound levels around the project.

Three locations were monitored to determine existing background sound levels, Monitors A, B, and C. A map of the monitor locations within the project area are shown in Figure 5.

Monitoring locations were selected to represent different areas and different soundscapes (i.e. unique sound characteristics) within the project.

Further information on the monitoring locations as well as a review of monitoring equipment and procedures is found in the following sections.

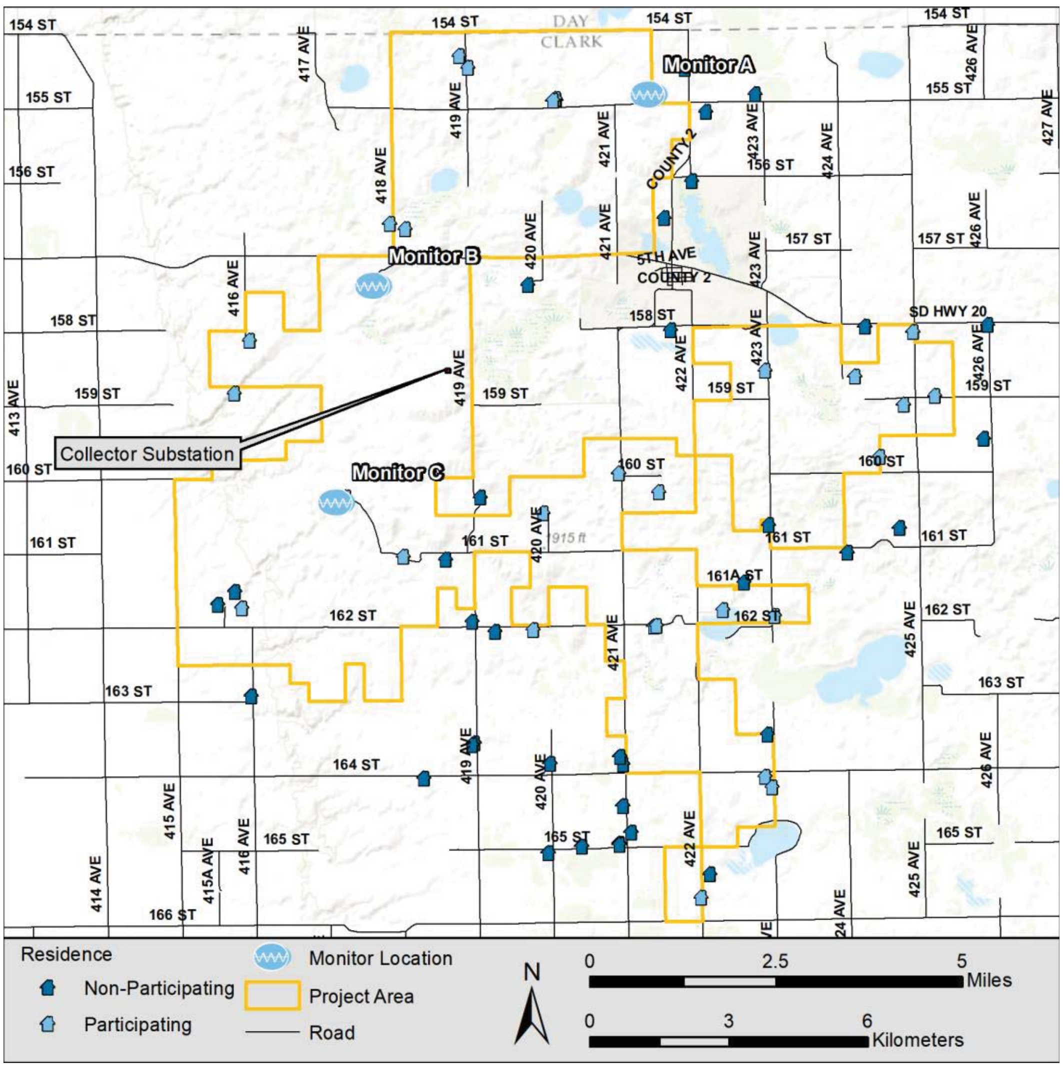

FIGURE 5: MONITORING LOCATION MAP

4.1 | EQUIPMENT

Background sound level monitoring was performed with ANSI/IEC Type 1 Svantek SV979 and ANSI/IEC Type 2 Rion NL22 sound level meters. The Svantek SV979 sound level meters were set to log, at a minimum, 1/3 octave band sound levels once each second for the entire measurement period and the Rion NL22 sound level meter was set to log A-weighted sound levels once each second for the entire measurement period. The Svanteks were set to record audio internally, and the Rion was attached to an external audio recorder. 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 distortion on measurements. Before and after the measurement periods, the meters were calibrated with either a Cesva CB-5 or Brüel and Kjær 4231 calibrator.

A list of the equipment used at each monitor is shown in Table 2. At each site, an ONSET anemometer was located at microphone height. Wind data was logged at a rate of once each minute. Precipitation and temperature data were obtained from the Weather Underground station located in Watertown, South Dakota.

TABLE 2: SOUND MONITOR SPECIFICATIONS BY SITE

Monitor Location	Sound Level Meter	Audio Recorder
A	Svantek SV979	Internal
B	Rion NL22	Edirol R-05
C	Svantek SV979	Internal

4.2 | DATA PROCESSING

After data collection, data was downloaded, processed, and summarized into 10-minute, overall day, overall night, and monitoring-period length periods. For each 10-minute period, equivalent average (Leq), upper 10^{th} percentile (L10), median (L50), and lower 10^{th} percentile (L90) 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;
- Anomalous events; or
- Equipment interaction either by RSG staff, other humans, or animals.

4.3 | MONITOR LOCATION DESCRIPTIONS

MONITOR A

Monitor A was located at an active farm which are common throughout the project area and is representative of that type of land use. A picture of the monitoring setup is shown in Figure 6, and a map of the monitoring location is shown in Figure 7.

Monitor A was situated in the northeastern part of the project area, approximately 3,700 meters (2.3 miles) north of the village of Crocker. County Road 42 was located approximately 180 meters (590 feet) to the south, with the intersection between County Road 42 and County Road 2 located approximately 930 meters (3,050 feet) to the southeast. The county boundary with Day County is approximately 1,600 meters (1 mile) to the north. The nextEra-owned Day County Wind Energy Center is located approximately 6,300 meters (3.9 miles) to the northwest.

The monitor was on the north side of barns that were part of a farm. Trees to the north of the monitor provided shelter. Farm buildings were located primarily to the south. A residence was located on another parcel to the southeast. The surrounding area is predominantly farmland, with scattered clumps of trees that surround homesteads and barns.

