SHADOW FLICKER ANALYSIS

Antrim Wind Energy Project

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1.0 EXECUTIVE SUMMARY

The Antrim Wind Energy Project (the Project) is a proposed 28.8 megawatt (MW) wind power generation facility composed of nine (9) wind turbines in Hillsborough County, New Hampshire. The proposed Project will be entirely within the Town of Antrim, generally located on Tuttle Hill south of NH Route 9. The Project is being developed by Antrim Wind Energy, LLC (AWE) who has retained Epsilon Associates, Inc. (Epsilon) to conduct a shadow flicker analysis for the proposed wind turbines for this Project.

The shadow flicker analysis includes nine wind turbines, all of which are proposed to be Siemens SWT-3.2-113 3.2 MW wind turbines. The purpose of this assessment is to predict the expected annual duration of shadow flicker at modeled locations in the vicinity of the Project due to the operation of the proposed wind turbines. There are no federal, state, or local regulations limiting the amount of shadow flicker resulting from the operation of the proposed wind turbines for this Project. However, the predicted shadow flicker at occupied buildings in the vicinity of the Project can be put into context by comparing the annual duration of shadow flicker to a typical guideline value. In the absence of a definitive regulation, the duration of shadow flicker is typically compared to a value of 30 hours per year for evaluating impacts as this annual duration of shadow flicker is often the limit identified in wind energy regulations with shadow flicker limits. The expected annual duration of shadow flicker at modeling locations for the current layout ranges from 0 hours, 0 minutes per year to 10 hours, 10 minutes per year, and therefore, will not result in a significant impact.

2.0 INTRODUCTION

The proposed Antrim Wind Energy Project to be located in Antrim, New Hampshire will consist of a nine (9) wind turbine layout. The proposed wind turbines are Siemens SWT-3.2-113 3.2 MW units with a rotor diameter of 113 meters. Eight (8) of the wind turbines will have a 92.5 meter hub height while one wind turbine will have a 79.5 meter hub height.

With respect to wind turbines, 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. Indoors, an observer experiences repeated changes in the brightness of the room as shadows cast from the wind turbine blades briefly pass by windows as the rotor gyrates. In order for this to occur, the wind turbine must be operating and the sun must be shining. A stationary wind turbine only generates a stationary shadow similar to any other structure.

This report presents the findings of the shadow flicker modeling for the proposed wind turbines at Antrim Wind. The wind turbines were modeled in WindPRO using information provided by AWE. The expected annual duration of shadow flicker was calculated at discrete modeling locations and shadow flicker isolines for the area surrounding the Project were generated. The results of this analysis are found within this report.

3.0 REGULATIONS AND EVALUATION CRITERIA

3.1 Federal Regulations

There are no federal shadow flicker regulations applicable to this Project.

3.2 New Hampshire State Regulations

There are no statewide shadow flicker regulations applicable to this Project.

3.3 Local Regulations

There are no county or municipal ordinances applicable to this Project regarding shadow flicker.

3.4 Evaluation Criteria

Although there are no shadow flicker regulations with specific limits directly applicable to this Project, this issue has been addressed in other jurisdictions. According to the Danish Wind Industry Association (DWIA), a German court has ruled that 30 hours of actual shadow flicker per year was acceptable at a neighbor's property.[1] In addition, a 30 hour per year limit has been adopted by multiple jurisdictions in the United States. For example, in Connecticut, Section 16-50j-95, part (c) of the Regulations of Connecticut State Agencies limits the annual duration of shadow flicker to 30 hours at any off-site occupied structure.[2] In 2008, the New Hampshire Office of Energy and Planning released a model ordinance for small wind energy systems which included a shadow flicker limit of 30 hours per year for abutting occupied buildings.[3] For a recent project in New Hampshire, a shadow flicker limit was not a component of the Certificate of Site and Facility with Conditions which was issued to Groton Wind, LLC.[4]

In the absence of regulations, the predicted duration of shadow flicker is often put into context by comparing expected shadow flicker impacts at residences to a guideline value of 30 hours per year. Therefore, 30 hours per year of shadow flicker was used as the evaluation level for occupied buildings in this analysis.

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1 Danish Wind Industry Association, 2003. http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/env/shadow/index.htm. Accessed in December 2014.

