APPENDIX D

Shadow Flicker Assessment

GL Garrad Hassan

SHADOW FLICKER ASSESSMENT

PUGWASH WIND FARM, CUMBERLAND COUNTY, NOVA SCOTIA

Client	Pugwash Wind Farm Inc.
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Issue	Issue Date	Summary
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B	26 January 2012	Revisions throughout

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1 INTRODUCTION

GL Garrad Hassan Canada, Inc. (GL GH), a member of the GL Group and part of the GL Garrad Hassan brand, has been commissioned by Pugwash Wind Farm Inc. ("Client") to independently assess the impact of the shadow flicker effects in the vicinity of the proposed Pugwash Wind Farm (the "Project"). The project is located in Cumberland County, Nova Scotia and consists of 12 Siemens SWT2.3-113 and 1 alternate Siemens SWT2.3-113 location, with a maximum blade tip height of 155.5 m, a hub height of 99 m and a rotor diameter of 113 m. These turbines can have an influence on the shadow flicker events experienced at sensitive locations in the vicinity of the Project. For the purpose of this shadow flicker analysis, all 13 turbines have been considered.

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 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 Project is located in the northern part of the county of Cumberland, Nova Scotia. More specifically, it is situated to the north and south of the Irishtown Road, east of the Village of Pugwash.

Land use around the Project is rural and mainly consists of agriculture, light industry, forestry and recreational. The area directly affected by the Project is located on private land. The elevation ranges from 10 m to 37 m.

2.2 Wind Farm Layout

The proposed turbine layout, which consists of 12 Siemens SWT2.3-113 and 1 alternate Siemens SWT2.3-113 wind turbine generator, 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 20N, NAD 1983 datum [1].

2.3 Receptors Locations

A list of receptors for this shadow flicker assessment has been provided by the Client [2]. This list includes 182 receptors, but only the 102 receptors within the study zone of 1555 m of a turbine, a distance calculated on the basis of the turbine's tip height x 10 (see methology section below), have been considered in this analysis. Information provided by the Client includes a number of buildings that may be barns, sheds or outbuildings and not habitable dwellings. These receptors are noted as "Dwelling Unsure". Therefore, the list of receptors noted below is likely much larger than the actual number of habitable dwellings.

Coordinates of the receptors considered in this study are presented in Appendix B. It should be noted that GL GH has not visited the site, and hence has not validated the buildings. Receptors in the vicinity of the proposed Project and included in the list have been validated by the Client.

2.4 Applicable Regulations

There are no applicable local or state requirements with regard to shadow flicker in the jurisdictions associated with this Project.

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;
- 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 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 subject 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 [3], while the Danish wind industry suggests a value of between 500 and 1000 m [4]. GL GH has adopted a conservative approach and has assumed the length, D, that a shadow can be cast on the basis of the following formula:

D = 10 x (hub height + rotor radius)

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.

Shadow flicker calculations can be adjusted using an annual cloud coverage figure which is based on historical meteorological data and statistics. According to data gathered from meteorological stations, an annual cloud cover can be estimated and applied as a percentage. 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 has 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 [5].

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 [5].

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.

3.4 Current Analysis

The shadow flicker assessment for the proposed Project has been conducted for the 12 Siemens SWT2.3-113 and 1 alternate Siemens SWT2.3-113 turbine using the method described in Section 3.2 above. All receptors are located at a distance D from the turbines, defined in Section 3.2 have been included in the study. For the Siemens SWT2.3-113 wind turbine generator this equates to 1555 m. It shall be noted that only 12 wind turbines are expected to be installed and thus the current analysis is conservative in assuming all 13 turbine positions.

In order to render more realistically the shadow flicker results, an annual cloud cover figure has been considered based on data gathered from Halifax and Shearwater Airports meteorological stations. It has been estimated that the cloud cover is sufficient to nullify shadow flicker occurrence 68.6 % of the time over the course of a year. Results both with and without consideration of cloud cover are presented in Section 4 and Appendix B. Furthermore, using the site-specific wind rose to consider the probability of the turbines being oriented in a given direction could lead to a further reduction in the expected annual shadow flicker occurrence.

The model does not take into account any obstacles like for example; vegetation, mountains, or other shielding effects, around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shut-down has not been considered. For these reasons and the other conservative assumptions listed in Section 3.3 above, and the consideration of cloud cover, it is likely that the adjusted shadow flicker durations presented here can still be regarded as conservative.

