Appendix E

Shadow Flicker Study

GL Garrad Hassan

SHADOW FLICKER ASSESSMENT

WATFORD WIND FARM, ONTARIO

Client	Green Breeze Energy Inc.
Contact	Brent Hall
Document No.	879/OT/03
Issue	C
Status	Final
Classification	Client's Discretion
Date	23 February 2011

Author:

C. Alzin

Checked by:

B. Ait-Driss

Approved by:

B. Ait-Driss

Helimax Energy Inc.
4100, rue Molson, bureau 100, Montréal, Quebec CANADA H1Y 3N1

IMPORTANT NOTICE AND DISCLAIMER

1. Acceptance of this document by the Client is on the basis that Helimax Energy Inc., a GL group member traded as GL Garrad Hassan (hereafter "GL GH"), is not in any way to be held responsible for the application or use made of the findings or the results of the analysis and that such responsibility remains with the Client.

   This report shall be for the sole use of the Client for whom the Report is prepared. The document is subject to the terms of the Agreement between the Client and GL GH, and should not be relied on by third parties for any use whatsoever without the express written authority of GL GH. The Report may only be reproduced and circulated in accordance with the Document Classification and associated conditions stipulated in the Agreement, and may not be disclosed in any offering memorandum without the express written consent of GL GH.

   GL GH does not provide legal, regulatory, tax and/or accounting advice. The recipient must make its own arrangements for consulting in these areas.

   This document has been produced from information at the date of this document and, where applicable, information relating to dates and periods referred to in this document. The Report is subject to change without notice and for any reason including, but not limited to, changes in information, conclusion and directions from the Client.

2. This report has been produced from information relating to dates and periods referred to in this report. The report does not imply that any information is not subject to change.

KEY TO DOCUMENT CLASSIFICATION

Strictly Confidential	For disclosure only to named individuals within the Client's organization
Private and Confidential	For disclosure only to individuals directly concerned with the subject matter of the Report within the Client's organization
Commercial in Confidence	Not to be disclosed outside the Client's organization
GL GH only	Not to be disclosed to non-GL GH staff
Client's Discretion	Distribution for information only at the discretion of the Client (subject to the above Important Notice and Disclaimer)
Published	Available for information only to the general public (subject to the above Important Notice and Disclaimer)

REVISION HISTORY

Issue	Issue Date	Summary
A	9 February 2011	Initial issue for review
B	16 February 2011	Minor changes
C	23 February 2011	Final issue

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Helimax Energy Inc. (GL GH), a member of the GL Group and part of the GL Garrad Hassan brand, has been commissioned by Green Breeze Energy Inc. to independently assess the impact of the shadow flicker experienced in the vicinity of the proposed Watford Wind Farm Wind Farm (the "Project"), which will use the Samsung 2.5 MW model 25XC. With a maximum blade tip height of 130 m, a hub height of 80 m and a rotor diameter of approximately 100 m, these turbines can have an influence on the shadow flicker experienced at sensitive locations in the vicinity of the site.

Shadow flicker is defined as the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and a viewer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative positions of the sun throughout the year, the wind turbines at the site, and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations in proximity to the Project.

It should be noted, however, that this analysis method tends to be conservative, as will be explained in Section 3.3 and, as such, typically results in an over-estimation of the number of hours of shadow flicker experienced at a given dwelling [4].

This report includes a brief presentation of the Project site, a description of the shadow flicker assessment methodology, results of the analysis including a map illustrating areas prone to shadow flicker, and concluding comments.

2 DESCRIPTION OF THE WIND FARM SITE

2.1 Site Description

The proposed Project is located in Lambton County, Ontario, approximately 4 km south-west of Watford, and 40 km east of Sarnia.

The area is primarily agricultural and consists of expansive fields. Homes, farms and barns are interspersed throughout the site, as well as small woodlots with trees ranging from approximately 1.5-8 m in height. The topography and ground cover in the surrounding region are similar to those of the site itself.

As seen in Figure 2-1 and Figure 2-2, the proposed Project is situated in flat agricultural terrain punctuated with small woodlots, houses and barns. The elevations of the proposed turbine locations range from approximately 317 m to 319 m.

Figure 2-1: Project Area (1)

Figure 2-2: Project Area (2)

2.2 Wind Farm Layout

The proposed turbine layout, which consists of 4 Samsung 2.5 MW model 25XC wind turbine generators, has been supplied by Green Breeze. The precise coordinates of each turbine are presented in Appendix A; coordinates are presented in this report in UTM zone 17N, NAD 1983 datum.