FIGURE 6: PHOTOGRAPH OF MONITOR A LOOKING EASTWARD

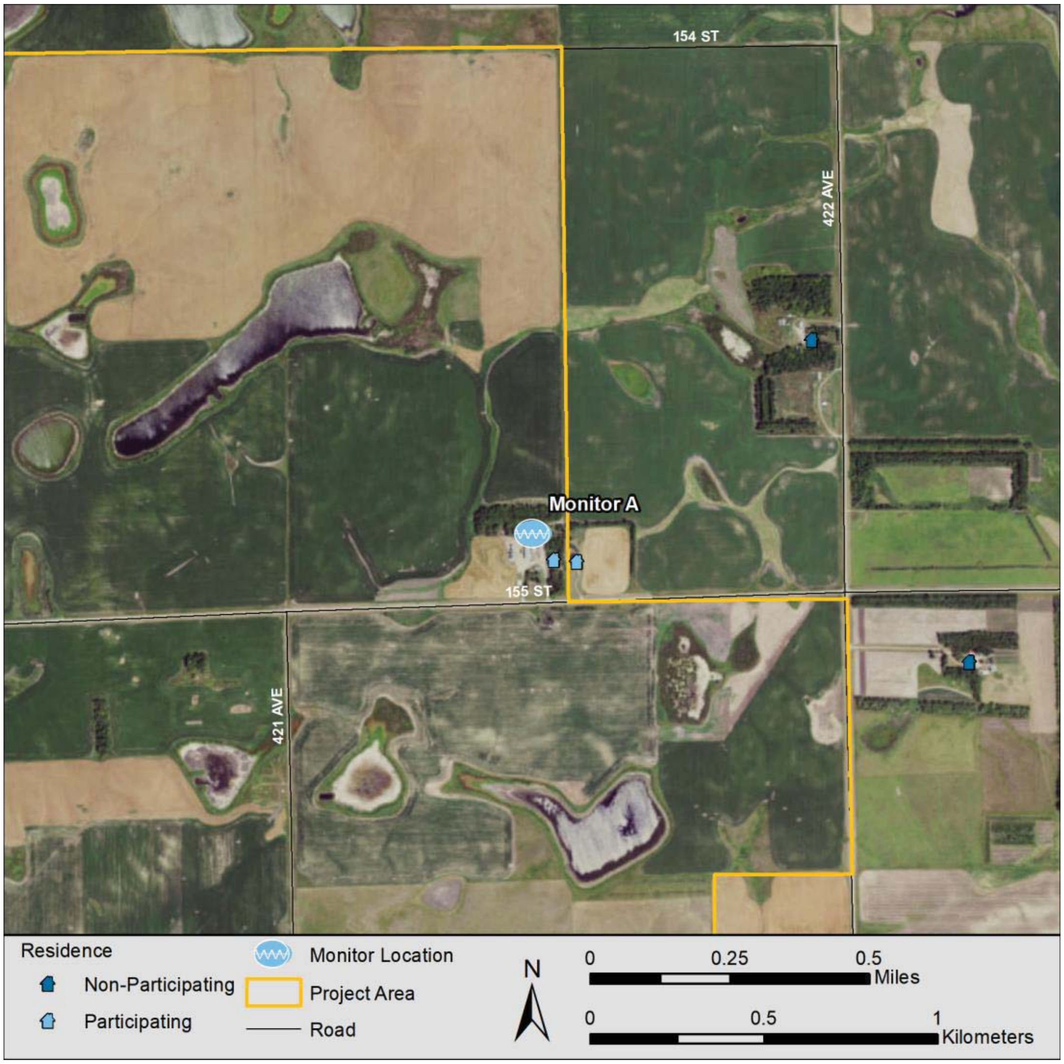

FIGURE 7: MONITOR A LOCATION AERIAL VIEW

MONITOR B

Monitor B was located at a homestead with less consistent sound sources than at Monitor A. It is representative of a rural residential farm in moderate proximity to a state highway. A picture of the monitor setup is shown in Figure 8, and a map of the monitoring location is shown in Figure 9.

Monitor B was situated in the western part of the proposed project area. South Dakota Highway 20 (SD 20) was the closest road, located approximately 640 meters (2,100 feet) to the north with the intersection between SD 20 and 418th Avenue located approximately 800 meters (2,600 feet) to the northeast. The village of Crocker was located approximately 6,500 meters (4.1 miles) to the east and the Day County Wind Energy Center was located approximately 6,400 meters (4 miles) to the north.

The monitor was located on a homestead, approximately northeast and slightly downhill of the residence, in an area with small trees, that surrounds a nearby residence. This general area is higher than the surrounding area. Cattle farming and haying take place in the fields surrounding the homestead, with ancillary barns located to the south, at a distance of approximately 90 meters (300 feet).

FIGURE 8: PHOTOGRAPH OF MONITOR B LOOKING EAST

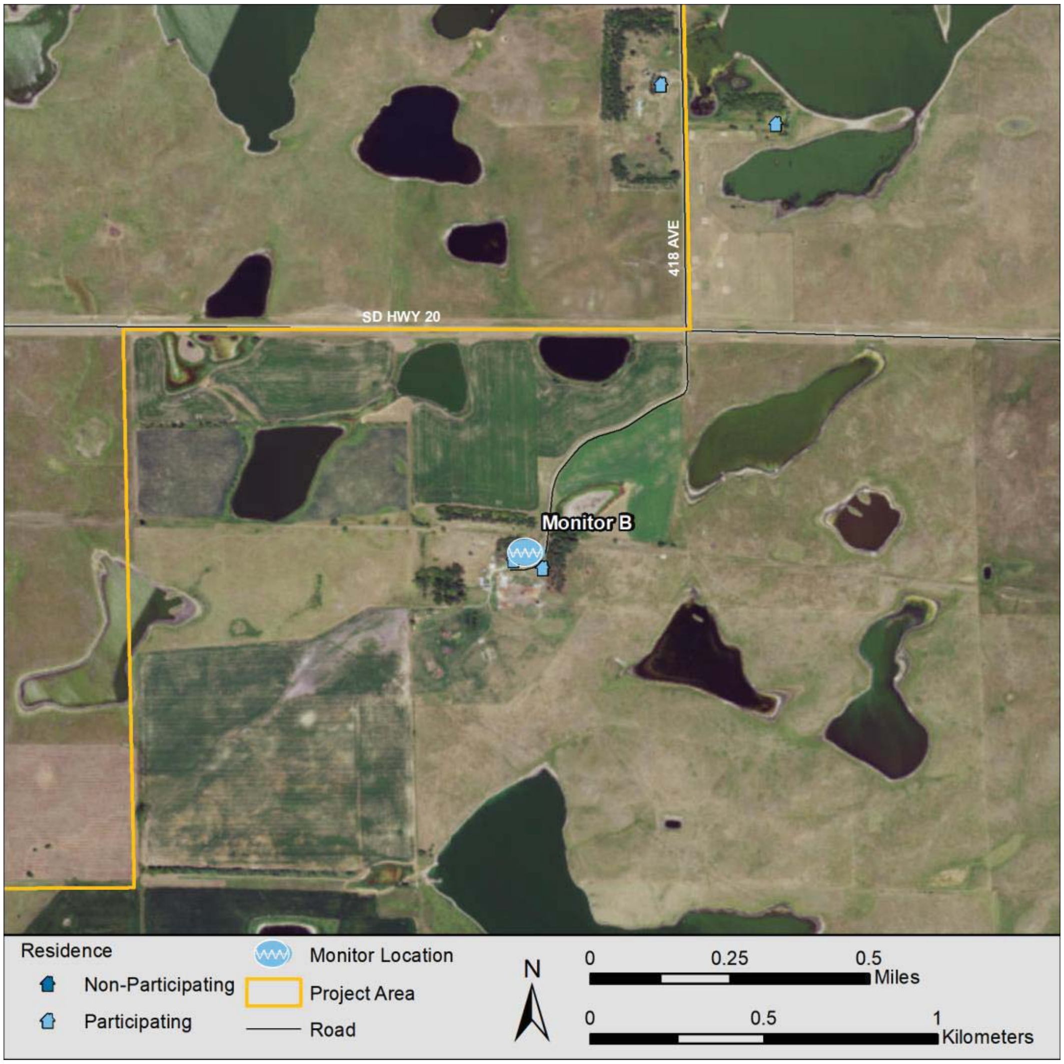

FIGURE 9: MONITOR B LOCATION AERIAL VIEW

MONITOR C

Monitor C was located just south of a residence, on a cattle-raising operation, and is representative of a rural residential farm that is not near any notable roadways. The residence was part of a series of three residences belonging to the family that owns the ranch. A picture of the monitoring setup is shown in Figure 10, and a map of the monitor location is shown in Figure 11. The area is in a low-lying area, with pasture and haying land covering the surrounding hills in all directions. While there were some trees near the monitor, the area was not consistently wooded.