2 State of Connecticut, 2014. http://www.sots.ct.gov/sots/lib/sots/regulations/recentlyadopted/ecopy_reg_6158.pdf. Accessed in December 2014.

3 New Hampshire Office of Energy and Planning. http://www.nh.gov/oep/resource-library/energy/wind-systems.htm. Accessed in December 2014.

4 State of New Hampshire Site Evaluation Committee. Docket No. 2010-01. May 6, 2011.

4.0 SHADOW FLICKER ANALYSIS

4.1 Modeling Methodology

Shadow flicker was modeled using a software package, WindPRO version 2.9.285. WindPRO is a software suite developed by EMD International A/S and is used for assessing potential environmental impacts from wind turbines. 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 modeling points, wind turbine dimensions, 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 the day and that the wind turbine is always operating. The WindPRO shadow flicker 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 for this further refinement, also known as the "expected" shadow flicker, are presented in this section.

The proposed wind turbine layout for the Project was provided by AWE. This layout includes nine (9) proposed wind turbines. The locations for the wind turbines to be located in the Town of Antrim are presented in Figure 4-1. All proposed wind turbines are Siemens SWT-3.2-113 3.2 MW units. Each proposed wind turbine has the following characteristics based on the technical data provided by AWE:

- Rated Power = 3,200 kW
- Hub Height = 92.5 meters (WTG #1-8) / 79.5 meters (WTG #9)
- Rotor Diameter = 113 meters
- Cut-in Wind Speed = 3 m/s
- Cut-out Wind Speed = 25 m/s

To-date, there are no federal, state, or local regulations or guidelines applicable to this Project regarding the maximum radial distance from a wind turbine to which shadow flicker should be analyzed. In the United States, shadow flicker is commonly evaluated out to a distance of ten times the rotor diameter or 1,000 meters. For example, the Ohio Power Siting Board has required shadow flicker to be analyzed out to 1,000 meters from a wind turbine. According to the Massachusetts Model Bylaw for wind energy facilities, shadow flicker impacts are minimal at and beyond a distance of ten rotor diameters.[5] Defining the shadow flicker calculation area has also been addressed in Europe where the ten times rotor diameter approach has been accepted in multiple European countries.[6] For this Project, ten

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

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

times the rotor diameter of the proposed wind turbine corresponds to a distance of 1,130 meters. The analysis includes shadow flicker calculations out to this specified distance from each wind turbine in the model.

The modeling locations in the vicinity of the Project were provided by AWE. A total of 155 locations were used in this shadow flicker analysis and are shown in Figure 4-1. Each modeling point was assumed to have a window facing all directions ("greenhouse" mode) which yields conservative results.

The model was set to limit calculations to 1,130 meters from a wind turbine, the equivalent of ten times the rotor diameter. Therefore, shadow flicker at any of the 155 modeling receptors greater than 1,130 meters from a wind turbine were zero. In addition to modeling discrete receptors, shadow flicker was calculated at grid points in the area surrounding the modeled wind turbines. 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 and processed by the U.S. Department of Agriculture Service Center Agencies. Conservatively, obstacles, i.e. buildings and vegetation, were excluded from the analysis. When accounted for, such obstacles may significantly mitigate or eliminate the shadow 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 Concord, New Hampshire from the National Climatic Data Center (NCDC).[7] Table 4-1 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. These hours were generated from a joint frequency distribution of wind speed and wind direction of extrapolated 92.5 meter wind data provided by AWE. 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 94% of the year due to cut-in and cut-out specifications of the proposed unit. Table 4-2 shows the distribution of operational hours for the 16 wind directions.

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7 NCDC, http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos12.txt. Accessed in October 2014.

4.2 Results

Following the modeling methodology outlined in section 4.1, WindPRO was used to calculate shadow flicker at the 155 discrete modeling points and to generate shadow flicker isolines based on the grid calculations. The table in Appendix A presents the results for the 155 modeling locations. The predicted shadow flicker duration ranged from 0 hours, 0 minutes per year to 10 hours, 10 minutes per year. The majority of the modeling locations (136) were predicted to experience no shadow flicker. A total of 18 locations were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that one (1) location would be expected to have 10 – 30 hours of shadow flicker per year while no locations would be expected to have over 30 hours of shadow flicker per year. The results of the shadow flicker modeling are shown graphically in Figure 4-2.

