Shadow Flicker Impact Analysis

for the

Sunflower Wind Energy Project

Stark and Morton Counties, North Dakota

Prepared for

Sunflower Wind Project, LLC

Prepared by

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Acronyms and Abbreviations

Hz	Hertz
MW	megawatts
Project	Sunflower Wind Energy Project
rpm	rotations per minute
Sunflower	Sunflower Wind Project, LLC
UTM	Universal Transverse Mercator

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1.0 OVERVIEW

Sunflower Wind Project, LLC (Sunflower), is proposing to develop the Sunflower Wind Energy Project (Project) in Morton and Stark counties, North Dakota. The Project would install up to 59 wind turbines with a maximum nameplate capacity of 110 megawatts (MW), with the number of turbines depending on the size and model of turbine used. Tetra Tech has conducted the following shadow flicker analysis for the Project to support the Project's application for a Certificate of Site Compatibility under the North Dakota Public Services Commission.

2.0 PROJECT COMPONENTS

The two wind turbine models being considered for the Project, and evaluated for potential shadow flicker impacts, have the following characteristics:

- **Vestas V-110** – 3-blade, 110-meter diameter rotor, with a hub height of 80 meters and generating capacity of 2.0 MW. The Vestas V-110 has a normal high rotor speed of approximately 14.9 rotations per minute (rpm) which translates to a blade pass frequency of 0.7 Hertz (Hz) which is less than 1 alternation per second. The Project would utilize up to 55 Vestas V-110 turbines; however, 64 potential Vestas turbine locations are included in this impact analysis to account for alternate locations that may be used.

- **General Electric (GE) 1.85-87** – 3-blade 87-meter diameter rotor, with a hub height of 80 meters and generating capacity of 1.85 MW. The GE 1.85-87 has a normal high rotor speed of 18.5 rpm which translates to a blade pass frequency of 0.93 Hz (less than 1 alternation per second). The Project would utilize up to 59 GE 1.85-87 turbines; however, 76 potential GE turbine locations are included in this impact analysis to account for alternate locations that may be used.

- **Vestas V-100** – 3-blade, 100-meter diameter rotor, with a hub height of 80 meters and generating capacity of 2.0 MW. The Vestas V-100 has a normal high rotor speed of approximately 14.9 rotations per minute (rpm) which translates to a blade pass frequency of 0.7 Hertz (Hz) which is less than 1 alternation per second. The Project would utilize up to 53 Vestas V-100 turbines; however, 67 potential Vestas turbine locations are included in this impact analysis to account for alternate locations that may be used.

The potential turbine locations for the different model options overlap to a large degree, so that together they represent a total of 85 unique potential turbine locations. Because the layout has not been finalized, the shadow flicker impact analysis considered all 85 potential turbine locations.

3.0 SHADOW FLICKER BACKGROUND

A wind turbine's moving blades can cast a moving shadow on locations within a certain distance of a turbine. These moving shadows are called shadow flicker, and can be a temporary phenomenon experienced at nearby residences or public gathering places. The impact area depends on the time of year and day (which determine the sun's azimuth and altitude angles) and the wind turbine's physical characteristics (height, rotor diameter, blade width, and orientation of the rotor blades). Shadow flicker impact to surrounding properties generally occurs during low angle sunlight conditions, typically during sunrise and sunset times of the day. However, when the sun angle gets very low (less than 3 degrees), sunlight passes through more atmosphere and becomes too diffused to form a coherent shadow. Shadow flicker will not occur when the sun is obscured by clouds or fog, at night, or when the source turbine(s) are not operating.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker intensity for receptor-to-turbine distances beyond 2,500 meters (8,202 feet) is very low and generally considered imperceptible. In general, increasing proximity to turbines may make shadow flicker more noticeable, with the largest number of shadow flicker hours, along with greatest shadow flicker intensity, occurring nearest the wind turbines.

Shadow flicker frequency is related to the wind turbine's rotor blade speed and the number of blades on the rotor. From a health standpoint, the low flicker frequencies associated with wind turbines, are harmless, and public concerns that flickering light from wind turbines can have negative health effects, such as triggering seizures in people with epilepsy are unfounded. Epilepsy Action (working name for the British Epilepsy Foundation) states that there is no evidence that wind turbines can cause seizures (Epilepsy Action 2008). However, they recommend that wind turbine flicker frequency be limited to 3 Hz. (For comparison, strobe lights used in discotheques have frequencies which range from about 3 Hz to 10 Hz (1 Hz = 1 flash per second). Since the proposed Project's wind turbine blade pass frequency is approximately 0.7-0.93 Hz (less than 1 alternation per second), no negative health effects to individuals with photosensitive epilepsy are anticipated.

