SHADOW FLICKER MODELING REPORT

Shelby Wind Project
Orleans County, New York

Prepared for:

Borrego Solar Systems, Inc
30 Century Hill Drive, Suite 301
Latham, NY 12110

Prepared by:

Epsilon Associates, Inc.
3 Mill & Main Place, Suite 250
Maynard, MA 01754

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1.0 EXECUTIVE SUMMARY

The Shelby Wind Project (the Project) is a proposed wind power generation facility expected to consist of two (2) wind turbines in Orleans County, New York. The Project is being developed by Borrego Solar Systems, Inc. (Borrego). Epsilon Associates Inc. (Epsilon) has been retained by Borrego to conduct a shadow flicker modeling study for this Project. This report presents results of the shadow flicker modeling of the proposed wind turbines in Orleans County.

Shadow flicker modeling was conducted for two Vestas wind turbines. The purpose of this analysis is to predict the annual durations of wind turbine shadow flicker at nearby receptors.

The maximum expected annual duration of shadow flicker at a modeling receptor resulting from the operation of the two proposed wind turbines is 19 hours, 34 minutes. 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").

Borrego is considering two possible wind turbine models for the Project, a Vestas V150-4.3 or a GE 3.4-140. Both potential wind turbines utilize a 120m hub height. This report presents results for the Vestas wind turbine. If the GE wind turbine was selected, predicted expected shadow flicker durations would be lower at all modeled locations due to the unit's shorter blade length.

2.0 INTRODUCTION

The proposed Project will consist of two (2) wind turbines. Both proposed wind turbines are Vestas V150-4.3 units with a hub height of 120 meters. Figure 2-1 shows the locations of the 2 wind turbines in Orleans County 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 Borrego. 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.

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Data Source: Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services

