HAND HILLS SHADOW FLICKER ANALYSIS

for

BER HAND HILLS WIND GP INC

January 14th, 2020

Report Title:

Hand Hills Shadow Flicker Analysis

Prepared By:

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Prepared For:

BER Hand Hills Wind GP Inc

(a subsidiary of BluEarth Renewables Inc.)

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CONTENTS

1. INTRODUCTION

Green Cat Renewables (GCR) has been retained to produce a shadow flicker analysis for the Hand Hills Wind Project located near Delia, Alberta, Canada.

BER Hand Hills Wind GP Inc., as a subsidiary of BluEarth Renewables Inc, hold a permitting approval (U2014-187) from the Alberta Utility Commission (AUC) to construct and operate the 32 turbine wind farm. GCR's objective for this assessment is to complete the shadow flicker impact assessment for the proposed BER Hand Hills Wind GP Inc. Project exclusively. The impact at each receptor within 1.5km of a turbine has been assessed. This report presents the results of analysing a theoretical worst-case scenario modelled in WindPRO software.

In the absence of any current guideline or protocol for shadow flicker assessment in Alberta, GCR will refer where appropriate to the consultation on changes to Rule 007 that is ongoing[1].

The assessment has been undertaken for 32, Siemens Gamesa SG-145-4.5 turbines, which have a 145m rotor diameter and a 107.5m hub height, totalling 180m in height.

1.1. Shadow Flicker Overview

Under certain combinations of geographical position and time of day, the sun may pass behind the rotor of a wind turbine and cast a moving shadow over neighbouring properties. Where this shadow passes over a narrow opening such as a window, the light levels within the room affected will decrease and increase as the blades rotate, hence the shadow causes light levels to 'flicker'. Predac, a European Union sponsored organization promoting best practice energy use and supply which draws on experience from Belgium, Denmark, France, the Netherlands, and Germany, suggests:

> *"Shadow flicker only occurs in certain specific combined circumstances, such as when: The sun is shining and is at a low angle (after dawn and before sunset), and the turbine is directly between the sun and the affected property, and there is enough wind energy to ensure that the turbine blades are moving."*[2]

Whilst the moving shadow can occur outside, the shadow flicker effect is only experienced inside buildings where the shadow passes over a narrow window opening. The seasonal duration of this effect can be calculated from the geometry of each turbine and the latitude of the site. A schematic of the geometry is shown in Appendix 1: WindPRO Shadow Flicker, **Figure A-1**. A single window in a single building is likely to

[1] https://engage.auc.ab.ca/Rule007, accessed December 6th, 2019

[2] English translation contained within: Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report.* Retrieved November 13, 2019, from Department of Energy and Climate Change: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf

be affected for a few minutes at certain times of the day for short periods of the year. The likelihood of this occurring and the duration of such an effect depend upon:

- The direction of the residence relative to the turbine(s);
- The distance from the turbine(s);
- The turbine hub-height and rotor diameter;
- The time of year;
- The proportion of day-light hours in which the turbine operates;
- The frequency of bright sunshine and cloudless skies (particularly at low elevations above the horizon); and
- The prevailing wind direction.

The further the window is from the turbine, the less pronounced the effect will be. There are several reasons for this:

- There are fewer times when the sun is low enough to cast a long shadow;
- When the sun is low it is more likely to be obscured by either cloud on the horizon or intervening buildings and vegetation;
- The centre of the rotor's shadow passes more quickly over the land reducing the duration of the effect; and,
- The blade covers a smaller proportion of the sun disc, as Predac comments:

> *"At distance, the blades do not cover the sun but only partly mark it, substantially weakening the shadow. This effect occurs first with the shadow from the blade tip, the tips being thinner in section than the rest of the blade. The shadows from the tips extend the furthest and so only a very weak effect is observed at distance from the turbines."* [3]

[3] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report.* Retrieved November 13, 2019, from Department of Energy and Climate Change: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf

2. SHADOW FLICKER ASSESSMENT PROCESS

The following section sets out the methodology that has been used within the assessment.

2.1. Identification of Potential Shadow Flicker Zone

The Hand Hills Wind Project is located within Starland County and Special Area 2. The project location is rural, consisting primarily of cultivated fields and near two provincial parks, Little Fish Lake Provincial Park and a portion of Dinosaur Provincial Park. For this analysis, 20 shadow receptor locations were identified, and their locations are disclosed in **Table 3-1**.

