Stantec

Memo

To:	James Cassida SunEdison Portland, Maine	From:	Theo Kindermans Stantec Planning and Landscape Architecture P.C. Boston, Massachusetts
File:	Antelope Hills Wind Project Project No. 212205229	Date:	July 15, 2015

Reference: Shadow Flicker Modeling
Antelope Hills Wind Project, Mercer County, North Dakota

Introduction

This memorandum provides a brief explanation of the shadow flicker phenomenon, the modeling approach employed for a flicker analysis of the Antelope Hills Wind Project (project), and a comparison of the results to the *Shadow Flicker Impact Analysis* completed previously in the project area (TetraTech August 2014) that assumed a greater number of turbines. The turbine layout, turbine specification, and receptor data were provided by SunEdison.

Two 87-turbine (86 locations and 1 alternate) scenarios were modeled: Vestas V100, 2.0 MW turbines and Vestas V110 2.0MW turbines, both with 80 meter hub heights.

Background

Shadow flicker from wind turbines results from brief reductions in light intensities caused by the rotating blades of the turbine casting shadows on receptors on the ground and stationary objects, such as a window at a residence. When the sun is obscured by clouds or storms, or when the turbine is not operating, no shadows will be cast.

Shadow flicker can occur on project area receptors when the wind turbine is located near the receptor and when the turbine blades interfere with the angle of the sunlight. The most typical effect is the visibility of an intermittent light reduction on the receptor facing the wind turbine and subject to the shadow flicker. Obstacles such as terrain, trees, or buildings between the wind turbine and a potential shadow flicker receptor significantly reduce or eliminate shadow flicker effects. No shadow flicker is present when the rotor of the turbine is perpendicular to the receptor.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensities diminish with increased distance from turbine to receptor and with lower visibility weather or atmospheric conditions such as haze or fog. Closer to a turbine the shadow will appear to be darker and wider as the rotors will block out a larger portion of sunrays. The shadow line will also be more defined. Farther from the turbine, the shadow will be less distinct and less intense or lighter.

Wind direction and the spatial relationship between a wind turbine and a receptor are key factors related to the amount of time any location might experience shadow flicker. Shadow flicker time is most commonly expressed in hours per year. Shadow flicker is most pronounced at distances from the turbine of less than 1000 feet and during sunrise and sunset when the sun's angle is lower and the resulting shadows are longer. Shadow flicker is typically present at a receptor for short periods

each day—rarely more than a half-hour at sunrise and at sunset. The phenomenon is more prevalent in the winter than the summer due to the sun's lower position on the horizon in winter months in North America (NAS 2007).

The analysis provided in this report does not evaluate the flicker intensity, but rather focuses on the total amount of time (hours and minutes per year) that shadow flicker can potentially occur at receptors regardless if the shadow flicker is barely noticeable or clearly distinct. As a result, it is likely that receptors will experience less shadow flicker impact than modeled and reported, especially those that are farther away from the turbines. It is likely that marginally affected receptors may not be able to identify shadow flicker at all as the shadows become more diffuse with increased distance.

The speed of the rotor and the number of blades determine the frequency of the flicker of the shadow. The maximum rotor speed of 14.9 RPM for both turbine types translates to a blade frequency of 0.7 Hz (less than 1 alternation per second).

Modeling Approach

For the shadow flicker modeling, a module of the WindPRO software was used. The computer model simulates the path of the sun over the course of the year and assesses at regular intervals the potential shadow flicker across a receptor. The color-coded map produced by the computer model is a conservative estimate of the number of hours per year that shadows could be cast by the rotation of the turbine blades. This report presents a flicker analysis for meteorologically adjusted conditions.

The shadow flicker model uses the following inputs:

- Turbine locations
- Turbine hub height
- Turbine rotor diameter
- Shadow flicker receptor locations (coordinates)
- USGS 1:24,000 topographic and USGS DEM (height contours)

In addition, we further refined the model using data that are reflective of typical conditions at the Antelope Hills Wind Project. The data used are local meteorological information on wind speed and direction and National Oceanic and Atmospheric Administration (NOAA) information on cloud cover. The data came from the following sources:

- Wind speeds and direction frequency distributions were acquired from the on-site meteorological towers.
- Sunshine hours, the time between sunrise and sundown for the area, was obtained from monthly reference data for the annual number of sunny or partly sunny days experienced at the airport in Bismarck, ND (the closest reporting station for cloudiness data for NOAA).

