Section 3
Shadow Flicker

Shadow Flicker

3.1 State Standards

According to the Small Wind Certification, a Small Scale Wind Energy Development:

> *Will be designed and sited to avoid unreasonable adverse shadow flicker effects.*

Maine currently has no numerical regulatory limits on exposure to shadow flicker. However, in all Maine projects that have considered flicker impact, the Department has used the common industry standard of 30 hours per year as a limit to reduce nuisance complaints.

3.2 Local Standards

The Town of Roxbury has not enacted a separate shadow flicker ordinance.

The Town of Rumford, an adjacent town to Roxbury, *has* adopted a section on shadow flicker in their wind energy ordinance. The Town of Rumford ordinance interprets "unreasonable adverse shadow flicker" from a Wind Energy Facility ["WEF"] to mean:

> *shadow flicker occurring for three (3) days or more in any one (1) month that, if annualized, would total more than twelve (12) hours of flicker per year. The application will not be approved if the study estimates that the duration of the flicker will be such that there are more than twelve (12) hours of flicker per year at any occupied structure located on a Non-Participating Parcel. If after construction, the WEF violates this condition, then the WEF will be in violation of this ordinance.*

While the Project is not located in Rumford, the Applicant's flicker study, reviewed below, demonstrates that there would be no "unreasonable adverse shadow flicker" as defined by the Town of Rumford from the Project at any occupied structure in Rumford.

3.3 Shadow Flicker Modeling Approach

The predictive shadow flicker modeling was performed by Epsilon and was designed to conform to State standards. The Project is wholly located in the Town of Roxbury's Mountain District, a Zoning District determined by the Town to be appropriate for wind energy development. The area surrounding the Project is primarily forested. Within roughly a mile and a half of the turbines, there are approximately forty-seven (47) structures including eight (8) in Rumford. These structures were verified by Kleinschmidt (as accessible) and Kleinschmidt also evaluated visibility of North Twin Mountain from accessible homes.

These structures were used to define the modeled locations surrounding the Project.

For more details about the flicker modeling, see Exhibit 3-A.

3.4 Shadow Flicker Modeling Results Summary

The shadow flicker modeling results predict that there will be no violations of the State's or Rumford's standards referenced in Section 3.1 and 3.2, respectively, of this application.

Of the forty-seven (47) locations evaluated, only twenty-six (26) are predicted to experience any shadow flicker from the project. Of the twenty-six (26) locations where shadow flicker may be experienced, zero (0) of the locations are anticipated to receive more than thirty (30) hours of shadow flicker in a given year. The two locations with the greatest level of predicted shadow flicker annually, locations 8 and 8A, are not expected to have any view of the wind turbines (see Visual Impact Assessment, Exhibit 5-A) and thus shadow flicker should be limited to occur in the vegetation on the property.

The eight (8) structures identified in the adjacent Town of Rumford are anticipated to receive less than eight (8) hours each annually – with six (6) structures modeled at zero (0) hours of flicker annually and two (2) structures modeled at under eight (8) hours of flicker annually. The modeled shadow flicker from the Project conforms to the Town of Rumford's bylaw.

3-A

Shadow Flicker Assessment Report

SHADOW FLICKER ASSESSMENT REPORT

RoxWind Project
Town of Roxbury, Maine

Prepared for:

RoxWind LLC
13 Elm Street, Suite 200
Cohasset, MA 02025

Prepared by:

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

March 6, 2018

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

RoxWind (the Project) is a proposed wind energy development (WED) composed of up to four (4) wind turbines in the Town of Roxbury, Maine. The Project is being developed by RoxWind LLC who has retained Epsilon Associates, Inc. (Epsilon) to conduct a shadow flicker assessment for the proposed wind turbines for this Project.

Shadow flicker modeling was conducted for four (4) General Electric (GE) 3.8-130 wind turbines. The purpose of this analysis is to predict the expected annual durations of wind turbine shadow flicker at residences in the vicinity of the Project due to the operation of the proposed wind turbines. There are no federal, state, or local regulations quantitatively limiting the amount of shadow flicker resulting from the operation of the Project. However, the predicted shadow flicker at residences can be put into context by comparing the annual duration 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 as this is often the limit identified in wind energy regulations that contain shadow flicker limits. Therefore, the design goal of the Project is to not exceed the industry guideline of 30 hours per year of expected shadow flicker at any residence to avoid unreasonable adverse shadow flicker effects.

The maximum expected annual duration of shadow flicker at a discrete modeling point (residence) resulting from the operation of the 4 wind turbines is 27 hours, 35 minutes. Therefore, the Project design goal is met and the Project avoids unreasonable adverse shadow flicker effects based on the industry guideline. 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").

