SHADOW FLICKER ASSESSMENT SUPPLEMENT

RoxWind Project
Town of Roxbury, Maine

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1.0 EXECUTIVE SUMMARY

RoxWind (the Project) is a proposed wind energy development (WED) composed of four (4) wind turbines in the Town of Roxbury, Maine. The Project is being developed by RoxWind LLC which has retained Epsilon Associates, Inc. (Epsilon) to conduct shadow flicker assessments for the proposed wind turbines for this Project. The original report, submitted with RoxWind's application, is based on four (4) General Electric (GE) 3.8-130 wind turbines. Those turbines were on 85 meter towers.

Revised shadow flicker modeling was conducted for four (4) General Electric (GE) 3.8-137 wind turbines. Since the initial shadow flicker report was submitted, RoxWind has proposed a minor modification using longer blades but keeping the same tip height by lowering the hub height of the four wind turbines. The hub height evaluated in the March 6, 2018 report was 85 meters. This supplement evaluates the Project with a hub height of 81.5 meters which is 3.5 meters shorter.

The design goal of the RoxWind Project, identified in the March 6, 2018 report, is no more than 30 hours per year at an occupied receptor. The purpose of this supplementary analysis is to predict the expected annual duration of wind turbine shadow flicker at residences in the vicinity of the Project due to the operation of these specific proposed wind turbines (GE-3.8-137) and the 30-hour annual limit for shadow flicker..

The highest modeled annual duration of shadow flicker at an occupied structure is 27 hours, 51 minutes, which is less than 30 hours per year.[1] As with the March 2018 report, the modeling results are conservative in that modeling receptors were treated as "greenhouses" and the surrounding area was assumed to be without vegetation or structures ("bare earth").

In summary, no occupied receptors exceeded 30 hours per year in the original analysis and no occupied receptors exceed 30 hours per year in the current analysis; therefore, the conclusions are the same.

[1] The maximum expected annual duration of shadow flicker at a modeling receptor resulting from the operation of the 4 wind turbines is 30 hours, 19 minutes. RoxWind LLC has determined that the receptor #8A is an abandoned structure; therefore it is not occupied and is exempt from the shadow flicker limit.

2.0 INTRODUCTION

The RoxWind Project to be located in the Town of Roxbury, Maine will consist of four (4) GE wind turbines. The wind turbines evaluated in this supplemental report are GE 3.8-137 units with a hub height of 81.5 meters and a rotor diameter of 137 meters.

This report presents the findings of a shadow flicker supplemental assessment for the Project. Similar to the March 2018 report, the wind turbines were modeled with the WindPRO software package using information provided by RoxWind LLC. The expected annual duration of shadow flicker was calculated at discrete modeling points and shadow flicker isolines for the area surrounding the Project were generated.

For a detailed explanation about flicker, see the March 2018 report.

The results of the modeling are found within this report.

3.0 SHADOW FLICKER ANALYSIS

3.1 Modeling Methodology Revisions

For this supplemental report, shadow flicker was modeled using an upgraded software package, WindPRO version 3.2.712.

The proposed wind turbine layout for the Project dated February 8, 2018 was provided by RoxWind LLC and is unchanged from the March 2018 report. Locations of the 4 wind turbines are shown in Figure 3-1 and the coordinates are provided in Appendix A. All wind turbines analyzed in this supplemental report are GE 3.8-137 units with a 137-meter rotor diameter and a hub height of 81.5 meters. Each wind turbine has the following characteristics based on the technical data provided by RoxWind LLC:

		GE 3.8-137
♦ Rated Power	=	3,800 kW
♦ Hub Height	=	81.5 meters
♦ Rotor Diameter	=	137 meters
♦ Cut-in Wind Speed	=	3 m/s
♦ Cut-out Wind Speed	=	34 m/s
♦ Maximum RPM	=	13.6 rpm

Except for the upgraded software and the change in the turbines, the analysis technique was the same as before and is repeated below for completeness.

The same receptor dataset provided by RoxWind LLC on January 30, 2018, was used in this analysis. The dataset included presumed residences within 1.5 miles of any of the four wind turbines and were input to the WindPRO model as discrete points. The 46[2] receptors were each assumed to have windows 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 1,609 meters from a wind turbine, the equivalent of 1 mile. Consequently, shadow flicker at any of the 46 receptors farther 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 10-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 particularly conservative for the heavily forested area for the Project. 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 Portland, Maine from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI).[3] 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 12 cardinal wind directions was input into the model. A preliminary energy production assessment was provided to Epsilon by RoxWind LLC that contained operational hours per wind direction sector. These hours are used by WindPRO to estimate the "wind direction" and "operation time" reduction factors. Based on this dataset, the wind turbines would operate 92% of the year. Table 3-2 shows the distribution of operational hours for the 12 wind directions.