Table 4-1 Monthly Percent of Possible Sunshine

Month	Possible Sunshine
January	52%
February	55%
March	53%
April	53%
May	55%
June	58%
July	62%
August	60%
September	56%
October	53%
November	42%
December	47%

Table 4-2 Operational Hours per Wind Direction Sector

Wind Sector	Operational Hours
N	263
NNE	124
NE	198
ENE	218
E	204
ESE	229
SE	324
SSE	304
S	392
SSW	419
SW	584
WSW	641
W	1,028
WNW	1,312
NW	1,372
NNW	628
Annual	8,240

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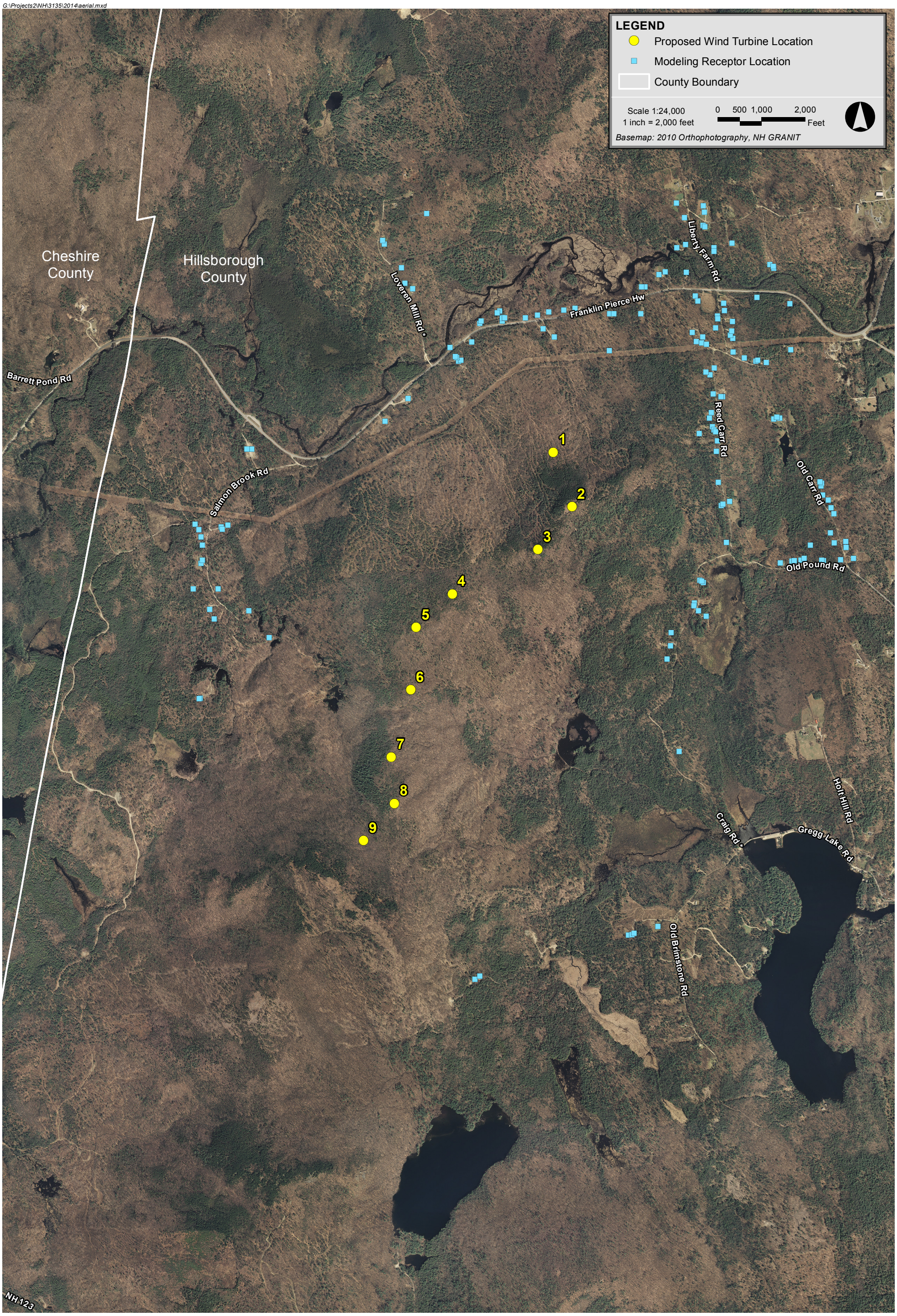