Given the latitude of the site (~51.6° north) it is considered safe to assess shadow flicker impacts within 135 degrees either side of north relative to the turbine and a distance of 1.5 km from the nearest turbine[4].

GCR has conservatively considered 1.5km as a safe assessment radius from each turbine[5].

2.2. Modelling of Windows

Each property has been modelled using WindPRO's 'green house' mode assuming dwellings and offices within the project area have windows oriented in every direction and therefore are always susceptible to flicker from each direction. Each receptor has been modelled as having a single window across the full length of wall facing the turbine. This represents a conservative approach to ensure that annual variations in timings of shadow flicker events are captured in the model.

2.3. Model Conditions

Calculations have been carried out using WindPRO software. This program uses the Shadow calculation method that accounts for simple geometric considerations: the position of the sun at a given date and time; assumes a 'green house' model for receptors; and the size of the turbine that may cast the shadows. The 'green house' model adopts a conservative approach by assuming that:

- The turbine is facing the sun at all times of the day;
- Sunlight is present, unobstructed by cloud cover, and is strong enough for shadow flicker to occur;
- The turbine is always operating; and
- There is no local screening from trees or other buildings.

The shadow effect of the blades gets gradually fainter as the distance between the turbine and the receptor increases. Where the average blade width is up to 2.8m, it is not expected that significant shadow flicker would theoretically be possible beyond the 1.5km study radius. WindPRO calculates the shadow propagation using the blade width method and the calculation requires that the blade width at 90% radius

[4] https://engage.auc.ab.ca/Rule007/forum_topics/6-shadow-flicker, accessed December 6th, 2019.
[5] *Ibid*

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and at the maximum blade width has been entered in the catalogue for the particular turbine type.[6] In this case, the turbine blades have a width at 90% radius of 1.16m and a maximum of 4.48m. The shadow propagation is calculated by a combination of the blade width and the minimum sun height of influence, which was set at 3° over the horizon, WindPRO's default setting. A minimum sun angle threshold was chosen because at low sun angles, the sunlight is more diffuse which limits any scope for coherent shadows to form, leading to less strong shadows.

2.4. Potential Impacts

The AUC is currently consulting with the public and experts on how to incorporate shadow flicker into Rule 007 - Applications for Power Plants. The AUC is considering the applicability of a level of 30 hours per year and/or 30 minutes per day. This report will use these values as the starting point at which potential for adverse shadow flicker impacts could exist. Therefore, any properties theoretically predicted to have potential to experience flicker at or above these levels have been noted by the report.

[6,7] Per Nielsen, E. I. (2010, October). *WindPRO 2.7 User Guide 3. edition.* Retrieved November 13, 2019, from http://www.emd.dk/files/windpro/manuals/for_print/MANUAL_2.7.pdf

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3. BASELINE

Twenty receptors have been identified as being within the 1.5km study radius and are therefore included in the assessment.

Figure 3-1 below shows the 1.5km boundary with the receptors and wind turbines identified forming the baseline for the analysis. Details of the identified receptors are listed in **Table 3-1**.

No other residential properties were identified within, or on the immediate boundary of, the study radius.