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2 One of the receptors (#39) in the dataset was found to be a duplicate and was removed from the analysis.

3 NCEI (formerly NCDC), http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos15.txt. Accessed in February 2018.

Data Source: Office of Geographic Information (MassGIS), Commonwealth of Massachusetts, Information Technology Division

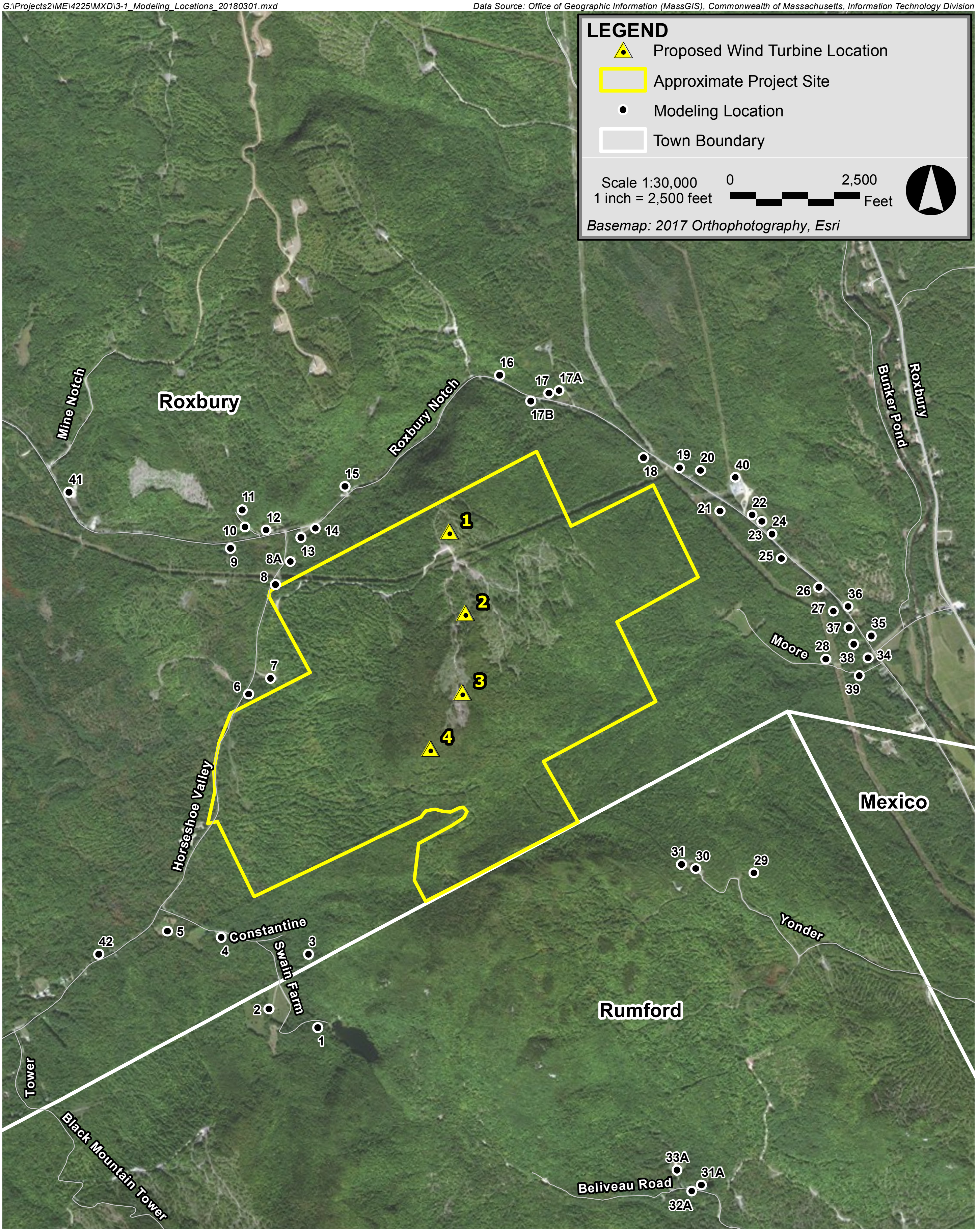

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Figure 3-1

Shadow Flicker Modeling Locations

Table 3-1 Monthly Percent of Possible Sunshine

Month	Possible Sunshine
January	57%
February	58%
March	53%
April	55%
May	53%
June	55%
July	62%
August	63%
September	60%
October	58%
November	47%
December	49%

Table 3-2 Operational Hours per Wind Direction Sector

Wind Sector	Operational Hours
N	170
NNE	170
ENE	191
E	281
ESE	622
SSE	538
S	472
SSW	504
WSW	518
W	1,312
WNW	2,831
NNW	489
Annual	8,096

3.2 Results

Following the modeling methodology outlined in Section 3.1, WindPRO was used to calculate shadow flicker at the same 46 discrete modeling points in the vicinity of the Project used in the original analysis for the GE-3.8-130 on 85 meter towers and to generate shadow flicker isolines based on the grid calculations.

