Appendix B – Shadow Flicker Assessment Results

SHADOW FLICKER MODELING REPORT

Langdon Wind Energy Center Repower Project
Cavalier County, North Dakota

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1.0 EXECUTIVE SUMMARY

The Langdon Wind Energy Center Repowering Project (the Project) is an existing wind park in Cavalier County, North Dakota that is planned to be repowered by Otter Tail Power Company (Otter Tail). Atwell has retained Epsilon Associates, Inc. (Epsilon) to conduct a shadow flicker assessment for the proposed Project. This report presents results of the shadow flicker modeling from the proposed repower and other existing Langdon Wind wind turbines in Cavalier County.

Shadow flicker modeling was conducted for the 27 Otter Tail Langdon General Electric (GE) repowered wind turbines and a total of 16 existing Langdon Wind I and Langdon Wind II wind turbines; thus, a grand total of 43 wind turbines were included in the shadow flicker model. The purpose of this analysis is to predict the annual durations of wind turbine shadow flicker at nearby receptors. Shadow flicker modeling was conducted for all Otter Tail Langdon Wind Repower wind turbines and existing Langdon Wind I and Langdon Wind II wind turbines within 1.5 miles of a modeling receptor.

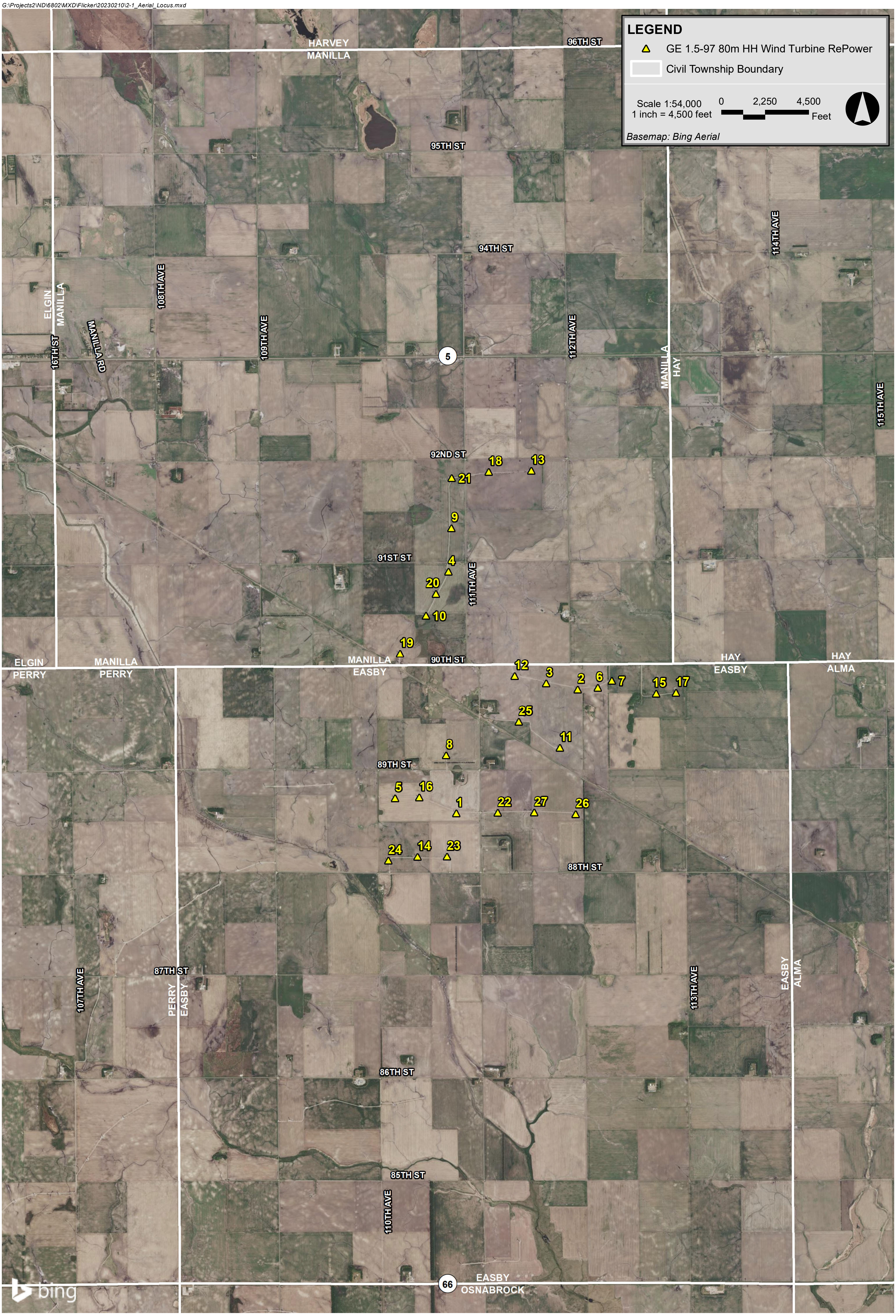
The maximum expected cumulative annual duration of shadow flicker at a modeling receptor resulting from the operation of all Otter Tail Langdon Wind and existing Langdon Wind I and Langdon Wind II wind turbines is 18 hours, 21 minutes per year. The modeling results are conservative in that modeling receptors were treated as "greenhouses" (i.e., having windows on all sides) and the surrounding area was assumed to be without vegetation or structures ("bare earth").