The turbine run-time and direction (seen from the receptor) are calculated from the site's long-term wind speed and direction distribution, while the actual sunshine hours add the probability of sunshine during any given period. This calculation reflects the expected shadow flicker time.

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The model calculates detailed shadow flicker results at each assessed receptor location and the amount of shadow flicker (hours and minutes per year) surrounding the project. A receptor in the model is defined as a 1 square meter area that is 1 meter above ground level, approximating a window. This omni-directional approach produces shadow flicker results at a receptor regardless of the direction of windows and provides similar results as a model with windows on various sides of the receptor.

Output from the model includes the following information:

- Calculated shadow flicker time at selected receptors,
- Tabulated and plotted time of day with shadow flicker at receptors,
- Tabulated time of impact from each turbine at a receptor,
- Map showing turbine locations, selected shadow flicker receptors and color-coded contour lines indicating projected shadow flicker time (hours per year).

The analysis assumes that windows are situated in direct alignment with the turbine-to-sun line of sight. Even when windows are so aligned, the analysis does not account for the difference between windows in rooms with primary use and enjoyment (e.g., living rooms) and other less frequently occupied or unoccupied rooms or garages.

Analysis

The original modeling for the project assumed 104 V100 turbines and 92 V110 turbines. In this modeling, the number of turbines is reduced to 87, and some turbine locations changed. As expected, with a reduction in the number of turbines modeled, the overall expected amount of shadow flicker impact on most receptors is also reduced.

Vestas V100

For the Vestas V100, the total number of receptors potentially experiencing shadow flicker impact declines from 19 to 11. In addition, the number of locations receiving more than 30 hours of flicker impact per year decreases from 7 to 5. All 5 receptors are project participants.

Of the 11 locations expected to experience some flicker impact, 6 have a decrease in impact from the original analysis, and 5 have an increase attributable to changes in some turbine locations. Four of the 5 have less than 2 hours per year predicted flicker increase. Receptor #19, a project participant, has an expected increase of approximately 22 hours (see Tables 1 and 2 for more detail).

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Antelope Hills Wind Project, Mercer County, North Dakota

Table 1. Summary of Predicted Shadow Flicker Impacts at Receptor Locations (Vestas V100, 2.0 MW Turbines)

Total Annual Shadow Flicker (expected)	Number of Receptors (104 Turbine Analysis)	Number of Receptors (87 Turbine Analysis)
= 0 Hours	19	27
> 0 Hours < 10 Hours	5	2
≥ 10 Hours < 20 Hours	2	3
≥ 20 Hours < 30 Hours	5	1
≥ 30 Hours	7	5
Total	38	38

Table 2. Shadow Flicker Analysis: Comparative Summary (Vestas V100, 2.0 MW Turbines)

Receptor	WindPro Predicted Shadow Flicker (Hours per Year)		Participation Status
	104 turbine analysis	87 turbine analysis	
1	8:23	10:24	Non-participant
2	2:59	0:00	Non-participant
3	9:43	0:00	Participant
4	0:00	0:00	Non-participant
5	51:40	29:05	Participant
6	0:00	0:00	Non-participant
7	35:39	37:23	Participant
8	48:05	38:47	Participant
9	22:40	0:00	Participant
10	36:56	14:23	Participant
11	0:48	2:16	Participant
12	0:00	0:00	Non-participant
13	0:00	0:00	Non-participant
14	0:00	0:00	Participant
15	0:00	0:00	Non-participant
16	10:57	0:00	Non-participant
17	31:20	33:09	Participant
18	0:00	0:00	Non-participant
19	29:06	51:28	Participant
20	0:00	0:00	Non-participant
21	3:32	0:00	Non-participant
22	46:25	4:32	Participant
23	29:32	0:00	Participant

Reference: Shadow Flicker Modeling
Antelope Hills Wind Project, Mercer County, North Dakota

Receptor	WindPro Predicted Shadow Flicker (Hours per Year)		Participation Status
	104 turbine analysis	87 turbine analysis	
24	21:54	0:00	Participant
25	0:00	0:00	Non-participant
26	0:00	0:00	Non-participant
27	0:00	0:00	Non-participant
28	0:00	0:00	Non-participant
29	0:00	0:00	Non-participant
30	0:00	0:00	Non-participant
31	0:00	0:00	Non-participant
32	0:00	0:00	Non-participant
33	0:00	0:00	Non-participant
34	25:16	0:00	Non-participant
35	38:57	32:19	Participant
36	0:00	0:00	Non-participant
37	0:00	0:00	Non-participant
38	13:15	12:32	Participant

Vestas V110

For the Vestas V110, the total number of receptors potentially experiencing shadow flicker impact declines from 20 to 13. In addition, the number of receptors receiving more than 30 hours of flicker impact per year decreases from 9 to 6. These 6 receptors are all project participants.