Shadow flicker impacts are not regulated in applicable state or federal law, and there is no permitting threshold with regard to hours per year of anticipated impacts to a receptor from a wind energy project.

4.0 WINDPRO SHADOW FLICKER ANALYSIS

An analysis of potential shadow flicker impacts from the Project was conducted using the WindPro software package. The analysis evaluated the following two turbine scenarios:

- Scenario A – 64 potential Vestas V-110 turbine locations (only 55 of these turbines would be constructed)
- Scenario B – 76 potential GE 1.85-87 turbine locations (only 59 of these turbines would be constructed)
- Scenario C – 67 potential Vestas V-100 turbine locations (only 53 of these turbines would be constructed)

The WindPro analysis was conducted to determine shadow flicker impacts under realistic impact conditions (actual expected shadow). This analysis calculated the total amount of time (hours and minutes per year) that shadow flicker could occur at receptors surrounding the Project. The realistic impact condition scenario is based on the following assumptions:

- The elevation and position geometries of the wind turbines and surrounding receptors (potentially occupied residences). Elevations were determined using US Geological Survey digital elevation model data. Positions geometries were determined using geographic information system and referenced to Universal Transverse Mercator (UTM) Zone 13 (NAD83).
- The position of the sun and the incident sunlight relative to the wind turbine and receptors on a minute-by-minute basis over the course of a year.
- Historical sunshine availability (percent of total hours available). Historical sunshine rates for the area (as summarized by the National Climatic Data Center [NCDC 2008] for nearby Bismarck, North Dakota) used in this analysis are as follows:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
53%	53%	58%	58%	61%	64%	73%	72%	65%	58%	43%	47%

- Estimated wind turbine operations and orientation (based on approximately 4 years of wind data, including wind speed / wind direction frequency distribution, measured at on-site meteorological towers).
- Receptor viewpoints (i.e., house windows) are assumed to always be directly facing turbine to sun line of sight (“greenhouse mode”).

WindPro incorporates terrain elevation contour information and the analysis accounts for terrain elevation differences. The sun’s path with respect to each turbine location is calculated by the software to determine the cast shadow paths every minute over a full year. Sun angles less than 3 degrees above the horizon were excluded, for the reasons identified earlier in this section. It should be noted however, that WindPro provides a conservative estimate of shadow flicker as obstacles such as trees, haze, and visual obstructions (window facing, coverings) are not fully accounted despite the likelihood of their reducing or eliminating shadow flicker impacts to receptors.

A total of 42 structures were identified within a minimum buffer of one mile of the proposed Project turbines; of these, 16 were residential structures and are considered potential shadow-flicker receptors for the purpose of this analysis. A receptor in the model is defined as a 1 meter squared area (approximate size of a typical window), 3.28 feet (1 meter) above ground level. Approximate eye level is set at 4.94 feet (1.5 meters). Figure 1 shows the locations of identified structures and the 16 potential shadow flicker receptors, along with the 85 potential turbine locations considered for Scenarios A, B, and C.

5.0 SHADOW FLICKER ANALYSIS RESULTS

As expected, WindPro predicts that shadow flicker impacts will be greatest at locations nearer to the wind turbines. Figures 2A, 2B, and 2C describe the WindPro predicted shadow flicker impact areas for turbine Scenarios A, B, and C, respectively. A detailed WindPro shadow flicker analysis summary, for each of the modeled receptor location, is provided in Attachment A.

Tables 1, 2, and 3 present the WindPro predicted shadow flicker impacts for the 16 identified receptors for each of the two turbines modelled. Because the Project is using a minimum turbine siting setback requirement of 1,320 feet (402 meters) to occupied residences, the most sensitive receptors are generally not located in the high potential shadow flicker impact zones. The maximum predicted shadow flicker impact at any occupied residence receptor is 36 hours 24 minutes per year (Receptor 1 in Scenario A), which is approximately 0.8 percent of the potential available daylight hours. This structure is owned by a landowner that is participating in the Project.

Table 1. WindPro Predicted Shadow Flicker Impacts for Receptors –Scenario A (Vestas V-110 Turbines)

Receptor ID	Shadow Hours per Year (expected) [hh:mm / year]	Receptor Type	Receptor Occupation Status
1	36:24	Home	Yes
2	5:04	Home	Yes
3	18:26	Home	Yes
4	0:00	Home	Yes
5	0:00	Home	Yes
6	0:00	Home	Yes
7	0:00	Home	Yes
8	0:00	Home	Yes
9	0:00	Home	Yes
10	0:00	Home	Yes
11	0:00	Home	Unknown
12	1:47	Home	Unknown
13	7:11	Home	Unknown
14	0:00	Home	Unknown
15	17:35	Home	Unknown
16	9:37	Home	No