2.0 INTRODUCTION

The Langdon Wind Energy Center Repower Project will consist of 27 repowered wind turbines. The proposed wind turbines are all GE 1.5 MW units with a rotor diameter of 97 meters and a hub height of 80 meters. Figure 2-1 shows the locations of the 27 wind turbines over aerial imagery.

Shadow flicker can be defined as an intermittent change in the intensity of light in a given area resulting from the operation of a wind turbine due to its interaction with the sun. An indoor observer experiences repeated changes in the brightness of the room as shadows cast from the wind turbine blades briefly pass by windows as the blades rotate. In order for this to occur, the wind turbine must be operating, the sun must be shining, and the window must be within the shadow region of the wind turbine, otherwise there is no shadow flicker. A stationary wind turbine only generates a stationary shadow similar to any other structure.

This report presents the findings of a shadow flicker modeling study for the Project. The wind turbines were modeled with the WindPRO software package using information provided by Atwell. The expected annual duration of shadow flicker was calculated at modeling receptors and shadow flicker isolines for the area surrounding the Project were generated. The results of the modeling are found within this report.



Otter Tail Langdon Wind Repower Cavalier County, North Dakota

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Figure 2-1
Aerial Locus

3.0 SHADOW FLICKER MODELING

3.1 Modeling Methodology

Shadow flicker was modeled using a software package, WindPRO version 3.6. WindPRO is a software suite developed by EMD International A/S and is used for assessing potential environmental impacts from wind turbines. Using the Shadow module within WindPRO, worst-case shadow flicker in the area surrounding the wind turbines was calculated based on data inputs including: location of the wind turbines, location of discrete receptor points, wind turbine dimensions, flicker calculation limits, and terrain data. Based on these data, the model was able to incorporate the appropriate sun angle and maximum daily sunlight for this latitude into the calculations. The resulting worst-case calculations assume that the sun is always shining during daylight hours and that the wind turbine is always operating. The WindPRO Shadow module can be further refined by incorporating sunshine probabilities and wind turbine operational estimates by wind direction over the course of a year. The values produced by this further refinement are known as the “expected” shadow flicker. Both worst-case and expected annual shadow flicker durations are presented in this section.

This analysis is for the wind turbine array sent to Epsilon on November 4, 2022. Locations of the turbines are shown in Figure 3-1 and the coordinates are provided in Appendix A. All 27 wind turbines are GE 1.5-97 wind turbines with a 97-meter rotor diameter and a hub height of 80 meters. This analysis also includes the 16 Langdon Wind I and Langdon Wind II wind turbines within 1.5 miles of a modeling receptor. Therefore, a total of 43 wind turbines were included in the shadow flicker model. Each wind turbine has the following characteristics based on either the technical data provided by Atwell or publicly available information:

		GE 1.5-97	GE 1.6-91
♦ Rated Power	=	1,600 kW	1,600 kW
♦ Hub Height	=	80 meters	80 meters
♦ Rotor Diameter	=	97 meters	91 meters
♦ Cut-in Wind Speed	=	3 m/s	3 m/s
♦ Cut-out Wind Speed	=	25 m/s	31 m/s
♦ Maximum RPM	=	16.2 rpm	-

To-date, there are no federal, state, or local regulations regarding the maximum radial distance from a wind turbine to which shadow flicker should be analyzed applicable to this Project. In the United States, shadow flicker is commonly evaluated out to a distance of ten times the rotor diameter. For this Project, ten times the largest rotor diameter of the proposed wind turbines corresponds to a distance of 0.6 miles (970 m). Conservatively, this analysis includes shadow flicker calculations out to 1.25 miles (2,012 m) from each wind turbine in the model for the proposed layout and existing wind turbines.

