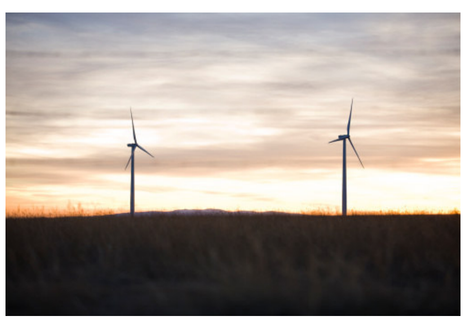
RENEWABLE ENERGY APPROVAL APPLICATION

SHADOW FLICKER ASSESSMENT

BORNISH WIND ENERGY CENTRE

July 2012



GL Garrad Hassan

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RENEWABLE ENERGY APPROVAL APPLICATION - SHADOW FLICKER ASSESSMENT

BORNISH WIND ENERGY CENTRE, ONTARIO

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Document No.	1008-CAMO-R-03
Issue	B
Status	Final
Classification	Client's Discretion
Date	19 July 2012

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REVISION HISTORY

Issue	Issue Date	Summary
A	20 December 2011	Initial issue for review
B	19 July 2012	Updated receptor list

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1 INTRODUCTION

GL GH Canada Inc. (GL GH), a member of the GL Group and part of the GL Garrad Hassan brand, has been commissioned by NextEra Energy Canada, ULC ("Client" or "NextEra") to independently assess the impact of the shadow flicker events experienced in the vicinity of the proposed Bornish Wind Energy Centre (the "Project"), which will use the General Electric GE1.6-100 with a blade tip height of 130 m, a hub height of 80 m and a rotor diameter of 100 m. These turbines can have an influence on the shadow flicker events experienced at receptor locations in the vicinity of the Project. Given that a shadow flicker analysis is not required under Ontario reg. 359/09, this report is presented as complementary information to the Renewable Energy Approval (REA) application for this Project.

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 duration of shadow flicker events at sensitive locations in the vicinity of the Project.

It should be noted, however, that this analysis method tends to be conservative and therefore typically results in an over-estimation of the number of hours of shadow flicker experienced at a given dwelling.

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 Bornish Wind Energy Centre is located in south-western Ontario, in the Municipality of North Middlesex, Middlesex County, Ontario. More specifically, the area being studied for the wind farm components is located south of Elginfield Road, west of Fort Rose Road, north of Elmtree Drive and east of Pete Sebe Road. Project components will be installed on privately-owned agricultural lots within this area.

The proposed wind farm is situated in relatively simple terrain, consisting of mostly flat areas and some rolling hills, with elevations ranging from 200 m to 255 m. The landscape in the study area is predominantly characterized by agricultural fields and associated farms punctuated with numerous hedgerows, isolated woodlands, and the occasional watercourse.

2.2 Wind Farm Layout

The proposed turbine layout, which consists of 48 General Electric GE1.6-100 wind turbine generators, has been supplied by the Client. The precise coordinates of each turbine are presented in Appendix A; coordinates are presented in this report in UTM Zone 17N, NAD 1983 datum [1]. The final layout will consists of only 45 GE 1.6-100 wind turbine generators, the study of 48 turbine positions results in a more conservative shadow flicker assessment.

2.3 Receptor Locations

Dwellings for the Project area were identified using base data from Canvec and MNR and were validated during a site visit in June 2011. Pursuant to this site visit, 129 dwellings were identified within a 1.5 km radius of the wind turbines. The ID numbers and coordinates of these dwellings are listed in Appendix B. The receptor locations (dwellings) for this flicker analysis are the same as the Points of Reception and participating receptor locations used in the Noise Impact Assessment.

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; when the sun passes behind the rotating blades of a wind turbine, a moving shadow is cast in front of or behind the turbine. When viewed from a stationary position, the moving shadows cause periodic flickering of the sunlight, otherwise known as the "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 on a number of variables, namely:

- Orientation of the building relative to the turbine;
- 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;
- Distance from turbine: the farther the observer from the turbine, the less pronounced the effect;
- 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;
- Vegetation and other obstacles that help to mask shadows; and
- Operational status of turbines.

