APPENDIX %

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NOISE AND FLICKER MAPPING AND ANALYSIS FOR THE PROPOSED COMMUNITY WIND SOUTH PROJECT

FOR

MINWIND ENERGY, LLC
800 S. Kniss Avenue; Suite 2
Luverne, MN 56156

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Prepared By:

WSB & Associates, Inc.
701 Xenia Ave. South, Suite 300
Minneapolis, MN, 55416
(763) 541-4800
(763) 541-1700 (Fax)

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I. Introduction & Purpose

Minwind Energy has proposed the construction of up to 15 turbines for the Community Wind South project south of the town of Wilmont, MN in Nobles County. The proposed wind farm location is bound approximately by 180th Street to the north, 210th Street to the south, Erickson Avenue to the west and King Avenue to the east. This report details the expected noise and flicker impact of the wind farm on residences within and near the project area.

II. Noise

i. Introduction

Any unwanted sound is called noise. Sound is carried through the air in compression waves of measurable frequency and amplitude. Sound can be tonal, predominating at a few frequencies, or it can contain a random mix of a broad range of frequencies and lack any tonal quality. This type of noise is often called white noise.

The human ear is sensitive to only a relatively narrow frequency range of air pressure changes – approximately 20-20,000 cycles per second or Hertz (Hz). Sub-audible frequency sound is often called infrasound. It cannot be heard, but it may be sensed as a vibration. Humans are also sensitive to changes in the amplitude of the air compression waves. Increasing amplitude, or increasing sound pressure, is perceived as increasing volume or loudness. The sound pressure level (SPL) is measured in micro Pascals (μPa). SPLs are typically converted to decibels (dB), which is a log scale, relative to a reference air pressure value of 20 μPa. When measuring sound, A-weighted decibels (dBA) are typically used to normalize readings to equal loudness over the audible range of frequencies at low loudness.

Table 1 provides a rough comparison of the noise levels of some common noise sources.

Table 1: Decibel Levels of Common Noise Sources

Sound Pressure Level (dBA)	Noise Source
140	Jet Engine (at 25 meters)
130	Jet Aircraft (at 100 meters)
120	Rock and Roll Concert
110	Pneumatic Chipper
100	Jointer/Planer
90	Chainsaw
80	Heavy Truck Traffic
70	Business Office
60	Conversational Speech
50	Library
40	Bedroom
30	Secluded Woods
20	Whisper

SOURCE: "A Guide to Noise Control in Minnesota"
Minnesota Pollution Control Agency (2008)

Along with the volume of the noise source and other factors (i.e. topography of the area) that contribute to the loudness of noise, the distance of a receptor from a sound's source is also an important factor. Sound levels decrease as distance from a source increases. The following rule of thumb regarding sound decreases due to distance is commonly used: Beyond approximately 50 feet, each time the distance between a source and a receptor is doubled, sound levels decrease by three decibels over hard ground, such as pavement or water, and by 4.5 decibels over vegetated areas.

ii. Noise from Wind Turbines

Mechanical noise
Mechanical noise from a wind turbine is sound that originates in the generator, gearbox, yaw motors (that intermittently turn the nacelle and blades to face the wind), tower ventilation system, and transformer. Generally, theses sounds are limited in new wind turbines so that they are a negligible fraction of the aerodynamic noise. Mechanical noise from the turbine or gearbox would only be heard above aerodynamic noise when they are not functioning properly.

Aerodynamic noise
Aerodynamic noise is caused by wind passing over the blade of the wind turbine. As wind passes over a moving blade, the blade interrupts the laminar flow of air, causing turbulence and noise. Unexpectedly high aerodynamic noise can be caused by improper blade angle or improper alignment of the rotor to the wind. This is correctable and is usually adjusted during the turbine break-in period. This is the primary source of noise produced by wind turbines. Wind turbines are generally quiet enough for people to hold a normal conversation while standing at the base of the tower.

Modulation of aerodynamic noise
Rhythmic modulation of noise, especially low frequency noise, is also perceptible by the human ear. To a receptor on the ground in front of the wind turbine, the detected blade noise is loudest as the blade is at the bottom of its rotation, and quietest when the blade is at the top of its rotation. For a modern 3-blade turbine, this distance-to-blade effect can cause a pulsing of the blade noise about once per second (1 Hz). The distance-to-blade effect diminishes as receptor distance increases because the relative difference in distance from the receptor to the top or bottom of the blade becomes smaller.

Another source of rhythmic modulation may occur if the wind through the rotor is not uniform. Horizontal layers with different wind speeds or directions can form in the atmosphere. This wind condition is called shear. If the winds at the top and bottom of the blade rotation are different, blade noise will vary between the top and bottom of blade rotation, causing modulation of aerodynamic noise.

Wind farm noise
The noise from multiple turbines similarly distant from a residence can be noticeably louder than a lone turbine through the addition of multiple noise sources. Under steady wind conditions, noise from a wind turbine farm may be greater than noise from the nearest turbine due to synchrony between noise from more than one turbine. If the dominant frequencies of different turbines vary by small amounts, an audible dissonance may be heard when wind conditions are stable.

iii. Assessment and Regulation

The Minnesota Pollution Control Agency is given power to adopt noise standards in Minnesota Statute 116.07 Subd. 2. The adopted standards are given in Minnesota Administrative Rules Chapter 7030. The MPCA standards require A-weighted noise measurements. Different standards are specified for daytime (7:00 AM – 10:00 PM) and nighttime (10:00 PM – 7:00 AM) hours. The noise standards specify the maximum allowable noise volumes that may not be exceeded for more than 10 percent of any hour (L_{10}) and 50 percent of any hour (L_{50}). Household units, including farm houses, are included in Land Use Classification 1. **Table 2** shows the MPCA State noise standards. All the land within the project area is considered Land Use Class 1.