The monitor was situated at the end of 161st Street, approximately 3,000 meters (1.9 miles) west of the intersection with 419th Avenue. The location is in the southwestern part of the project in a sparsely populated area, except for the immediately surrounding residences.

FIGURE 10: PHOTOGRAPH OF MONITOR C LOOKING NORTHEAST

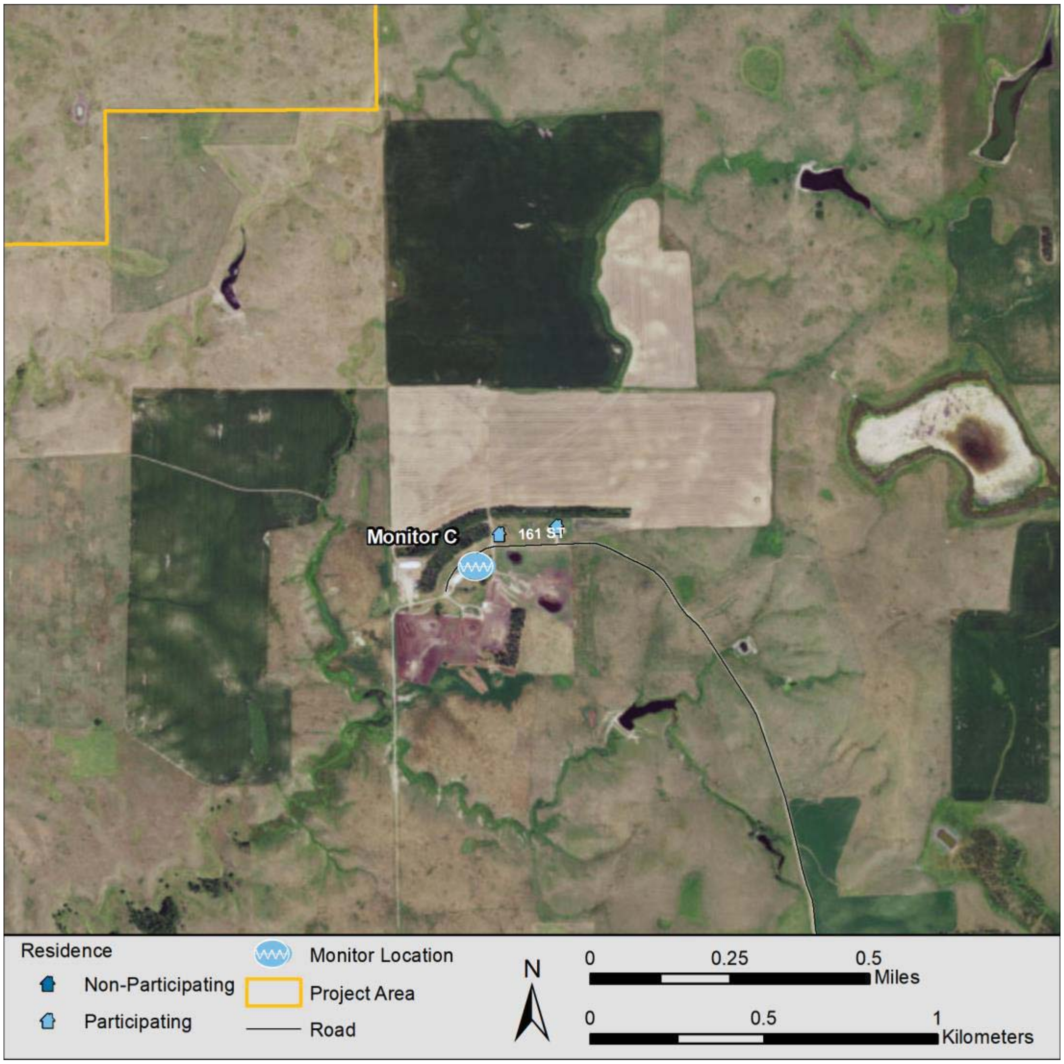

FIGURE 11: MONITOR C LOCATION AERIAL VIEW

5.0 SOUND LEVEL MONITORING RESULTS

For each monitor site, sound level monitoring results are presented this report section. Each chart contains 10-minute sound levels, gust wind speed measured adjacent to each microphone, the temperature obtained from a Weather Underground site in Watertown, SD, and indications of data exclusions. Points on the sound level graph represent data summarized for a single 10-minute interval. All portions of the chart exhibit day/night shading: night is defined as 22:00 to 07:00 and shaded in grey.

The specific sound level metrics reported are the L_{EQ} and L_{90}. 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. 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, square markers on the upper 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.

5.1 | RESULTS SUMMARY

METEOROLOGY

Local meteorological data was collected from anemometers alongside the monitors and a Weather Underground site in Watertown, SD. According to the airport, local temperatures ranged from -1.7°C to 19.2°C over the duration of the monitoring period. There were no precipitation events.

A summary of the 1.5-meter (5-foot) wind speeds measured at each monitoring location is provided in Table 3. The table reveals that Monitors B and C had equal average wind speeds, with the highest gust measured at monitor C. Monitor A consistently had the lowest wind speeds.

TABLE 3: SUMMARY OF MEASURED 10-MINUTE 1.5-METER (5-FOOT) WIND SPEEDS

Monitor	10-min Wind Speed (mph)		10-min Gust Speed (mph)	
	Average	Maximum	Average	Maximum
A	3.1	11.2	6.8	20.3
B	4.8	17.3	8.5	25.9
C	4.8	21.4	8.2	30.4

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. For Monitor B, where the monitor did not log 1/3 octave band data, processing was performed by listening to the audio files of time periods where sound levels were atypical of the rest of the monitoring period. In this way, typical sources and anomalous events were identified.

There were no rainy periods during monitoring. Automated processing of wind speed permitted the identification of gusts above 11 mph on a one-minute basis. That is, if a gust within a specific one-minute period was measured above 11 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. The most time was excluded from Monitor B (2 days of data, or 29%) due to the effect of strong winds at microphone height.

TABLE 4: SUMMARY OF RUNTIME AND EXCLUSION PERIODS AT EACH MONITOR

Locations	Run-time	Exclusion Statistics							
		Rain		High Wind		Anomalies		Total	
	(hours)	(hours)	(%)	(hours)	(%)	(hours)	(%)	(hours)	(%)
A	165.8	0	0.0%	28.6	17.2%	0.4	0.2%	29.0	17.5%
B	166.5	0	0.0%	48.2	28.9%	0.0	0.0%	48.2	29.0%
C	166.2	0	0.0%	43.6	26.2%	1.85	1.1%	45.4	27.3%

BACKGROUND SOUND LEVELS

The measured background sound levels are listed for all seven sites in Table 5. The reported levels represent all valid periods, that is, all periods that were not excluded due to weather or anomalous activity, as discussed above.

Sound levels are less at night than during the day, except for at Monitor A. The large difference between L_{EQ} and 10th-percentile levels (L_{90}) indicates that the soundscapes at Monitors B and C are often dominated by transient or intermittent sounds (such as aircraft overflights, passing automobiles, or farming activity). Monitor A is dominated by equipment fan noise, which maintained a constant sound level and operated throughout the nighttime hours and much of the day.