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 takes into account the sun's position, topography of the wind farm site and wind turbine specifications such as rotor diameter and hub height. The modeling of shadow flicker at the Project has been conducted for the General Electric GE1.6-100 wind turbine generator model using the method described below.

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.

Shadow flicker has been calculated at the receptors (i.e. dwellings) at a height of 2 m to represent ground floor windows. Rather than facing a particular direction, shadow flicker receptors (windows) are simulated as horizontal planes, meaning they experience shadow flicker over 360°; this assumption therefore represents a worst case scenario. 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. The UK wind industry considers this distance to be equivalent to 10 rotor diameters [2], while the Danish wind industry suggests a value of between 500 and 1000 m [3]. GL GH has adopted a conservative approach and has assumed the length, D, that a shadow can be cast to be defined as follows:

D = 10 x (hub height + rotor radius)

For the GE1.6-100 wind turbine generator, this equates to 1.3 km. Beyond this distance, a viewer does not perceive the turbine blade to be interrupting the light, but rather as an object passing in front of the sun.

For this study, shadow flicker calculations were adjusted using an annual cloud coverage figure which is based on historical meteorological data and statistics. According to data gathered from the London Airport meteorological station, it has been estimated that the cloud cover is sufficient to nullify shadow flicker occurrence 66.8% of the time. Results both with and without consideration of cloud cover are presented in Section 4 and Appendix B. Further, using the site-specific wind rose to consider the probability of the turbines being oriented in a given direction could lead to significant further reduction in the annual shadow flicker occurrence.

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 occurrences have not been considered.

3.3 Conservative Assumptions

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

1. 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 [4].

2. 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. Additionally, the orientation of windows on a given house has not been taken into account, i.e. the model assumes that a window is always facing the turbine(s).

   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; however this has not been done in this study.

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 [4].

4 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.

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 (see Section 3.2).

5 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.

6 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.

In light of the reasons listed above, it is likely that the shadow flicker durations presented in Section 4 can be regarded as conservative.

4 RESULTS

The predicted shadow flicker duration at receptors in the vicinity of the Bornish Wind Energy Centre is presented in the form of a shadow flicker map in Figure 4-1. The map takes into account average annual cloud cover.

This analysis indicates that flicker occurrence is highest at Receptor 108, where a total of 27 hours/year of flicker was calculated, when taking into account cloud cover. This receptor could also experience a maximum of 40 minutes/day of flicker. Appendix B presents the predicted shadow flicker durations (maximum minutes per day and total hours per year) at all receptor locations.

