Appendix

I

SHADOW FLICKER ASSESSMENT

WISOKOLAMSON ENERGY LP

SHADOW FLICKER ASSESSMENT

WISOKOLAMSON ENERGY PROJECT

APRIL 5, 2018

SHADOW FLICKER ASSESSMENT

WISOKOLAMSON ENERGY PROJECT

WISOKOLAMSON ENERGY LP

VERSION 3

PROJECT NO.: 161-08790-00
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REVISION HISTORY

Version	Issue Date	Description
1	March 20, 2018	Overview of shadow flicker assumptions, procedure, and calculations. Presentation of shadow flicker results using provided shadow receptors and turbine layout.
2	April 2, 2018	Updated with new turbine layout.
3	April 5, 2018	Fixed inconsistent naming of SR01.

SIGNATURES

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1 EXECUTIVE SUMMARY

The Wisokolamson Energy Project is being developed by Wisokolamson Energy LP and is located approximately 12 kilometres southwest the town of Riverside-Albert, New Brunswick. The purpose of this analysis is to quantify the impact of shadow flicker at each identified receptor.

Impact of shadow flicker was quantified as total hours per year and maximum minutes per day. The SHADOW module of the WindPRO software package was used to model “worst-case” and “corrected-case” scenarios for the shadow flicker at 3 receptor locations within or near project boundaries.

The analysis assumes that the receptors are sensitive to shadow flicker from any direction (this is referred to as “greenhouse mode”). Inputs to the model include terrain data, turbine specifications, geographic location of the project (to determine the daily sun path), and on-site meteorological data. The shadow flicker modelled for the worst-case assumes that the sky is clear during all daylight hours, the turbine rotor is always perpendicular to the sun, and that the turbine blades are always rotating. In contrast, the shadow flicker modelled for the corrected-case reduces the hours of shadow flicker to account for the times when the sun is not shining, the turbine is not operating, or the orientation of the turbine (due to the direction of the wind) is not perpendicular to the sun. Public weather station data is used to determine the probability of bright sunshine and meteorological data is used to estimate the periods of turbine operation and turbine orientation.

This analysis considers one layout with 5 Vestas V126-3.6 MW on 117 m towers. The receptors with shadow flicker impact from the project are listed in Table 1, below.

Table 1: Impacted Shadow Flicker Receptors

Receptor		Location NAD83, UTM Zone 20			Worst Case [HH:MM]		Real Case [HH:MM]	Largest Contribution	
ID	**Type**	**X**	**Y**	**Elevation**	**Annual**	**Max Daily**	**Annual**	**Turbine**	**Month**
Lake Shore Access (SR01)	Public Place	352379	5063236	336	30:34	00:31	7:08	T04	September

It is important to consider that the modelling assumptions used in the shadow calculation are conservative and may result in an overestimation of the shadow flicker amounts. The model assumes receptors are susceptible to shadow flicker from all directions but this may not be the case. The actual size, location and orientation of the receptor's windows relative to turbine locations may reduce the degree of flicker inside the dwellings. As well, the presence of buildings, trees, and other obstacles are not considered by the model and may also reduce the effects of shadow flicker on these receptors.

2 INTRODUCTION

2.1 OBJECTIVE

This report presents the algorithm, assumptions and results of the shadow flicker assessment. The impact of shadow flicker on receptors was assessed for both the “corrected-case” and “worst-case” modelling scenarios.

2.2 OVERVIEW OF SHADOW FLICKER

Shadow flicker occurs when the rotating blades of a turbine pass through the path between the sun and a receptor window when the sun is not obstructed by clouds. This phenomenon is dependent on weather conditions, site topography, and wind direction. The severity of shadow flicker will change both seasonally and hourly as a result of the daily and seasonal movements of the sun.