Table 2: MPCA State Noise Standards – Hourly A-Weighted Decibels

Land Use	Code	Day (7:00 AM - 10:00 PM) dBA		Night (10:00 PM - 7:00 AM) dBA	
		L_{10}	L_{50}	L_{10}	L_{50}
Residential	NAC-1	65	60	55	50
Commercial	NAC-2	70	65	70	65
Industrial	NAC-3	80	75	80	75

Since wind farms generate a relatively constant noise volume, the anticipated noise from wind farms are typically reported in terms of an equivalent sound level (L_{eq} that has the same energy and A-weighted level as the community noise over a given time interval rather than reporting both L_{10} and L_{50}. When describing relatively constant sound levels, the L_{10} and L_{50} values will be roughly equal. This equivalent sound level is most appropriately compared to the State L_{50} standards. The difference between L_{eq} and L_{50} is mathematically similar to the difference between the *mean* and the *median* for a data set. These values will be roughly equal for data sets without extreme values or statistical outliers (such as wind turbine noise).

iv. Methods

The existing noise levels were evaluated at three locations during August 2011. A total of 12 measurements were recorded. **Table 3** displays the typical sound levels observed during daytime and nighttime hours. The noise monitoring was completed using a Larson Davis Model 820 Sound Level Meter. The locations of the three monitoring sites are shown on **Figure 1**. The monitoring locations are believed to be representative of the project area. Site 1 is located near the intersection of CSAH 13 and 200th Street, the highest traffic volume location within the project area. Site 2 is located along CSAH 13 near the north side of the project area. Site 3 is located along County Road 60. It is anticipated that the monitoring sites will accurately reflect the noise caused by the existing nearby turbines.

Generally, the current L_{50} sound levels range from 49 to 55 dBA during both the daytime and nighttime. The monitoring revealed that the existing noise volumes at Site #3 during the nighttime hours already exceed the State Noise Standards.

Table 3: Existing Sound Levels

Time Period	Location	L_{10}	L_{50}
Nighttime 5:00 - 7:00 AM 8/3/2007	Site 1	52.4	49.3
	Site 2	54.6	49.8
	Site 3	56.5	54.2
Daytime 7:00 - 9:00 AM 8/3/2007	Site 1	57.7	50.3
	Site 2	59.5	55.1
	Site 3	57.6	51.8
MN State Standards		L_{10}	L_{50}
Nighttime		55	50
Daytime		65	60

Sound level modeling was completed using WindPro Decibel software. The analysis assumes the attenuation of sound propagation as specified by the International Organization for Standardization (ISO) Standard 9613-2 and a ground attenuation factor of 0.5. The proposed locations of the wind turbines were provided by Minwind Energy. This analysis considered the cumulative impacts of 15 wind turbines. All turbines were modeled assuming the REpower MM92 turbine specifications and using the International Electrotechnical Commission (IEC) 61400-11 acoustic reference wind speed of 8.0 meters per second (m/s) (18 miles per hour [mph]) measured at 10 meters (33 ft) above ground level. The MM92 was assumed to have a hub height of 100 meters (328 feet) and a rotor diameter of 92.5 meters (303 feet). A total of 200 potentially impacted receptors were included in the model. The approximate location of each proposed turbine and each modeled receptor is shown on **Figure 1**. The approximate distance between each wind turbine and the nearest potentially impacted receptor is shown in **Table 4**.

Table 4: Distance from Each Turbine to Nearest Potential Receptor

Turbine ID	Receptor ID	Distance (m)	Distance (ft)
4	16	383	1,256
14	26	395	1,296
3	27	474	1,555
2	3	487	1,597
5	19	535	1,755
6	5	553	1,814
11	19	577	1,893
1	31	581	1,906
7	5	623	2,043
10	19	707	2,319
8	4	791	2,594
9	27	797	2,614
15	26	823	2,699
13	21	894	2,932
12	25	1,099	3,605

The wind turbines to be used within the project site are warranted to generate a maximum apparent sound power level of 104 dBA +/- 2 dBA immediately adjacent to the turbine hub (100 meters [328 feet] above ground). The decibels decrease as the receptor moves further away from the turbine. Assuming a featureless plain and constant attenuation, a single turbine is expected to generate less than 50 decibels at approximately 100 meters (328 feet). **Figure 2** shows the relationship between the sound volumes created by a single turbine and the receptor distance from the base of the turbine.

v. Results

Figure 3 depicts the sound contours anticipated by the construction of the Community Wind South project. **Figure 3** depicts only turbine-generated sound, and does not represent cumulative noise volumes including background or existing noise. Since actual background noise levels are not known for each receptor, the sound impacts are summarized for three assumed L_{50} background noise levels: 40 dBA, 50 dBA and 60 dBA. **Table 5** displays the sound levels from the turbines at each modeled receptor as well as the resulting cumulative sound levels.

In Minnesota, the MPCA State Noise Standards restrict noise levels to 60 dBA during the daytime. The analysis indicates that construction of the Community Wind South project will not have an impact of 60 dBA or greater on any modeled receptor, nor will the cumulative impact on any residence exceed 60 dBA when assuming a 40 dBA or 50 dBA background sound level. During the daytime, only with a background sound level already approaching or exceeding the 60 dBA threshold would the cumulative sound level (background and wind turbine sound) exceed 60 dBA. At Receptor 19, the daytime background sound levels would need to exceed 59.9 dBA during the daytime for the resulting cumulative sound level to exceed 60 dBA.