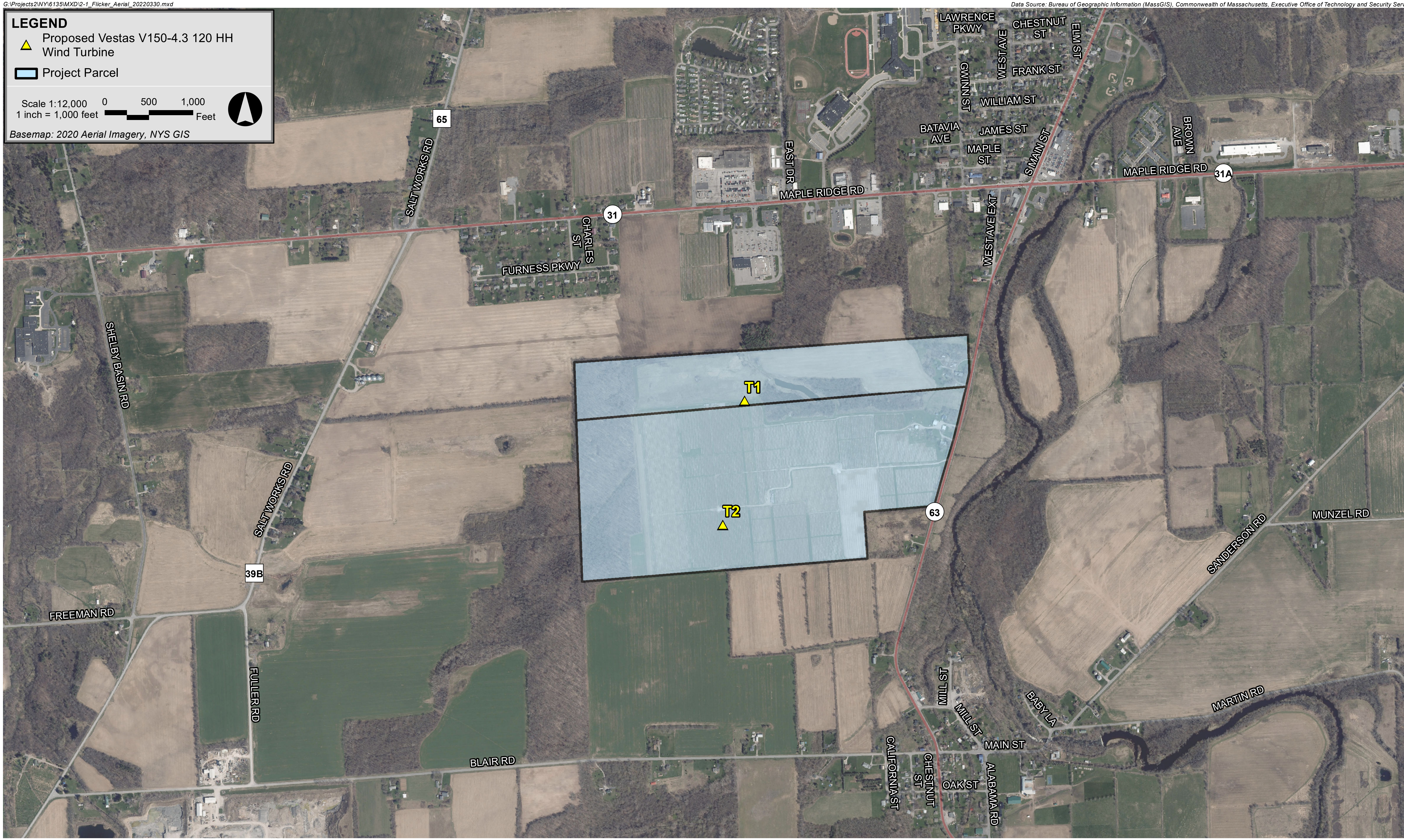

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Figure 2-1

Aerial Locus

3.0 SHADOW FLICKER MODELING

3.1 Modeling Methodology

Shadow flicker was modeled using a software package, WindPRO version 3.4. 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 provided to Epsilon on March 24, 2022. Locations of the turbines are shown in Figure 3-1 and the coordinates are provided in Appendix A. Both wind turbines are Vestas V150-4.3 units with a 150-meter rotor diameter and a hub height of 120 meters. Each wind turbine has the following characteristics based on the technical data provided by Borrego:

		Vestas <u>V150-4.3</u>
♦ Rated Power	=	4,300 kW
♦ Hub Height	=	120 meters
♦ Rotor Diameter	=	150 meters
♦ Cut-in Wind Speed	=	3 m/s
♦ Cut-out Wind Speed	=	24.5 m/s

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. According to the Massachusetts Model Bylaw for wind energy facilities, shadow flicker impacts are minimal at and beyond a distance of ten rotor diameters.[1] Defining the shadow flicker calculation area has also been addressed in Europe where the ten times rotor diameter approach

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[1] Massachusetts Department of Energy Resources, "Model As-of-Right Zoning Ordinance or Bylaw: Allowing Use of Wind Energy Facilities" 2009.

has been accepted in multiple European countries.[2] Some jurisdictions conservatively require a larger calculation area. The New Hampshire Site Evaluation Committee through rulemaking docket 2014-04 adopted rules on December 15, 2015 outlining application requirements and criteria for energy facilities, including wind energy facilities. As part of these revised regulations, Site 301.08(a)(2) requires an evaluation distance of at least 1 mile from a wind turbine.[3] Section 16-50j-94, part (g), of the Regulations of Connecticut State Agencies identifies the components required in a shadow flicker evaluation report which includes the calculation of shadow flicker from each proposed wind turbine to any off-site occupied structure within a 1.25 mile radius.[4] For this Project, ten times the largest rotor diameter of the proposed wind turbines corresponds to a distance of 0.93 miles (1,500 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.

Epsilon generated a modeling receptor dataset consisting of 166 receptors via a desktop analysis. The dataset is representative of residential, commercial, and industrial buildings in the vicinity of the Project. 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 166 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 as shown in Figure 3-2.

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 Buffalo, New York from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental

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2 Parsons Brinckerhoff, "Update of UK Shadow Flicker Evidence Base" Prepared for Department of Energy and Climate Change, 2011.

