Shadow Flicker Impact Analysis for the Antelope Hills Wind Energy Project

Mercer County, North Dakota

Prepared for

Antelope Hills Wind Project, LLC

Prepared by

TETRA TECH

Tetra Tech, Inc.

160 Federal Street – 3rd Floor

Boston, Massachusetts 02110

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1.0 OVERVIEW

Antelope Hills Wind Project, LLC (Antelope), is proposing to develop the Antelope Hills Wind Project (Project) in Mercer County, North Dakota. The Project would install up to 86 wind turbines with a maximum nameplate capacity of 172 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 regulations.

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 2.0 V-110** – 3-blade 110-meter diameter rotor, with a hub height of 80 meters. The Vestas 2.0 V-110 has a normal high rotor speed of approximately 14.9 rotations per minute (rpm) which translates to a blade pass frequency of 0.75Hertz (Hz) which is less than 1 alternation per second. Although 92 Vestas turbines are included in this impact analysis to account for alternate locations that may be used, a maximum of 86 of these turbines would be constructed.

- **Vestas 2.0 V-100** – 3-blade 100-meter diameter rotor, with a hub height of 80 meters. The Vestas 2.0 V-100 has a normal high rotor speed of 14.9 rpm which translates to a blade pass frequency of 0.75 Hz (less than 1 alternation per second). Although 104 Vestas V-100 turbines are included in this impact analysis to account for alternate locations that may be used, a maximum of 86 of these turbines would be constructed.

- **Siemens 2.3/108** - 3-blade, 108-meter diameter rotor, with a hub height of 80 meters. The Siemens 2.3/108 has a normal high rotor speed of approximately 16 rpm which translates to a blade pass frequency of 0.80 Hz (less than 1 alternation per second). The Siemens turbine layout uses the identical locations as the Vestas V-110, however only 75 of the 92 locations would be used. Since the V-110 is slightly larger, the analysis should be applicable to the Siemens 2.3/108 turbine as well.

Because the layout has not been finalized, the shadow flicker impact analysis considered both the primary and alternative turbine locations, which represent 6, 17 or 18 more turbines than will be constructed for the Vestas V-110, Siemens 2.3/108 and Vestas V-100 scenarios. Figure 1 shows the proposed turbine locations, along with the potential receptor locations in the project area. All potential receptors are residences, either occupied or with occupation status unknown.

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. In addition, shadow flicker is only an issue when at least 20% of the sun's area is covered by the turbine blades.

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 (the 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 less than 1 alternation per second for all turbines being considered, 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 turbine array provided by Antelope (layout dated August 7, 2014), which includes up to 104 turbine locations, was included in the analysis. The analysis evaluated the following turbine scenarios:

- Scenario A – 92 Vestas 2.0 V-110 turbines (only 86 of these turbines would be constructed)
- Scenario B – 104 Vestas 2.0 V-100 turbines (only 86 of these turbines would be constructed)
- Scenario C – 92 Siemens 2.3/108 turbines (only 75 of thess turbines would be constructed). The locations of the Siemens turbines are identical to those for the Vestas V-110.

A third turbine type is also under consideration, the Siemens 2.3 108. The potential locations of this turbine type are identical to the Vestas V-110, however only 75 turbines would be used as opposed to 86 for the Vestas. The Siemens turbine has identical specifications as the Vestas V-110 except that the rotor is slightly shorter (108 m vs 110 m). The shadow flicker impact of the Siemens turbine is expected to be slightly less. The results of the V-110 shadow flicker analysis are applicable to the Siemens turbine.

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 United States Geological Survey (USGS) digital elevation model (DEM) data. Positions geometries were determined using geographic information system (GIS) 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 (June 2010 – July 2014) 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. Since shadow flicker is only noticeable when at least 20% of the sun disc is covered by the blades, WindPro uses blade width dimension data to calculate the maximum distance from the turbine where shadow flicker would be a potential impact.