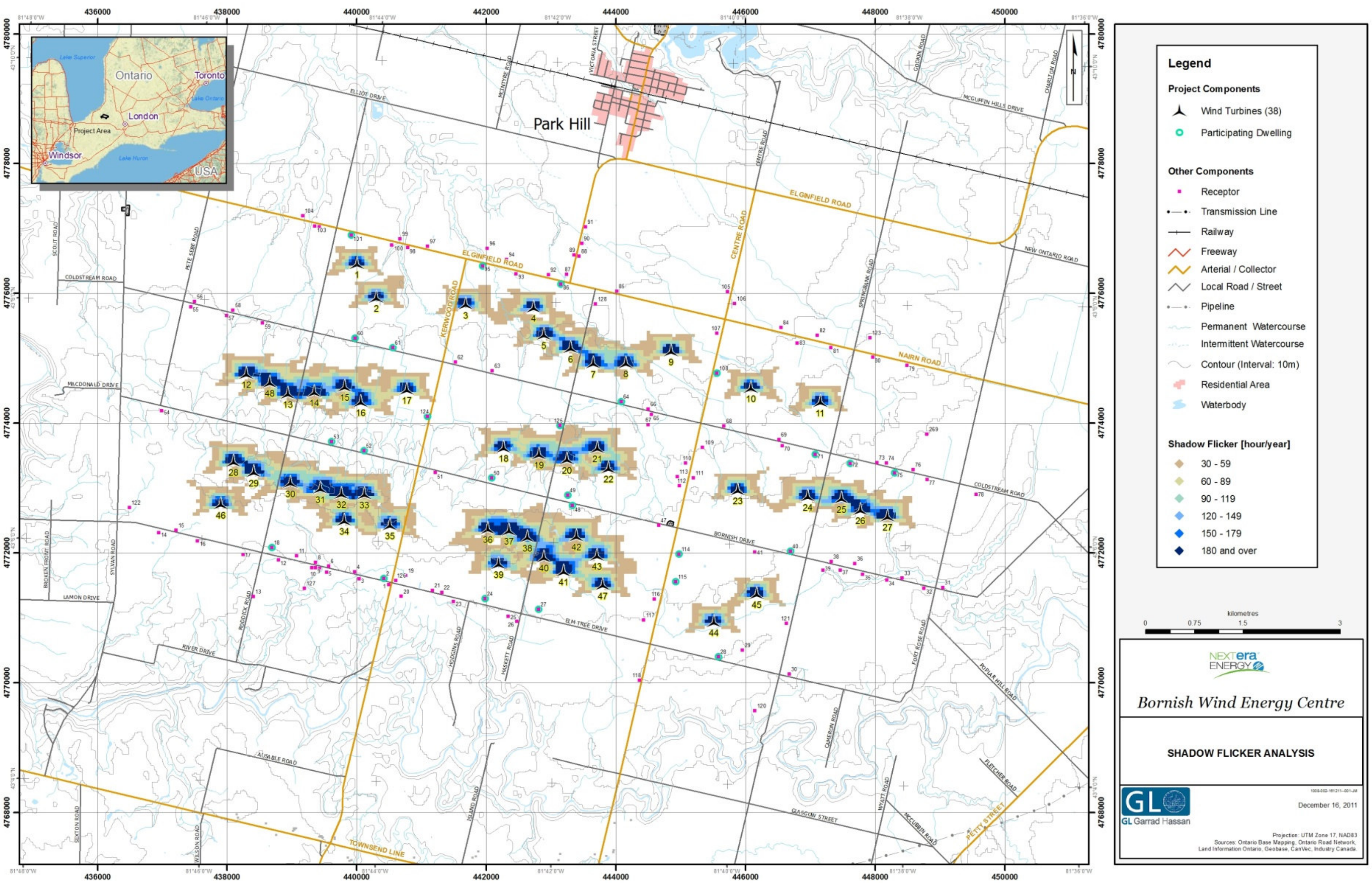

Figure 4-1: Modeled hours of shadow flicker for the Bornish Wind Energy Centre

5 CONCLUSION

An analysis has been conducted to determine the duration of shadow flicker events likely to be experienced at receptors in the vicinity of the Bornish Wind Energy Centre in Middlesex County, Ontario. This analysis was realized specifically for the General Electric GE1.6-100 wind turbine with a blade tip height of 130 m. Given that a shadow flicker analysis is not required under Ontario reg. 359/09, this report is presented as complementary information to the Renewable Energy Approval (REA) application for this Project.

6 REFERENCES

[1] Turbine layout locations sent by email, by Tom Bird, NextEra, to Nancy O'Blenes, GL GH, November 17, 2011. "CAN_Bornish_Optimized_72_8MW_Hybrid_GExle1_6_100RD_80HH_44T_3Alts_GExle1_5_100RD_80HH_1T_2011_11_16.shp"

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

[4] 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, February 2002.

APPENDIX A TURBINE LAYOUT

Coordinates of turbines

Turbine ID	Easting [m][1]	Northing [m][1]
1	440000	4776435
2	440302	4775915
3	441679	4775810
4	442726	4775763
5	442888	4775342
6	443298	4775136
7	443646	4774902
8	444147	4774906
9	444848	4775090
10	446083	4774524
11	447155	4774304
12	438297	4774740
13	438935	4774435
14	439343	4774461
15	439811	4774541
16	440057	4774307
17	440771	4774498
18	442262	4773605
19	442807	4773502
20	443243	4773422
21	443709	4773598
22	443882	4773285
23	445877	4772947
24	446958	4772850
25	447480	4772818
26	447771	4772644
27	448192	4772544
28	438099	4773385
29	438407	4773226
30	438971	4773061
31	439437	4772972
32	439760	4772893
33	440119	4772886
34	439808	4772479
35	440509	4772411