A modeling receptor dataset dated October 24, 2022 was provided to Epsilon. The dataset included 30 receptors. Atwell provided additional information indicating if each receptor was inhabited or uninhabited, the resulting 21 inhabited receptors were input to the WindPRO model. Each modeling point was assumed to have a window facing all directions ("greenhouse" mode) which yields conservative results. All modeling receptors are identified in Figure 3-1. The model was set to limit calculations to 2,012 meters from a wind turbine, the equivalent of 1.25 miles. Consequently, shadow flicker at any of the modeling receptors greater than the corresponding limitation distance from a wind turbine was zero. In addition to modeling discrete points, shadow flicker was calculated at grid points in the area surrounding the modeled wind turbines to generate flicker isolines. A 20-meter spacing was used for this grid.

The terrain height contour elevations for the modeling domain were generated from elevation information derived from the National Elevation Dataset (NED) developed by the U.S. Geological Survey. Conservatively, obstacles, i.e., buildings and vegetation, were excluded from the analysis. This is effectively a "bare earth" scenario which is conservative. When accounted for in the shadow flicker calculations, such obstacles may significantly mitigate or eliminate the flicker effect depending on their size, type, and location. In addition, shadow flicker durations were calculated only when the angle of the sun was at least 3° above the horizon.

Monthly sunshine probability values were input for each month from January to December. These numbers were obtained from a publicly available historical dataset for Bismarck, North Dakota from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI).[1] Table 3-1 shows the percentage of sunshine hours by month used in the shadow flicker modeling. These values are the percentages that the sun is expected to be shining during daylight hours.

The number of hours the wind turbines are expected to operate for the 16 cardinal wind directions was input into the model. A publicly available dataset[2] using measured data for a five-year period of hourly wind directions and wind speeds at 3 meters and 10 meters was obtained by Epsilon. Epsilon then scaled this dataset to 80 meters to calculate the typical annual number of operational hours per wind direction sector. These hours per wind direction sector are used by WindPRO to estimate the "wind direction" and "operation time" reduction factors. Based on this dataset, the wind turbines would operate 83% of the year. Table 3-2 shows the distribution of operational hours for the 16 wind directions.

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1 NCEI (formerly NCDC), https://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos20.dat. Accessed in December 2022.