Table 2. WindPro Predicted Shadow Flicker Impacts for Receptors –Scenario B (GE 1.85-87 Turbines)

Receptor ID	Shadow Hours per Year (expected) [hh:mm / year]	Receptor Type	Receptor Occupation Status
1	31:17	Home	Yes
2	4:20	Home	Yes
3	17:41	Home	Yes
4	0:00	Home	Yes
5	1:19	Home	Yes
6	0:00	Home	Yes
7	0:00	Home	Yes
8	0:00	Home	Yes
9	0:00	Home	Yes
10	0:00	Home	Yes
11	0:00	Home	Unknown
12	0:59	Home	Unknown
13	6:57	Home	Unknown
14	0:00	Home	Unknown
15	6:49	Home	Unknown
16	7:56	Home	No

Table 3. WindPro Predicted Shadow Flicker Impacts for Receptors –Scenario C (Vestas V-100 Turbines)			
Receptor ID	**Shadow Hours per Year (expected) [hh:mm / year]**	**Receptor Type**	**Receptor Occupation Status**
1	30:45	Home	Yes
2	22:26	Home	Yes
3	10:17	Home	Yes
4	0:00	Home	Yes
5	0:00	Home	Yes
6	0:00	Home	Yes
7	0:00	Home	Yes
8	0:00	Home	Yes
9	0:00	Home	Yes
10	0:00	Home	Yes
11	0:00	Home	Unknown
12	5:03	Home	Unknown
13	0:00	Home	Unknown
14	0:00	Home	Unknown
15	13:06	Home	Unknown
16	0:00	Home	No

The shadow flicker impact prediction statistics are summarized in Tables 4, 5, and 6.

Table 4. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Scenario A (Vestas V-110 Turbines)	
Cumulative Shadow Flicker Time (expected)	**Number of Receptors**
Total	16
= 0 Hours	9
> 0 Hours < 10 Hours	4
≥ 10 Hours < 20 Hours	2
≥ 20 Hours < 30 Hours	0
≥ 30 Hours	1

Table 5. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Scenario B (GE 1.85-87 Turbines)	
Cumulative Shadow Flicker Time (expected)	**Number of Receptors**
Total	16
= 0 Hours	8
> 0 Hours < 10 Hours	6
≥ 10 Hours < 20 Hours	1
≥ 20 Hours < 30 Hours	0
≥ 30 Hours	1

Table 6. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Scenario C (Vestas V-100 Turbines)	
Cumulative Shadow Flicker Time (expected)	**Number of Receptors**
Total	16
= 0 Hours	11
> 0 Hours < 10 Hours	1
≥ 10 Hours < 20 Hours	2
≥ 20 Hours < 30 Hours	1
≥ 30 Hours	1

The slightly higher shadow flicker impacts for Scenario A (Vestas V-110 turbines) can be explained by the longer blades for this turbine.

6.0 CONCLUSION

The analysis of potential shadow flicker impacts from the Project on nearby receptors shows that shadow flicker impacts within the area of study are expected to be minor and well within acceptable ranges for avoiding health hazards. Shadow flicker is not expected to be a significant environmental impact.

The analysis was deliberately conservative and actual shadow flicker is expected to occur for less than the modeled durations. The analysis assumes that the receptors all have a direct in-line view of the incoming shadow flicker sunlight and does not account for trees or other obstructions which may block sunlight. In reality, the windows of many houses will not face the sun directly for the key shadow flicker impact times. Adding to the analysis' conservatism, Sunflower will construct fewer wind turbines than were included in the modeled results.

7.0 REFERENCES

Epilepsy Action. 2008. Information Web Page on Photosensitive Epilepsy. British Epilepsy Association. http://www.epilepsy.org.uk/info/photo_other.html. Accessed 3/1/10.

National Climatic Data Center (NCDC). 2008. Sunshine Average Percent of Possible. http://www.ncdc.noaa.gov/oa/climate/online/ccd/pctpos.txt. Accessed 3/1/10