3 State of New Hampshire Site Evaluation Committee Site 300 Rules (2015), available at http://www.gencourt.state.nh.us/rules/state_agencies/site100-300.html Accessed in April 2021.

4 State of Connecticut CSC Wind Regulations (2014), available at https://eregulations.ct.gov/eRegsPortal/Browse/RCSA?id=Title_16Subtitle_16-50jSection_16-50j-94&content=shadow%20flicker/ Accessed in April 2021.

Information (NCEI).[5] 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 10-minute dataset for a one year period of wind directions and wind speed was provided by Borrego at various heights, Epsilon then scaled this data to the hub height of 120 meters. Epsilon used this data 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 90% of the year. Table 3-2 shows the distribution of operational hours for the 16 wind directions.

5 NCEI (formerly NCDC), http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos15.dat. Accessed in April 2021.

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Data Source: Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services

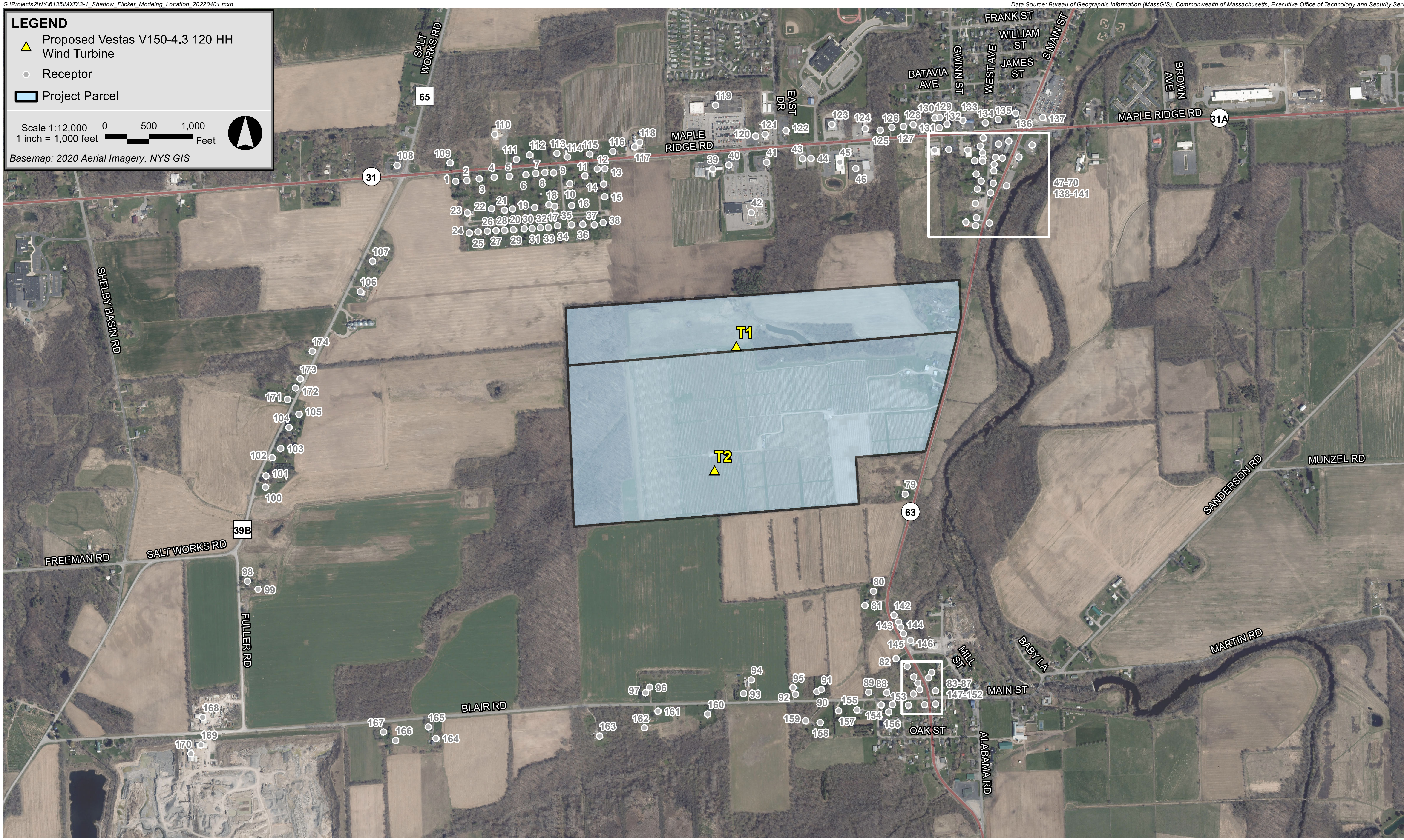

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Figure 3-1

Shadow Flicker Modeling Locations

Table 3-1 Monthly Percent of Possible Sunshine

Month	Possible Sunshine
January	31%
February	36%
March	45%
April	54%
May	59%
June	62%
July	66%
August	63%
September	56%
October	44%
November	29%
December	23%

Table 3-2 Operational Hours per Wind Direction Sector

Wind Sector	Operational Hours
N	190
NNE	157
NE	262
ENE	364
E	333
ESE	295
SE	295
SSE	276
S	383
SSW	780
SW	1413
WSW	992
W	712
WNW	671
NW	466
NNW	284
Annual	7873

3.2 Shadow Flicker Modeling Results

Following the modeling methodology outlined in Section 3.1, WindPRO was used to calculate shadow flicker at the 166 discrete modeling receptor points. In addition to the discrete modeling points, shadow flicker isolines were generated based on the grid calculations for the Project.

Table B-1 in Appendix B presents the modeling results, both worst-case and expected values are presented.

The predicted expected annual shadow flicker duration ranged from 0 hours, 0 minutes per year to 19 hours, 34 minutes per year for all 166 receptors. The maximum expected flicker modeled occurs at receptor #79. 63 of the 166 receptors were predicted to experience no annual shadow flicker. 95 receptors were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that eight (8) 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 hours per year) over aerial imagery in relation to modeled wind turbines and modeling receptors.

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Data Source: Bureau of Geographic Information (MassGIS), Commonwealth of Massachusetts, Executive Office of Technology and Security Services