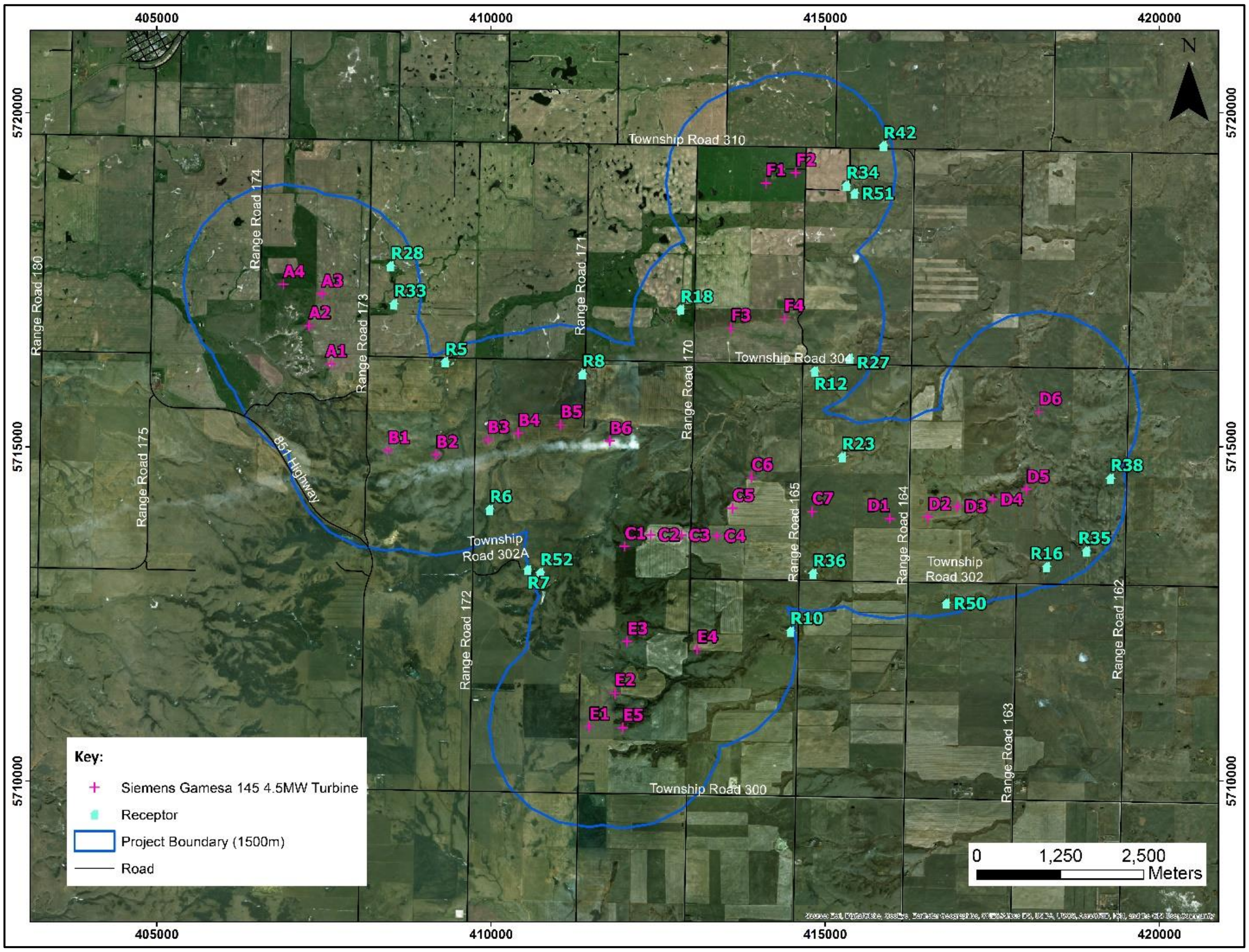

Figure 3-1 – Hand Hills Baseline Map

Table 3-1 – Potentially Sensitive Shadow Receptors

Receptor ID	Receptor Height (m)	Distance to Nearest Turbine (m)	Orientation of receptor (Degrees from north)
R05	4.5	1328	151
R06	1.5	1041	358
R07	1.5	1499	77
R08	1.5	828	203
R10	4.5	1425	259
R12	4.5	907	330
R16	1.5	1184	345
R18	4.5	804	110
R23	1.5	927	209
R27	1.5	1148	301
R28	1.5	1111	248
R33	4.5	1089	278
R34	1.5	782	284
R35	1.5	1286	315
R36	1.5	930	359
R38	4.5	888	310
R42	1.5	1375	253
R50	4.5	1321	348
R51	4.5	932	289
R52	1.5	1324	73

The effects of shadow flicker are typically predicted to be worst at the bottom of dwellings in the absence of screening, so this assessment used a calculation height of 1.5m for all dwellings to provide a conservative, worst-case estimation of potential shadow flicker impacts.

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4. MODELING RESULTS

The detailed results of the WindPRO shadow flicker model are presented in **Table 4-1** which includes the "worst-case" shadow hours per year, and max shadow hours per day. Appendix 3: Shadow Flicker Map includes the iso-contour map of the "worst-case" annual hours of shadow flicker for the entire project space.