TABLE 5: PRECONSTRUCTION MONITORING SUMMARY SOUND LEVELS (IN dBA)

Monitor Location	Overall				Day				Night			
	Leq	L90	L50	L10	Leq	L90	L50	L10	Leq	L90	L50	L10
A	51	34	51	53	50	32	50	52	52	50	51	53
B	39	21	31	41	41	21	32	43	36	20	29	39
C	42	17	31	43	44	20	33	45	36	15	26	38

5.2 | MONITORING RESULTS FOR MONITOR A

Background sound level monitoring results for Monitor A are shown in Figure 12 and Figure 13. Sound levels at this site were driven by the existence of fans at the agricultural barns located just to the south of the site. The fans typically operated all through the night, and a large portion of the day, dominating overall sound levels. As a result, there is no particular pattern to sound levels. Other sound sources included the ingress and egress of trucks and other farm equipment to the property. There were few audible biogenic sounds other than wind.

Daytime and nighttime equivalent average sound levels (L_{EQ}) were 50 and 52 dBA respectively. Daytime and nighttime lower 10th percentile sound levels (L_{90}) were 32 and 50 dBA respectively. The daytime lower 10th percentile sound levels were higher than the nighttime sound levels due to the continuous nighttime operation of the nearby equipment fans and more intermittent daytime operation.

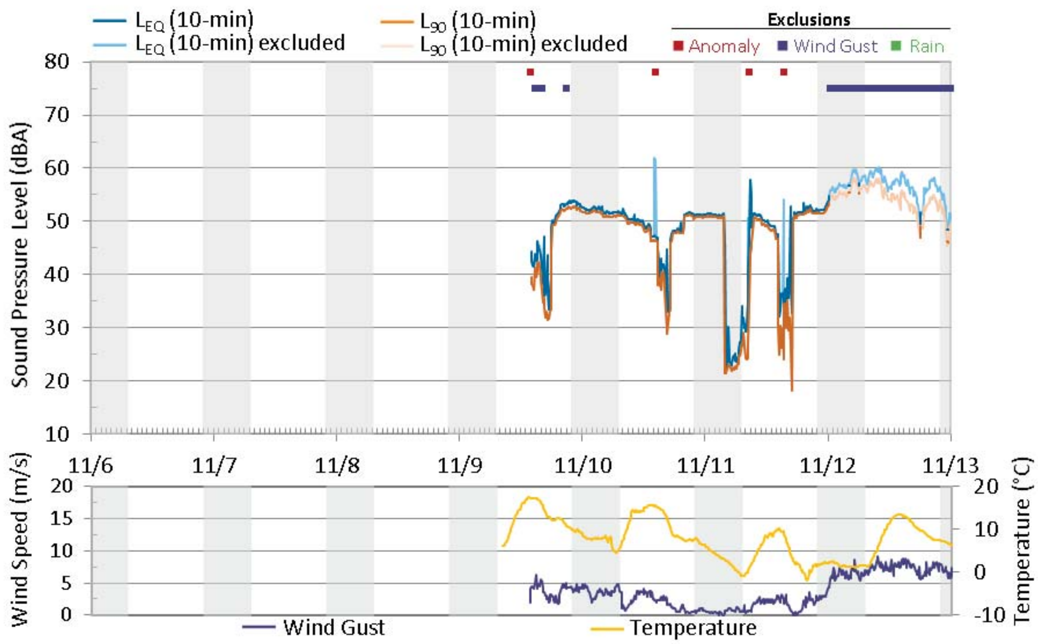

FIGURE 12: SOUND PRESSURE LEVELS OVER TIME - MONITOR A, N0VEMBER 9 TO NOVEMBER 13, 2016

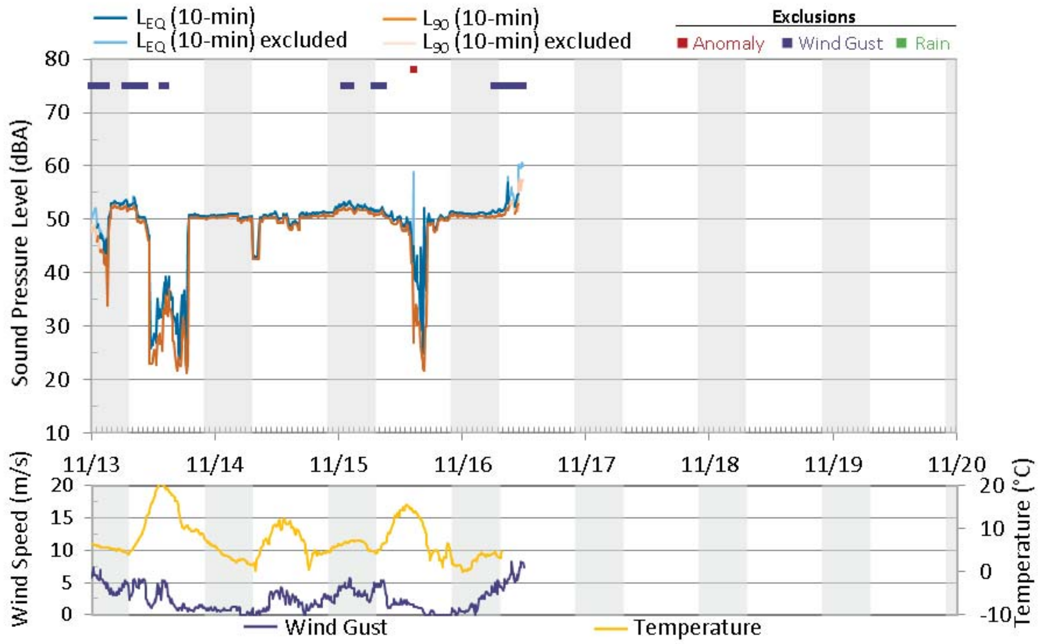

FIGURE 13: SOUND PRESSURE LEVELS OVER TIME - MONITOR A, NOVEMBER 13 TO NOVEMBER 16, 2016

5.3 | MONITORING RESULTS FOR MONITOR B

Background sound level monitoring results for Monitor B are shown in Figure 14 and Figure 15. Sound sources at the site include farming equipment, farm animals, domestic animals, occasional coyotes, and distant car passbys from South Dakota Highway 20. Sound levels exhibit a diurnal pattern, though not in overall sound level. Instead, sound levels become more constant at night, as is demonstrated by convergence of the equivalent average and lower 10th percentile sound levels. This is caused by a nighttime reduction in anthropogenic sound sources.

Equivalent average sound levels were 41 dBA during the day and 36 dBA at night and lower 10th percentile sound levels (L_{90}) were 21 dBA during the day and 20 dBA at night. Lower 10th percentile sound levels are quite low overall, demonstrating the rural nature of the site, with few consistent sound sources.