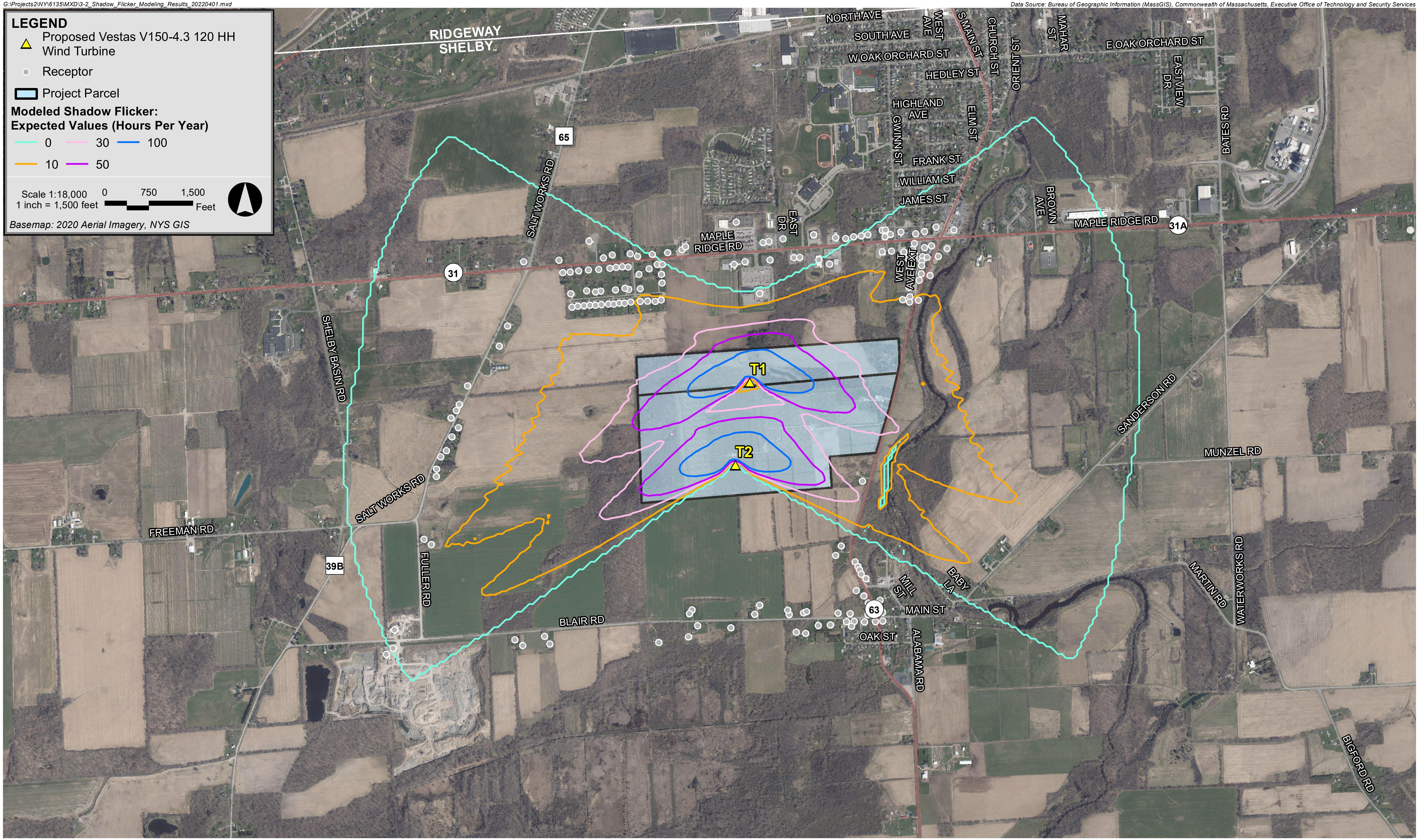

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Figure 3-2

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 17N (meters)	
			X (Easting)	Y (Northing)
1	Vestas V150 4.3 or GE 3.4-140	120	711203.89	4786388.16
2	Vestas V150 4.3 or GE 3.4-140	120	711128.92	4785959.76

Appendix B

Shadow Flicker Modeling Results: Modeling Receptors

Table B-1: Shadow Flicker Modeling Results at Discrete Points - Sorted by Receptor ID

Receptor ID	Coordinates UTM NAD83 Zone 17N (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	710235.63	4786955.88	24:48	3:47
2	710274.79	4786958.77	28:22	4:13
3	710317.50	4786965.68	34:27	4:54
4	710369.26	4786970.64	44:21	5:59
5	710421.51	4786973.37	46:50	6:14
6	710479.38	4786979.08	46:09	6:04
7	710512.36	4786983.45	43:48	5:42
8	710543.74	4786986.66	40:59	5:18
9	710574.83	4786985.95	38:13	4:54
10	710630.34	4786947.71	43:47	5:39
11	710681.72	4786975.49	26:45	3:17
12	710724.65	4786998.75	9:07	1:03
13	710750.99	4786999.82	3:07	0:20
14	710746.91	4786947.01	26:43	3:16