4 RESULTS

A map illustrating predicted shadow flicker duration at receptors within 1555 m of the Pugwash Wind Farm turbines is presented in Figure 4-1. This map takes into account average annual cloud cover. For illustrative purposes shadow flicker is shown when occurring 30 hours or more per year.

The results of the shadow flicker assessment are presented for all receptors locations provided by the Client and within the study zone (in terms of maximum minutes per day and total hours per year) in tabular format in Appendix B.

As per the predicted levels from this analysis, dwelling ID76 (PID 25453523) would experience the most shadow flicker with a maximum of 36 minutes per day (on December 24) and 9 hours per year. Results in hours per year take into account the cloud cover from the Environment Canada meteorological stations at Halifax and Shearwater Airports but, as described in Section 3.3, these results are still considered to be overestimated.

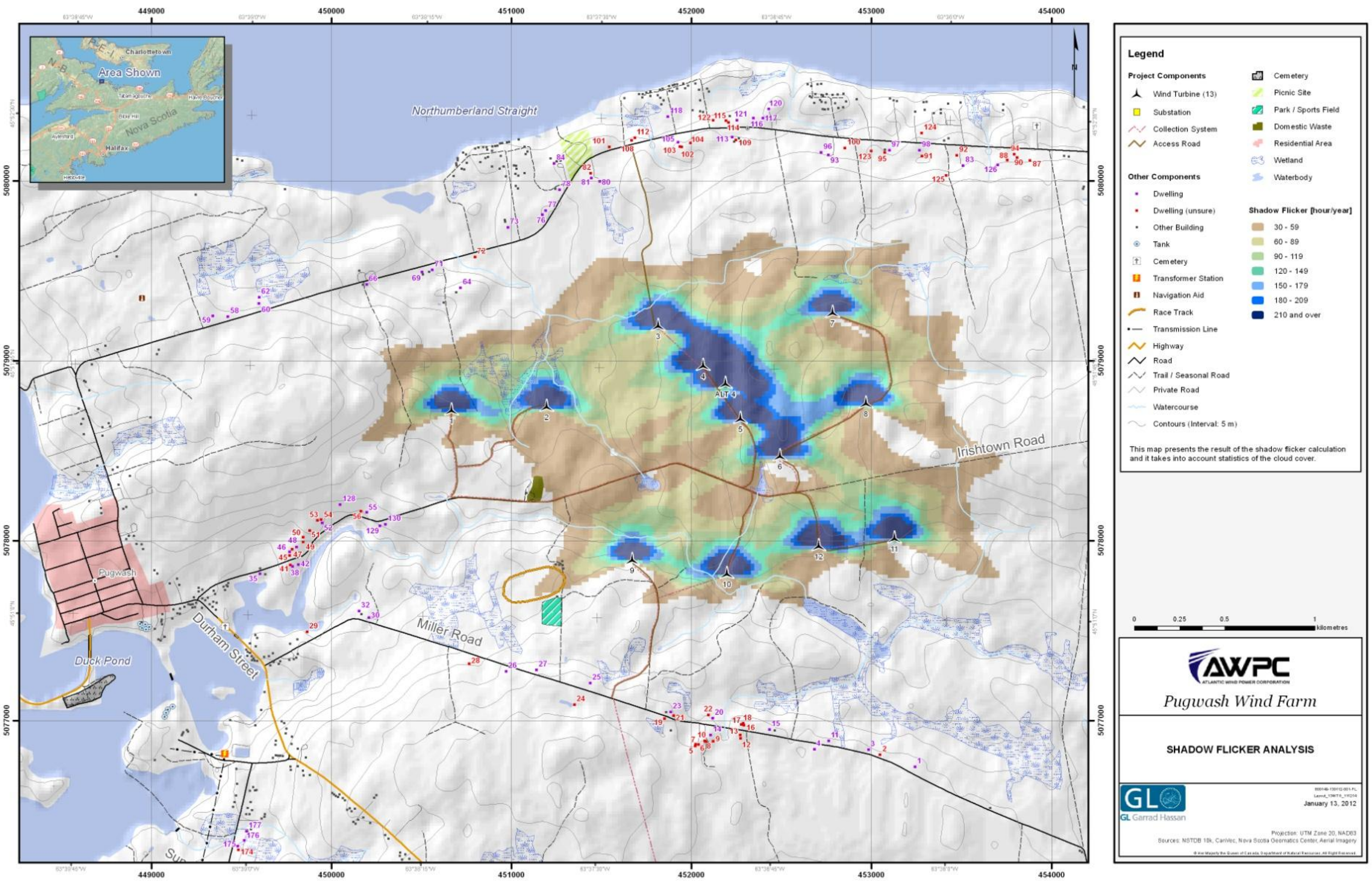

Figure 4-1: Modeled hours of shadow flicker at Pugwash Wind Farm Wind Farm

5 CONCLUSION

An analysis has been conducted to estimate the duration of shadow flicker to be experienced at receptors in the vicinity of the Pugwash Wind Farm Wind Farm in County, Cumberland County, Nova Scotia. This analysis was realized specifically for the Siemens SWT2.3-113 wind turbine with a blade tip height of 155.5 m.

As per the predicted levels from this analysis, dwelling ID76 (PID 25453523) would experience the most shadow flicker with a maximum of 36 minutes per day (on December 24) and 9 hours per year. Results in hours per year take into account the cloud cover from the Environment Canada meteorological stations at Halifax and Shearwater Airports but, as described in Section 3.3, these results are still considered to be overestimated.

6 REFERENCES

[1] Turbine layout locations sent by email, by Charles Demond, to Shant Dokouzian, 16 December 2011, “turbine_coordinates_dec-14-2011.xls”.

[2] Dwellings locations sent by email, by Charles Demond, to Shant Dokouzian, 21 December 2012, “pugwash_buildings_and_dwellings.shp”

[3] 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.

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

[5] 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.

APPENDIX A TURBINE LAYOUT