It is also useful to consider the magnitude of the increase in sound levels anticipated by the construction of the Community Wind South. **Table 5** illustrates the magnitude of the potential

noise impact on residential receptors. When assuming background sound levels of 50 dBA, the cumulative sound levels range from 50.0 dBA to 50.7 dBA, indicating that the change in sound levels caused by the wind farm would range from 0.0 dBA to 0.7 dBA. Similarly, when assuming background sound levels of 60 dBA, the cumulative sound levels range from 60.0 dBA to 60.1 dBA, indicating that the change in sound level caused by the wind farm would range from 0.0 dBA to 0.1 dBA. This additional sound from the wind turbines would not be noticeable.

Table 5: Sound Levels at Potential Receptors

Receptor ID	Turbine Sound Impact (dBA)	Resulting Sound when Combined with Indicated Background Sound Level		
		40 dBA	50 dBA	60 dBA
19	42.1	44.2	50.7	60.1
27	41.7	43.9	50.6	60.1
26	41.2	43.7	50.5	60.1
5	40.8	43.4	50.5	60.1
16	40.6	43.3	50.5	60.0
3	39.2	42.6	50.3	60.0
4	39.1	42.6	50.3	60.0
31	38.5	42.3	50.3	60.0
2	37.6	42.0	50.2	60.0
8	36	41.5	50.2	60.0
14	36	41.5	50.2	60.0
7	35.5	41.3	50.2	60.0
18	35.3	41.3	50.1	60.0
9	34.9	41.2	50.1	60.0
21	34.9	41.2	50.1	60.0
25	34.8	41.1	50.1	60.0
17	34.7	41.1	50.1	60.0
1	34.1	41.0	50.1	60.0
22	33.4	40.9	50.1	60.0
34	33.2	40.8	50.1	60.0
29	32.5	40.7	50.1	60.0
32	32.5	40.7	50.1	60.0
13	32.2	40.7	50.1	60.0
30	31.5	40.6	50.1	60.0
20	31.4	40.6	50.1	60.0
28	31.3	40.5	50.1	60.0
23	30.2	40.4	50.0	60.0
15	30	40.4	50.0	60.0
33	30	40.4	50.0	60.0
24	29.9	40.4	50.0	60.0
36	29.4	40.4	50.0	60.0
6	29.2	40.3	50.0	60.0
11	29.1	40.3	50.0	60.0
10	28.8	40.3	50.0	60.0
12	27.9	40.3	50.0	60.0
35	27.2	40.2	50.0	60.0

Guide to Reading **Table 5**:
At receptor 19, we can predict that the sound impact from the proposed turbines will be 42.1 dBA. However, the existing sound levels at this specific location can only be estimated based on the sound monitoring results presented earlier. If the existing sound level is 50 dBA, the resulting sound level (background noise + turbine noise) at receptor 19 will be 50.7 dBA, an imperceptible increase.

III. Flicker

i. Introduction

Shadow flicker occurs when the rotating blades of a wind turbine repeatedly pass in front of the sun to create recurring shadows or a repeating cycle of changing light intensity. When these shadows fall on sensitive receptors such as homes or outdoor activity areas, the result is referred to as shadow flicker.

Flickering is not unique to wind turbines. Many everyday objects also produce flickering, though it is not always perceivable. Light sources that flicker at a high enough frequency are imperceptible to the human eye. Cyclical fluctuation of a light source is often measured in hertz (Hz), which is defined as the number of cycles per second. The human eye is able to perceive flicker up to about 50 Hz, though it varies with intensity. Above 50 Hz, the brain's response to the flash lasts longer than the flash itself. Generally, lights flashing with a frequency of 10 Hz to 25 Hz is associated with health impacts, including eye strain, headaches, nausea, and other impacts. **Table 6** provides a rough comparison of the frequencies of some common flicker sources.

Table 6: Frequencies of Common Flicker Sources

Source of Flicker	Flicker Rate
Florescent lights	120 Hz
Computer screens	75 Hz
Televisions	60 Hz
Vehicle turn signals	1-3 Hz
Wind Turbine Shadow	0.5-1.25 Hz

Shadow flicker is influenced by many conditions, including the amount of cloud cover, time of day, the portion of time the turbine is operating, the orientation of windows, ambient lighting conditions, sun path across the sky (varies with the seasons), and the orientation of turbine blades.

ii. Assessment and Regulation

There is no standard set by the State of Minnesota relating to shadow flicker from wind turbines. However every effort should be utilized to minimize the shadow flicker impacts on residences. Shadow flicker is typically measured and reported in terms of number of hours flickering is experienced per year. It is also sometimes reported in terms of hours per day, although this measurement varies throughout the calendar years due to seasonal sun angle changes. Guidance from the Minnesota Department of Commerce directs wind project developers to document the project impacts, including isopleths representing 100, 50, and 25 hours per year of potential shadow flicker. In addition, developers should provide a figure illustrating the likely hours of shadow flicker per year in each directions 1000 feet away from a typical turbine.

iii. Methods

WindPro software was used to model the anticipated shadow flicker due to the proposed turbines. Two flicker scenarios were developed. The worst-case scenario estimates the potential

shadow flicker while assuming no shadow cover, and that the turbines are always directly perpendicular to the sun. The real-case scenario uses the estimated operating hours per direction and meteorological data to estimate the most flicker scenario. Since the flicker impacts to any residence will vary based on which direction the turbine is pointing (which depends on the direction the wind is blowing), assumptions were made about the number of hours per year the turbines will be operating in each direction. The real-case scenario is based on the operating assumptions presented in **Table 7**.