Shadow flicker can be calculated using the worst-case scenario or the corrected-case scenario. The worst-case, or “astronomical maximum” shadow flicker analysis, considers only the relative geographical location between turbines and receptors and assumes the sun is shining and the turbine rotor is spinning perpendicular to the path of the sunlight at all times. The corrected-case, or “meteorologically probable”, shadow flicker analysis utilizes on-site wind data and expected sunshine probability statistics to account for periods when: the turbine is not operational; the orientation of the turbine is not perpendicular to the path of the sunlight; and the sunlight is not strong enough to cast a shadow.

The occurrence of shadow flicker within a residence occurs when the rotating blades of a turbine momentarily interrupt the sunlight shining into the window of a receptor. The occurrence of shadow flicker may be reduced by the following:

- Obstructions that block the sunlight from reaching the window during some or all of the time that shadow flicker is occurring;
- The orientation of the turbine due to changing wind direction.

In the event that the amount of shadow flicker is a concern, introduction of obstacles and turbine operation adjustment for specific wind directions or times of day may be effective mitigation techniques. New Brunswick has regulations stipulating that shadow flicker at a receptor must be limited to 30 hours per year and a maximum of 30 minutes per day for the worst case.

2.3 SITE DESCRIPTION

The Wisokolamson Energy Project is located approximately 12 km southwest of the town of Riverside-Alberta, New Brunswick. The project location is rural, consisting mainly of forested areas, scrub brush, and some cultivated fields.

For this analysis, 3 receptors were identified. Receptor locations have been listed in *Appendix B: Shadow Flicker Results* and are shown in *Appendix E: Maps*.

The shadow flicker assessment was completed for a 5 turbine layout (Rev 5, 2018-03-21) using the Vestas V126-3.6MW on 117 m towers.

Locations of wind turbines are listed in *Appendix D: Turbine Locations* and are shown in *Appendix E: Maps*.

3 METHOD

3.1 SHADOW FLICKER ALGORITHM & ASSUMPTIONS

The WindPRO SHADOW module was used to model the shadow flicker at the Wisokolamson Energy Project. WindPRO calculates the cumulative effect of shadowing from all turbines with a line of sight to each receptor. The worst-case results are evaluated on yearly and daily averaging periods; the corrected-case on a yearly averaging period.

The blade shadow gets gradually fainter as the distance from the turbine and at some distance from the turbine; the edge of the turbine shadow will be hard to distinguish by the human eye. Within WindPRO, the maximum distance of shadow propagation may be calculated using the turbine blade width or may be set to a constant – usually ten times the turbine's rotor diameter[1]. A conservative constant distance of 2,000 m was selected for the analysis. Due to atmospheric diffusion and lower light levels, shadow flicker is ignored when the sun is lower than 3° above the horizon. The presented shadow flicker amounts are based only on total frequency of shadow flicker and do not distinguish the character of the shadow flicker.

WindPRO executes a site-specific simulation of the solar trajectory relative to the wind project for an entire year. The complete description and shadow flicker calculation algorithm of WindPRO is provided in *Appendix A: WindPRO Model.*

Both the worst-case and corrected-case shadow flicker modelling scenarios assume that receptors have windows oriented in every direction and are, as a result, susceptible to flicker from all directions. This is known as the "greenhouse mode" and represents a conservative estimate of the impact of shadow flicker. Obstacles such as trees or large structures, which could block some or all of the shadow flicker effect at a receptor, are not considered in the analysis thus making the shadow flicker additionally more conservative. Topography was included in the modelling; however, elevation changes smaller than the resolution of the sourced data may not have been captured[2] .

The calculations of modelled worst-case results assume the following:

- The sun is unobstructed by cloud cover for all daylight hours for the entire year.
- The turbine blades are always rotating.

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[1] Parsons Brinckerhoff, Update of UK Shadow Flicker Evidence Base, Department of Energy and Climate Change.

[2] Lidar15 (Elevation data) has a grid spacing of 15 m with a horizontal accuracy of 50 cm. The vertical accuracy is 30 cm. ---OR--- CDED (Elevation data) has a grid spacing of 8-23 m with a horizontal accuracy of 10 m. The vertical accuracy is 6 m.