Coordinates of turbines

Turbine ID	Easting [m][1]	Northing [m][1]
1	450666	5078715
2	451195	5078736
3	451813	5079184
4	452064	5078963
5	452271	5078668
6	452490	5078461
7	452783	5079258
8	452968	5078753
9	451670	5077885
10	452197	5077807
11	453128	5078004
12	452706	5077961
ALT 4	452187	5078863

1. Coordinate system is UTM Zone 20N, NAD83 datum.

APPENDIX B RECEPTOR LOCATIONS AND ASSOCIATED SHADOW FLICKER

Shadow flicker at dwellings

Receptors		UTM Coordinates		Type	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	PID	Easting [m]	Northing [m]					without Cloud Cover	with Cloud Cover		Distance [m]	ID
76	25453523	451171	5079813	Dwelling	62	24-Dec	36	30	9	3 4 ALT 4	899	3
77	25154022	451190	5079835	Dwelling	53	16-Dec	36	24	8	3 4 ALT 4	901	3
73	25154345	450980	5079741	Dwelling	70	10-Nov	28	22	7	3 4 ALT 4	1002	3
27	25158288	451139	5077283	Dwelling	74	1-Jun	23	20	6	10	802	9
56	25331687	450163	5078165	Dwelling (unsure)	75	29-Jun	23	19	6	2 9	746	1
72	25275504	450798	5079577	Dwelling (unsure)	59	25-Oct	27	18	6	3 4 ALT 4	872	1
63	25154386	450693	5079380	Dwelling	75	13-Mar	24	18	6	2 3 4 ALT 4	665	1
64	25154386	450717	5079406	Dwelling	62	1-Oct	24	16	5	3 4 ALT 4	692	1
52	25276353	449948	5078100	Dwelling	68	8-Jul	20	16	5	2	946	1
90	25152786	453810	5080130	Dwelling (unsure)	51	19-Dec	22	16	5	7	1348	7
87	25152786	453880	5080113	Dwelling (unsure)	63	10-Jan	21	16	5	7	1391	7
128	25361247	450049	5078201	Dwelling	63	26-May	22	15	5	2	803	1
55	25331687	450197	5078159	Dwelling	67	19-Jun	18	15	5	2 9	728	1
54	25276353	449942	5078117	Dwelling (unsure)	72	30-May	19	15	5	2	939	1
108	25346198	451667	5080225	Dwelling (unsure)	52	3-Jan	20	15	5	7	1051	3
51	25353723	449878	5078057	Dwelling (unsure)	66	8-Jul	19	14	5	2	1027	1
88	25152786	453754	5080116	Dwelling (unsure)	47	22-Dec	23	14	4	7	1296	7
126	25392028	453702	5080089	Dwelling	45	15-Dec	23	14	4	7	1239	7
50	25158650	449842	5078019	Dwelling (unsure)	62	2-Jul	17	13	4	2	1079	1
94	25152786	453793	5080149	Dwelling (unsure)	45	28-Dec	22	13	4	7	1347	7
112	25346198	451685	5080240	Dwelling (unsure)	46	27-Dec	20	13	4	7	1064	3
53	25276353	449922	5078114	Dwelling (unsure)	60	30-May	19	12	4	2	957	1
66	25154410	450196	5079425	Dwelling	47	19-Nov	23	12	4	2	851	1
49	25158650	449842	5077993	Dwelling (unsure)	55	27-Jun	17	11	4	2	1096	1
69	25154402	450502	5079495	Dwelling	48	7-Oct	21	11	3	2 3	797	1