Table 7: Modeled Annual Operating Hours by Direction

Direction	Operating Hours per Year
N	1,320
NE	901
E	731
SE	966
S	1,611
SW	1,007
W	890
NW	1,336

iv. Results

Figure 4 shows the results of the worst-case flicker analysis. **Figure 5** shows the results of the real-case flicker analysis. **Table 8** shows the results of the worst-case and real-case flicker analysis. **Figure 6** shows the real-case isopleths around a typical turbine and shadow hours per year at 1,000 feet from the center of the turbine base. **Table 9** shows the anticipated hours per day of flicker in each direction 1,000 feet from the center of the base of a typical turbine. The flicker analysis indicates that the proposed turbines will have a realistic impact of no greater than 32 hours of shadow flickering per year on any single receptor.

Table 8: Flicker Analysis Results

Receptor ID	Worst-Case Shadow Hours per Year (h/year)	Real-Case Shadow Hours per Year (h/year)
16	73:24	31:25
26	78:32	25:08
19	54:26	20:42
5	43:49	19:12
31	31:14	11:21
14	20:22	8:17
4	15:31	6:32
3	10:17	5:05
22	15:13	4:51
27	12:31	4:46
18	12:09	4:44
21	11:07	4:40
36	8:42	4:17
34	13:15	4:09
23	7:27	2:22
29	8:55	2:15
2	4:30	1:55
17	4:12	1:41
32	3:27	1:24
20	3:19	1:19
25	2:32	0:48
1	0:00	0:00
6	0:00	0:00
7	0:00	0:00
8	0:00	0:00
9	0:00	0:00
10	0:00	0:00
11	0:00	0:00
12	0:00	0:00
13	0:00	0:00
15	0:00	0:00
24	0:00	0:00
28	0:00	0:00
30	0:00	0:00
33	0:00	0:00
35	0:00	0:00

Table 9: Flicker Characteristics at 1,000 feet from Turbine Base

Direction	Worst-Case Shadow Hours per Year (h/year)	Worst-Case Shadow Days per Year (days/year)	Worst-Case Max Shadow Hours per Day (h/day)	Real-Case Shadow Hours per Year (h/year)
N	71:08	72	1:12	21:33
NE	90:35	106	1:08	26:11
E	98:03	124	1:05	43:51
SE	0:00	0	0:00	0:00
S	0:00	0	0:00	0:00
SW	0:00	0	0:00	0:00
W	100:04	115	1:09	43:05
NW	124:39	144	1:13	41:40

APPENDIX

- Figure 1: Turbine, Receptor, and Monitoring Locations
- Figure 2: Sound Level and Distance – Single Turbine
- Figure 3: Turbine Induced Sound Contours
- Figure 4: Worst-Case Flicker Isopleths
- Figure 5: Real-Case Flicker Isopleths
- Figure 6: Real-Case Flicker Isopleths - 1,000 ft. Results