2 North Dakota Agricultural Weather Network (NDAWN), 2017-2021, Langdon, ND.

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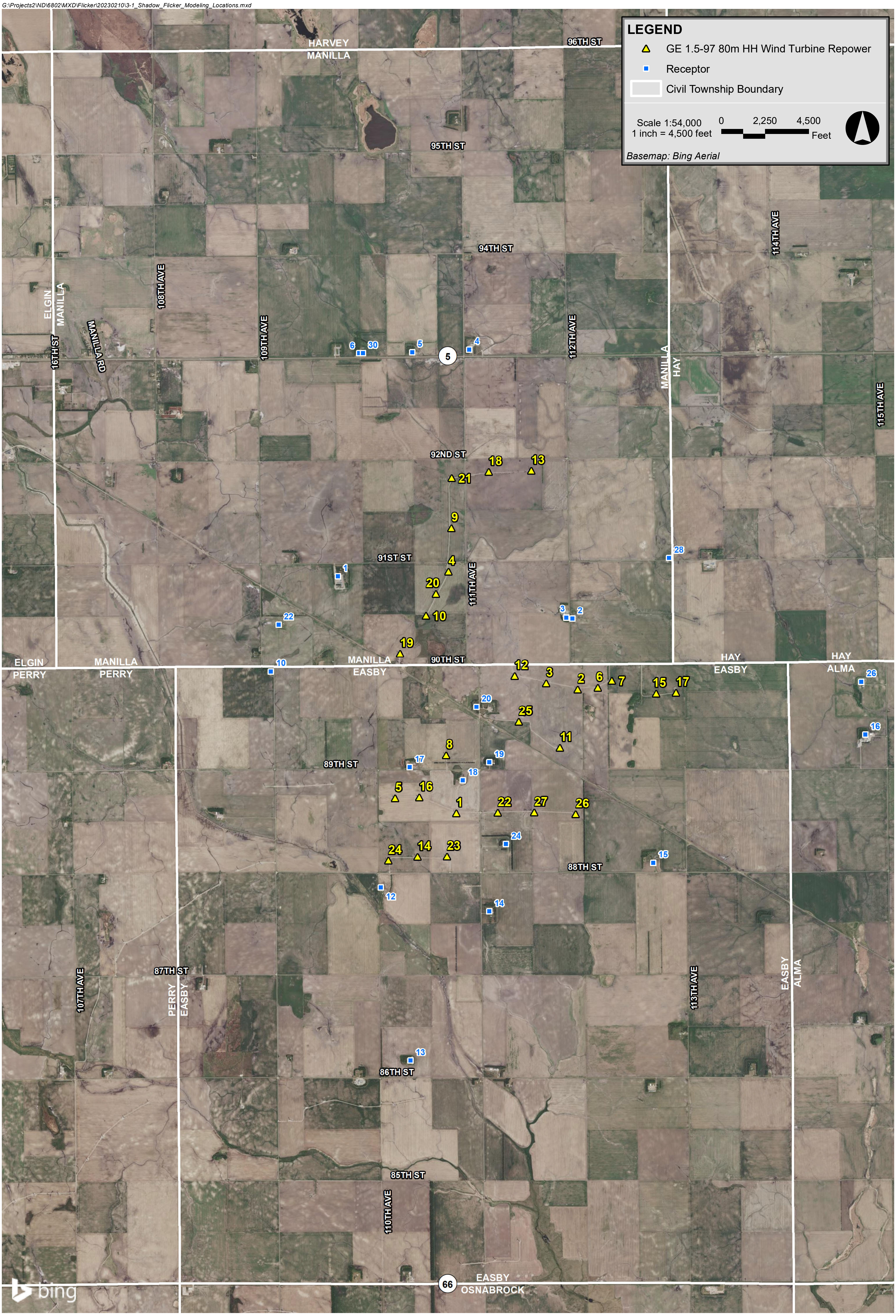

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Figure 3-1

Shadow Flicker Modeling Locations

Table 3-1 Monthly Percent of Possible Sunshine

Month	Possible Sunshine
January	54%
February	52%
March	61%
April	58%
May	64%
June	67%
July	75%
August	72%
September	67%
October	53%
November	42%
December	45%

Table 3-2 Operational Hours per Wind Direction Sector

Wind Sector	Operational Hours
N	455
NNE	394
NE	334
ENE	289
E	237
ESE	233
SE	307
SSE	402
S	550
SSW	581
SW	487
WSW	483
W	566
WNW	733
NW	775
NNW	411
Annual	7,237

3.2 Results

Following the modeling methodology outlined in Section 3.1, WindPRO was used to calculate shadow flicker at the 21 discrete modeling receptor points. Calculations were conducted for the Project + existing Langdon I and Langdon II (cumulative) scenarios. In addition to the discrete modeling points, shadow flicker isolines were generated based on the grid calculations for the cumulative scenario. Table B-1.1 in Appendix B presents the modeling results for the receptors sorted by ID. Table B-1.2 in Appendix B presents the modeling results for the receptors sorted by Expected Flicker. Both worst-case and expected values are presented.

The modeled worst-case annual shadow flicker duration for all 21 receptors ranged from 0 hours, 0 minutes per year to 61 hours, 13 minutes per year. The maximum flicker duration was at receptor #18.

The predicted expected annual shadow flicker duration ranged from 0 hours, 0 minutes per year to 18 hours, 21 minutes per year. The maximum expected flicker duration calculated was at receptor #17. Eight (8) of the receptors were predicted to experience no annual shadow flicker. Nine (9) of the receptors were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that 4 of the receptors would be expected to have between 10 hours and 30 hours of shadow flicker per year. Zero (0) receptors are expected to have over 30 hours of flicker per year. Figure 3-2 displays the modeled flicker isolines (expected hrs/yr) over aerial imagery in relation to modeled wind turbines and modeling receptors.