Receptors		UTM Coordinates		Type	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	PID	Easting [m]	Northing [m]					without Cloud Cover	with Cloud Cover		Distance [m]	ID
71	25336769	450560	5079506	Dwelling	46	4-Mar	21	10	3	3 4	798	1
123	25153040	452999	5080166	Dwelling (unsure)	43	1-Jan	18	10	3	3	934	7
48	25158619	449806	5077966	Dwelling	53	19-Jun	16	10	3	2	1141	1
95	25336025	453073	5080158	Dwelling (unsure)	54	10-Jan	16	10	3	3	946	7
101	25154006	451544	5080188	Dwelling (unsure)	48	18-Jan	19	10	3	7	1040	3
26	25159062	450970	5077274	Dwelling	40	24-Jul	19	8	3	10	929	9
62	25154428	449599	5079353	Dwelling	36	2-Feb	22	8	3	1	1243	1
60	25154436	449597	5079319	Dwelling	34	5-Feb	22	8	2	1	1228	1
28	25158247	450765	5077318	Dwelling (unsure)	54	7-May	15	8	2	9 10	1068	9
80	25154014	451490	5079998	Dwelling	30	6-Nov	19	6	2	7	876	3
81	25350372	451444	5080016	Dwelling	28	3-Feb	19	6	2	7	910	3
82	25350372	451439	5080042	Dwelling (unsure)	28	2-Feb	19	6	2	7	936	3
130	25331695	450300	5078091	Dwelling	24	29-Sep	19	5	2	9	724	1
25	25158296	451437	5077209	Dwelling	42	21-Jun	11	5	2	12	715	9
30	25158262	450208	5077573	Dwelling	26	21-Aug	19	5	2	9	1231	1
129	25158692	450268	5078083	Dwelling	23	16-Mar	18	5	2	9	747	1
32	25276734	450153	5077610	Dwelling	24	18-Apr	17	5	2	9	1219	1
58	25357682	449425	5079246	Dwelling	26	17-Feb	17	5	2	1	1350	1
59	25157413	449340	5079249	Dwelling	23	19-Feb	16	4	1	1	1430	1
1	25359365	453242	5076745	Dwelling	0	-	0	0	0	-	1264	11
2	25158403	453048	5076810	Dwelling (unsure)	0	-	0	0	0	-	1197	11
3	25357542	452984	5076839	Dwelling	0	-	0	0	0	-	1156	12
4	25277054	452684	5076842	Dwelling	0	-	0	0	0	-	1081	10
5	25339078	452021	5076859	Dwelling (unsure)	0	-	0	0	0	-	964	10
6	25159260	452040	5076868	Dwelling (unsure)	0	-	0	0	0	-	952	10
7	25339078	452023	5076869	Dwelling (unsure)	0	-	0	0	0	-	954	10
8	25159260	452080	5076884	Dwelling (unsure)	0	-	0	0	0	-	930	10
9	25159260	452121	5076886	Dwelling (unsure)	0	-	0	0	0	-	924	10
10	25159260	452074	5076888	Dwelling (unsure)	0	-	0	0	0	-	927	10