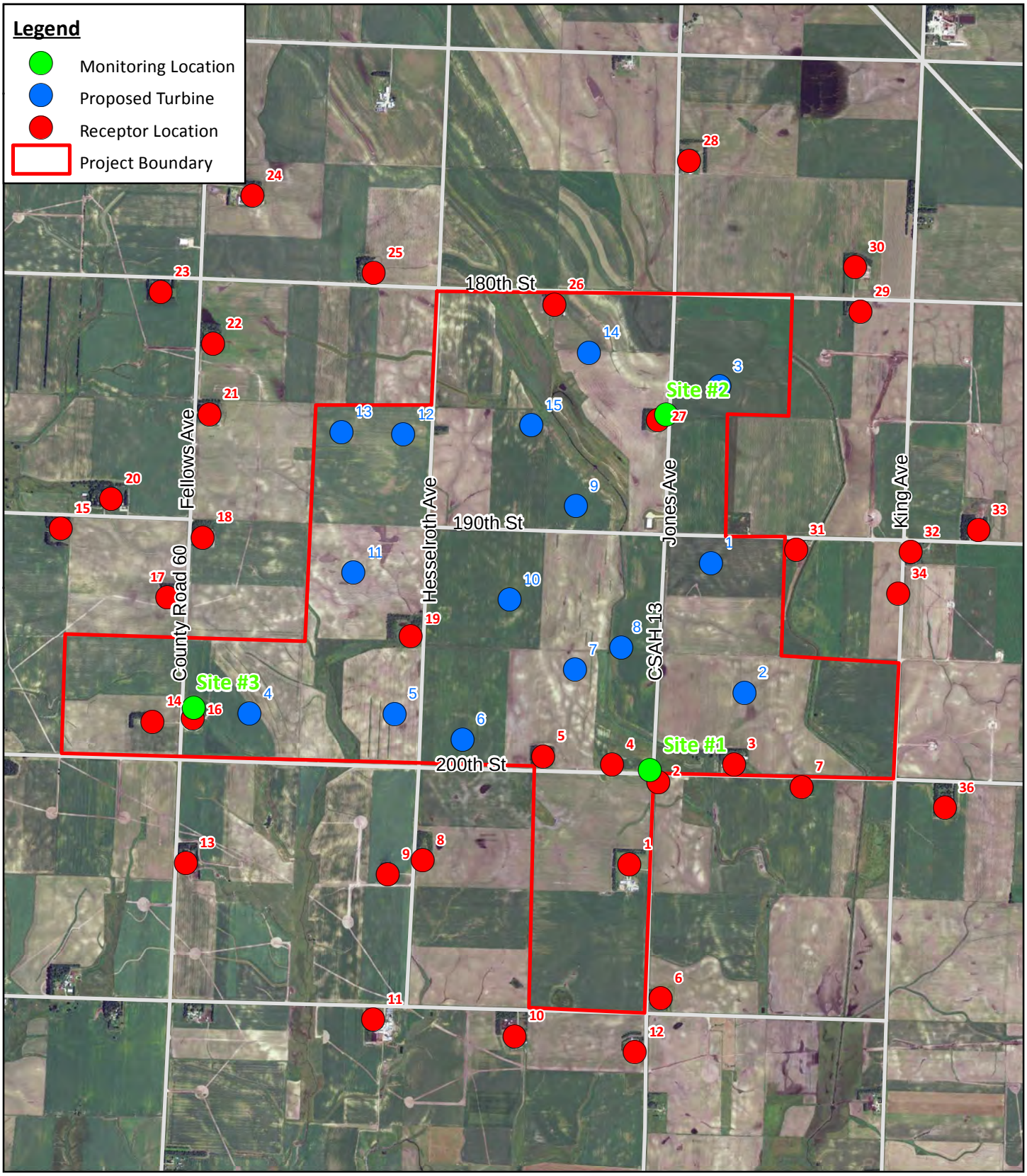

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Figure 1: Noise Monitoring Locations

N

Feet

0 1,500 3,000 6,000

NOBLES COUNTY, MN

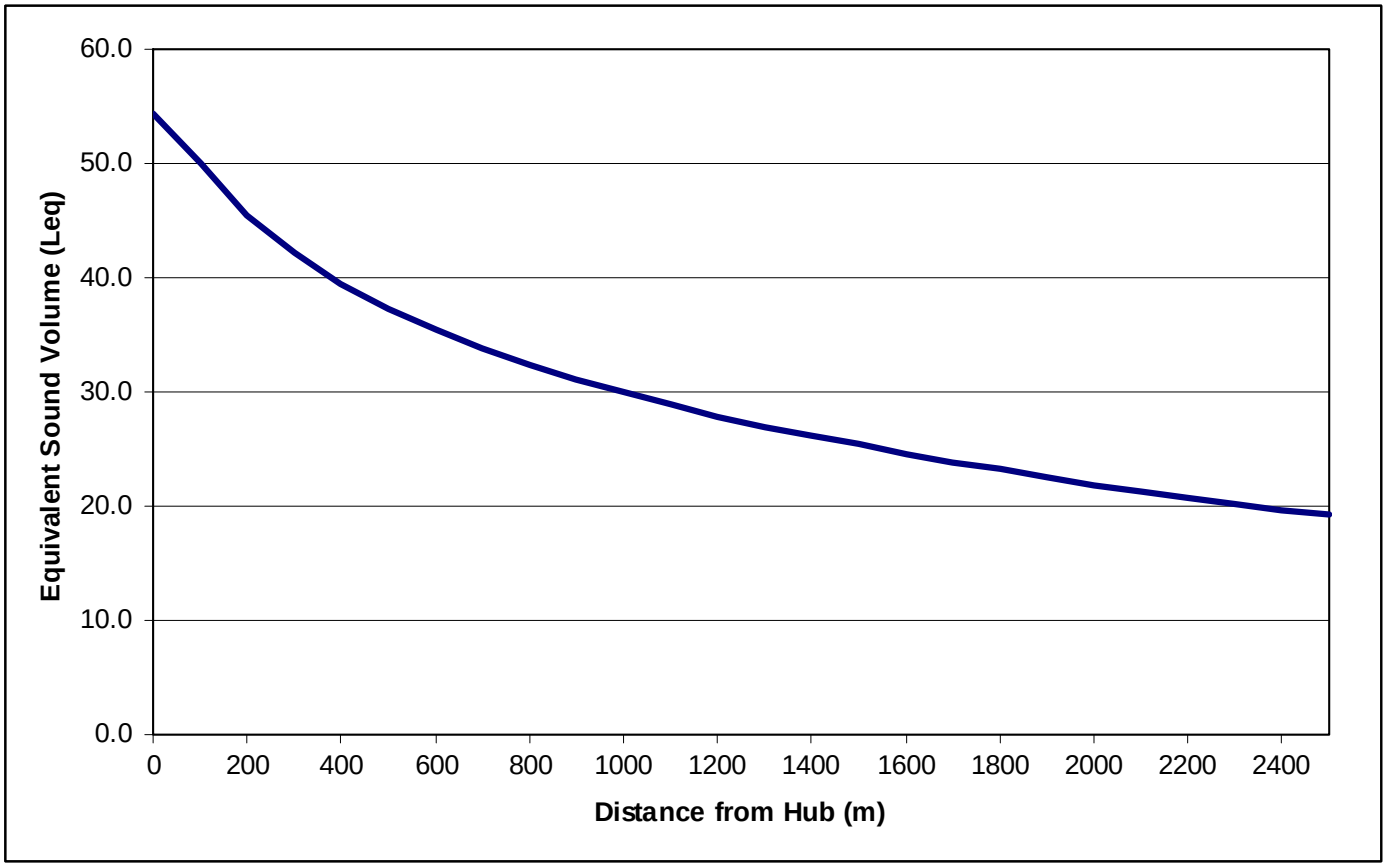

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Figure 2: Single Turbine Noise Impact