2.3 House Locations

Dwellings for the Project area were identified using base data from Canvec and MNR and were validated during the site visit on 12 August 2010. In all 106 dwellings were identified within a 1.5 km radius of the wind turbines. The ID numbers and coordinates of these residences are listed in Appendix B.

3 SHADOW FLICKER ASSESSMENT

3.1 Overview

Shadow flicker may occur under certain combinations of circumstances with regards to the sun's position and wind direction; the sun passes behind the rotating blades of a wind turbine which casts a moving shadow in front of or behind the turbine. When viewed from a stationary position, the moving shadows cause periodic flickering of the sunlight, hence the so-called "shadow flicker" phenomenon.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of variable factors, namely:

- Direction of the building relative to the turbine;
- Distance from turbine: the farther the observer from the turbine, the less pronounced the effect;
- Wind direction: the shape and intensity of the shadow are determined by the position of the sun relative to the blades (the turbine rotor continuously yaws to face the wind so the rotor plane will always be perpendicular to the wind direction;
- Turbine height and rotor diameter: a larger turbine rotor diameter will cast a larger shadow meaning a larger area will be prone to incidences of shadow flicker;
- Time of year and day: position of sun relative to the horizon;
- Weather conditions: cloud cover reduces the occurrence of shadow flicker.

3.2 Assessment Methodology

The number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun's path, topographic variation over the wind farm site and wind turbine specifications such as rotor diameter and hub height.

The shadow flicker calculations for this study have been undertaken using an annual cloud coverage figure of 65.4%, which is based on historical meteorological data and statistics.

Shadow flicker has been calculated at the subject receptors (i.e. residences) at a height of 2 m to represent ground floor windows. The shadow flicker receptor is simulated as mounted horizontal points, representing the worst case scenario, whereas in reality windows face a particular, selective direction. The simulations have been carried out with a resolution of 1 minute; if shadow flicker occurs in any 1-minute period, the model registers this as 1 minute of shadow flicker.

It is generally accepted that shadow flicker from wind turbines does not occur beyond a distance, D, from a given wind turbine which is calculated using the following formula:

$$D = 10 \times (\text{hub height} + \text{rotor radius})$$

For the Samsung 2.5 MW model 25XC wind turbine generator, this equates to 1,300 m. Beyond this distance, a viewer does not perceive the turbine blade to be chopping the light, but rather as an object passing in front of the sun.

3.3 Factors Affecting Shadow Flicker Duration

Shadow flicker duration calculated in the manner described above over-estimates the annual number of hours of shadow flicker experienced at a specified location for several reasons, namely:

1 The wind turbine will not always be yawed such that its rotor is perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow, and thus the incidence of shadow flicker.

   The wind speed frequency distribution, or wind rose, at the site can be used to determine probable turbine orientation in order to calculate the resulting reduction in shadow flicker duration.

2 The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover, and to provide an indication of the resulting reduction in shadow flicker duration.

3 Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

   The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which in turn is dependent on the amount of dispersants (humidity, smoke and other aerosols) in the path between the light source (sun) and the receiver [3].

4 The modeling of the wind turbine blades as discs rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade [3].

5 Modeling the sun as a point light source rather than a disc results in an overestimate of the shadow flicker duration. The fact that the light source is a disc results in a shadow which is less well defined and of lower intensity as compared to a point light source.

6 The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.

7 Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce shadow flicker occurrence.

3.4 Current Analysis

The modeling of shadow flicker at the Project has been conducted for the Samsung 2.5 MW model 25XC wind turbine generator using the method described in Section 3.2 above. The wind turbine has been modeled assuming all wind turbines are disc objects oriented perpendicular to the sun-turbine vector, representing the maximum duration for which there is potential for shadow flicker to occur.

An assessment of the conservatism in the results of this worst case analysis has been conducted by considering the cloud cover statistics. According to the results gathered at London Airport and Windsor Airport meteorological stations, it has been estimated that the cloud cover is sufficient to nullify shadow flicker occurrence 65.4% of the time. In addition, using the site-specific wind rose to consider the probability of the turbines being oriented in any one direction can lead to significant further reduction in the annual shadow flicker occurrence.

An assumption has been made regarding the maximum length a shadow can be cast that will cause flicker. The UK wind industry considers that 10 rotor diameters is appropriate [2], while the Danish wind industry suggests a distance of between 500 m and 1 km [1]. GL GH has adopted a conservative approach and has limited the length that a shadow can be cast to 10 * (hub height + rotor radius).