Table B-1 in Appendix B presents the modeling results for the 46 receptors. The predicted expected annual shadow flicker duration ranged from 0 hours, 0 minutes per year to 27 hours, 51 minutes per year at an occupied residence.[4] Many locations (27) were predicted to experience no shadow flicker. Eight (8) locations were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that 10 locations could be expected to have 10 to 30 hours of shadow flicker per year.[5] Figure 3-2 displays the modeled flicker isolines over aerial imagery in relation to modeled wind turbines and the modeled locations.

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[4] The maximum expected shadow flicker occurs at location 8A. 8A is an abandoned, unoccupied structure and therefore does not need to satisfy the 30-hour annual flicker goal stated in the original analysis.

[5] This is the same number of locations that were predicted to have 10 to 30 hours of shadow flicker per year in the March 2018 report, after excluding the abandoned structure (8A).

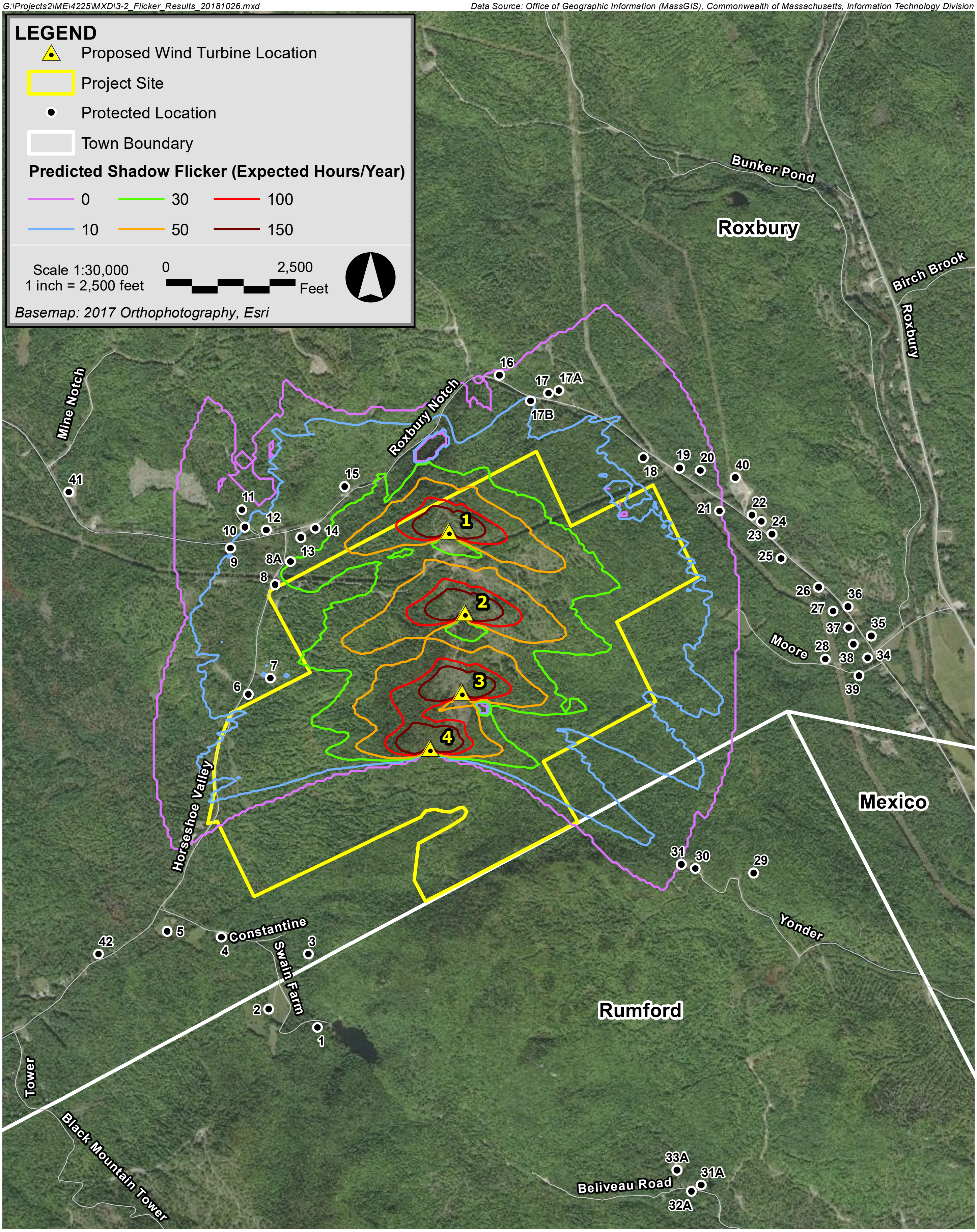

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Figure 3-2
Flicker Modeling Results