Figures

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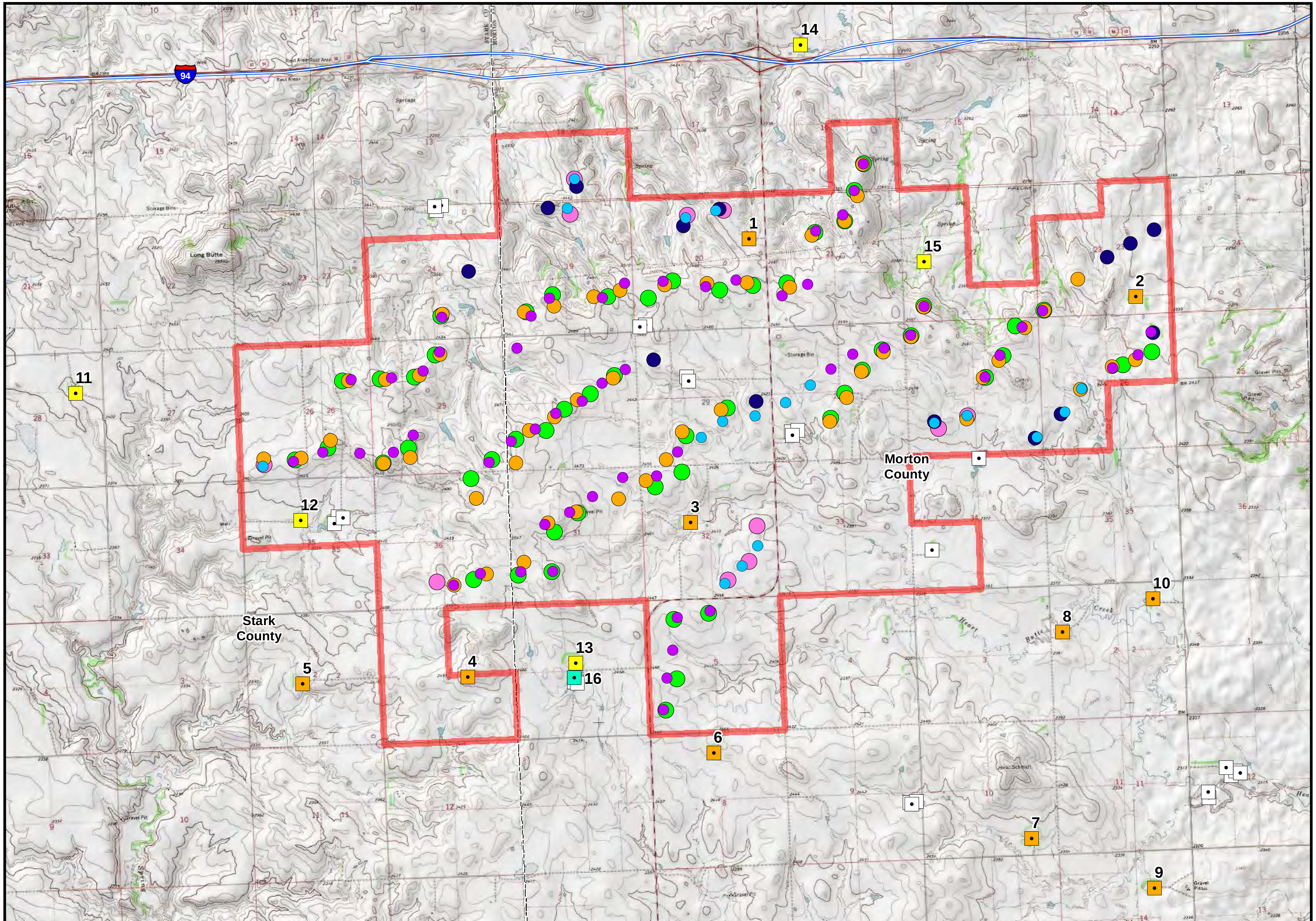

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Figure 1

Receptor Locations Modeled with WindPro to Predict Expected Shadow Flicker Impacts

Morton and Stark Counties, ND

November 2014

Project Area

Occupied Residence

Unoccupied Residence

Residential Structure (Occupation Unknown)