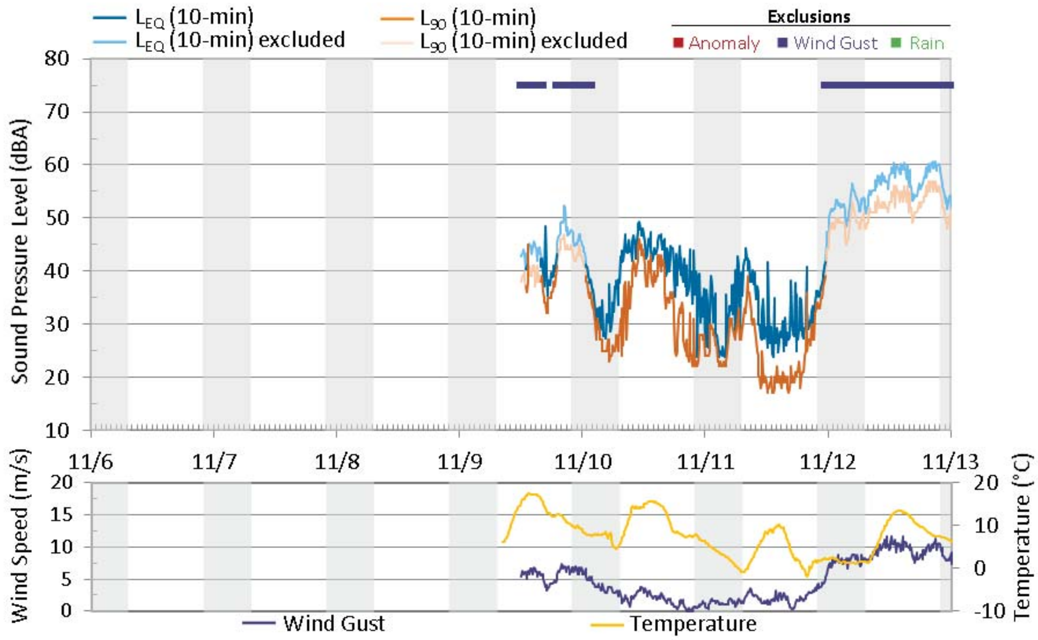

FIGURE 14: SOUND PRESSURE LEVELS OVER TIME - MONITOR B, NOVEMBER 9 TO NOVEMBER 13, 2016

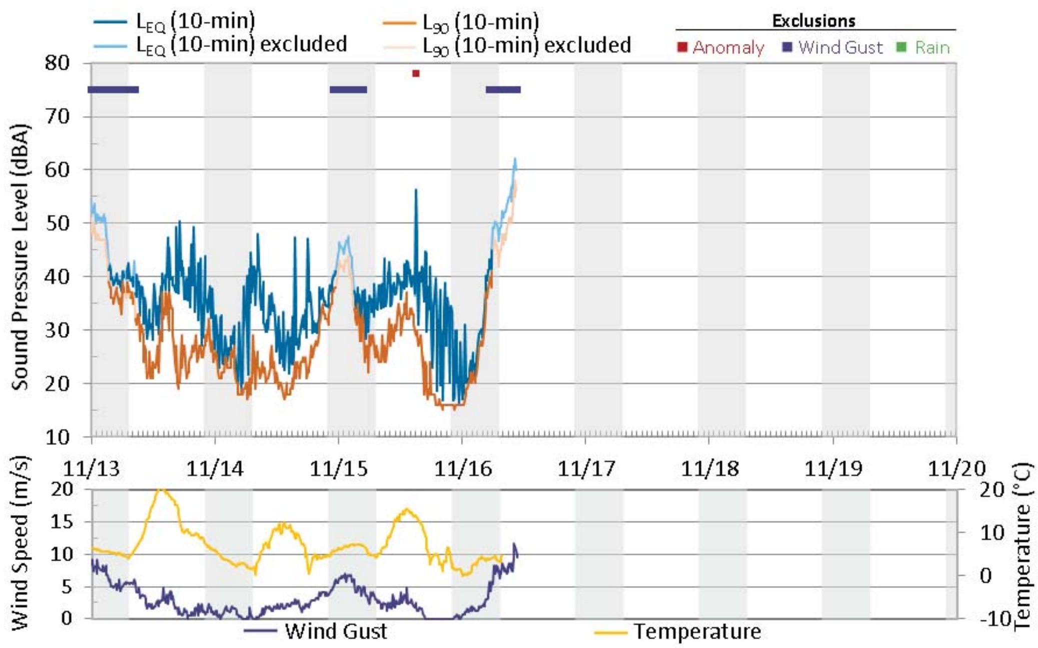

FIGURE 15: SOUND PRESSURE LEVELS OVER TIME - MONITOR B, NOVEMBER 13 TO NOVEMBER 16, 2016

5.4 | MONITORING RESULTS FOR MONITOR C

Background sound level results for Monitor C are shown in Figure 16 and Figure 17. Major sound sources at this site are farm equipment, farm animals, dogs, vehicle passbys, birds, and airplane overflights. Sound levels have a diurnal pattern, with sounds overall lower at night, except during windy periods or when dogs are barking near the monitor. Similar to other locations, sound levels are less dynamic at night, causing a convergence of the equivalent average and lower 10th percentile sound levels.

Daytime and nighttime equivalent average sound levels were 44 and 36 dBA respectively, and daytime and nighttime lower 10th percentile sound levels were 20 and 15 dBA respectively. The equivalent average sound levels reasonably low, particularly for a site with agricultural activity. Lower 10th percentile sound levels were close to the noise floor of the sound level meter that was used when there was no measurable wind. This is the most remote monitoring site, with a lack of major roadways for miles and few other homes, which contributes to the lower background sound level.