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in the calculations of shadow flicker duration. Similarly, turbine shut-down has not been considered. For this reason, it is therefore likely that the adjusted shadow flicker durations presented here can still be regarded as conservative.

4 SHADOW FLICKER ASSESSMENT

A map illustrating predicted shadow flicker duration at receptors lying within 1,500 m of the Watford Wind Farm wind farm is presented in Figure 4-1. This map takes into account average annual cloud cover.

The results of the shadow flicker assessment are presented for all dwellings in the study area (in terms of maximum minutes per day and total hours per year) in tabular format in Appendix B.

None of the dwellings in the study area are predicted to experience more than 30 hours of shadow flicker per year or more than 30 minutes per day. These results take into account the cloud cover from the Environment Canada meteorological stations at Windsor and London Airports but, as described in Section 3.3, these results are still considered to be overestimated.

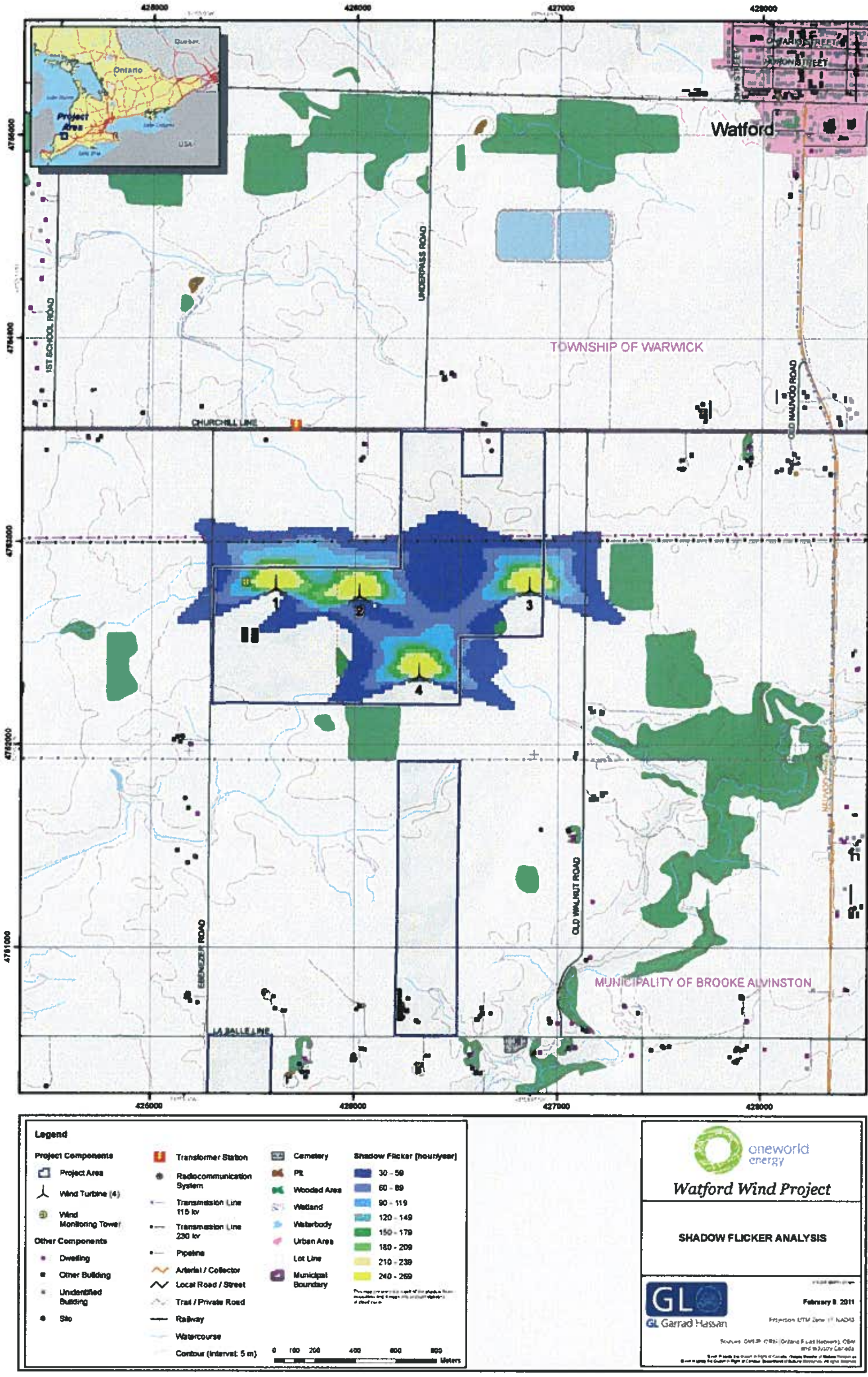

Figure 4-1: Modeled Hours of Shadow Flicker at Watford Wind Farm

CONCLUSION

An analysis has been conducted to determine the duration of shadow flicker likely to be experienced at receptors in the vicinity of the Watford Wind Farm Wind Farm in Lambton County, Ontario. This analysis was realized specifically for the Samsung 2.5 MW model 25XC wind turbine with a blade tip height of 130 m.