Antrim Wind **Antrim, New Hampshire**

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Figure 4-1
Aerial Locus Map

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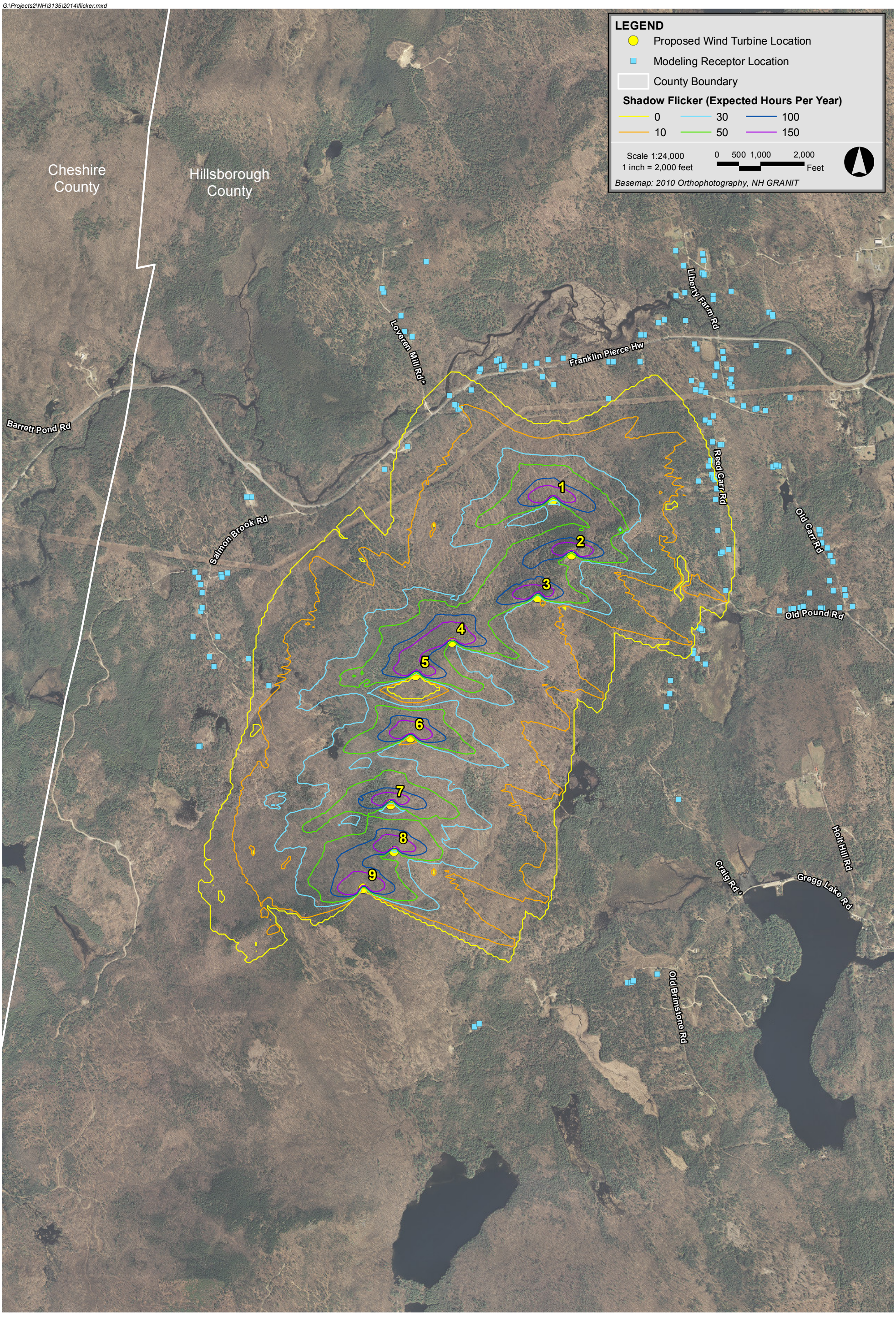

Antrim Wind **Antrim, New Hampshire**

Epsilon ASSOCIATES INC.