NOBLES COUNTY, MN

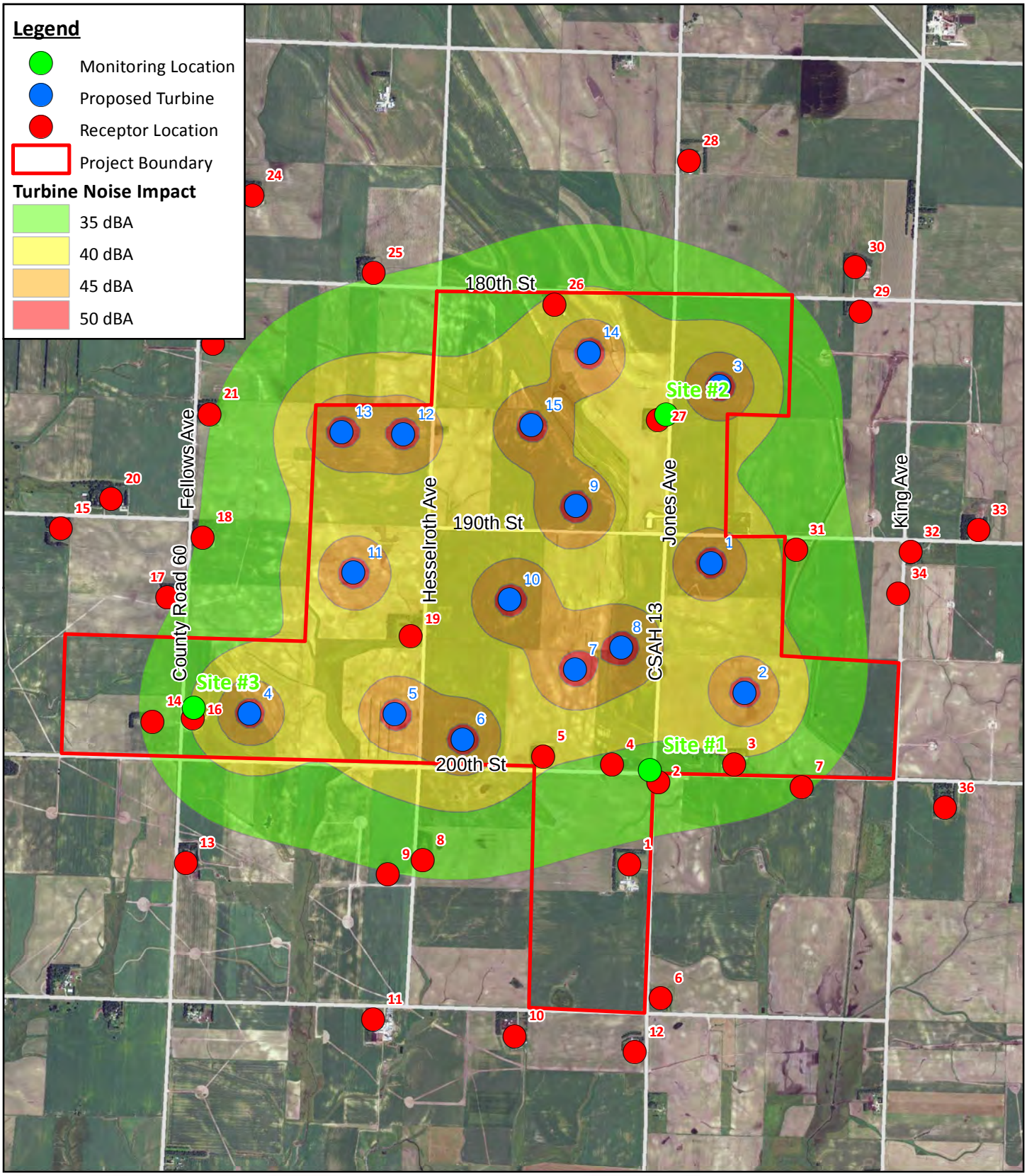

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Figure 3: Noise Modeling Results