Other Nonresidential Structure

GE

Turbine Location

Alternate Turbine Location

Vestas 100

Turbine Location

Alternate Turbine Location

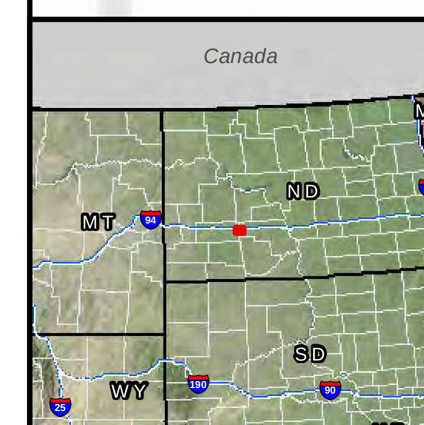
Vestas 110

Turbine Location

Alternate Turbine Location

County Boundary

Interstate Highway



1:45,000 WGS84 UTM Zone 13N

0 2 4 Miles

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Figure 2A

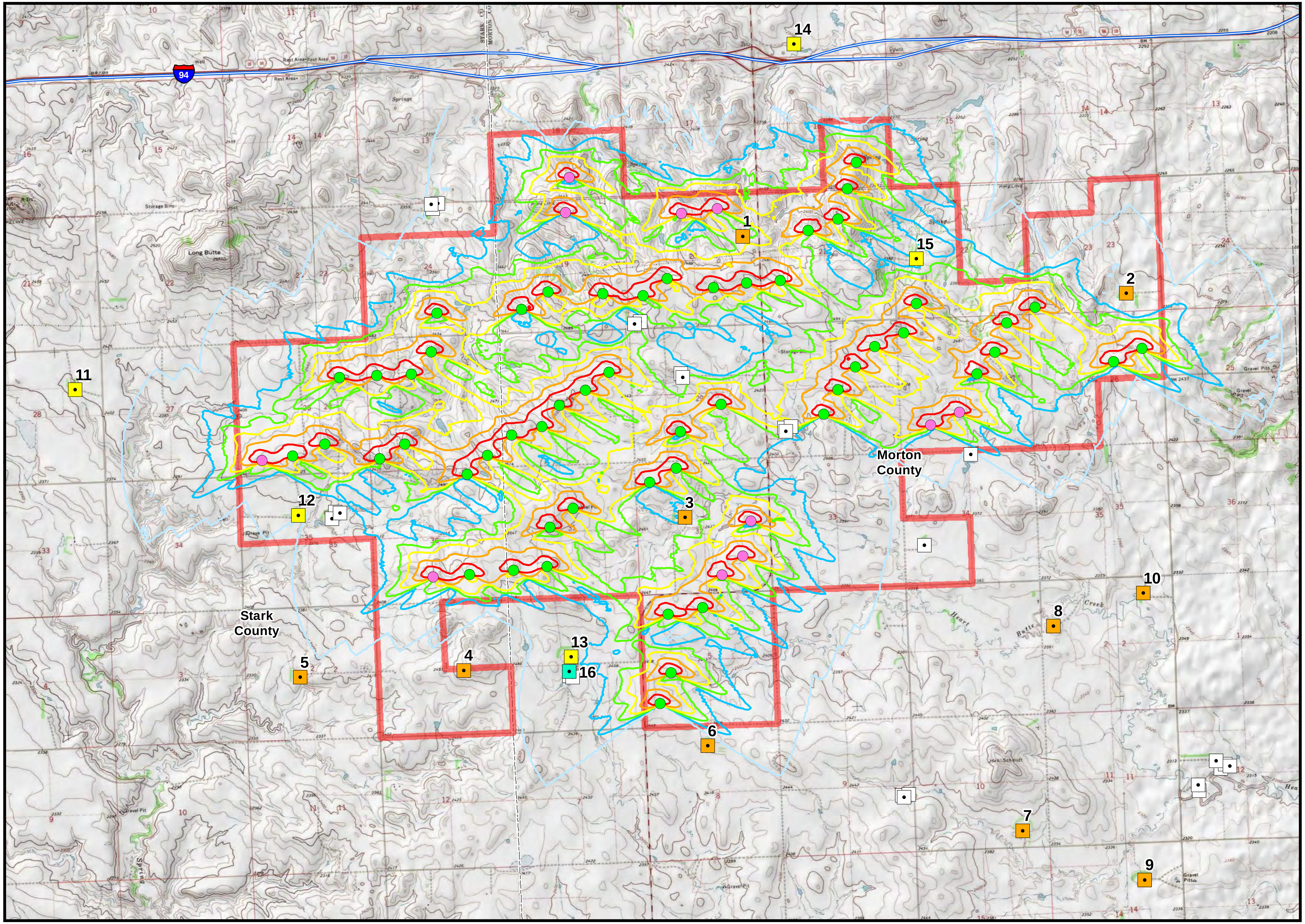
WindPro Predicted Expected Shadow Flicker Impact Areas

Scenario A

(Vestas 2.0 V-110 Turbines)

Morton and Stark Counties, ND

February 2014



- Project Area
- Turbine Location
- Alternate Turbine Location
- Occupied Residence
- Unoccupied Residence
- Residential Structure (Occupation Unknown)
- Other Nonresidential Structure
- County Boundary
- Interstate Highway