Theoretical periods of shadow flicker were calculated using WindPRO's software for the above properties. The conservative results are summarised in **Table 4-1** below:

Table 4-1 – Theoretical Shadow Flicker Assessment

Receptor ID	Location NAD83, UTM Zone 12			Theoretical Shadow hours per year	Max shadow hours per day	Largest Contribution		
	Easting	Northing	Elevation (m)	(hh:mm)	(hh:mm)	Turbine ID	Distance to Receptor (m)	Month
R05	409316	5716269	961	0:00	0:00	N/A	N/A	N/A
R06	409983	5714064	1,003	0:00	0:00	N/A	N/A	N/A
R07	410547	5713163	1,025	5:48	0:19	C1	1499	April/ August
R08	411372	5716090	943	45:22	0:46	B5	828	December
R10	414484	5712240	959	9:04	0:23	E4	1425	March
R12	414842	5716133	903	26:58	0:26	F3	1423	July
R16	418315	5713207	920	0:00	0:00	N/A	N/A	N/A
R18	412839	5717055	929	28:37	0:41	F3	804	March
R23	415254	5714847	933	55:12	1:05	C7 and D1	C7: 927 D1: 1173	December
R27	415368	5716321	899	26:56	0:32	F4	1148	June
R28	408502	5717703	945	15:45	0:31	A3	1111	October
R33	408549	5717136	958	53:21	0:31	A1	1322	January
R34	415320	5718909	951	54:11	0:44	F2	1334	August
R35	418910	5713440	922	0:00	0:00	N/A	N/A	N/A
R36	414820	5713104	953	2:52	0:08	D1	1896	June
R38	419268	5714528	930	8:37	0:26	D5	888	March
R42	415876	5719504	876	9:47	0:25	F2	1375	October
R50	416814	5712658	930	0:00	0:00	N/A	N/A	N/A
R51	415442	5718792	885	44:41	0:37	F2	932	May
R52	410740	5713118	1,014	11:01	0:26	C1	1324	August
Total hours/year				398:12				

No shadow flicker impacts are expected at R05, R06, R16, R35, or R50 due to their location relative to the turbines.

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A further 7 properties are expected to experience less than 30 hours annually or 30 minutes daily of shadow flicker: R07, R10, R12, R36, R38, R42, and R52. As such, these 7 properties have not been considered further within the assessment.

3 properties, R18, R27, R28, are predicted to theoretically experience less than 30 hours of shadow flicker annually. However, these properties are predicted to experience more than 30 minutes of shadow flicker on one or more days during the year.

5 properties: R08, R23, R33, R34, and R51, are theoretically predicted to experience greater than 30 hours annually or 30 minutes daily of shadow flicker.

The results shown in **Table 4-1** are modelled under worst-case assumptions and are conservative values. This conservative approach should yield an overestimation of actual shadow flicker amounts for all properties.

Since the shadow receptors were modelled under the 'green house' simulation, the actual location and window orientation relative to the turbine location may reduce the realistic flicker inside the dwelling or office. This analysis could be optimized further if the orientation of the property, window dimension and number, presence of other buildings, trees, obstacles, etc were known.

In practice, a further reduction in flicker will result from the fact that: the turbines will not always be turning (because it is not always windy); the turbines will not always be directly facing the properties in question; and the weather is not always sunny. Another factor to consider is the time of year the estimated flicker is predicted to occur. For this assessment WindPRO uses weather data from the Suffield weather station located 164km from the Hand Hills site. Suffield sees an average of 6.6 hours of sunshine per day. In December and January, when the greatest potential for flicker exists, the average sunshine per day is approximately 2.92-4.39 hours per day. So, in practice, the flicker may likely be less than half of what the model predicts due to the actual amount of sunshine experienced.

If flicker became problematic to residents, mitigation measures could be employed to reduce the level of flicker. The most common such measure is programming the relevant turbines to switch off at times when flicker could be present. This could be targeted to times of day and/or year when the occupant is most likely to be affected by any flicker, in consultation with the resident. Another possibility might be some form of vegetative screening close enough to the affected window(s) to mitigate the worst effects without unduly preventing light reaching the property. If such mitigation was impractical, then adding shutters or external shading elements to the dwelling on a case by case basis would be a consideration. This would recognise that any flicker impact also has some dependence on how the affected dwelling is used.