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 38 receptor locations were identified within approximately one mile of proposed Project turbines, all of these are residences, either known to be occupied or whose occupation status was unknown. A receptor in the model is defined as a 1 meter squared area (approximate size of a typical window), 1 meter (3.28 feet) aboveground level. Approximate eye level is set at 1.5 meters (4.94 feet). Figure 1 shows the receptor locations and proposed Project turbines considered for Scenarios A and B.

Because the Project is using a minimum turbine siting setback requirement of 1,320 feet (402 meters) to occupied residences, receptors are generally not located in the high potential shadow flicker impact zones.

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 and 2B describe the WindPro predicted shadow flicker impact areas for turbine Scenarios A and B, respectively. A detailed WindPro shadow flicker analysis summary for each of the modeled receptor location is provided in Attachment A.

Tables 1A and 1B present the WindPro predicted shadow flicker impacts for the ten receptors with the greatest total annual shadow flicker impact for each of the two turbines modelled. Considering all turbine scenarios, only 9 of the 38 receptors modeled had expected shadow flicker impacts of more than 30 hours per year; and all of these receptors are project participants. The maximum predicted shadow flicker impact at any receptor is 66 hours 13 minutes per year (Receptor 8), which is approximately 1.5 percent of the potential available daylight hours.

Table 1A. WindPro Predicted Shadow Flicker Impacts for Receptors with Maximum Expected Impacts – Turbine Scenario A and C (92 Vestas 2.0 V-110 or Siemens 2.3/108 Turbines)

Receptor ID*	Expected Shadow Flicker [hh:mm / year]	Project Participation Status
8	66:13	Yes
5	63:14	Yes
22	54:59	Yes
19	50:01	Yes
17	44:42	Yes
10	42:50	Yes
23	42:07	Yes
7	40:35	Yes
35	33:54	Yes
38	27:25	Yes

Table 1B. WindPro Predicted Shadow Flicker Impacts for Receptors with Maximum Expected Impacts – Turbine Scenario B (104 Vestas 2.0 V-100 Turbines)

Receptor ID*	Expected Shadow Flicker [hh:mm / year]	Project Participation Status
5	51:40	Yes
8	48:05	Yes
22	46:25	Yes
35	38:57	Yes
10	36:56	Yes
7	35:39	Yes
17	31:20	Yes
23	29:32	Yes
19	29:06	Yes
34	25:16	No

The shadow flicker impact prediction statistics are summarized in Tables 2A and 2B.

Table 2A. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Turbine Scenario A and C (92 Vestas 2.0 V-110 or Siemens 2.3/108 Turbines)

Cumulative Shadow Flicker Time (expected)	Number of Receptors
Total	38
= 0 Hours	18
> 0 Hours < 10 Hours	5
≥ 10 Hours < 20 Hours	4
≥ 20 Hours < 30 Hours	2
≥ 30 Hours	9

Table 2B. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Turbine Scenario B (104 Vestas 2.0 V-100 Turbines)

Cumulative Shadow Flicker Time (expected)	Number of Receptors
Total	38
= 0 Hours	19
> 0 Hours < 10 Hours	5
≥ 10 Hours < 20 Hours	2
≥ 20 Hours < 30 Hours	5
≥ 30 Hours	7

The slightly higher shadow flicker impacts for Scenario A and C (represented by the 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 shadow flicker is not expected to be a significant environmental impact. All of the residential receptors with the highest shadow flicker hours are owned by participating landowners, with land under lease to Antelope, and have agreements with Antelope providing allowance for such potential nuisance issues.

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, Antelope will construct fewer turbines than were modeled.