N

Feet

0 1,500 3,000 6,000

NOBLES COUNTY, MN

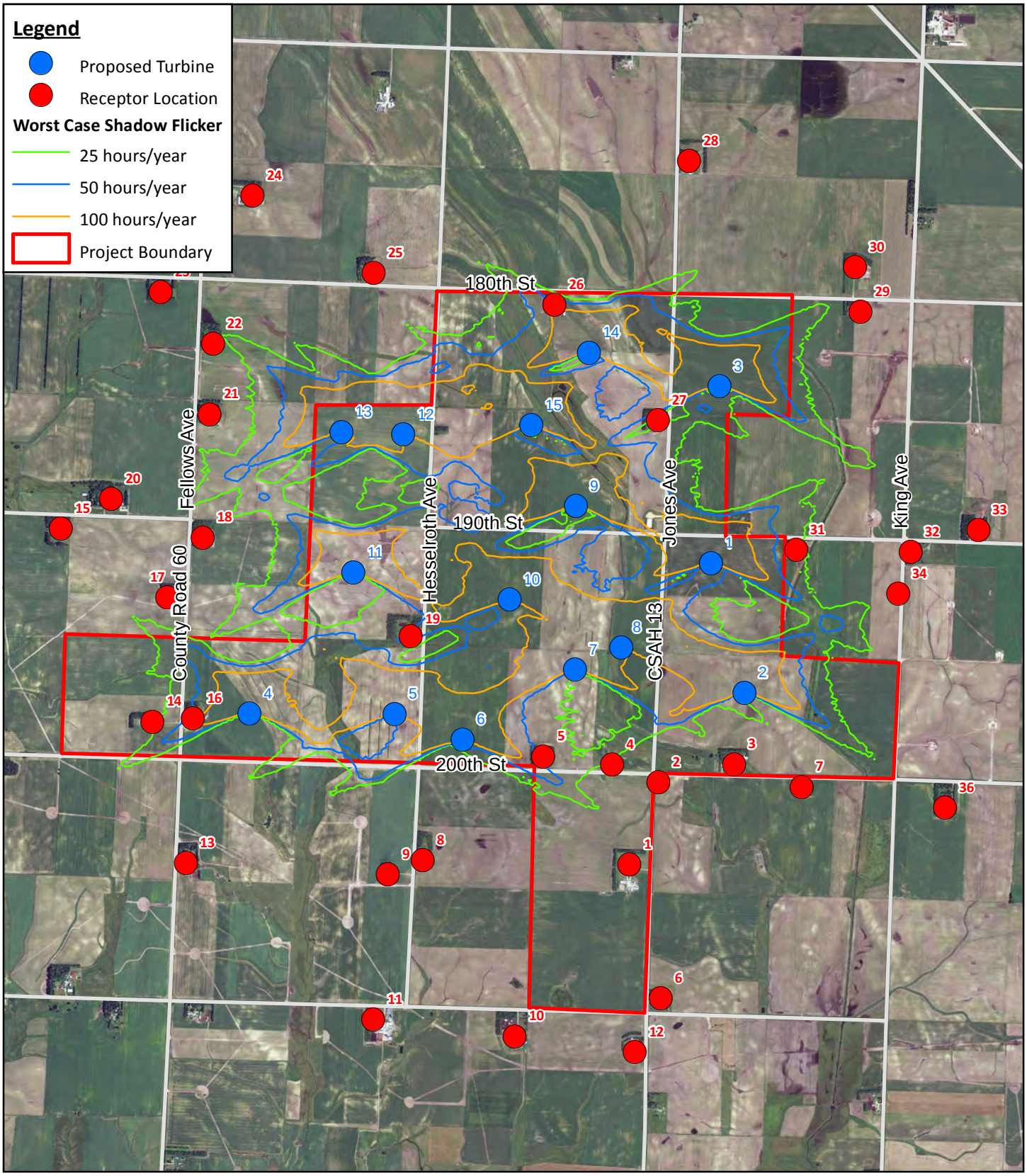

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Figure 4: Worst Case Flicker Modeling Results