— The turbine rotor is always perpendicular to the path between the sun and the receptor.

The calculation of modelled "corrected-case" shadow flicker incorporated the probability of sunshine (hours of bright sunshine per month). The sunshine hours for the Wisokolamson site were derived from the measurements from the "Moncton A" (New Brunswick) Environment Canada Monitoring station located approximately 47 km from the project site. Environment Canada uses the Campbell-Stokes sunshine recorder. This recorder consists of a 10-cm glass sphere which focuses sunlight on a card calibrated in hours. Sunlight burns a trace on the card, allowing the observer to determine to the nearest tenth of an hour the amount of sunshine that occurs on a given day. It should be noted that the recorder measures only "bright" sunshine, which is less than "visible" sunshine. For example, sunshine immediately after sunrise and just before sunset would not be bright enough to register. The monthly probabilities of sunshine used in the modelling are presented in Table 2[3].

---

[3] Environment Canada, October, 2017: http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=Moncton+A&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=6207&dispBack=1

Table 2: Average Daily Hours of Bright Sunshine for the "Moncton A" Environment Canada Station

Month	Bright Sunshine [hours/day]
January	3.8
February	4.4
March	4.5
April	5.5
May	6.7
June	7.8
July	8.3
August	7.8
September	5.8
October	4.8
November	3.2
December	3.3

Twenty-one (21) years (1988 to 2018 inclusive) of MERRA-2 reanalysis data was used as an input into the shadow flicker calculations. The MERRA-2 grid point is located at 45.5° N and 65.0° W, approximately 25 kilometres away from the site centre. The estimated annual number of hours of operation at the Wisokolamson project is 8,518 hours. For the periods when the wind speed at the project is outside the operational range of the turbines, WindPRO assumes that the blades do not turn and consequently that there will be no shadow flicker. The real case shadow flicker hours include a reduction of 2.8% from worst case shadow flicker hours to account for the frequency the wind turbine blades are not rotating due to low winds.

The yaw system of the wind turbine changes the orientation of the rotor according to the wind direction, thus the shadow cast by the rotating blades changes according to the wind direction. The wind rose representing the wind direction distribution at the Wisokolamson Energy Project is presented in Figure 1, below. Shadow flicker will have a maximum impact when the rotor is perpendicular to the path of the sun and a minimum impact when the rotor is parallel to a line between the sun and the receptor. Based on the wind rose and orientation of each turbine to each receptor, a yaw correction factor was estimated for each pair and this correction factor is presented in *Appendix C: Direction Reduction Factor for the Corrected Case*. The yaw correction factor has only been estimated for turbine-receptor pairs with at least 1 minute of shadow flicker in a year.