7.0 REFERENCES

Epilepsy Action. 2008. 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

WindPower. 2003. Danish Wind industry Association. Shadow Casting From Wind Turbines. http://guidedtour.windpower.org/en/tour/env/shadow/index.htm, Accessed 4/28/10

FIGURES

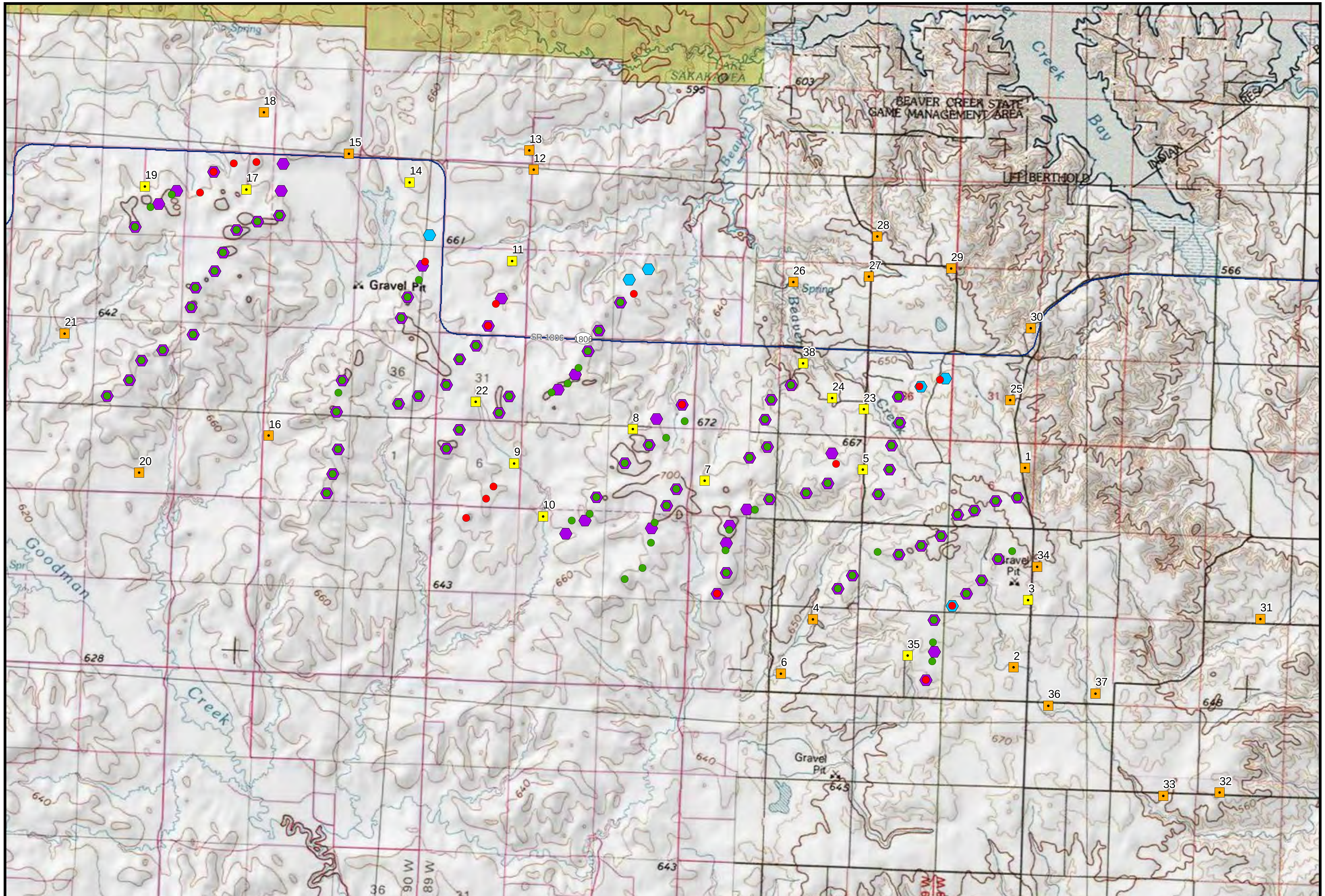

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Figure 1: Receptors Modeled with WindPro to Predict Potential Shadow Flicker Imapcts