Of the 13 locations expected to experience some flicker impact, 7 have a decrease in impact from the original analysis, and 6 have an increase attributable to changes in some turbine locations. Of the 6 receptors with increased potential impact, all but one has an increase that is less than 10 hours per year. Receptor #19, a project participant, has an expected increase of approximately 10:48 hours per year (see Tables 3 and 4 for more detail).

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Antelope Hills Wind Project, Mercer County, North Dakota

Table 3. Summary of Predicted Shadow Flicker Impacts at Receptor Locations (Vestas V110, 2.0 MW Turbines)

Total Annual Shadow Flicker (expected)	Number of Receptors (92 Turbine Analysis)	Number of Receptors (87 Turbine Analysis)
= 0 Hours	18	25
> 0 Hours < 10 Hours	5	3
≥ 10 Hours < 20 Hours	4	3
≥ 20 Hours < 30 Hours	2	1
≥ 30 Hours	9	6
Total	38	38

Table 4. Shadow Flicker Analysis: Comparative Summary (Vestas V110, 2.0 MW Turbines)

Receptor	WindPro Predicted Shadow Flicker (Hours per Year)		Participation Status
	92 turbine analysis	87 turbine analysis	
1	9:45	15:29	Non-participant
2	2:17	0:00	Non-participant
3	11:26	0:00	Participant
4	0:00	0:00	Non-participant
5	63:14	43:15	Participant
6	0:00	0:00	Non-participant
7	40:35	47:49	Participant
8	66:13	44:24	Participant
9	12:53	13:43	Participant
10	42:50	23:58	Participant
11	2:01	5:29	Participant
12	0:00	0:00	Non-participant
13	0:00	0:00	Non-participant
14	0:00	0:00	Participant
15	3:01	0:00	Non-participant
16	13:03	0:00	Non-participant
17	44:42	38:21	Participant
18	0:00	0:00	Non-participant
19	50:01	60:49	Participant
20	0:00	0:00	Non-participant
21	4:05	0:00	Non-participant
22	54:59	5:23	Participant
23	42:07	0:00	Participant

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Receptor	WindPro Predicted Shadow Flicker (Hours per Year)		Participation Status
	92 turbine analysis	87 turbine analysis	
24	25:13	6:38	Participant
25	0:00	0:00	Non-participant
26	0:00	0:00	Non-participant
27	0:00	0:00	Non-participant
28	0:00	0:00	Non-participant
29	0:00	0:00	Non-participant
30	0:00	0:00	Non-participant
31	0:00	0:00	Non-participant
32	0:00	0:00	Non-participant
33	0:00	0:00	Non-participant
34	10:12	0:00	Non-participant
35	33:54	38:03	Participant
36	0:00	0:00	Non-participant
37	0:00	0:00	Non-participant
38	27:25	15:01	Participant

Conclusion

The shadow flicker model assumptions applied to this project are very conservative and as such, results are expected to over-predict the impacts. Additionally, many of the modeled shadow flicker hours are expected to be of very low intensity. The modeling demonstrated that the number of receptors potentially impacted by shadow flicker and the duration of that impact would be limited under either 87-turbine configuration.

It is my opinion that shadow flicker will not pose an adverse impact on the receptors identified in this report. For clarifications and more detailed analysis of expected influence at selected receptors, please do not hesitate to contact me.

STANTEC PLANNING AND LANDSCAPE ARCHITECTURE P.C.