Figure 4-2
Shadow Flicker Modeling Results

5.0 CONCLUSIONS

A shadow flicker analysis was conducted to calculate the duration and location of shadow flicker in the vicinity of the Antrim Wind Energy Project. Nine (9) Siemens SWT-3.2-113 3.2 MW wind turbines are proposed for the Project. Shadow flicker resulting from the operation of these nine (9) wind turbines was calculated at 155 discrete modeling points and isolines were generated from a grid encompassing the area surrounding the wind turbines. There are no federal, state, or local regulations limiting the amount of shadow flicker resulting from the operation of the proposed wind turbines for this Project. However, in the absence of a definitive regulation, the duration of shadow flicker is typically compared to a value of 30 hours per year for evaluating impacts as this annual duration of shadow flicker is often the limit identified in wind energy regulations with shadow flicker limits. The expected annual duration of shadow flicker at modeling locations for the current layout ranges from 0 hours, 0 minutes per year to 10 hours, 10 minutes per year, and therefore, will not result in a significant impact. This analysis is conservative in that modeling locations were treated as "greenhouses" and obstacles such as structures and vegetation were not included.

Appendix A
Shadow Flicker Modeling Results – Discrete Points

Appendix A - Shadow Flicker Modeling Results - Discrete Points

Modeling ID	NAD83 New Hampshire State Plane Coordinates (meters)		Expected Shadow Flicker Hours per Year (hr:min/year)
	X (Easting)	Y (Northing)	
1	271037.60	63320.34	0:00
2	271199.03	63480.59	3:35
3	271549.49	63740.04	9:23
4	271565.96	63747.81	10:10
5	271538.09	63766.01	9:29
6	271527.52	63771.85	9:19
7	271642.21	63874.28	4:08
8	271854.78	64020.19	0:00
9	271859.64	64044.57	0:00
10	271853.23	64040.81	0:00
11	271872.10	64042.11	0:00
12	271837.47	64092.07	0:00
13	271697.84	64003.97	0:00
14	271707.18	64020.31	0:00
15	271230.21	64248.07	0:00
16	271177.00	64284.88	0:00
17	271150.82	64390.89	0:00
18	270108.13	63128.77	0:00
19	270074.87	63129.11	0:00
20	272139.47	63965.98	0:00
21	272217.26	63910.14	0:00
22	272603.90	64071.82	0:00
23	272631.35	64072.22	0:00
24	272600.41	63813.96	0:00
25	272820.86	64071.77	0:00
26	273208.47	63877.67	0:00
27	273243.71	63869.43	0:00
28	273252.17	63908.32	0:00
29	273278.86	63857.92	0:00
30	273179.22	63943.51	0:00
31	273341.88	63972.65	0:00
32	273353.92	64054.13	0:00
33	273355.99	64038.20	0:00
34	273199.77	64192.79	0:00
35	273332.51	63694.16	0:00
36	273302.32	63643.97	0:00
37	273273.49	63664.84	0:00
38	273541.15	63762.19	0:00
39	273463.52	63806.26	0:00
40	273460.44	63901.10	0:00
41	273443.27	63923.11	0:00
42	273453.75	63950.34	0:00
43	273458.15	64018.33	0:00