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Legend

Vestas 2.0 V-100 Turbine

- Alternate Turbine Location
- Primary Turbine Location

Vestas 2.0 V-110 Turbine

- Alternate Turbine Location
- Primary Turbine Location

Receptor

- Non-Participating
- Participating

Secondary State and County Road

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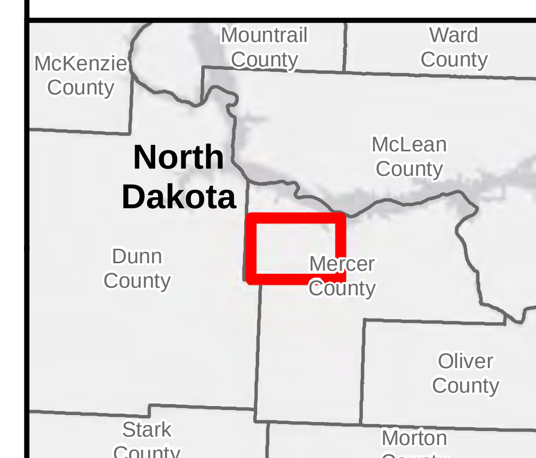

N

1 in = 1 miles

0 2 4 6 8 10 Miles

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Figure 2A: WindPro Expected Shadow Flicker Imapcts Acreas: Turbine Scenario A (Vestas 2.0 V-110 Turbines)

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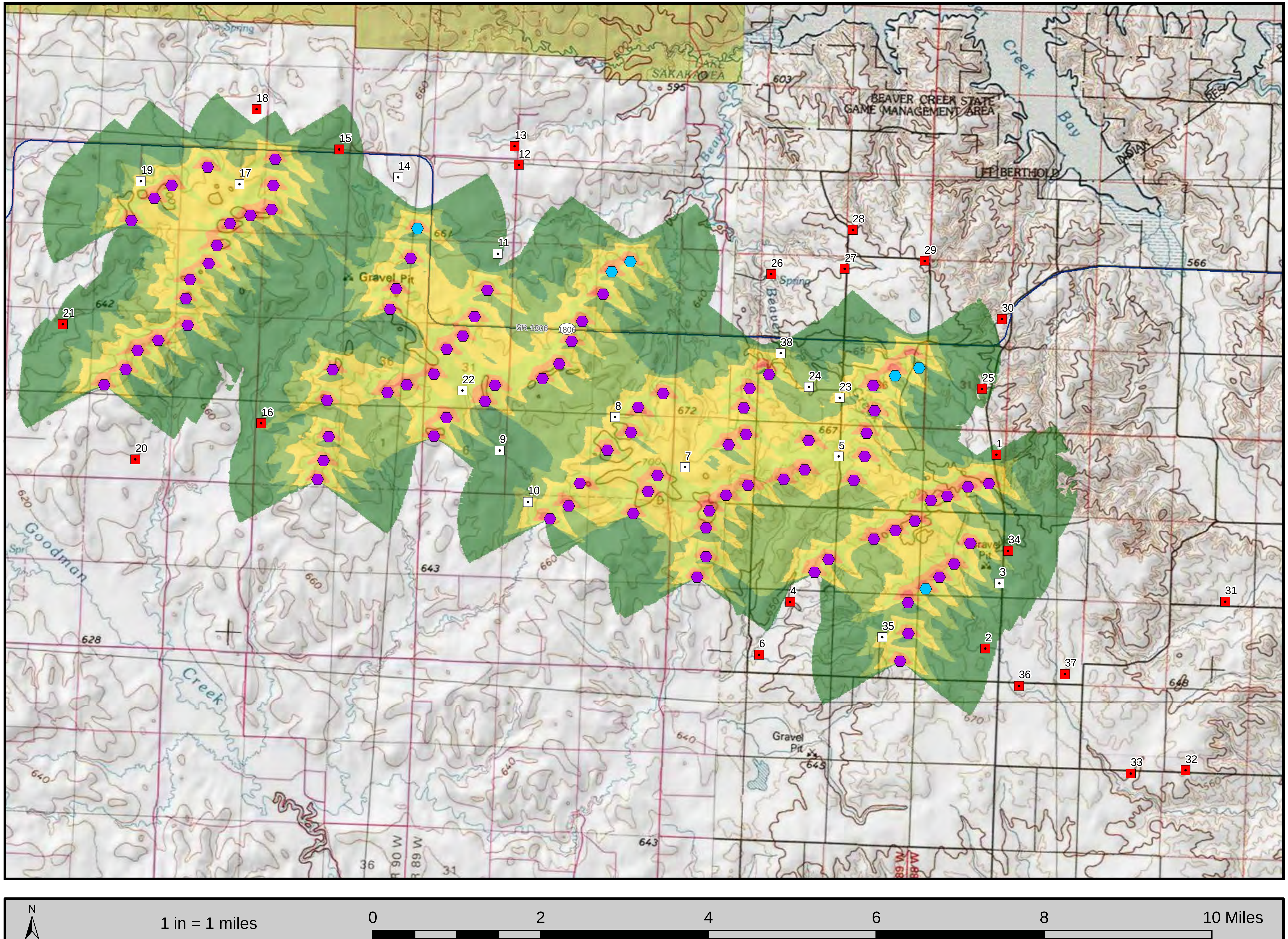