5. SUMMARY AND CONCLUSION

Properties within the potential shadow flicker zone of the Hand Hills Wind Project have been modelled within WindPRO software. The AUC is consulting on how to assess shadow flicker for receptors. Therefore, properties with potential to have more flicker than 30 hours per year or 30 minutes per day have been highlighted.

Twenty properties were identified within 1.5km of any of the turbines. Following modelling, it has been shown that eight of the properties could theoretically experience shadow flicker above 30 hours annually and/or 30 minutes daily. Twelve of the twenty properties required no further consideration.

The shadow receptors with potential for exceeding the 30 hours/year or 30 minutes/day levels are listed in **Table 5-1** below.

Table 5-1 – Estimated Theoretical Shadow Flicker for the Most Impacted Receptors

Receptor ID	Location NAD83, UTM Zone 12			Shadow hours per year (hh:mm/year)	Max shadow hours per day (hh:mm/day)	Largest Contribution	
	Easting	Northing	Elevation (m)			Turbine ID	Month
R08	411372	5716090	943.7	45:22	0:46	B5	December
R18	412839	5717055	929.7	28:37	0:41	F3	March
R23	415254	5714847	933.6	55:12	1:05	C7 and D1	December
R27	415368	5716321	899.9	26:56	0:32	F4	June
R28	408502	5717703	945.4	15:45	0:31	A3	October
R33	408549	5717136	958.7	53:21	0:31	A1	January
R34	415320	5718909	951.0	54:11	0:44	F2	August
R51	415442	5718792	885.8	44:41	0:37	F2	May

These receptors were modelled using the worst-case assumptions in WindPRO and it is worth noting that this assessment may result in an overestimation of the actual shadow flicker amounts. Since the WindPRO's 'green house' model assumes receptors are susceptible to shadow flicker from all directions, the actual location and orientation of the dwelling's windows in relation to the turbine location may reduce the duration and number of days that flicker occurs inside the dwelling. A more precise and realistic analysis could be performed if the actual window locations and orientations were considered, as well as if the presence of other buildings, trees, and obstacles were identified between the turbines and the dwellings.

In practice, a further reduction in flicker will result from the fact that: the turbines will not always be turning (because it is not always windy); the turbines will not always be directly facing the properties in question; the weather is not always sunny; and the estimated average sunshine per month changes from month to month with noteworthy decreases in sunshine hours in the winter months. If all of these parameters were known in advance, the model could be evaluated under a 'real-case' scenario, which would reduce the number of hours of flicker predicted.

If any dwelling experienced shadow flicker in practice that was found to be unacceptable, possible mitigation measures such as turning the turbines off during the flicker periods, planting trees, or installing shutters could be considered. The month in which the worst flicker impacts occur may also affect the actual duration of flicker as the potential for sunny days is greater in the summer months and the days are shorter in the winter months.

In conclusion, of the twenty dwellings assessed, eight had theoretical shadow flicker effects for a duration greater than 30 hours annually or 30 minutes daily. Mitigation measures outlined could be utilized to decrease any real effect of shadow flicker on the affected dwellings. The remaining twelve dwellings would experience a low level of or no flicker and therefore required no further consideration.

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ANNEX A. WINDPRO SHADOW FLICKER

WindPRO is the most common software package used in Canada and Alberta for shadow flicker assessments. It is often used by wind turbine manufacturers to run their own internal assessments. This analysis employed the SHADOW calculation method. This method considers the position of the sun relative to the wind turbine rotor disc and the resulting shadow is calculated in 1-minute steps throughout an entire year. If or when the shadow of the rotor, specified by choosing a wind turbine profile from WindPRO's database, casts a reflection on the façade then this step will be registered as 1 minute of potential shadow impact to the dwelling. WindPRO requires the following data[7]:

- The position of the turbine (x, y, z coordinates)
- The hub height and rotor diameter
- The position of the shadow receptor object (x, y, z coordinate)
- The geographic position
- A simulation model, which holds information about the earth's orbit and rotation relative to the sun.