Turbine ID	Easting [m][1]	Northing [m][1]
36	442023	4772350
37	442348	4772325
38	442633	4772221
39	442186	4771810
40	442888	4771912
41	443189	4771699
42	443389	4772239
43	443706	4771937
44	445507	4770915
45	446168	4771350
46	437898	4772729
47	443792	4771485
48	438655	4774608

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

APPENDIX B HOUSE LOCATIONS AND ASSOCIATED SHADOW FLICKER

Shadow flicker at dwellings

Receptors		UTM Coordinates		Participating	Entity	No. of Days per Year	Worst Day	Max Minutes per Day [min/day]	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
#	ID	Easting [m]	Northing [m]						without Cloud Cover	with Cloud Cover		Distance [m]	ID
108	108	445556	4774768	P	Residential	142	15-Feb	40	66	27	9 10	581	10
125	125	443131	4773964	P	Residential	117	9-Feb	42	49	20	18 21 22	553	20
86	86	443148	4776144	P	Residential	75	1-Jan	45	48	19	4	569	4
48	48	443326	4772729	P	Residential	107	11-Jan	30	37	15	37 38	494	42
50	50	442080	4773157	P	Residential	101	5-Jun	31	35	14	19 20	484	18
100	100	440538	4776746	NP	Residential	67	31-Jan	38	32	13	1	621	1
72	72	447611	4773383	P	Residential	58	22-Dec	31	24	10	24	580	25
22	22	441310	4771389	NP	Residential	70	8-Jun	26	24	10	39	972	39
116	116	444591	4771289	NP	Residential	76	26-Apr	28	23	9	44 47	823	47
128	128	443682	4775839	NP	Residential	0	24-Jan	26	23	9	4 5	801	6
76	76	448583	4773286	NP	Residential	78	15-Dec	25	22	9	25 26	839	27
99	99	440666	4776840	P	Residential	61	28-Jan	32	22	9	1	779	1
52	52	440110	4773577	P	Residential	73	20-Dec	26	22	9	30 31	691	33
74	74	448171	4773387	NP	Residential	52	24-Dec	29	20	8	25	843	27
14	14	436943	4772310	P	Residential	82	17-Jul	24	20	8	46	1043	46
61	61	440556	4775164	P	Residential	80	20-Dec	26	19	8	3 15	700	17
44	44	444787	4772434	NP	Cemetery	101	9-Feb	19	19	8	23 43	1190	43
66	66	444496	4774220	NP	Residential	53	1-Jan	26	19	8	21	770	8
111	111	445193	4773159	NP	Residential	42	27-Feb	32	17	7	23	716	23
93	93	442456	4776303	NP	Residential	58	21-Jan	26	17	7	3	604	4
110	110	445068	4773388	NP	Residential	66	2-Feb	25	17	7	22 23	921	23
62	62	441521	4774943	NP	Residential	52	27-Jan	29	17	7	17	872	17
95	95	441938	4776421	P	Residential	50	14-Dec	25	17	7	4	664	3
107	107	445553	4775384	NP	Residential	44	15-Feb	31	16	7	9	764	9
8	8	439363	4771853	NP	Residential	66	5-Jun	20	16	6	35	768	34