2.0 INTRODUCTION

The RoxWind Project to be located in the Town of Roxbury, Maine will consist of up to four (4) GE wind turbines. The proposed wind turbines will all be GE 3.8-130 units with a hub height of 85 meters and a rotor diameter of 130 meters.

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. While 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 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 assessment for the Project. 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 (nearby residences) and shadow flicker isolines for the area surrounding the Project were generated. The results of the modeling are found within this report.

3.0 SHADOW FLICKER MODELING

3.1 Modeling Methodology

Shadow flicker was modeled using a software package, WindPRO version 3.1.633. 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 refined by incorporating sunshine probabilities and wind turbine operational estimates by wind direction over the course of a year. The values produced by this refinement, also known as the "expected" shadow flicker, are presented in this section.

The proposed wind turbine layout for the Project dated February 8, 2018 was provided by RoxWind LLC. Locations of the 4 wind turbines are shown in Figure 3-1 and the coordinates are provided in Appendix A. All wind turbines are proposed to be GE 3.8-130 units with a 130 meter rotor diameter and a hub height of 85 meters. Each wind turbine has the following characteristics based on the technical data provided by RoxWind LLC:

		GE 3.8-130
♦ Rated Power	=	3,800 kW
♦ Hub Height	=	85 meters
♦ Rotor Diameter	=	130 meters
♦ Cut-in Wind Speed	=	3 m/s
♦ Cut-out Wind Speed	=	34 m/s
♦ Maximum RPM	=	12.1 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. 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 has been accepted in multiple European

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

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 rotor diameter of the proposed wind turbine corresponds to a distance of 0.81 miles (1,300 m). Conservatively, this analysis follows the Connecticut guidance and includes shadow flicker calculations out to 1.25 miles (2,012 m) from each wind turbine in the model for the proposed layout.

A residence dataset was provided by RoxWind LLC on January 30, 2018. The dataset included identified residences within 1.5 miles of any of the four wind turbines and were input to the WindPRO model as discrete points. The 47 residences 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 2,012 meters from a wind turbine, the equivalent of 1.25 miles. Consequently, shadow flicker at any of the 47 residences 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 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.

---

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 January 2018.

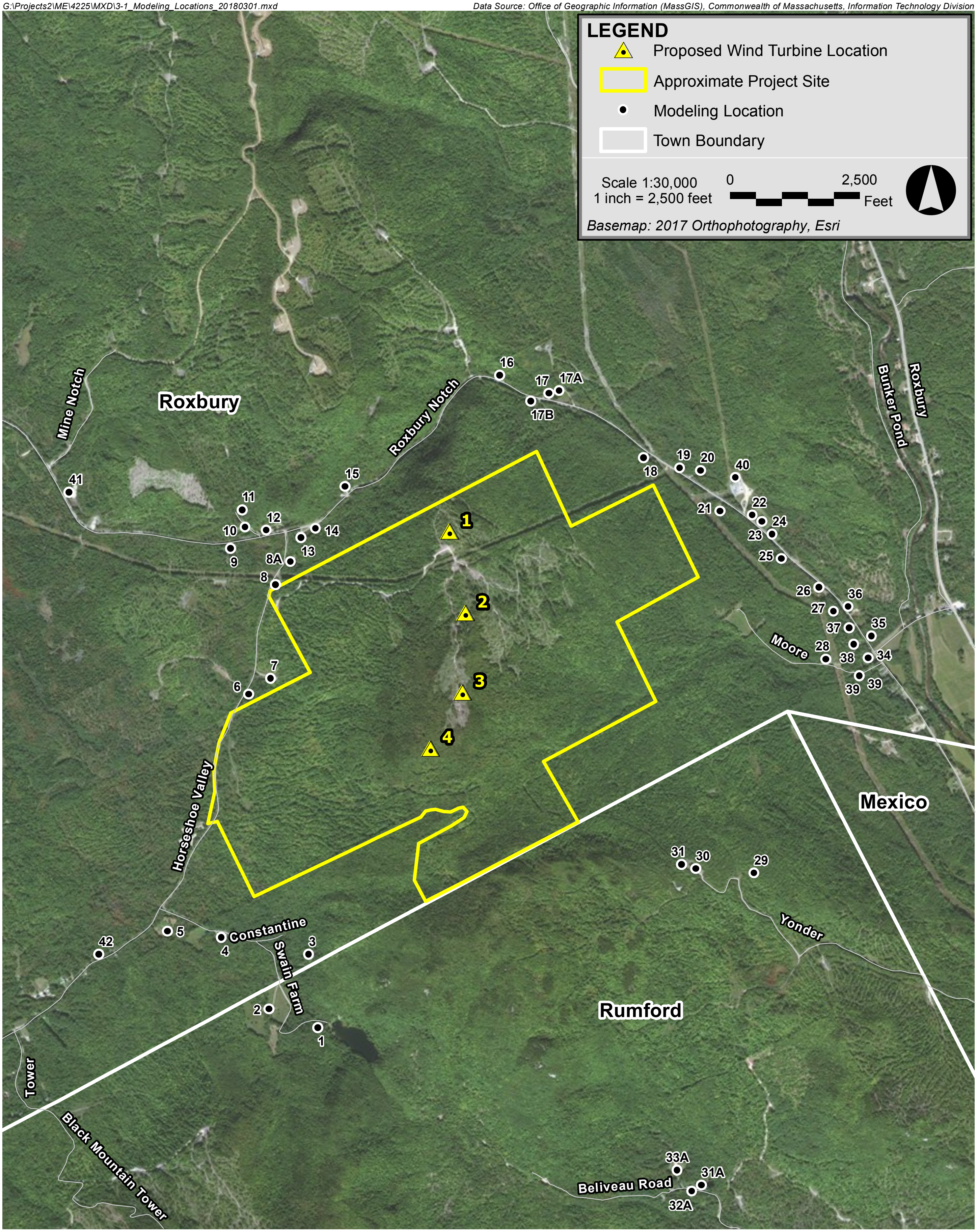
4 State of Connecticut CSC Wind Regulations (2014), available at https://www.cga.ct.gov/aspx/CGARegulations/CGARegulations.aspx?Yr=2014&Reg=2012-054&Amd=E Accessed in January 2018.