Receptors		UTM Coordinates		Type	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	PID	Easting [m]	Northing [m]					without Cloud Cover	with Cloud Cover		Distance [m]	ID
11	25158387	452764	5076888	Dwelling	0	-	0	0	0	-	1075	12
12	25158379	452274	5076902	Dwelling (unsure)	0	-	0	0	0	-	908	10
13	25158379	452270	5076920	Dwelling (unsure)	0	-	0	0	0	-	890	10
14	25159260	452107	5076920	Dwelling	0	-	0	0	0	-	891	10
15	25338625	452433	5076951	Dwelling	0	-	0	0	0	-	888	10
16	25393877	452292	5076975	Dwelling (unsure)	0	-	0	0	0	-	837	10
17	25393877	452278	5076980	Dwelling (unsure)	0	-	0	0	0	-	831	10
18	25393877	452287	5076985	Dwelling (unsure)	0	-	0	0	0	-	827	10
19	25330333	451851	5077012	Dwelling (unsure)	0	-	0	0	0	-	867	10
20	25395005	452118	5077015	Dwelling	0	-	0	0	0	-	796	10
21	25330325	451900	5077028	Dwelling (unsure)	0	-	0	0	0	-	833	10
22	25097510	452095	5077032	Dwelling (unsure)	0	-	0	0	0	-	781	10
23	25330325	451884	5077049	Dwelling	0	-	0	0	0	-	820	10
24	25462292	451351	5077090	Dwelling (unsure)	0	-	0	0	0	-	856	9
29	25158056	449865	5077493	Dwelling (unsure)	0	-	0	0	0	-	1462	1
35	25158627	449603	5077817	Dwelling	0	-	0	0	0	-	1392	1
38	25159310	449783	5077857	Dwelling	0	-	0	0	0	-	1232	1
41	25159310	449771	5077866	Dwelling (unsure)	0	-	0	0	0	-	1234	1
42	25158635	449816	5077867	Dwelling	0	-	0	0	0	-	1201	1
45	25158643	449767	5077918	Dwelling (unsure)	0	-	0	0	0	-	1202	1
46	25158643	449767	5077939	Dwelling	0	-	0	0	0	-	1188	1
47	25158643	449781	5077952	Dwelling (unsure)	0	-	0	0	0	-	1169	1
78	25154048	451268	5079951	Dwelling	0	-	0	0	0	-	941	3
83	25340431	453510	5080085	Dwelling	0	-	0	0	0	-	1101	7
84	25051202	451237	5080097	Dwelling	0	-	0	0	0	-	1080	3
91	25454323	453281	5080138	Dwelling (unsure)	0	-	0	0	0	-	1011	7
92	25373713	453475	5080143	Dwelling (unsure)	0	-	0	0	0	-	1124	7
93	25153362	452760	5080144	Dwelling	0	-	0	0	0	-	886	7
96	25153370	452721	5080159	Dwelling	0	-	0	0	0	-	903	7

Receptors		UTM Coordinates		Type	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	PID	Easting [m]	Northing [m]					without Cloud Cover	with Cloud Cover		Distance [m]	ID
97	25336025	453100	5080170	Dwelling	0	-	0	0	0	-	966	7
98	25454323	453267	5080171	Dwelling	0	-	0	0	0	-	1034	7
100	25200627	452853	5080183	Dwelling (unsure)	0	-	0	0	0	-	928	7
102	25153602	451946	5080188	Dwelling (unsure)	0	-	0	0	0	-	1013	3
103	25153602	451936	5080191	Dwelling (unsure)	0	-	0	0	0	-	1015	3
104	25153750	451994	5080210	Dwelling (unsure)	0	-	0	0	0	-	1042	3
105	25153602	451925	5080215	Dwelling	0	-	0	0	0	-	1037	3
109	25362013	452248	5080228	Dwelling (unsure)	0	-	0	0	0	-	1108	7
113	25362013	452227	5080244	Dwelling	0	-	0	0	0	-	1132	7
114	25348574	452205	5080325	Dwelling (unsure)	0	-	0	0	0	-	1207	3
115	25348574	452192	5080336	Dwelling (unsure)	0	-	0	0	0	-	1213	3
116	25393828	452345	5080350	Dwelling	0	-	0	0	0	-	1177	7
117	25153396	452398	5080350	Dwelling	0	-	0	0	0	-	1158	7
118	25153677	451869	5080358	Dwelling	0	-	0	0	0	-	1176	3
120	25153404	452430	5080400	Dwelling	0	-	0	0	0	-	1195	7
121	25393794	452253	5080338	Dwelling	0	-	0	0	0	-	1203	7
122	25348558	452121	5080337	Dwelling (unsure)	0	-	0	0	0	-	1194	3
124	25451865	453278	5080266	Dwelling (unsure)	0	-	0	0	0	-	1123	7
125	25165440	453416	5080031	Dwelling (unsure)	0	-	0	0	0	-	999	7