15	710750.29	4786903.51	45:43	5:50
16	710636.71	4786873.31	65:21	8:45
17	710578.05	4786869.51	64:40	8:47
18	710558.23	4786875.51	62:41	8:31
19	710509.02	4786866.21	56:50	7:53
20	710431.81	4786860.31	37:50	5:49
21	710404.91	4786856.37	34:03	5:24
22	710359.78	4786861.97	30:05	4:53
23	710276.88	4786847.35	24:03	4:16
24	710282.43	4786778.30	29:59	5:21
25	710313.33	4786781.97	26:55	5:03
26	710345.41	4786784.13	26:54	5:06
27	710375.49	4786786.62	28:54	5:21
28	710404.76	4786787.53	31:05	5:37
29	710435.13	4786790.02	33:51	5:57
30	710472.59	4786793.13	37:57	6:26
31	710499.87	4786793.97	41:35	6:52
32	710528.51	4786797.19	46:26	7:25
33	710555.82	4786797.26	51:53	8:02
34	710587.78	4786803.31	64:49	9:24
35	710636.62	4786806.38	76:42	10:45
36	710674.94	4786809.12	81:25	11:15
37	710714.27	4786806.84	85:05	11:40
38	710744.77	4786814.40	83:33	11:21
39	711122.65	4786998.64	0:00	0:00
40	711178.59	4787013.34	0:00	0:00
41	711308.64	4787022.57	0:00	0:00
42	711255.75	4786848.57	16:23	2:15
43	711432.47	4787034.83	0:00	0:00