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).[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 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.

---

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



RoxWind **Roxbury, Maine**

Epsilon ASSOCIATES INC.

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%

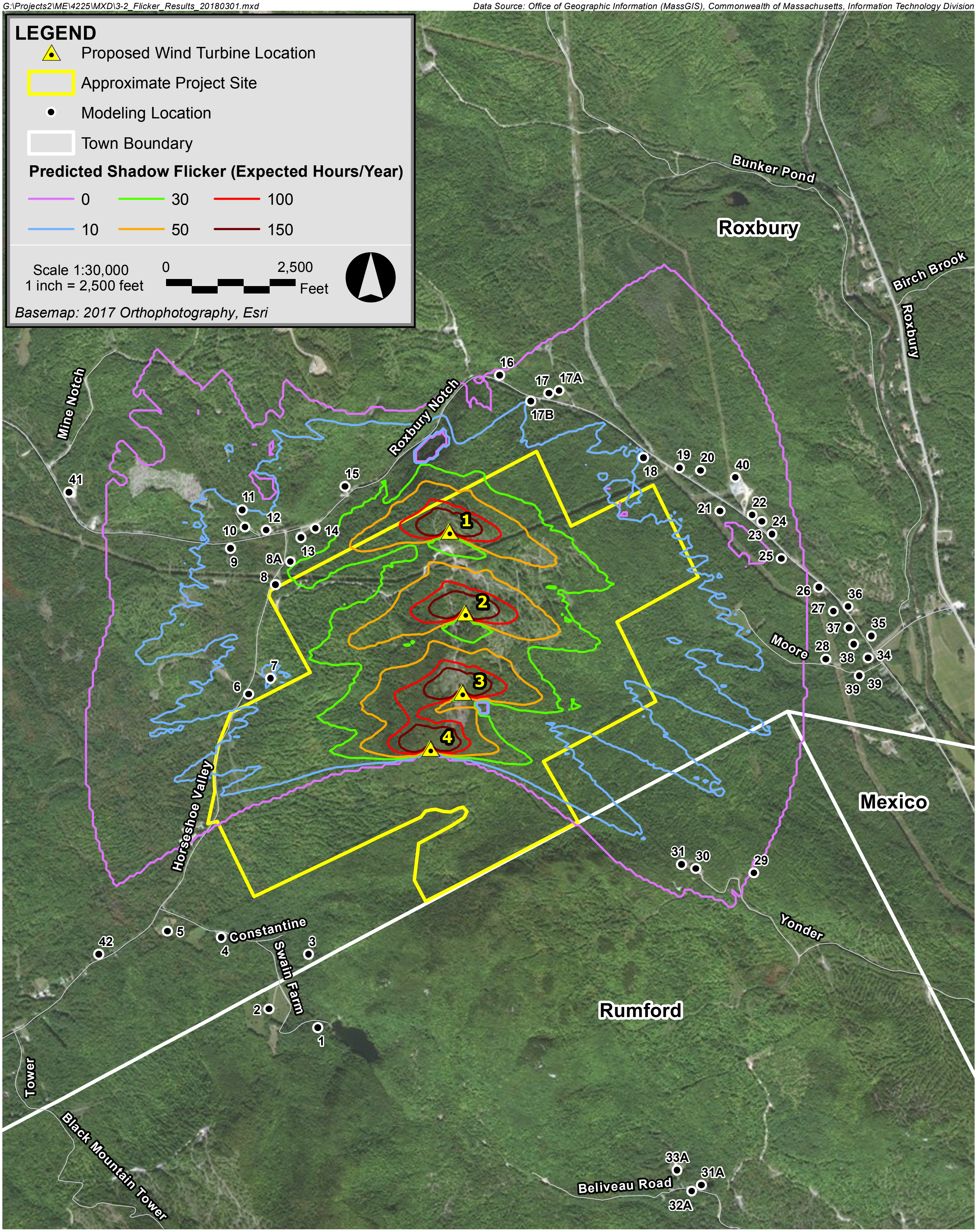
Table 3-2 Operational Hours per Wind Direction Sector