Shadow Flicker Iso Line

- 0.015 hrs/yr
- 15 hrs/yr
- 30 hrs/yr
- 50 hrs/yr
- 100 hrs/yr
- 200 hrs/yr

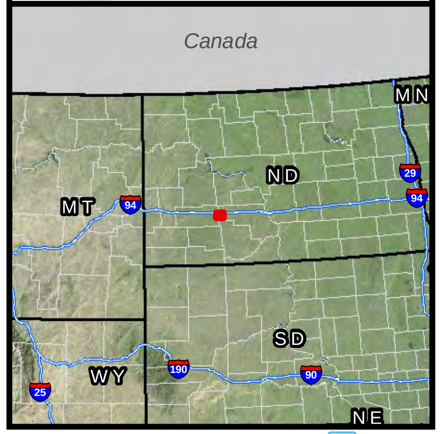


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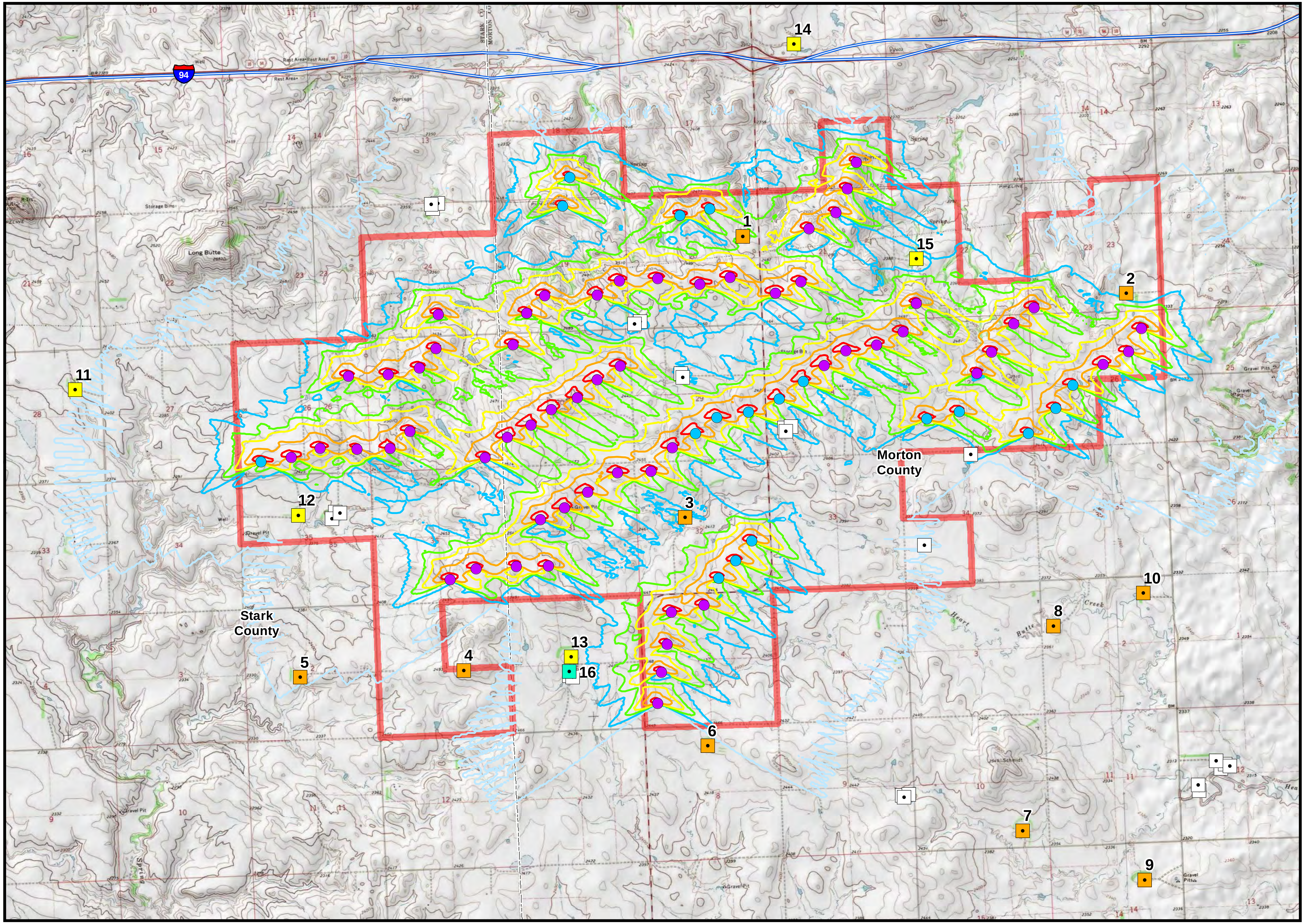
Figure 2B
WindPro Predicted Expected Shadow Flicker Impact Areas
Scenario B
(GE 1.85-87 Turbines)

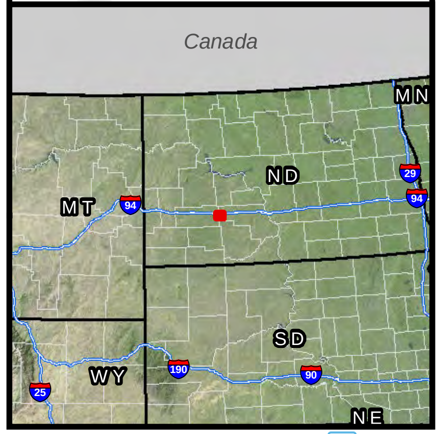
Morton and Stark Counties, ND
February 2014