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Attachment: Shadow Flicker Map

Legend

Wind Turbines

Receptors

Max. Potential Shadow Flicker Hours Per Year (Meteorological Adjustment)

0-5

5-10

10-50

>50

N

0 1,500 3,000 6,000 9,000 12,000 Feet

Antelope Hills Wind Project - Vestas V100 - 2.0MW 80m Hub
Beulah, North Dakota

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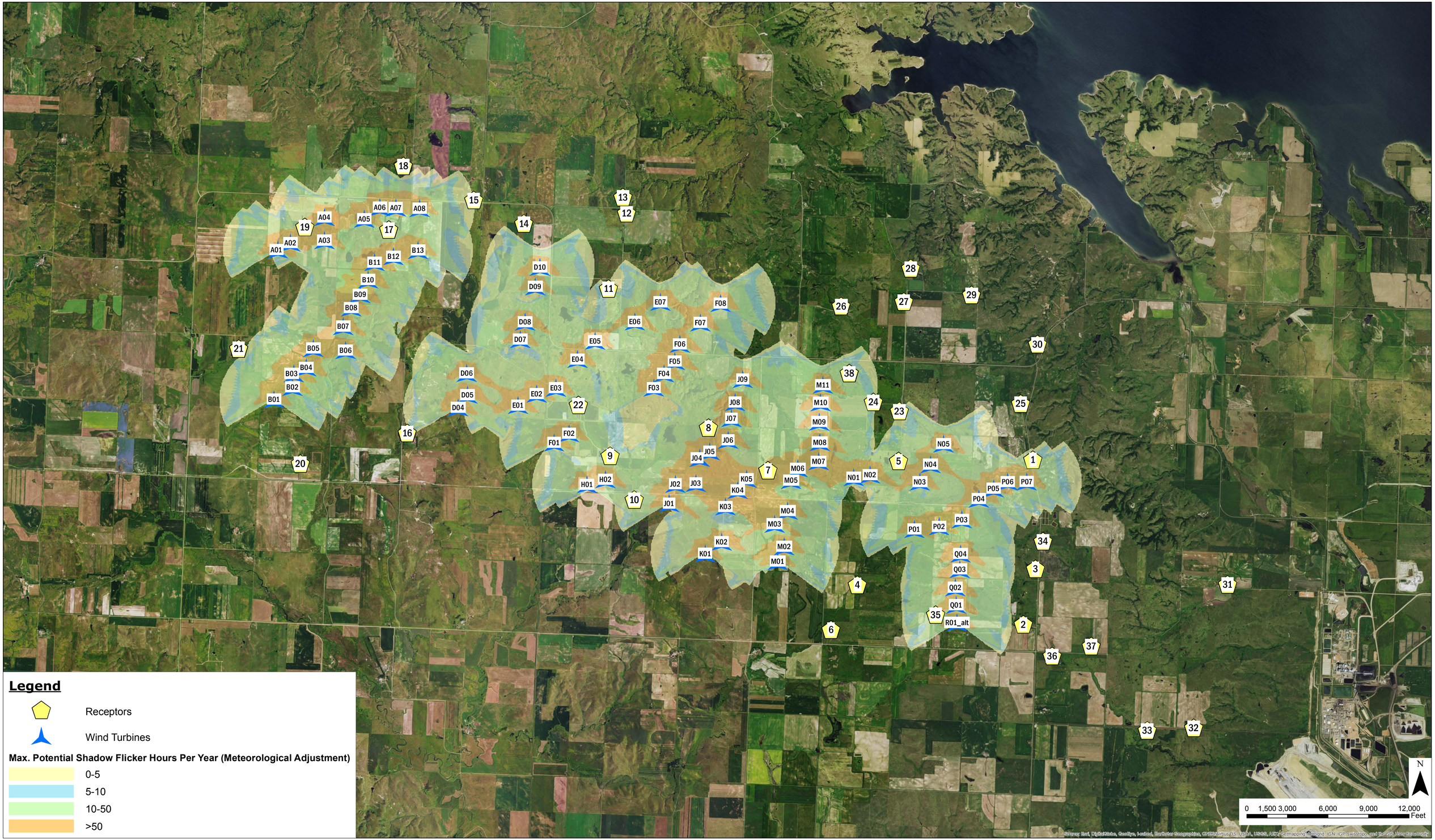
Meteorological Adjustment Shadow Flicker Study

July 1, 2015

Data Source: USGS topographic, Aerial from ESRI



Antelope Hills Wind Project - Vestas V110 - 2.0MW 80m Hub
Beulah, North Dakota

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Meteorological Adjustment Shadow Flicker Study

July 10, 2015

Data Source: USGS topographic, Aerial from ESRI