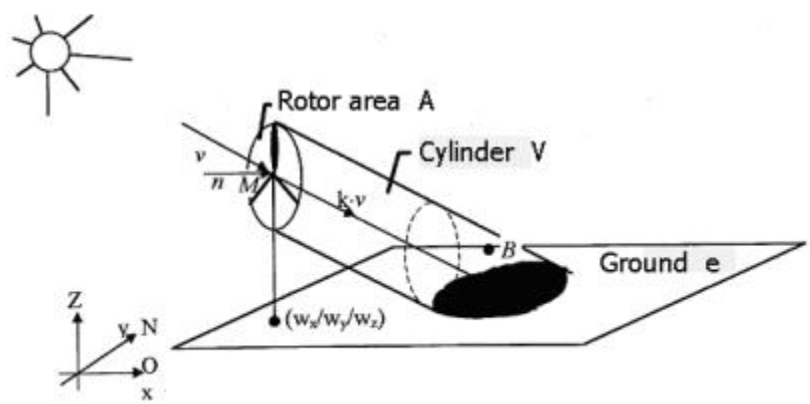

Figure A-1 – Diagram of sun angle relative to the turbine and shadow receptor

7 Per Nielsen, E. I. (2010, October). *WindPRO 2.7 User Guide 3. edition.* Retrieved November 13, 2019, from http://www.emd.dk/files/windpro/manuals/for_print/MANUAL_2.7.pdf

The following **Table A-1** discusses the calculation parameters WindPRO considers for this assessment:

Table A-1 – WindPRO Analysis Parameters

Category	Parameter	WindPRO
Site Data	Latitude and longitude	Yes
	Time zone	Yes
	Angle from grid north to true north	N/A
Turbine Data	Turbine locations	Yes-user input from GIS or other mapping tools
	Turbine dimensions	Yes-WindPRO has a wind turbine database that allows user to define the turbine specific to the project
	Blade thickness	Yes-Calculations only for >20% of sun covered by blade. User can override this setting
	Icing	Optional—user defined. Not considered for this analysis.
Receptor Data	Orientation of affected window(s)	Yes-user defined green house mode
	Window dimensions	Green house mode
	Location of window relative to centre of the property	Green house mode
	Window vertical tilt angle	Green house mode
Terrain Model	Elevation above mean sea level	Yes
	Above ground structures	Green house mode
	Intervening terrain/screening	Green house mode
	Earth curvature	Yes
Environmental Factors	Wind direction	Green house mode
	Sunshine hours	Green house mode
	Cloud cover	Green house mode
	Sun model	Disc
	Assessment distance	Input, defaults to 2.5 km or 20% of the sun disk, whichever is shortest

This analysis was performed using WindPRO's 'green house' mode. 'Green house' mode assumes that the receptor is not facing a particular direction, but instead faces all directions[8]. This mode is useful if the actual properties of the shadow receptor are unknown, if there are wind turbines on multiple sides of a dwelling, or if a conservative analysis is intended.

[8] Per Nielsen, E. I. (2010, October). *WindPRO 2.7 User Guide 3. edition.* Retrieved November 13, 2019, from http://www.emd.dk/files/windpro/manuals/for_print/MANUAL_2.7.pdf

ANNEX B. TURBINE LOCATIONS

Table A-1 – Modeled Wind Turbine Locations and Heights

Turbine ID	Longitude	Latitude	Height (m)
A1	-112.333682°	51.589604°	982.6
A2	-112.338553°	51.594728°	978.0
A3	-112.335951°	51.599028°	964.6
A4	-112.344214°	51.600196°	948.2
B1	-112.321007°	51.578138°	1,022.2
B2	-112.310616°	51.577652°	982.3
B3	-112.299551°	51.579798°	981.5
B4	-112.292983°	51.580788°	980.3
B5	-112.283823°	51.581986°	973.0
B6	-112.273157°	51.579917°	952.9
C1	-112.269559°	51.565793°	1,008.0
C2	-112.263991°	51.567409°	1,005.2
C3	-112.257383°	51.567426°	996.0
C4	-112.249677°	51.567382°	985.0
C5	-112.246391°	51.571185°	977.7
C6	-112.242478°	51.575345°	964.9
C7	-112.229241°	51.570934°	960.3
D1	-112.212395°	51.570156°	938.0
D2	-112.204250°	51.570447°	929.9
D3	-112.197941°	51.571932°	923.7
D4	-112.190247°	51.572937°	913.0
D5	-112.183062°	51.574355°	920.6
D6	-112.180615°	51.584827°	895.6
E1	-112.276525°	51.541475°	1,065.0
E2	-112.271144°	51.546065°	1,049.0
E3	-112.268655°	51.553025°	1,052.9
E4	-112.253600°	51.552081°	1,008.1
E5	-112.269326°	51.541373°	1,056.0
F1	-112.240383°	51.614995°	903.6
F2	-112.234038°	51.616438°	905.9
F3	-112.247472°	51.595380°	949.9
F4	-112.236018°	51.596796°	933.0