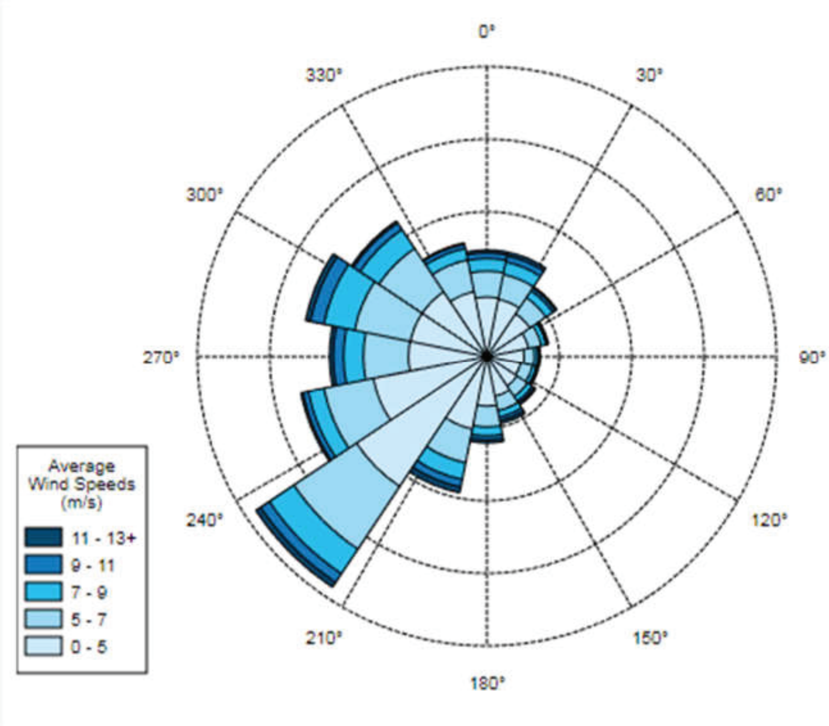


Figure 1: Wind Direction Distribution (Frequency %) at Wisokolamson (MERRA-2 Grid 45.5° N and 65.0° W, 1988 through 2018)

4 SHADOW FLICKER RESULTS

4.1 GREENHOUSE MODE SHADOW FLICKER RESULTS

The detailed results of the WindPRO shadow flicker model are presented in tabular form in *Appendix B: Shadow Flicker Results* which includes the "corrected-case" annual hours, the “worst-case” annual hours, and the maximum daily minutes of shadow flicker for the “worst-case” scenario. Maps showing the iso-contour of the shadow flicker results have been included in *Appendix E: Maps*:

- For the “corrected-case” annual hours,
- For the “worst case” annual hours and daily maximum minutes.

The results shown in *Appendix B: Shadow Flicker Results*, and tabulated in Table 3, below, represent the predicted cumulative shadow flicker results from the Wisokolamson Energy Project. The results are sorted from most to least time per year for the corrected case. Only receptors experiencing more than 1 minute of shadow flicker originating from a Wisokolamson wind turbine are presented in the tables. The table also includes the largest contributing wind turbine and month.

Table 3: Estimated Shadow Flicker on Impacted Shadow Receptors

Receptor		**Location NAD83, UTM Zone 20**			**Worst Case HH:MM**		**Real Case HH:MM**	**Largest Contribution**	
ID	**Type**	**X**	**Y**	**Elevation**	**Annual**	**Max Daily**	**Annual**	**Turbine**	**Month**
Lake Shore Access (SR01)	Public Place	352379	5063236	336	30:34	00:31	7:08	T04	September

5 CONCLUSIONS

The present study estimates the cumulative shadow flicker caused by the Wisokolamson Energy Project surrounding 3 receptors. The only receptor with subject to shadow flicker from the project are listed in Table 4, below.

Table 4: The Five Most Impacted Shadow Flicker Receptors

Receptor		Location NAD83, UTM Zone 20			Worst Case [HH:MM]		Real Case [HH:MM]	Largest Contribution	
ID	**Type**	**X**	**Y**	**Elevation**	**Annual**	**Max Daily**	**Annual**	**Turbine**	**Month**
Lake Shore Access (SR01)	Public Place	352379	5063236	336	30:34	0:31	7:08	T04	September

In cases where mitigation is necessary, Wisokolamson Energy LP has various mitigation measures at their disposal that can be investigated. For example, shutters could be installed on windows or trees planted between the proposed wind turbine and the houses in order to block the shadow.

APPENDIX

A

WINDPRO MODEL

The following information has been modified from section 4.2 of the WindPRO help files.

A.1 INTRODUCTON TO SHADOW

SHADOW is the WindPRO calculation module that calculates how often and in which intervals a specific area will be affected by shadows generated by one or more wind turbines. These calculations are expected case scenarios (i.e. calculations which are solely based on the probability of sunshine as calculated from the monthly maximum total duration of bright sunshine and the position of the turbine relative to the sun or the astronomical maximum shadow). Shadow flicker impact may occur when the blades of a wind turbine pass through the sun's rays seen from a specific spot (e.g. a window in an adjacent settlement). If the weather is overcast or calm, or if the wind direction forces the rotor plane of the wind turbine to stand parallel with the line between the sun and the neighbour, the wind turbine will not produce shadow flicker impacts.