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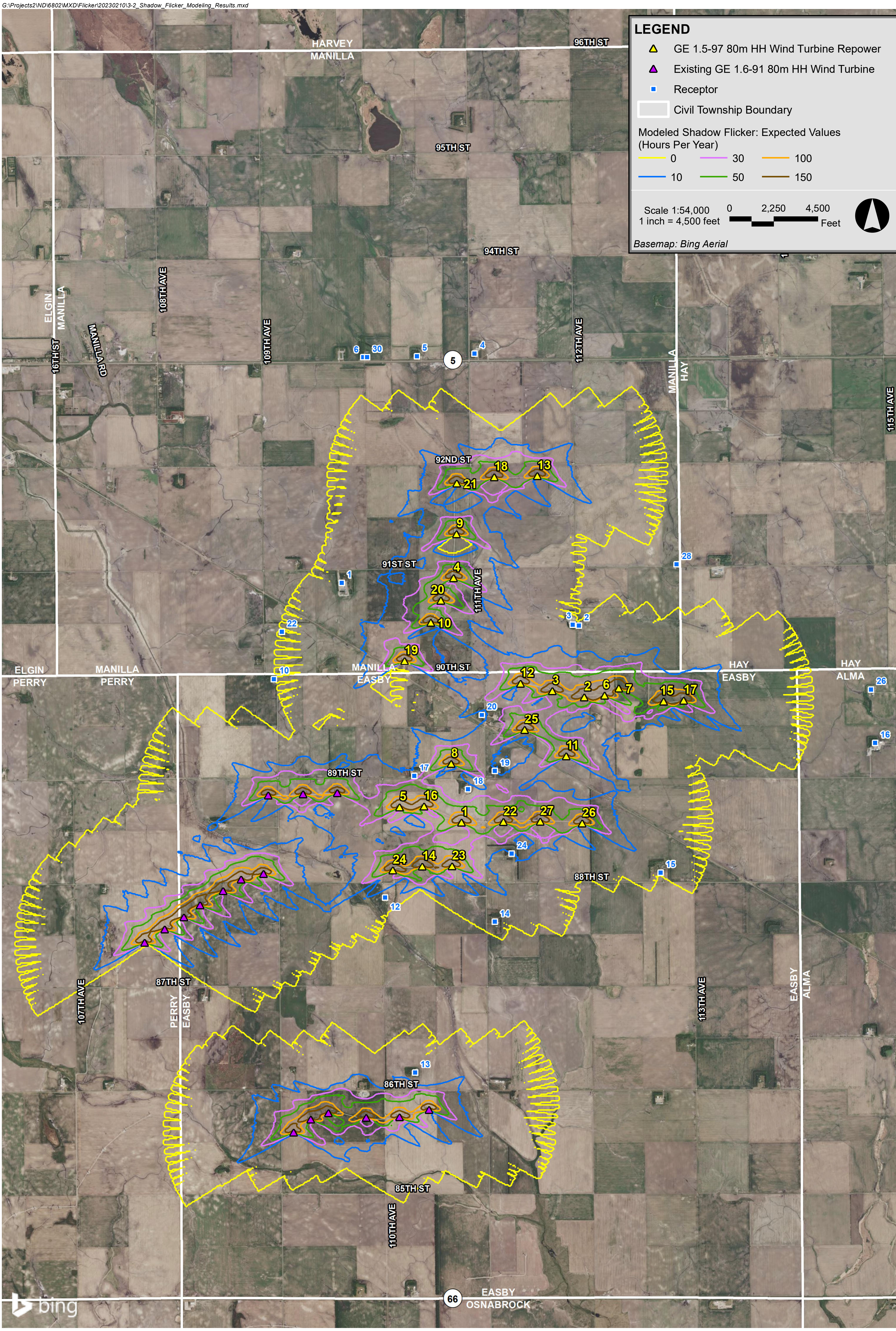