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ANNEX C. SHADOW FLICKER MAP

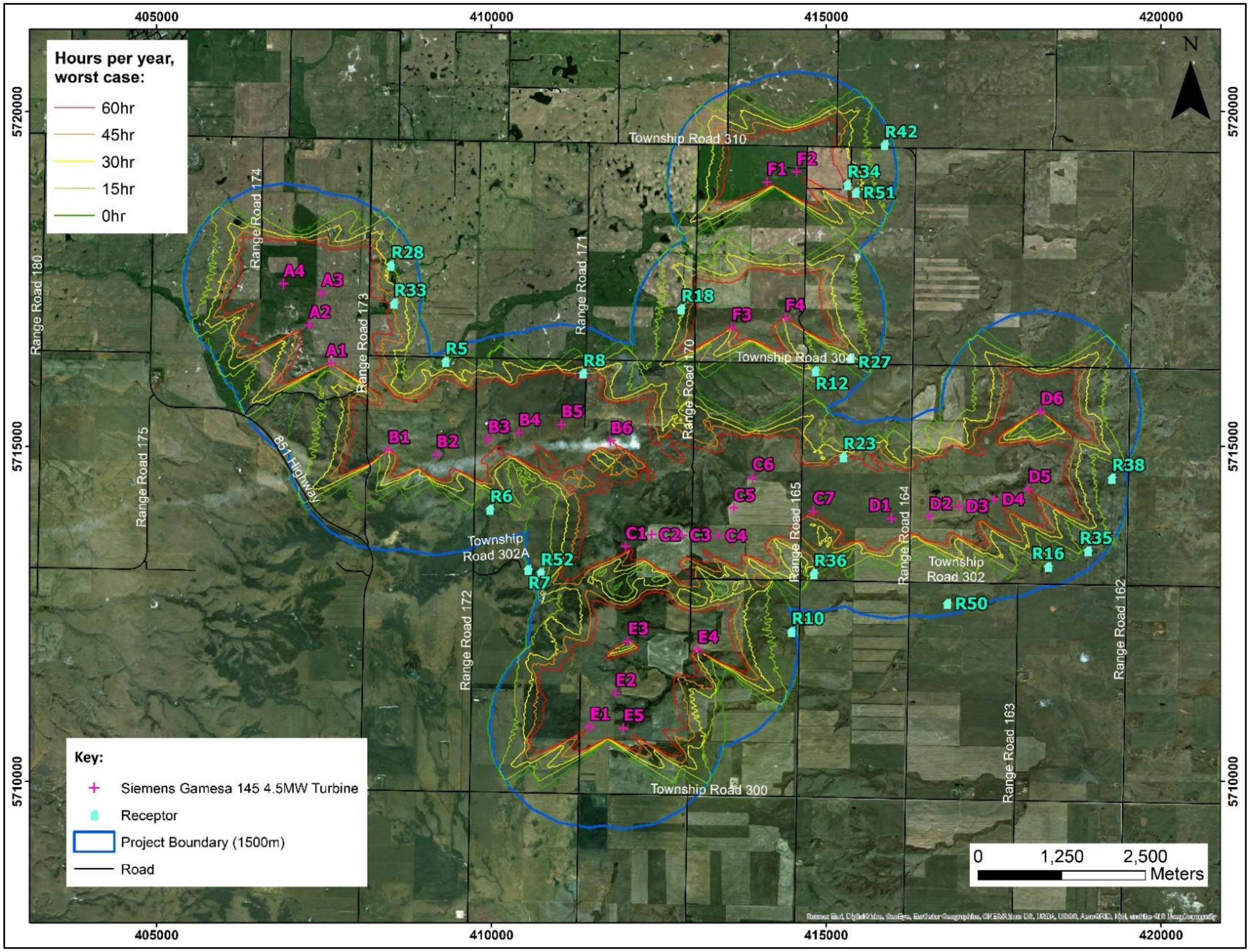

Figure A-2 – Shadow Flicker Map

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