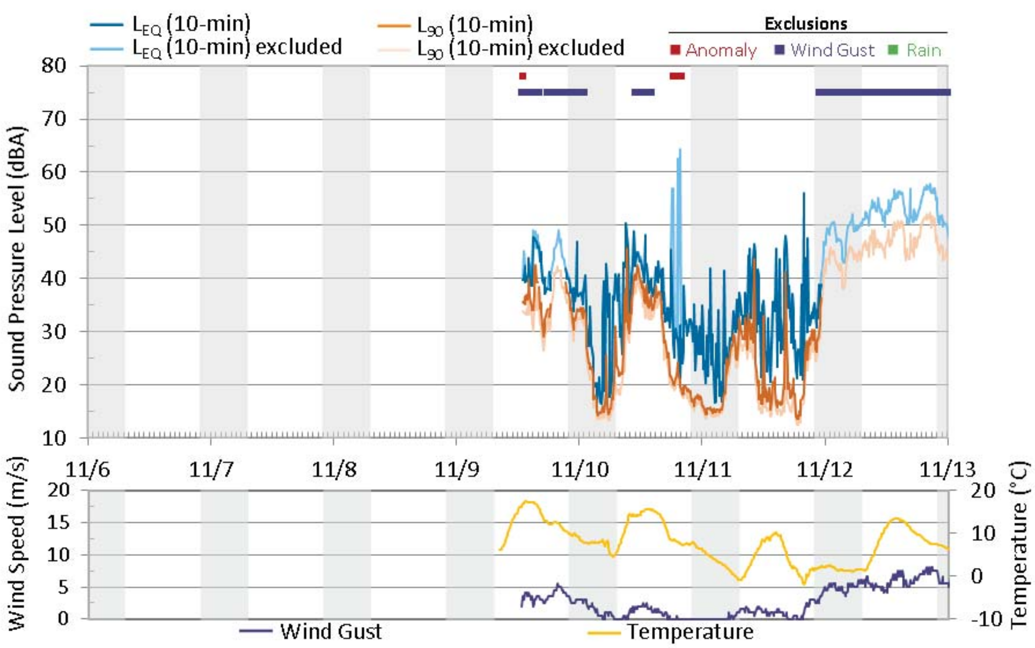

FIGURE 16: SOUND PRESSURE LEVELS OVER TIME – MONITOR C, NOVEMBER 9 TO NOVEMBER 13, 2016

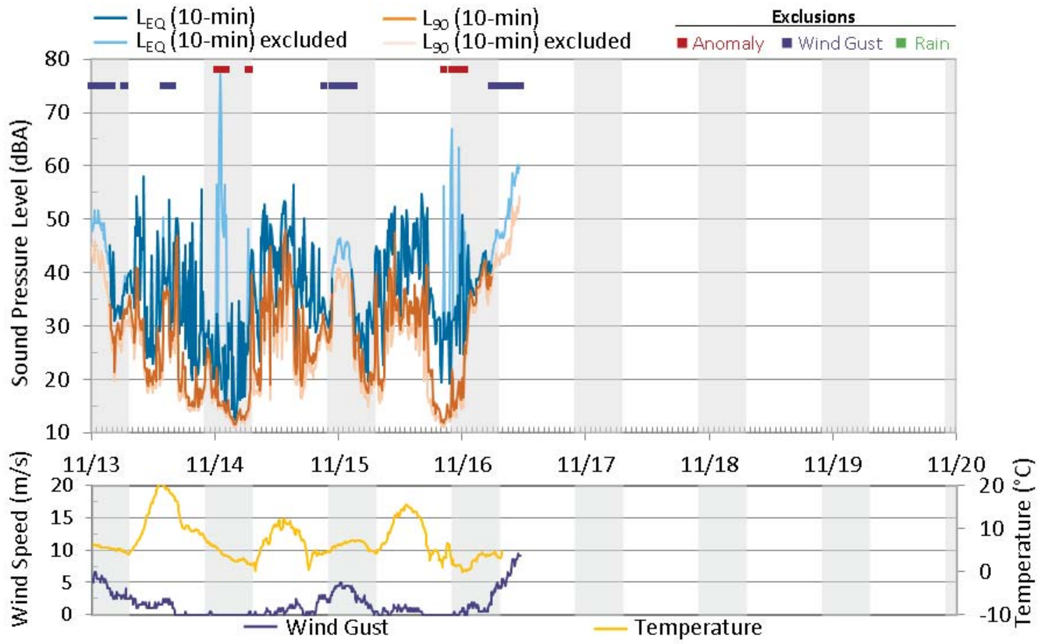

FIGURE 17: SOUND PRESSURE LEVELS OVER TIME - MONITOR C, NOVEMBER 13 TO NOVEMBER 16, 2016

6.0 SOUND PROPAGATION MODELING

6.1 | MODELING PROCEDURES

Modeling for the project was in accordance with the standard ISO 9613-2, "Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation." The ISO standard states,

> This part of ISO 9613 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level … under meteorological conditions favorable to propagation from sources of known sound emissions. These conditions are for downwind propagation … or, equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occurs at night.

The model takes into account source sound power levels, surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain. The acoustical modeling software used here was CadnaA, from Datakustik GmbH. CadnaA is a widely accepted acoustical propagation modeling tool, used by many noise control professionals in the United States and internationally.

ISO 9613-2 also assumes downwind sound propagation between every source and every receiver, consequently, all wind directions, including the prevailing wind directions, are taken into account.

Model input parameters are listed in Appendix B including the modeled sound power spectra for each turbine model.

For this analysis, we utilized a ground absorption factor for mixed porous and hard ground of G = 0.5, which is appropriate for comparing modeled results to the L_{EQ} metric used in the state standard. A 2 dB uncertainty factor was added to the turbine sound power per typical manufacturer specifications.

Two distinct receiver heights are included in the analysis. Residences are modeled as discrete receivers at 4 meters (13 feet) above ground level. The 4-meter (13-foot) receiver height mimics the height of a second-story window. The sound pressure level contours in Figures 18 to 21 are calculated at a height of 1.5 meters (5 feet), to represent average listening height outside of homes.

A search distance up to 8,000 meters (5 miles) allows for the contributions of distant turbines to be considered at receivers. The contribution of distant turbines will depend on the geometry and geography of the project.

Four iterations were performed using the currently proposed turbine layouts and turbine models which include the Gamesa G126 2.625 MW, GE 2.5-116 LNTE, Vestas V110 STE 2.0 MW, Vestas V136 3.45 MW. Each model included sound from the proposed transformer at the collector substation. The modeled sound power spectra for each turbine is provided in Appendix B. Some individual turbines were modeled in a noise reduced operating (NRO) mode, so that all residences would meet the applicable limits. Turbines operating in NRO mode are indicated in the model results and in Appendix B.

6.2 | MODEL RESULTS

A summary of the sound propagation model results for each turbine model is provided in Table 6, and Appendix C provides a list of the calculated sound pressure levels at each receiver for all four models and a map showing all receiver identification numbers for reference in the chart.

As shown in Table 6, all residences are projected at 50 dBA or less from the proposed project, and the average across all residences is 38 to 43 dBA depending on which turbine model/array is selected.

TABLE 6: MODEL RESULTS SUMMARY

Residence Classification	GE2.5			G126			V110			V136		
	Avg. Leq	Max. Leq	Min. Leq	Avg. Leq	Max. Leq	Min. Leq	Avg. Leq	Max. Leq	Min. Leq	Avg. Leq	Max. Leq	Min. Leq
All	41	50	28	41	50	27	43	50	32	38	50	26
Participating	44	50	29	44	50	28	46	50	35	41	50	27
Non-Participating	38	45	28	38	45	27	40	47	32	36	44	26

Model results are also shown in Figure 18 through Figure 21 in a contour line map format. Results are presented as contour lines representing 5-dB increments of calculated A-weighted sound pressure levels.