Appendix A - Shadow Flicker Modeling Results - Discrete Points

Modeling ID	NAD83 New Hampshire State Plane Coordinates (meters)		Expected Shadow Flicker Hours per Year (hr:min/year)
	X (Easting)	Y (Northing)	
44	273401.91	64093.41	0:00
45	273398.75	64144.21	0:00
46	273136.53	64359.87	0:00
47	272991.03	64362.98	0:00
48	272945.73	64345.79	0:00
49	272849.18	64259.51	0:00
50	272824.95	64260.55	0:00
51	272361.49	64109.80	0:00
52	272179.12	64085.09	0:00
53	272100.70	64063.08	0:00
54	272014.08	64041.40	0:00
55	273324.86	63513.01	0:00
56	273391.08	63494.12	0:00
57	273379.35	63493.54	0:00
58	273313.64	63381.73	0:00
59	273296.81	63344.24	3:12
60	273227.80	63238.36	7:34
61	273319.69	63284.01	6:21
62	273330.44	63262.55	3:06
63	273342.62	63248.34	0:00
64	273347.28	63110.39	3:07
65	273360.41	62895.16	3:35
66	273380.77	62733.32	4:08
67	273391.93	62742.55	4:01
68	273417.14	62477.48	6:44
69	273192.25	62054.82	0:00
70	273189.78	62036.16	0:00
71	273255.35	62195.58	0:00
72	273276.22	61962.48	0:00
73	273223.46	62001.69	0:00
74	273231.52	62213.74	0:00
75	273244.11	62209.50	0:00
76	273027.43	61757.62	0:00
77	273003.69	61664.41	0:00
78	273088.37	61021.20	0:00
79	270088.73	62000.89	0:00
80	270229.12	61814.37	8:26
81	269895.16	62587.51	0:00
82	269903.87	62570.23	0:00
83	269941.36	62598.80	0:00
84	272733.78	59740.28	0:00
85	272759.08	59743.14	0:00
86	272772.70	59752.71	0:00

Appendix A - Shadow Flicker Modeling Results - Discrete Points

Modeling ID	NAD83 New Hampshire State Plane Coordinates (meters)		Expected Shadow Flicker Hours per Year (hr:min/year)
	X (Easting)	Y (Northing)	
87	272938.57	59798.56	0:00
88	271491.33	63836.90	8:46
89	269749.54	61392.46	0:00
90	269742.58	61387.33	0:00
91	269814.82	62012.35	0:00
92	269847.87	61946.23	0:00
93	269700.63	62152.84	0:00
94	271664.48	59431.94	0:00
95	271698.24	59452.36	0:00
96	271032.13	64557.99	0:00
97	271021.23	64581.52	0:00
98	271327.38	64768.16	0:00
99	273068.34	64843.57	0:00
100	273124.20	64739.32	0:00
101	273070.58	64532.57	0:00
102	273131.16	64554.46	0:00
103	273254.38	64689.85	0:00
104	273265.92	64677.24	0:00
105	273329.58	64530.23	0:00
106	273328.89	64506.27	0:00
107	273456.49	64561.22	0:00
108	273256.58	64823.94	0:00
109	273264.74	64779.66	0:00
110	273746.97	64387.75	0:00
111	273718.64	64416.83	0:00
112	273744.85	64400.99	0:00
113	273630.42	64185.36	0:00
114	273858.95	64141.64	0:00
115	273866.78	63820.13	0:00
116	273621.46	63739.43	0:00
117	273634.49	63747.18	0:00
118	273694.98	63730.76	0:00
119	273438.58	62762.08	3:32
120	273746.57	63338.00	0:00
121	273787.70	63341.65	0:00
122	273769.00	63348.85	0:00
123	274076.44	62871.30	0:00
124	274079.65	62890.46	0:00
125	274068.68	62897.83	0:00
126	274088.30	62806.32	0:00
127	274127.15	62771.68	0:00
128	274146.75	62717.74	0:00
129	274166.37	62677.48	0:00

Appendix A - Shadow Flicker Modeling Results - Discrete Points

Modeling ID	NAD83 New Hampshire State Plane Coordinates (meters)		Expected Shadow Flicker Hours per Year (hr:min/year)
	X (Easting)	Y (Northing)	
130	274248.66	62483.12	0:00
131	274250.27	62443.57	0:00
132	274303.01	62365.08	0:00
133	273793.83	62336.12	0:00
134	273873.06	62348.62	0:00
135	273891.63	62350.18	0:00
136	273937.36	62356.09	0:00
137	273959.24	62364.93	0:00
138	274003.32	62457.15	0:00
139	274093.76	62351.25	0:00
140	274079.87	62353.21	0:00
141	274213.47	62357.08	0:00
142	274169.66	62475.39	0:00
143	274141.73	62546.15	0:00
144	269753.56	62331.44	0:00
145	269764.15	62355.49	0:00
146	269764.06	62459.23	0:00
147	269754.11	62517.10	0:00
148	269712.13	62603.20	0:00
149	269739.00	62566.50	0:00
150	273031.28	61847.99	0:00
151	273353.68	63183.49	3:03
152	273217.01	64159.22	0:00
153	272283.75	64096.24	0:00
154	271819.36	64075.55	0:00
155	269873.54	62153.08	0:00