4.0 CONCLUSIONS

A shadow flicker analysis was conducted to determine the duration of shadow flicker in the vicinity of the proposed RoxWind Project within the Town of Roxbury, Maine, and surrounding towns. Shadow flicker resulting from the operation of the proposed wind turbine layout was calculated at 46 discrete modeling points, and isolines were generated from a grid encompassing the area surrounding the wind turbines.

The maximum expected annual duration of shadow flicker at an occupied structure is 27 hours, 51 minutes. Shadow flicker at all occupied buildings is below 30 hours per year; therefore, these minor revisions to the Project are consistent with the prior stated goals with respect to shadow flicker. Similar to the March 2018 report, the modeling results are conservative in that modeling receptors were treated as "greenhouses" and the surrounding area was assumed to be without vegetation or structures ("bare earth").

In summary, no occupied receptors exceeded 30 hours per year in the March 2018 analysis and no occupied receptors exceed 30 hours per year in the current analysis; therefore, the conclusions are the same.

Appendix A
Wind Turbine Coordinates

Table A-1

Wind Turbine ID	Coordinates UTM NAD83 Zone 19N	
	X (m)	Y (m)
1	371671.76	4942589.02
2	371765.42	4942109.33
3	371748.24	4941642.94
4	371559.14	4941313.32

Appendix B

Expected Wind Energy Development Shadow Flicker at Discrete Modeling Points

Table B-1

Receptor ID	Coordinates NAD83 UTM Zone 19N (meters)		Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM)
1	370,904.08	4,939,668.64	0:00
2	370,617.83	4,939,776.20	0:00
3	370,850.79	4,940,099.90	0:00
4	370,337.28	4,940,200.01	0:00
5	370,021.44	4,940,234.25	0:00
6	370,496.85	4,941,628.36	15:55
7	370,627.83	4,941,722.81	11:17
8	370,655.92	4,942,273.02	27:51
8A	370,745.01	4,942,407.66	30:19
9	370,392.60	4,942,487.28	10:58
10	370,478.84	4,942,613.29	11:37
11	370,460.17	4,942,714.36	8:02
12	370,603.42	4,942,593.67	18:45
13	370,806.18	4,942,551.53	23:05
14	370,892.55	4,942,603.81	24:15
15	371,063.77	4,942,851.09	22:54
16	371,973.09	4,943,505.01	1:45
17	372,263.00	4,943,398.33	8:30
17A	372,324.69	4,943,414.04	6:51
17B	372,156.04	4,943,354.39	10:23
18	372,819.01	4,943,021.33	6:44
19	373,033.49	4,942,960.86	5:35
20	373,154.58	4,942,946.04	2:34
21	373,268.87	4,942,705.38	2:38
22	373,458.83	4,942,683.63	0:00
23	373,516.11	4,942,645.34	0:00
24	373,576.15	4,942,571.36	0:00
25	373,631.16	4,942,426.67	0:00
26	373,851.15	4,942,259.42	0:00
27	373,937.13	4,942,117.86	0:00
28	373,892.65	4,941,835.46	0:00
29	373,470.33	4,940,577.37	0:00
30	373,125.81	4,940,602.51	0:00
31	373,042.94	4,940,628.67	0:00
31A	373,160.94	4,938,740.66	0:00
32A	373,104.89	4,938,704.67	0:00
33A	373,017.10	4,938,828.80	0:00
34	374,140.46	4,941,841.18	0:00
35	374,160.81	4,941,971.70	0:00
36	374,023.56	4,942,143.50	0:00
37	374,029.34	4,942,020.83	0:00

Table B-1

Receptor ID	Coordinates NAD83 UTM Zone 19N (meters)		Expected Shadow Flicker Hours per Year
	X (Easting)	Y (Northing)	(HH:MM)
38	374,056.02	4,941,923.20	0:00
39	374,089.69	4,941,739.18	0:00
40	373,360.55	4,942,904.27	0:00
41	369,440.58	4,942,817.22	0:00
42	369,617.33	4,940,099.02	0:00