N

Feet

0 1,500 3,000 6,000

NOBLES COUNTY, MN

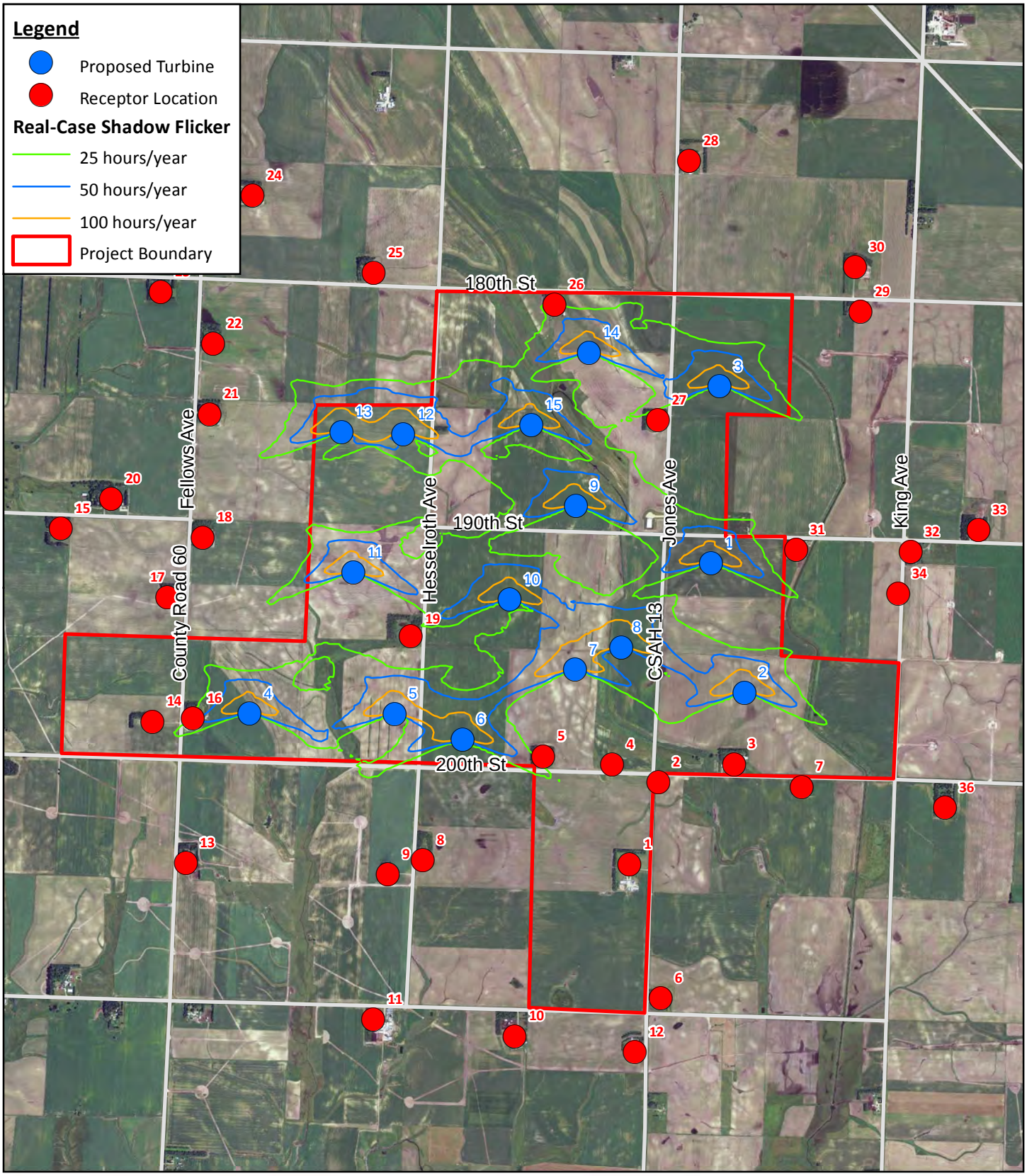

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Figure 5: Real-Case Flicker Modeling Results

N

Feet

0 1,500 3,000 6,000

NOBLES COUNTY, MN

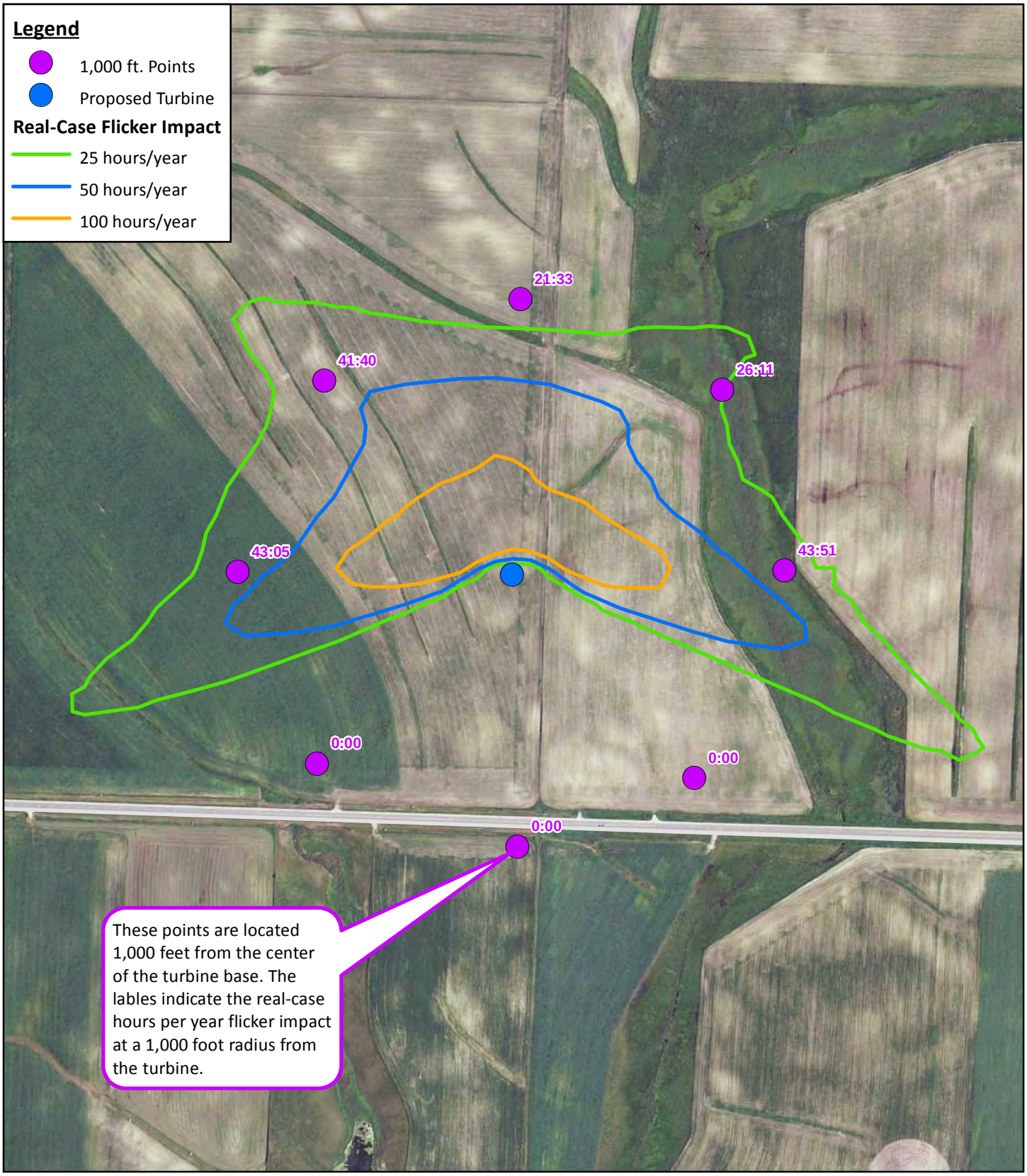

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Figure 6: Real-Case Flicker Impact at 1,000 ft. Radius

N

Feet

0 250 500 1,000

NOBLES COUNTY, MN