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 47 discrete modeling points (nearby residences) in the vicinity of the Project and generate shadow flicker isolines based on the grid calculations.

Table B-1 in Appendix B presents the modeling results for the 47 residences. The predicted expected annual shadow flicker duration ranged from 0 hours, 0 minutes per year to 27 hours, 35 minutes per year. The maximum expected shadow flicker occurs at location #8A. Many locations (21) were predicted to experience no shadow flicker. 15 locations were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that 11 locations would be expected to have 10 to 30 hours of shadow flicker per year. No receptors were expected to have over 30 hours of flicker per year. Figure 3-2 displays the modeled flicker isolines over aerial imagery in relation to modeled wind turbines and the modeled locations.



RoxWind Roxbury, Maine

Epsilon ASSOCIATES INC.

Figure 3-2
Shadow 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 47 discrete modeling points, and isolines were generated from a grid encompassing the area surrounding the wind turbines.

The shadow flicker design goal at residences is less than 30 hours per year. The maximum expected annual duration of shadow flicker at a residence is 27 hours, 35 minutes. Therefore, the Project design goal is met and the Project avoids unreasonable adverse shadow flicker effects. 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").

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	370904.08	4939668.64	0:00
2	370617.83	4939776.20	0:00
3	370850.79	4940099.90	0:00
4	370337.28	4940200.01	0:00
5	370021.44	4940234.25	0:00
6	370496.85	4941628.36	14:09
7	370627.83	4941722.81	10:15
8	370655.92	4942273.02	25:16
8A	370745.01	4942407.66	27:35
9	370392.60	4942487.28	13:00
10	370478.84	4942613.29	15:32
11	370460.17	4942714.36	12:39
12	370603.42	4942593.67	17:02
13	370806.18	4942551.53	20:51
14	370892.55	4942603.81	21:48
15	371063.77	4942851.09	20:29
16	371973.09	4943505.01	1:41
17	372263.00	4943398.33	6:57
17A	372324.69	4943414.04	5:55
17B	372156.04	4943354.39	9:27
18	372819.01	4943021.33	9:29
19	373033.49	4942960.86	6:48
20	373154.58	4942946.04	5:59
21	373268.87	4942705.38	5:58
22	373458.83	4942683.63	4:59
23	373516.11	4942645.34	3:26
24	373576.15	4942571.36	3:21
25	373631.16	4942426.67	3:26
26	373851.15	4942259.42	0:00
27	373937.13	4942117.86	0:00
28	373892.65	4941835.46	0:00
29	373470.33	4940577.37	0:00
30	373125.81	4940602.51	7:10
31	373042.94	4940628.67	7:37
31A	373160.94	4938740.66	0:00
32A	373104.89	4938704.67	0:00
33A	373017.10	4938828.80	0:00
34	374140.46	4941841.18	0:00
35	374160.81	4941971.70	0:00
36	374023.56	4942143.50	0:00
37	374029.34	4942020.83	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	374056.02	4941923.20	0:00
39	374089.69	4941739.18	0:00
39	374089.69	4941739.18	0:00
40	373360.55	4942904.27	3:35
41	369440.58	4942817.22	0:00
42	369617.33	4940099.02	0:00