- Project Area
- Turbine Location
- Alternate Turbine Location
- Occupied Residence
- Unoccupied Residence
- Residential Structure (Occupation Unknown)
- Other Nonresidential Structure
- County Boundary
- Interstate Highway

Shadow Flicker Iso Line

- 0.015 hrs/yr
- 15 hrs/yr
- 30 hrs/yr
- 50 hrs/yr
- 100 hrs/yr
- 200 hrs/yr



N 1:45,000 WGS84 UTM Zone 13N 0 2 4 Miles

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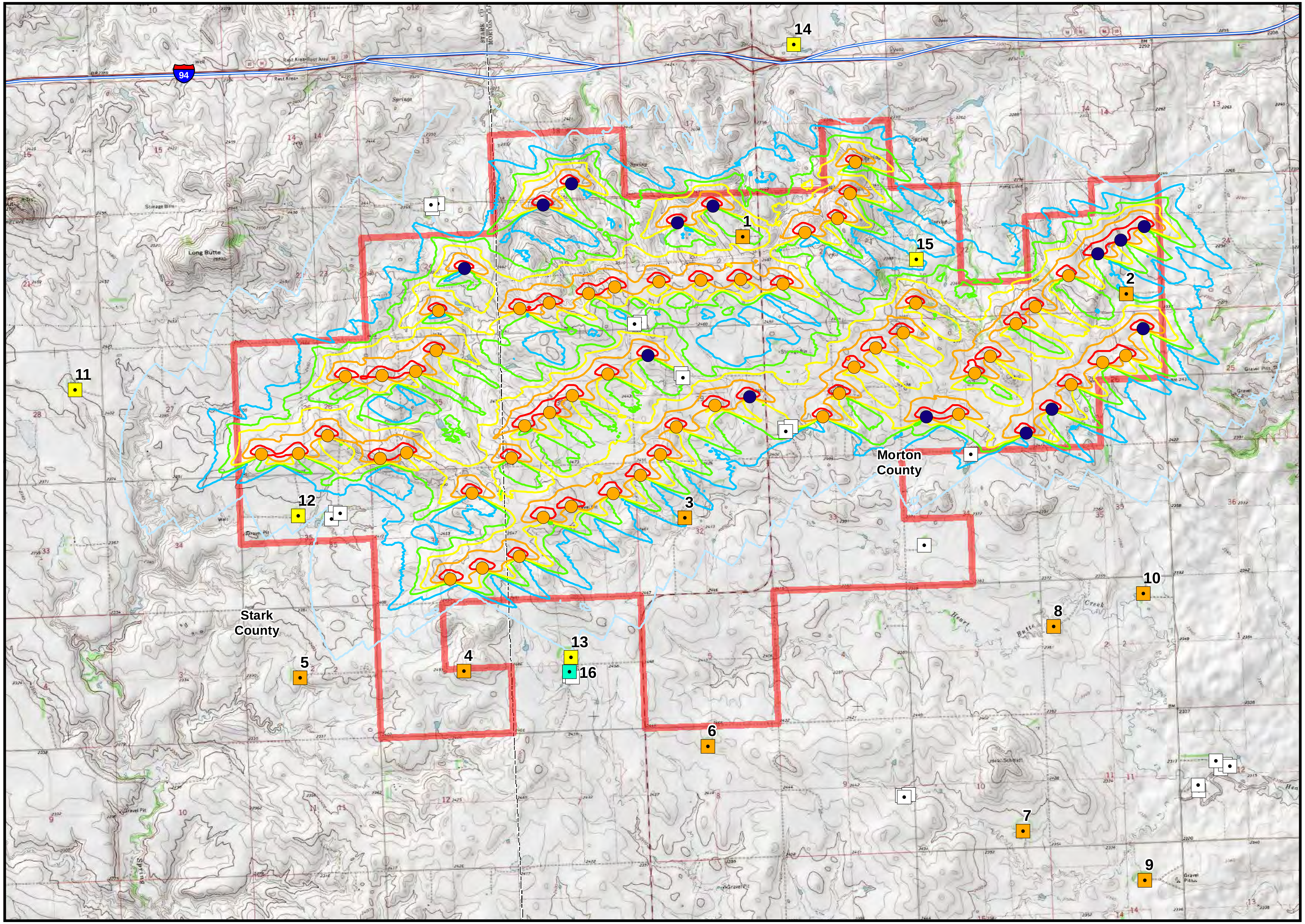
Figure 2C