None of the 106 dwellings located within 1,500 m of the Project is predicted to experience more than 30 hours per year of shadow flicker. Detailed results can be found in Appendix B. The duration experienced takes into account average yearly cloud cover but is nevertheless considered to be overestimated, as explained in Sections 3.2 and 3.3.

5 REFERENCES

[1] Danish Wind Industry Association, "Shadow variations from Wind turbines", http://guidedtour.windpower.org/en/tour/env/shadow/shadow2.htm, viewed 22 July 2010.

[2] Department for Business Enterprise & Regulatory Reform, UK, "Onshore Wind: Shadow Flicker", http://www.berr.gov.uk/whatwedo/energy/sources/renewables/planning/onshore-wind/shadow-flicker/page18736.html , viewed 23 July 2010.

[3] Freud H-D, Kiel F.H., "Influences of the opaqueness of the atmosphere, the extension of the sun and rotor blade profile on the shadow impact of wind turbine", DEWI Magazine No. 20 pp 43-51, Feb 2002.

[4] Turbine layout confirmed by email, by Brent Hall, Green Breeze, to Chrystel Alzin, GL GH, 25 January 2011.

Appendix A Turbine Layout

Turbine ID	Easting [m][1]	Northing [m][1]
1	425609	4752769
2	426024	4752730
3	426859	4752760
4	426320	4752340

1. Coordinate system is UTM Zone 17, NAD83 datum.

Appendix B House Locations and Associated Shadow Flicker

Receptors		UTM Coordinates		Number of Days per Year	Worst Day	Max per Day [min/day]	Total Annual Occurrence [hours/year]		Turbine(s) Responsible
#	ID	Easting [m]	Northing [m]				No Cloud Cover	With Cloud Cover	
1	1	423960	4753507	0	-	0	0	0	-
2	2	424436	4753850	0	-	0	0	0	-
3	3	424428	4753972	0	-	0	0	0	-
4	4	426053	4753478	14	21 Dec	9	2	1	3
5	5	426655	4753492	62	15 Jan	16	9	3	1
6	6	426640	4753578	36	20 Dec	17	8	3	1
7	7	427657	4753422	41	22 Dec	23	12	4	3
8	8	427725	4753601	0	-	0	0	0	-
9	9	427940	4753465	43	20 Jan	17	7	2	3
10	10	428162	4753432	23	4 Feb	12	3	1	3
11	11	428314	4753360	0	-	0	0	0	-
12	13	428114	4753719	0	-	0	0	0	-
13	14	428223	4753714	0	-	0	0	0	-
14	16	428389	4753578	0	-	0	0	0	-
15	17	428384	4753611	0	-	0	0	0	-
16	18	426490	4753812	0	-	0	0	0	-
17	19	424433	4753674	38	1 Jan	15	8	3	1
18	20	424691	4753508	41	16 Dec	21	12	4	1
19	21	424086	4753616	0	-	0	0	0	-
20	22	427940	4750636	0	-	0	0	0	-
21	23	427894	4750502	0	-	0	0	0	-
22	24	427370	4750470	0	-	0	0	0	-
23	26	427529	4750507	0	-	0	0	0	-
24	27	427337	4750711	0	-	0	0	0	-
25	28	427007	4750626	0	-	0	0	0	-
26	29	426922	4750482	0	-	0	0	0	-
27	30	426814	4750540	0	-	0	0	0	-
28	31	427094	4750509	0	-	0	0	0	-
29	32	427062	4750500	0	-	0	0	0	-
30	33	427076	4750626	0	-	0	0	0	-
31	34	427157	4750588	0	-	0	0	0	-
32	35	426581	4750468	0	-	0	0	0	-
33	36	426373	4750465	0	-	0	0	0	-
34	37	426324	4750631	0	-	0	0	0	-
35	38	426060	4750496	0	-	0	0	0	-
36	39	425764	4750452	0	-	0	0	0	-
37	40	425665	4750688	0	-	0	0	0	-
38	42	423889	4750512	0	-	0	0	0	-