Otter Tail Langdon Wind Repower Cavalier County, North Dakota

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Figure 3-2

Shadow Flicker Modeling Results

Appendix A

Wind Turbine Coordinates

Table A-1: Wind Turbine Coordinates

Wind Turbine ID	Wind Turbine Type	Hub Height (m)	Coordinates NAD83 UTM Zone 14N (meters)	
			X (Easting)	Y (Northing)
1	GE 1.5-97	80	554586.54	5394016.06
2	GE 1.5-97	80	556487.15	5395957.99
3	GE 1.5-97	80	555993.44	5396053.20
4	GE 1.5-97	80	554460.98	5397805.59
5	GE 1.5-97	80	553627.01	5394251.82
6	GE 1.5-97	80	556803.45	5395983.30
7	GE 1.5-97	80	557022.92	5396097.03
8	GE 1.5-97	80	554422.73	5394925.71
9	GE 1.5-97	80	554506.00	5398484.16
10	GE 1.5-97	80	554107.45	5397113.03
11	GE 1.5-97	80	556209.54	5395043.50
12	GE 1.5-97	80	555499.47	5396170.35
13	GE 1.5-97	80	555761.58	5399385.76
14	GE 1.5-97	80	553974.95	5393332.01
15	GE 1.5-97	80	557716.46	5395892.46
16	GE 1.5-97	80	554002.47	5394266.09
17	GE 1.5-97	80	558025.59	5395907.10
18	GE 1.5-97	80	555093.15	5399368.14
19	GE 1.5-97	80	553701.25	5396519.70
20	GE 1.5-97	80	554265.70	5397458.96
21	GE 1.5-97	80	554512.89	5399273.42
22	GE 1.5-97	80	555233.79	5394022.39
23	GE 1.5-97	80	554438.15	5393336.49
24	GE 1.5-97	80	553518.98	5393272.06
25	GE 1.5-97	80	555565.55	5395448.41
26	GE 1.5-97	80	556455.78	5394000.98
27	GE 1.5-97	80	555807.60	5394028.07

Appendix B

Shadow Flicker Modeling Results: Modeling Receptors

Table B-1.1: Shadow Flicker Modeling Results at Discrete Points - Sorted by Receptor ID

Receptor ID	Coordinates NAD83 UTM Zone 14N (meters)		Worst Case Shadow Flicker Hours per Year	Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM/year)	(HH:MM/year)
1	552727.47	5397731.93	5:10	1:34
2	556403.32	5397067.11	12:47	3:07
3	556310.83	5397083.06	3:28	0:56
4	554786.86	5401286.18	0:00	0:00
5	553893.01	5401245.18	0:00	0:00
6	553064.00	5401229.01	0:00	0:00
10	551679.19	5396237.94	0:00	0:00
12	553399.70	5392853.28	9:32	3:24
13	553865.94	5390139.19	20:11	5:01
14	555099.83	5392477.80	1:52	0:41
15	557670.73	5393238.99	4:26	1:37
16	560994.89	5395249.28	0:00	0:00
17	553852.25	5394735.12	56:50	18:21
18	554687.38	5394531.49	61:13	16:39
19	555101.52	5394814.86	33:36	10:41
20	554900.85	5395685.10	26:44	8:06
22	551800.82	5396971.39	0:26	0:07
24	555362.96	5393534.70	30:17	10:28
26	560931.88	5396078.47	0:00	0:00
28	557918.14	5398017.75	0:00	0:00
30	553120.55	5401228.25	0:00	0:00

Table B-1.2: Shadow Flicker Modeling Results at Discrete Points - Sorted by Expected Flicker

Receptor ID	Coordinates NAD83 UTM Zone 14N (meters)		Worst Case Shadow Flicker Hours per Year	Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM/year)	(HH:MM/year)
17	553852.25	5394735.12	56:50	18:21
18	554687.38	5394531.49	61:13	16:39
19	555101.52	5394814.86	33:36	10:41
24	555362.96	5393534.70	30:17	10:28
20	554900.85	5395685.10	26:44	8:06
13	553865.94	5390139.19	20:11	5:01
12	553399.70	5392853.28	9:32	3:24
2	556403.32	5397067.11	12:47	3:07
15	557670.73	5393238.99	4:26	1:37
1	552727.47	5397731.93	5:10	1:34
3	556310.83	5397083.06	3:28	0:56
14	555099.83	5392477.80	1:52	0:41
22	551800.82	5396971.39	0:26	0:07
4	554786.86	5401286.18	0:00	0:00
5	553893.01	5401245.18	0:00	0:00
6	553064.00	5401229.01	0:00	0:00
10	551679.19	5396237.94	0:00	0:00
16	560994.89	5395249.28	0:00	0:00
26	560931.88	5396078.47	0:00	0:00
28	557918.14	5398017.75	0:00	0:00
30	553120.55	5401228.25	0:00	0:00