Legend

Vestas 2.0 V-110 Turbine

- Alternate Turbine Location
- Primary Turbine Location

Receptor

- Non-Participating
- Participating
- Secondary State and County Road

Shadow Flicker (hours per yer)

- 0 - 15
- 15 - 30
- 30 - 50
- 50 - 100
- 100 - 200
- > 200

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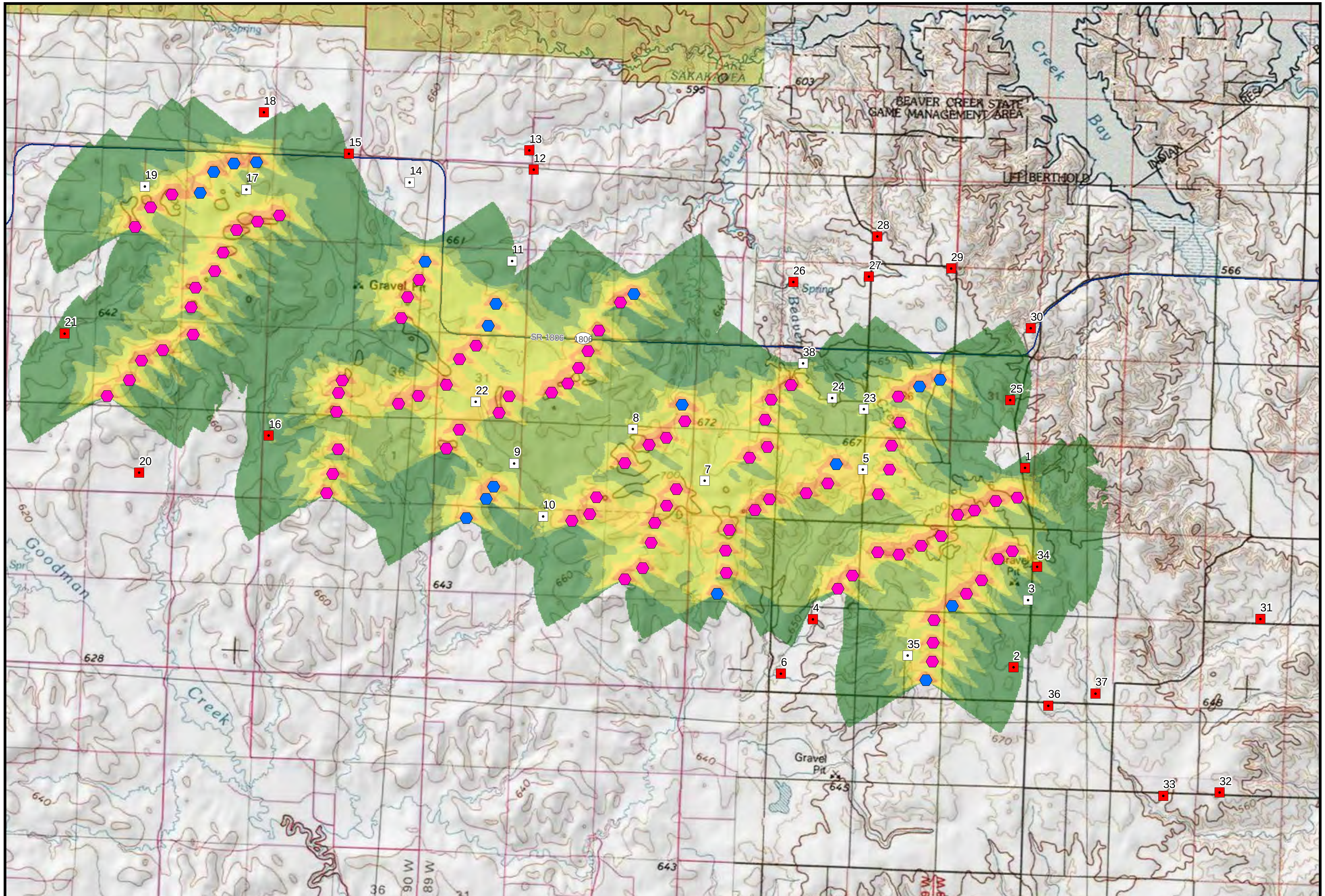