Receptors		UTM Coordinates		Participating	Entity	No. of Days per	Worst Day	Max Minutes	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
15	15	437210	4772352	NP	Residential	46	18-Jun	26	15	6	46	785	46
65	65	444543	4774133	NP	Residential	55	21-Jan	25	15	6	21	869	8
112	112	444977	4773035	NP	Residential	60	20-Mar	25	15	6	22 23	904	23
46	46	444943	4772456	NP	Cemetery	58	19-Jun	22	15	6	23	1055	23
43	43	444801	4772492	NP	Cemetery	74	21-Jul	20	15	6	23 43	1168	23
42	42	444909	4772422	NP	Church	75	26-Jun	18	15	6	23 43	1101	23
113	113	444945	4773179	NP	Residential	57	8-Oct	25	14	6	22 23	960	23
67	67	444493	4773978	NP	Residential	42	31-Oct	27	14	6	21	871	21
115	115	444918	4771559	P	Residential	70	21-Mar	19	14	5	43 45 47	873	44
49	49	443253	4772892	P	Residential	61	23-Jan	23	13	5	22 37	530	20
98	98	440782	4776706	NP	Residential	38	18-Oct	29	13	5	1	828	1
51	51	441208	4773238	NP	Residential	62	22-Feb	21	13	5	18 33	1083	35
47	47	444657	4772426	NP	Residential	57	6-Nov	22	12	5	42 43	1069	43
75	75	448300	4773234	P	Residential	40	5-Nov	26	12	5	25	698	27
124	124	441090	4774106	P	Residential	55	19-Apr	22	12	5	16 18	505	17
106	106	445829	4775845	NP	Residential	43	2-Jan	19	12	5	9	1238	9
21	21	441164	4771421	NP	Residential	43	16-May	23	11	4	39	1094	39
27	27	442804	4771133	P	Residential	42	13-May	23	10	4	47	685	41
103	103	439351	4777038	NP	Residential	34	19-Dec	23	10	4	1	886	1
77	77	448799	4773131	NP	Residential	46	1-Nov	20	9	4	26 27	844	27
18	18	438688	4772081	NP	Residential	36	12-May	21	8	3	34	1020	30
114	114	444972	4771983	P	Residential	46	28-Oct	16	8	3	43 47	1195	44
39	39	447191	4771732	NP	Residential	30	17-Feb	20	7	3	45	1081	26
73	73	448024	4773393	NP	Residential	30	4-Feb	18	6	2	24	791	26
117	117	444425	4770964	NP	Residential	26	26-Mar	21	6	2	44	820	47
24	24	441977	4771297	P	Residential	30	5-Aug	17	6	2	41	554	39
121	121	446627	4770918	NP	Residential	26	14-Sep	20	6	2	44	630	45
97	97	441091	4776727	P	Residential	26	1-Mar	19	5	2	1	1089	3
38	38	447320	4771865	NP	Residential	28	31-Oct	18	5	2	45	900	26
53	53	439608	4773718	P	Residential	26	14-Feb	18	5	2	29	741	16
45	45	444930	4772401	NP	Cemetery	37	20-Jun	12	5	2	23	1093	23

Receptors		UTM Coordinates		Participating	Entity	No. of Days per	Worst Day	Max Minutes	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
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63	63	442089	4774807	NP	Residential	26	29-Apr	16	5	2	6	962	5
40	40	446689	4772025	P	Residential	37	18-Jun	11	5	2	26	853	45
87	87	443235	4776297	NP	Residential	16	22-Dec	13	3	1	4	738	4
102	102	439421	4777027	NP	Residential	8	23-Dec	7	1	0	1	828	1
80	80	447960	4775018	NP	Residential	7	20-Dec	4	0	0	11	1076	11
7	7	439422	4771758	NP	Residential	11	18-Jun	2	0	0	35	818	34
1	1	440492	4771514	NP	Residential	0	-	0	0	0		897	35
2	2	440418	4771606	P	Residential	0	-	0	0	0		810	35
3	3	440033	4771602	NP	Residential	0	-	0	0	0		905	34
4	4	439966	4771712	NP	Residential	0	-	0	0	0		783	34
5	5	439532	4771702	NP	Residential	0	-	0	0	0		825	34
6	6	439562	4771796	NP	Residential	0	-	0	0	0		726	34
9	9	439361	4771770	NP	Residential	0	-	0	0	0		838	34
10	10	439307	4771775	NP	Residential	0	-	0	0	0		864	34
11	11	439071	4771955	P	Residential	0	-	0	0	0		904	34
13	13	438402	4771331	NP	Residential	0	-	0	0	0		1486	46
16	16	437540	4772183	P	Residential	0	-	0	0	0		653	46
17	17	438244	4771973	NP	Residential	0	-	0	0	0		831	46
19	19	440754	4771654	P	Residential	0	-	0	0	0		796	35
20	20	440685	4771333	NP	Residential	0	-	0	0	0		1092	35
23	23	441490	4771253	NP	Residential	0	-	0	0	0		891	39
25	25	442335	4771021	NP	Residential	0	-	0	0	0		803	39
26	26	442469	4770950	NP	Residential	0	-	0	0	0		905	39
28	28	445577	4770404	P	Residential	0	-	0	0	0		516	44
29	29	445950	4770504	NP	Residential	0	-	0	0	0		604	44
30	30	446671	4770136	NP	Residential	0	-	0	0	0		1314	45
31	31	449038	4771469	NP	Residential	0	-	0	0	0		1368	27
32	32	448751	4771458	NP	Residential	0	-	0	0	0		1221	27
33	33	448414	4771614	NP	Residential	0	-	0	0	0		956	27
34	34	448177	4771580	NP	Residential	0	-	0	0	0		964	27