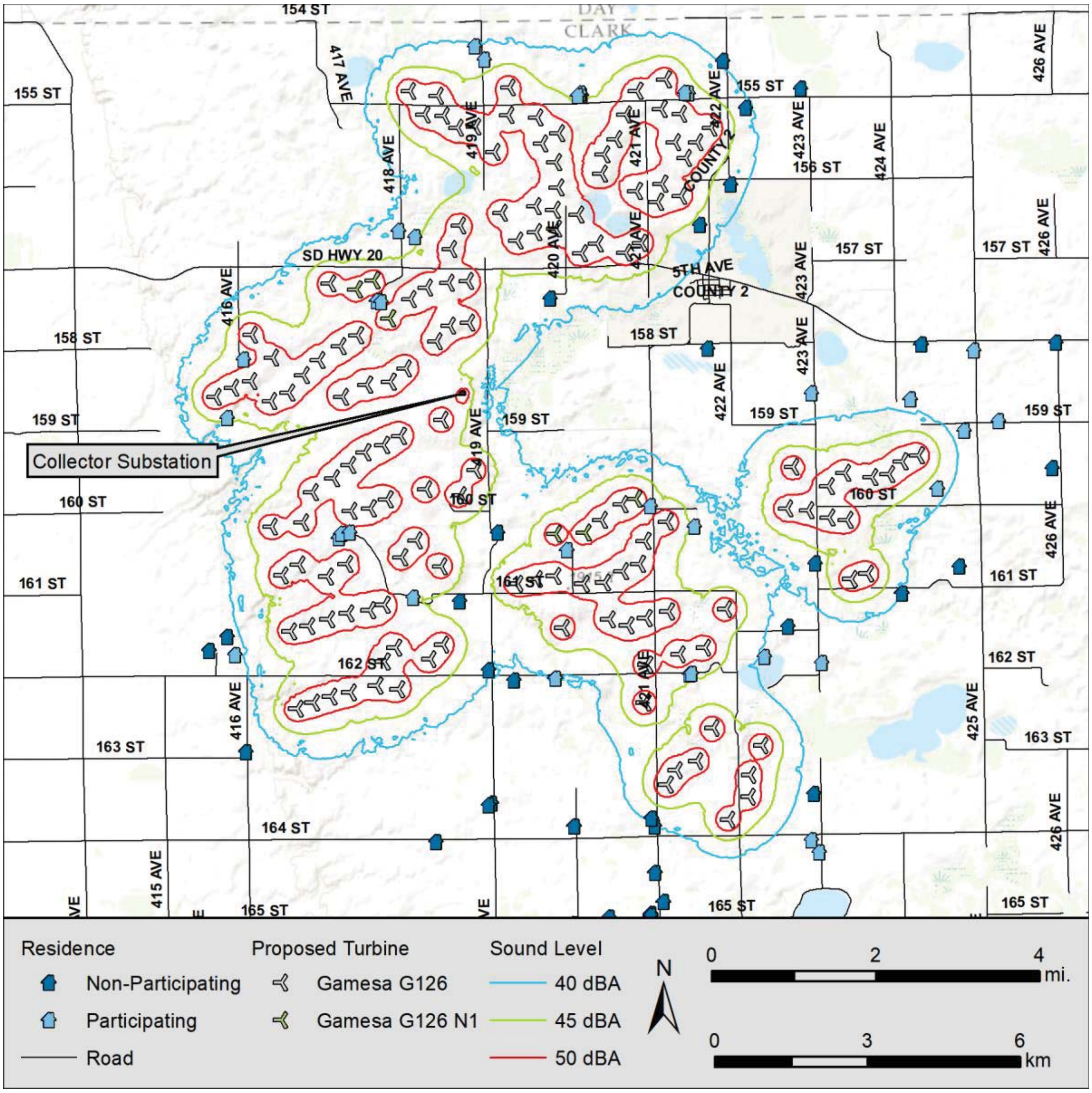

FIGURE 18: GAMESA G126 2.625 MW SOUND PROPAGATION MODELING RESULTS

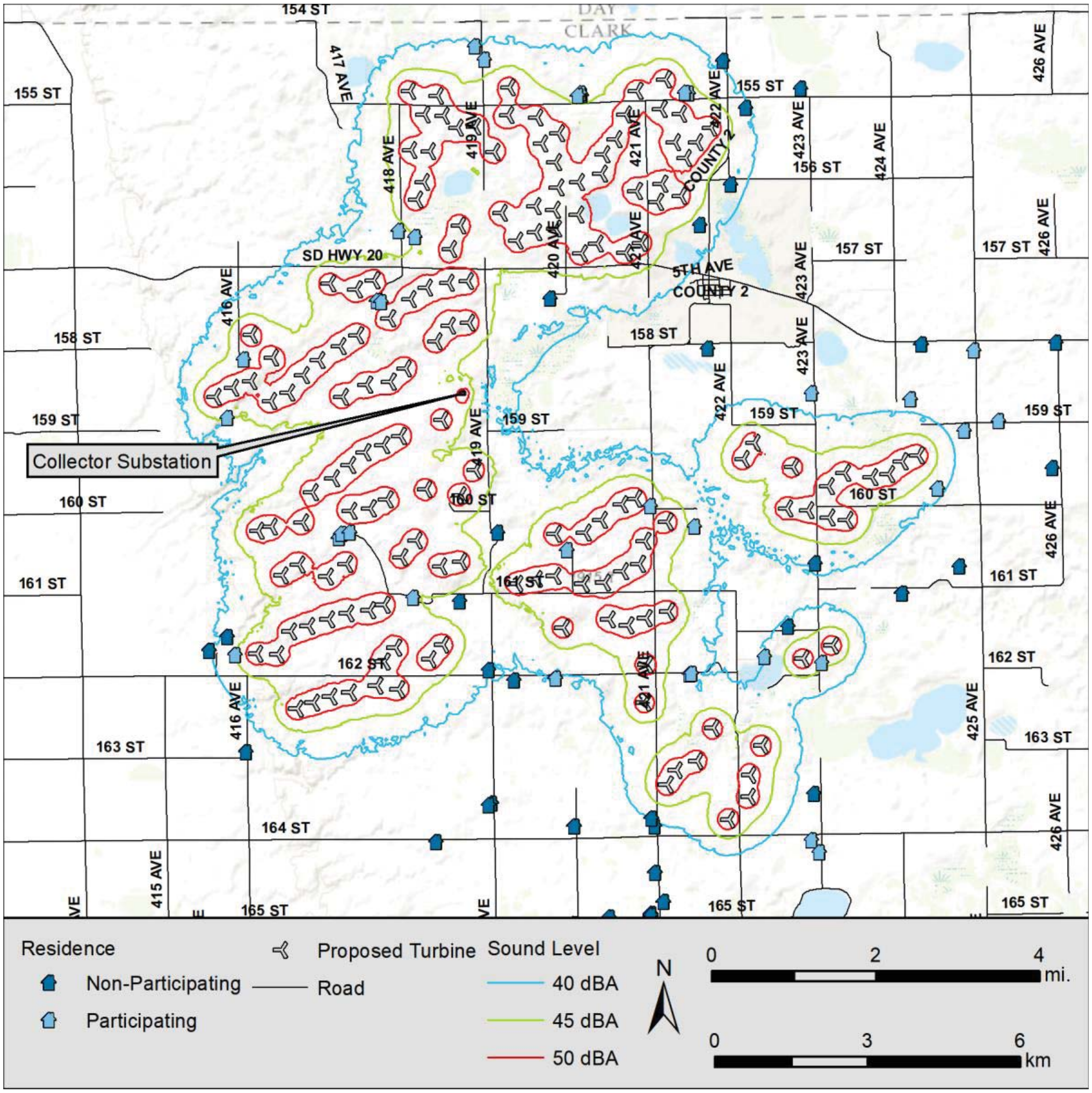

FIGURE 19: GE 2.5-116 LNTE SOUND PROPAGATION MODELING RESULTS

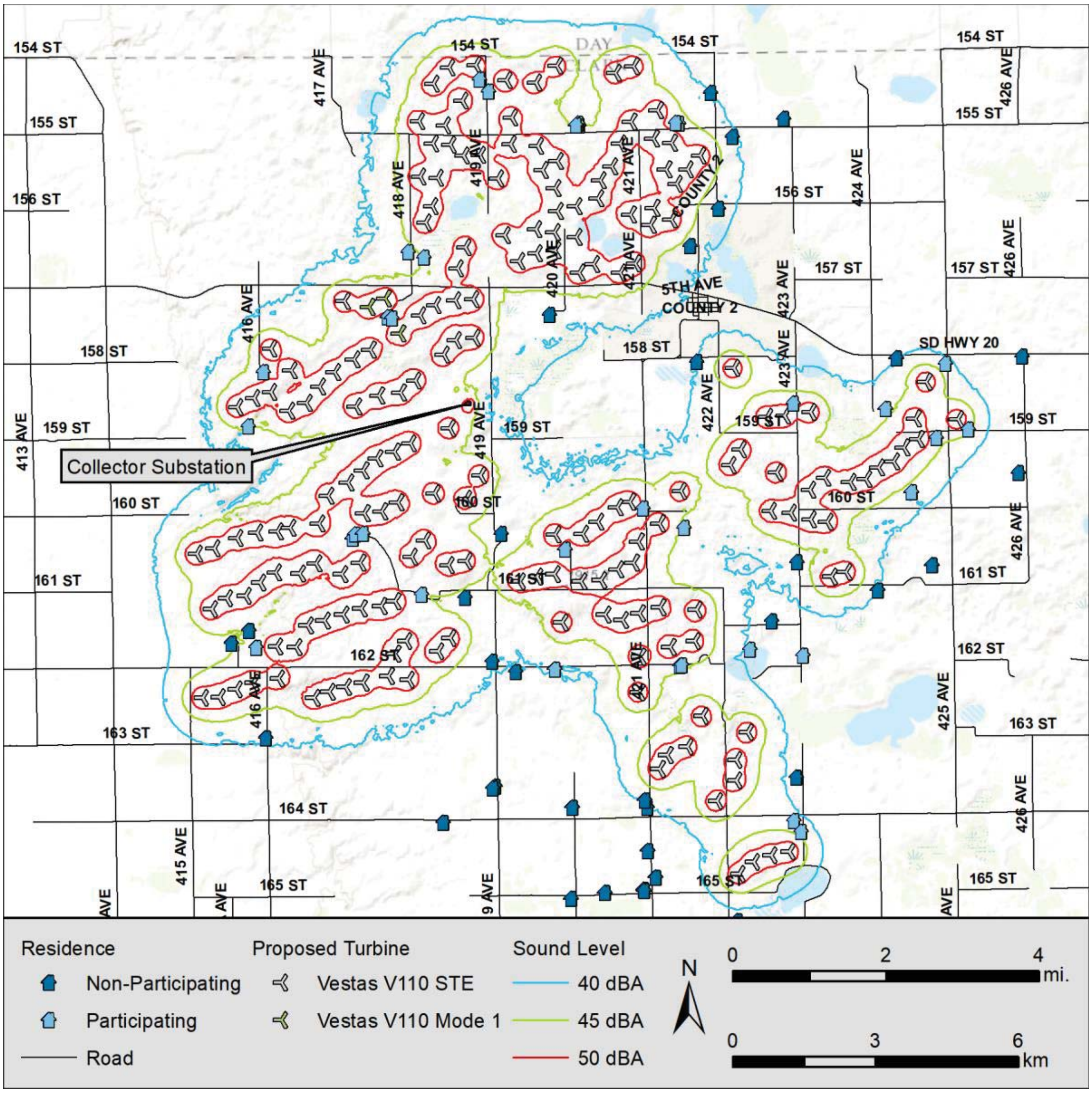

FIGURE 20: VESTAS V110 STE 2.0 MW SOUND PROPAGATION MODELING RESULTS

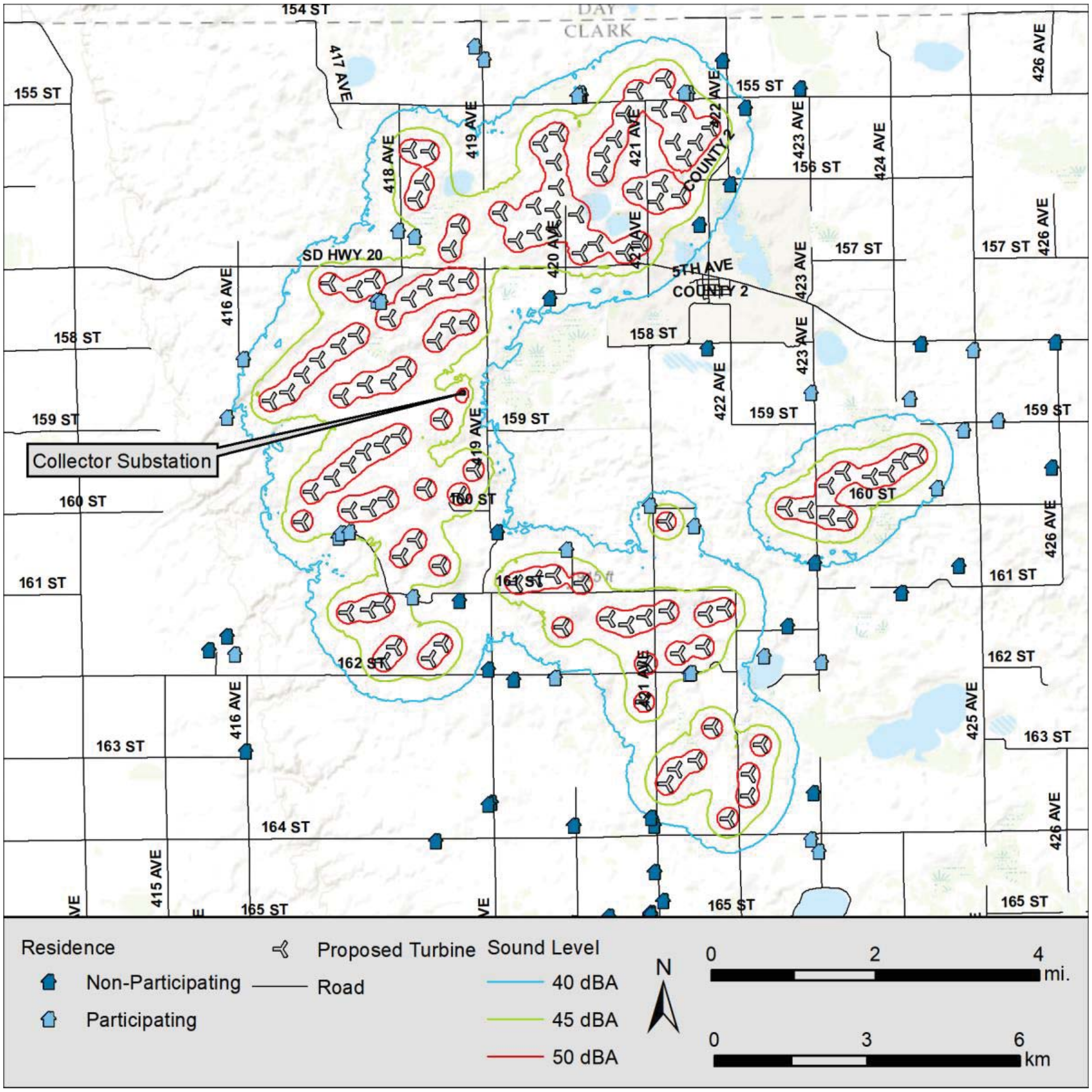

FIGURE 21: VESTAS V136 3.45 MW SOUND PROPAGATION MODELING RESULTS

7.0 CONCLUSIONS

Crocker Wind Farm is a proposed wind power generation facility in Clark County, South Dakota. The facility will include up to 200 wind turbines for a project rating of up to 400 MW. In preparation for its Site Permit Application, RSG conducted a noise compliance assessment of the project comparing projected wind farm sound levels with the Clark County and PUC noise limits for wind energy systems. Conclusions of the assessment are as follows:

1. Sound sources in the existing soundscape include agricultural equipment, farm animals and pets, vehicle passbys, birds, airplane overflights, and geophonic sounds such as wind in the trees or ground cover.
    a. Background sound levels vary some around the project site. For two of the monitor locations (Monitor B & C) the overall equivalent continuous sound level (Leq) at nighttime was 36 dBA, while at Monitor A, the nighttime sound level (Leq) was 52 dBA due to a fan for agricultural use which ran fairly consistently.