Table B-1: Shadow Flicker Modeling Results at Discrete Points - Sorted by Receptor ID

Receptor ID	Coordinates UTM NAD83 Zone 17N (meters)		Worst Case Shadow Flicker Hours per Year	Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM/year)	(HH:MM/year)
44	711462.63	4787035.77	0:00	0:00
45	711561.71	4787022.98	0:00	0:00
46	711616.96	4787000.90	19:52	3:06
47	711889.56	4787064.15	39:05	6:49
48	711938.22	4787067.25	41:13	7:17
49	712002.77	4787063.71	42:28	7:40
50	712046.45	4787077.77	40:11	7:18
51	712056.57	4787106.66	38:17	6:52
52	712055.10	4787055.10	39:31	7:20
53	712055.83	4787036.79	36:37	6:58
54	712055.10	4787026.17	33:55	6:36
55	712026.91	4787026.91	40:40	7:38
56	712032.40	4786981.51	31:48	6:22
57	712049.24	4786957.35	28:31	5:54
58	712036.43	4786929.89	31:55	6:34
59	712029.11	4786880.47	39:18	8:10
60	712033.50	4786831.05	47:16	9:57
61	712030.57	4786803.59	51:18	10:54
62	711996.53	4786816.41	48:42	10:20
63	712109.28	4787085.48	35:30	6:37
64	712144.79	4787095.00	30:15	5:47
65	712099.40	4787039.35	29:09	5:44
66	712123.19	4787036.06	26:25	5:16
67	712094.64	4787015.56	27:45	5:33
68	712093.17	4786993.23	26:31	5:24
69	712091.71	4786950.39	31:24	6:21
70	712081.83	4786916.71	35:58	7:20
79	711787.07	4785876.38	57:14	19:34
80	711678.31	4785540.99	0:00	0:00
81	711648.70	4785492.59	0:00	0:00
82	711755.68	4785308.60	0:00	0:00
83	711795.11	4785281.64	0:00	0:00
84	711817.14	4785245.41	0:00	0:00
85	711830.76	4785224.25	0:00	0:00
86	711837.14	4785201.64	0:00	0:00
87	711815.98	4785185.98	0:00	0:00
88	711723.51	4785190.04	0:00	0:00
89	711661.47	4785192.94	0:00	0:00
90	711482.53	4785194.01	0:00	0:00
91	711497.87	4785201.35	0:00	0:00
92	711408.14	4785185.67	0:00	0:00
93	711229.67	4785187.00	0:00	0:00
94	711256.03	4785235.04	0:00	0:00

Table B-1: Shadow Flicker Modeling Results at Discrete Points - Sorted by Receptor ID