WindPro Predicted Expected Shadow Flicker Impact Areas Scenario A (Vestas 2.0 V-100 Turbines)

Morton and Stark Counties, ND

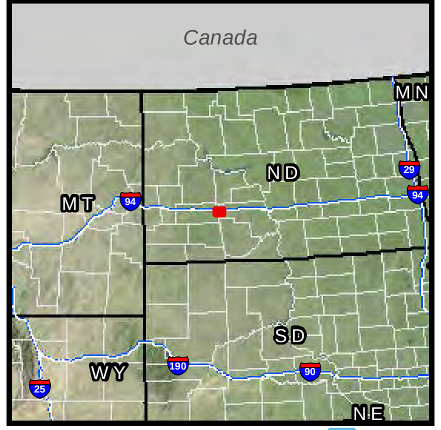
November 2014



- Project Area
- Turbine Location
- Alternate Turbine Location
- Occupied Residence
- Unoccupied Residence
- Residential Structure (Occupation Unknown)
- Other Nonresidential Structure
- County Boundary
- Interstate Highway

Shadow Flicker Iso Line

- 0.015 hrs/yr
- 15 hrs/yr
- 30 hrs/yr
- 50 hrs/yr
- 100 hrs/yr
- 200 hrs/yr



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Attachment A: Detailed Summary of WindPro Shadow Flicker Analysis Results

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Table A-1. WindPro Shadow Flicker Analysis Results Summary - Scenario A (Vestas V-110 Turbines)

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Receptor Type	Occupied Status
1	724,362	5,191,938	36:24	Home	Yes
2	728,996	5,191,250	5:04	Home	Yes
3	723,663	5,188,542	18:26	Home	Yes
4	720,993	5,186,693	0:00	Home	Yes
5	719,013	5,186,609	0:00	Home	Yes
6	723,940	5,185,782	0:00	Home	Yes
7	727,748	5,184,755	0:00	Home	Yes
8	728,120	5,187,230	0:00	Home	Yes
9	729,223	5,184,161	0:00	Home	Yes
10	729,204	5,187,627	0:00	Home	Yes
11	716,294	5,190,086	0:00	Home	Unknown
12	718,990	5,188,567	1:47	Home	Unknown
13	722,287	5,186,857	7:11	Home	Unknown
14	724,981	5,194,263	0:00	Home	Unknown
15	726,461	5,191,667	17:35	Home	Unknown
16	722,267	5,186,682	9:37	Home	No

Table A-2. WindPro Shadow Flicker Analysis Results Summary - Scenario B (GE 1.85-87 Turbines)

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Receptor Type	Occupied Status
1	724,362	5,191,938	31:17	Home	Yes
2	728,996	5,191,250	4:20	Home	Yes
3	723,663	5,188,542	17:41	Home	Yes
4	720,993	5,186,693	0:00	Home	Yes
5	719,013	5,186,609	1:19	Home	Yes
6	723,940	5,185,782	0:00	Home	Yes
7	727,748	5,184,755	0:00	Home	Yes
8	728,120	5,187,230	0:00	Home	Yes
9	729,223	5,184,161	0:00	Home	Yes
10	729,204	5,187,627	0:00	Home	Yes
11	716,294	5,190,086	0:00	Home	Unknown
12	718,990	5,188,567	0:59	Home	Unknown
13	722,287	5,186,857	6:57	Home	Unknown
14	724,981	5,194,263	0:00	Home	Unknown
15	726,461	5,191,667	6:49	Home	Unknown
16	722,267	5,186,682	7:56	Home	No

Table A-3. WindPro Shadow Flicker Analysis Results Summary - Scenario C (Vestas V-100 Turbines)

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Receptor Type	Occupied Status
1	724,362	5,191,938	30:45	Home	Yes
2	728,996	5,191,250	22:26	Home	Yes
3	723,663	5,188,542	10:17	Home	Yes
4	720,993	5,186,693	0:00	Home	Yes
5	719,013	5,186,609	0:00	Home	Yes
6	723,940	5,185,782	0:00	Home	Yes
7	727,748	5,184,755	0:00	Home	Yes
8	728,120	5,187,230	0:00	Home	Yes
9	729,223	5,184,161	0:00	Home	Yes
10	729,204	5,187,627	0:00	Home	Yes
11	716,294	5,190,086	0:00	Home	Unknown
12	718,990	5,188,567	5:03	Home	Unknown
13	722,287	5,186,857	0:00	Home	Unknown
14	724,981	5,194,263	0:00	Home	Unknown
15	726,461	5,191,667	13:06	Home	Unknown
16	722,267	5,186,682	0:00	Home	No