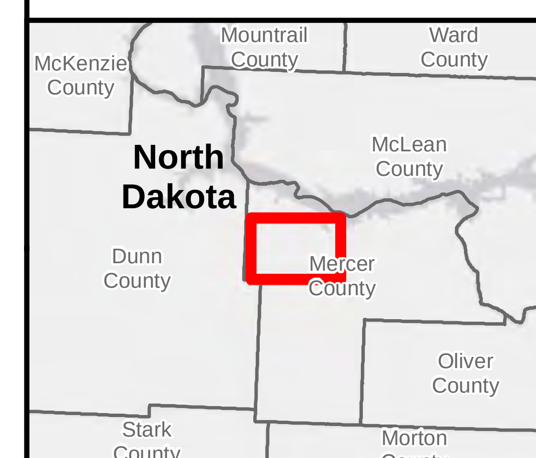

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1 in = 1 miles

0 2 4 6 8 10 Miles

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Figure 2B: WindPro Expected Shadow Flicker Imapcts Acreas: Turbine Scenario B (Vestas 2.0 V-100 Turbines)

August 2014

Legend

Vestas 2.0 V-100 Turbine

- Alternate Turbine Location
- Primary Turbine Location

Receptor

- Non-Participating
- Participating

Shadow Flicker (hours per yer)

- 0 - 15
- 15 - 30
- 30 - 50
- 50 - 100
- 100 - 200
- > 200
- Secondary State and County Road

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ATTACHMENT A.

Detailed Summary of WindPro Shadow Flicker Analysis Results

Antelope Hills Wind Project
WindPro Shadow Flicker Analysis Results Summary
Turbine Scenario A and C (Vestas 2.0 V-110 or Siemens 2.3/108 Turbines)