Receptor ID	Coordinates UTM NAD83 Zone 17N (meters)		Worst Case Shadow Flicker Hours per Year	Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM/year)	(HH:MM/year)
95	711400.80	4785208.35	0:00	0:00
96	710905.44	4785209.45	0:00	0:00
97	710891.81	4785190.54	0:00	0:00
98	709517.31	4785575.19	14:57	5:51
99	709554.60	4785548.15	17:56	7:07
100	709579.99	4785900.09	14:01	4:53
101	709581.60	4785939.11	13:54	4:44
102	709602.98	4786002.18	14:06	4:42
103	709632.91	4786034.25	14:44	4:53
104	709661.24	4786106.41	15:32	4:57
105	709695.45	4786152.91	16:31	5:05
106	709907.20	4786575.68	25:09	5:14
107	709949.99	4786680.44	30:02	5:26
108	710033.60	4787012.42	15:56	2:32
109	710216.56	4787019.80	27:45	3:59
110	710370.99	4787119.15	25:54	3:15
111	710446.73	4787032.09	37:28	4:50
112	710491.49	4787047.83	30:26	3:51
113	710585.43	4787053.24	16:34	1:59
114	710622.31	4787040.95	14:10	1:41
115	710698.55	4787050.29	0:00	0:00
116	710778.72	4787059.63	0:00	0:00
117	710853.47	4787075.37	0:00	0:00
118	710871.18	4787091.11	0:00	0:00
119	711132.83	4787218.99	0:00	0:00
120	711271.53	4787112.26	0:00	0:00
121	711303.50	4787118.65	0:00	0:00
122	711375.79	4787131.93	0:00	0:00
123	711534.65	4787153.08	0:00	0:00
124	711649.25	4787138.33	0:00	0:00
125	711700.89	4787133.41	0:00	0:00
126	711742.21	4787142.75	0:00	0:00
127	711781.55	4787146.69	2:18	0:20
128	711815.00	4787152.59	6:47	1:01
129	711890.25	4787175.71	12:43	2:01
130	711906.97	4787176.69	15:04	2:25
131	711905.00	4787141.77	23:12	3:50
132	711932.05	4787154.07	23:38	3:56
133	711987.14	4787167.35	26:26	4:28
134	712063.86	4787158.00	33:05	5:48
135	712108.62	4787170.30	32:59	5:49
136	712168.13	4787192.43	31:48	5:39

Table B-1: Shadow Flicker Modeling Results at Discrete Points - Sorted by Receptor ID

Receptor ID	Coordinates UTM NAD83 Zone 17N (meters)		Worst Case Shadow Flicker Hours per Year	Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM/year)	(HH:MM/year)
137	712261.57	4787176.69	24:27	4:39
138	712225.67	4787081.77	21:05	4:14
139	712179.93	4787040.45	23:48	4:44
140	712137.14	4786940.61	35:06	7:03
141	712077.63	4786813.23	50:31	10:42
142	711749.09	4785458.25	0:00	0:00
143	711764.83	4785434.15	0:00	0:00
144	711772.21	4785417.42	0:00	0:00
145	711781.55	4785394.80	0:00	0:00
146	711805.65	4785371.19	0:00	0:00
147	711879.43	4785260.04	0:00	0:00
148	711869.10	4785242.33	0:00	0:00
149	711891.72	4785197.09	0:00	0:00
150	711892.28	4785151.59	0:00	0:00
151	711854.81	4785149.29	0:00	0:00
152	711798.60	4785147.64	0:00	0:00
153	711744.37	4785150.93	0:00	0:00
154	711704.60	4785148.96	0:00	0:00
155	711621.11	4785131.54	0:00	0:00
156	711730.24	4785123.98	0:00	0:00
157	711558.33	4785128.91	0:00	0:00
158	711493.57	4785088.15	0:00	0:00
159	711444.27	4785093.41	0:00	0:00
160	711105.71	4785116.75	0:00	0:00
161	710934.13	4785127.27	0:00	0:00
162	710887.13	4785069.41	0:00	0:00
163	710733.30	4785041.15	0:00	0:00
164	710168.27	4785033.26	0:00	0:00
165	710141.65	4785072.04	0:00	0:00
166	710028.90	4785026.03	0:00	0:00
167	709987.16	4785054.95	0:00	0:00
168	709363.57	4785105.89	7:39	3:08
169	709357.22	4785010.64	12:20	5:06
170	709322.29	4784979.95	0:00	0:00
171	709656.41	4786203.76	15:49	4:41
172	709683.55	4786243.22	16:25	4:42
173	709699.27	4786274.06	16:49	4:45
174	709741.82	4786369.95	18:10	4:46