Receptors		UTM Coordinates		Participating	Entity	No. of Days per	Worst Day	Max Minutes	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
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37	37	447456	4771732	NP	Residential	0	-	0	0	0		965	26
41	41	446141	4772012	NP	Residential	0	-	0	0	0		663	45
54	54	436989	4774194	NP	Residential	0	-	0	0	0		1374	28
55	55	437435	4775794	NP	Residential	0	-	0	0	0		1362	12
56	56	437496	4775876	NP	Residential	0	-	0	0	0		1390	12
57	57	437989	4775657	NP	Residential	0	-	0	0	0		967	12
58	58	438086	4775744	NP	Residential	0	-	0	0	0		1026	12
59	59	438543	4775543	P	Residential	0	-	0	0	0		840	12
60	60	439974	4775313	P	Residential	0	-	0	0	0		686	2
64	64	444080	4774330	P	Residential	0	-	0	0	0		580	8
68	68	445664	4773957	NP	Residential	0	-	0	0	0		705	10
69	69	446511	4773750	NP	Residential	0	-	0	0	0		850	11
70	70	446563	4773650	NP	Residential	0	-	0	0	0		882	11
71	71	447074	4773519	P	Residential	0	-	0	0	0		679	24
78	78	449553	4772906	NP	Residential	0	-	0	0	0		1408	27
269	269	448795	4773833	NP	Residential	0	-	0	0	0		1423	27
79	79	448486	4774894	NP	Residential	0	-	0	0	0		1456	11
81	81	447316	4775164	NP	Residential	0	-	0	0	0		875	11
82	82	447105	4775353	NP	Residential	0	-	0	0	0		1050	11
83	83	446795	4775234	NP	Residential	0	-	0	0	0		997	11
84	84	446545	4775477	NP	Residential	0	-	0	0	0		1059	10
85	85	444009	4776036	NP	Residential	0	-	0	0	0		1138	8
88	88	443429	4776574	NP	Residential	0	-	0	0	0		1073	4
89	89	443349	4776596	NP	Residential	0	-	0	0	0		1040	4
90	90	443471	4776774	NP	Residential	0	-	0	0	0		1256	4
91	91	443526	4777025	NP	Residential	0	-	0	0	0		1494	4
92	92	442955	4776289	NP	Residential	0	-	0	0	0		574	4
94	94	442311	4776526	NP	Residential	0	-	0	0	0		869	4
96	96	442012	4776698	NP	Residential	0	-	0	0	0		948	3

Receptors		UTM Coordinates		Participating	Entity	No. of Days per	Worst Day	Max Minutes	Total Hours in Year [hrs/yr]		Turbine ID Contributing to Events	Nearest Turbine	
101	101	439911	4776901	P	Residential	0	-	0	0	0		474	1
104	104	439165	4777198	NP	Residential	0	-	0	0	0		1131	1
105	105	445721	4776028	NP	Residential	0	-	0	0	0		1281	9
109	109	445333	4773628	NP	Residential	0	-	0	0	0		872	23
118	118	444358	4770042	NP	Residential	0	-	0	0	0		1443	44
119	119	444440	4770060	NP	Church	0	-	0	0	0		1367	44
120	120	446141	4769567	NP	Residential	0	-	0	0	0		1490	44
122	122	436488	4772701	NP	Residential	0	-	0	0	0		1410	46
123	123	447915	4775316	NP	Residential	0	-	0	0	0		1266	11
126	126	440597	4771573	NP	Residential	0	-	0	0	0		843	35
127	127	439189	4771452	NP	Residential	0	-	0	0	0		1199	34