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
1	278,806	5,254,954	9:45:00	Non-participant
2	278,591	5,251,239	2:17:00	Non-participant
3	278,865	5,252,493	11:26:00	Participant
4	274,851	5,252,134	0:00:00	Non-participant
5	275,780	5,254,924	63:14:00	Participant
6	274,254	5,251,124	0:00:00	Non-participant
7	272,833	5,254,718	40:35:00	Participant
8	271,493	5,255,678	66:13:00	Participant
9	269,279	5,255,041	12:53:00	Participant
10	269,821	5,254,052	42:50:00	Participant
11	269,241	5,258,813	2:01:00	Participant
12	269,646	5,260,514	0:00:00	Non-participant
13	269,567	5,260,873	0:00:00	Non-participant
14	267,336	5,260,278	0:00:00	Participant
15	266,202	5,260,810	3:01:00	Non-participant
16	264,706	5,255,559	13:03:00	Non-participant
17	264,288	5,260,144	44:42:00	Participant
18	264,616	5,261,580	0:00:00	Non-participant
19	262,398	5,260,201	50:01:00	Participant
20	262,293	5,254,866	0:00:00	Non-participant
21	260,903	5,257,460	4:05:00	Non-participant
22	268,565	5,256,188	54:59:00	Participant
23	275,798	5,256,049	42:07:00	Participant
24	275,210	5,256,258	25:13:00	Participant
25	278,530	5,256,220	0:00:00	Non-participant
26	274,486	5,258,418	0:00:00	Non-participant
27	275,895	5,258,521	0:00:00	Non-participant
28	276,052	5,259,267	0:00:00	Non-participant
29	277,426	5,258,672	0:00:00	Non-participant
30	278,912	5,257,558	0:00:00	Non-participant
31	283,193	5,252,142	0:00:00	Non-participant
32	282,431	5,248,908	0:00:00	Non-participant
33	281,382	5,248,849	0:00:00	Non-participant
34	279,035	5,253,117	10:12:00	Non-participant
35	276,616	5,251,460	33:54:00	Participant
36	279,237	5,250,527	0:00:00	Non-participant
37	280,120	5,250,752	0:00:00	Non-participant
38	274,669	5,256,903	27:25:00	Participant

Antelope Hills Project
WindPro Shadow Flicker Analysis Results Summary
Turbine Scenario B (Vestas 2.0 V-100 Turbines)

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
1	278,806	5,254,954	8:23:00	Non-participant
2	278,591	5,251,239	2:59:00	Non-participant
3	278,865	5,252,493	9:43:00	Participant
4	274,851	5,252,134	0:00:00	Non-participant
5	275,780	5,254,924	51:40:00	Participant
6	274,254	5,251,124	0:00:00	Non-participant
7	272,833	5,254,718	35:39:00	Participant
8	271,493	5,255,678	48:05:00	Participant
9	269,279	5,255,041	22:40:00	Participant
10	269,821	5,254,052	36:56:00	Participant
11	269,241	5,258,813	0:48:00	Participant
12	269,646	5,260,514	0:00:00	Non-participant
13	269,567	5,260,873	0:00:00	Non-participant
14	267,336	5,260,278	0:00:00	Participant
15	266,202	5,260,810	0:00:00	Non-participant
16	264,706	5,255,559	10:57:00	Non-participant
17	264,288	5,260,144	31:20:00	Participant
18	264,616	5,261,580	0:00:00	Non-participant
19	262,398	5,260,201	29:06:00	Participant
20	262,293	5,254,866	0:00:00	Non-participant
21	260,903	5,257,460	3:32:00	Non-participant
22	268,565	5,256,188	46:25:00	Participant
23	275,798	5,256,049	29:32:00	Participant
24	275,210	5,256,258	21:54:00	Participant
25	278,530	5,256,220	0:00:00	Non-participant
26	274,486	5,258,418	0:00:00	Non-participant
27	275,895	5,258,521	0:00:00	Non-participant
28	276,052	5,259,267	0:00:00	Non-participant
29	277,426	5,258,672	0:00:00	Non-participant
30	278,912	5,257,558	0:00:00	Non-participant
31	283,193	5,252,142	0:00:00	Non-participant
32	282,431	5,248,908	0:00:00	Non-participant
33	281,382	5,248,849	0:00:00	Non-participant
34	279,035	5,253,117	25:16:00	Non-participant
35	276,616	5,251,460	38:57:00	Participant
36	279,237	5,250,527	0:00:00	Non-participant
37	280,120	5,250,752	0:00:00	Non-participant
38	274,669	5,256,903	13:15:00	Participant