Receptors		UTM Coordinates		Number of Days per Year	Worst Day	Max per Day [min/day]	Total Annual Occurrence [hours/year]		Turbine(s) Responsible
#	ID	Easting [m]	Northing [m]				No Cloud Cover	With Cloud Cover	
39	43	425200	4751999	31	3 May	18	6	2	1
40	44	425216	4751449	0	-	0	0	0	-
41	45	427179	4752159	108	22 Apr	28	26	9	2, 4
42	46	427089	4751937	60	20 June	29	21	7	1
43	47	427079	4751537	0	-	0	0	0	-
44	48	427175	4751729	0	-	0	0	0	-
45	49	427175	4751226	0	-	0	0	0	-
46	50	427165	4750951	0	-	0	0	0	-
47	51	426618	4750645	0	-	0	0	0	-
48	52	427218	4749632	0	-	0	0	0	-
49	54	427182	4748492	0	-	0	0	0	-
50	55	427033	4748078	0	-	0	0	0	-
51	56	424422	4747968	0	-	0	0	0	-
52	57	424469	4747754	0	-	0	0	0	-
53	58	424674	4747803	0	-	0	0	0	-
54	59	424750	4747968	0	-	0	0	0	-
55	60	425330	4747928	0	-	0	0	0	-
56	61	425174	4747926	0	-	0	0	0	-
57	62	425219	4747788	0	-	0	0	0	-
58	63	425472	4747963	0	-	0	0	0	-
59	64	425746	4747729	0	-	0	0	0	-
60	65	426044	4747962	0	-	0	0	0	-
61	66	426024	4747643	0	-	0	0	0	-
62	67	426323	4747947	0	-	0	0	0	-
63	68	426326	4747727	0	-	0	0	0	-
64	69	426758	4747879	0	-	0	0	0	-
65	3H	424456	4754895	0	-	0	0	0	-
66	3G	424440	4754753	0	-	0	0	0	-
67	3F	424459	4754677	0	-	0	0	0	-
68	3D	424484	4754475	0	-	0	0	0	-
69	3C	424459	4754380	0	-	0	0	0	-
70	3B	424456	4754291	0	-	0	0	0	-
71	3A	424402	4754149	0	-	0	0	0	-
72	3E	424474	4754579	0	-	0	0	0	-
73	0	428163	4754805	0	-	0	0	0	-
74	0A	428241	4754924	0	-	0	0	0	-
75	1B	423500	4753644	0	-	0	0	0	-
76	1A	423618	4753504	0	-	0	0	0	-
77	44A	425231	4751658	0	-	0	0	0	-
78	42D	423373	4750980	0	-	0	0	0	-
79	42C	423495	4751746	0	-	0	0	0	-

Receptors		UTM Coordinates		Number of Days per Year	Worst Day	Max per Day [min/day]	Total Annual Occurrence [hours/year]		Turbine(s) Responsible
#	ID	Easting [m]	Northing [m]				No Cloud Cover	With Cloud Cover	
80	42E	423577	4750469	0	-	0	0	0	-
81	61A	425120	4747924	0	-	0	0	0	-
82	56E	424203	4747771	0	-	0	0	0	-
83	56D	423878	4748002	0	-	0	0	0	-
84	56C	423848	4747736	0	-	0	0	0	-
85	56B	423729	4747795	0	-	0	0	0	-
86	56A	423476	4747909	0	-	0	0	0	-
87	69A	427432	4747705	0	-	0	0	0	-
88	69B	428203	4747751	0	-	0	0	0	-
89	69C	428377	4748292	0	-	0	0	0	-
90	69D	428217	4748535	0	-	0	0	0	-
91	69E	428363	4748678	0	-	0	0	0	-
92	69F	428240	4749109	0	-	0	0	0	-
93	69G	428359	4749150	0	-	0	0	0	-
94	69H	428419	4749274	0	-	0	0	0	-
95	69I	428396	4749320	0	-	0	0	0	-
96	69J	428368	4749357	0	-	0	0	0	-
97	69K	428281	4749393	0	-	0	0	0	-
98	69L	428386	4749407	0	-	0	0	0	-
99	70	428419	4750795	0	-	0	0	0	-
100	71	428382	4751162	0	-	0	0	0	-
101	72	428412	4751523	0	-	0	0	0	-
102	73	428425	4751694	0	-	0	0	0	-
103	74	428474	4752373	0	-	0	0	0	-
104	29A	426974	4750634	0	-	0	0	0	-
105	23A	428027	4750499	0	-	0	0	0	-
106	23B	428233	4750467	0	-	0	0	0	-