    b. On a 10-minute basis, nighttime equivalent continuous sound levels (Leq) generally ranged between 16 and 40 dBA at Monitors B and C, with the lowest levels coincident with low ground wind speeds.
2. Both the County noise limit and the State recommended limit that applies to this project is a 50 dBA equivalent continuous sound pressure level (Leq) at residences.
    a. Sound propagation modeling was performed in accordance with ISO 9613-2 at 70 discrete receivers that surround the project with spectral ground attenuation and a ground factor of G=0.5. These modeling parameters represent the Leq of the proposed facility.
    b. Modeling was completed for four different turbine models: Gamesa G126 2.625 MW, GE 2.5-116, Vestas V110 STE 2.0 MW, Vestas V136 3.45 MW. Each model run also included sound emissions from the transformer at the collector substation. For the G126 and V110, some turbines were operated in lower noise modes in order to meet the applicable limits and achieve the results presented in Section 6.
    c. For all turbine models, projected sound levels from the project are less than 50 dBA at all residences, and the average sound level (Leq) across all residences is 38 or 43 dBA depending on the turbine model.

The information presented in this report leads us to conclude that the proposed Crocker Wind Farm can be constructed and operated in such a way as to comply with the Clark County and PUC noise limits for wind energy systems at all non-participating residences.