Apart from calculating the potential shadow flicker impact at a given neighbour, a map rendering the iso-lines of the shadow flicker impact can be printed. This printout will render the amount of shadow flicker impact for any spot within the project area.

The time of the day for which shadow flicker impact is critical and the definition of a receptor for which shadow flicker impact is calculated are less rigidly defined by best practices and is often something which should be evaluated in each individual case.

As an example, a factory or office building would not be affected if all the shadow flicker impact occurred after business hours, whereas it would be more acceptable for private homes to experience shadow flicker impact during working hours, when the family members are at work/school.

Finally, the actual amount of shadow flicker impact as a fraction of the calculated potential risk will depend heavily on the geographic location in question. In areas with high rates of overcast weather the problem would obviously decrease, and during potential hours of shadow flicker impact in the summer the wind turbine may often be stationary due to lack of wind.

Statistics regarding the wind conditions and number of hours with clear sky can also be taken into account.

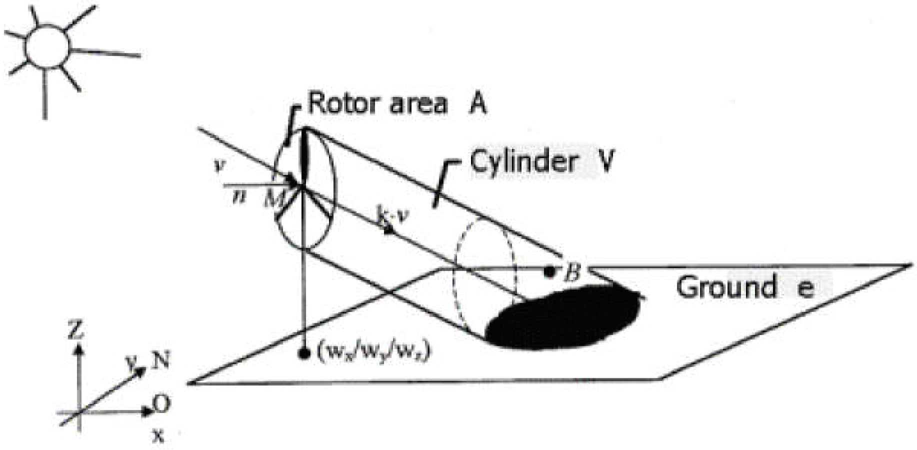
As in the other WindPRO modules, input of data can be based solely on entering coordinates and characteristics for the individual wind turbine and shadow flicker receptors manually.

A significant strength in the WindPRO system is the option of direct graphic on-screen input of wind turbines and receptors on a map.

A.2 THE SHADOW CALCULATION METHOD

The calculation of the potential shadow flicker impact at a given receptor is carried out simulating the situation. The position of the sun relative to the wind turbine rotor disk and the resulting shadow flicker is calculated in steps of 1 minute throughout a complete year. If the shadow flicker of the rotor disk (which in the calculation is assumed solid) at any time casts a shadow flicker reflection on the window, which has been defined as a receptor object, then this step will be registered as 1 minute of potential shadow flicker impact. The following information is required:

- The position of the wind turbines (x, y, z coordinates)
- The hub height and rotor diameter of the wind turbines
- The position of the receptor object (x, y, z coordinates)
- The size of the window and its orientation, both directional (relative to south) and tilt (angle of window plane to the horizontal).
- The geographic position (latitude and longitude) together with time zone and daylight-saving time information.
- A simulation model, which holds information about the earth's orbit and rotation relative to the sun.



A.3 THE SHADOW CALCULATION MODULE

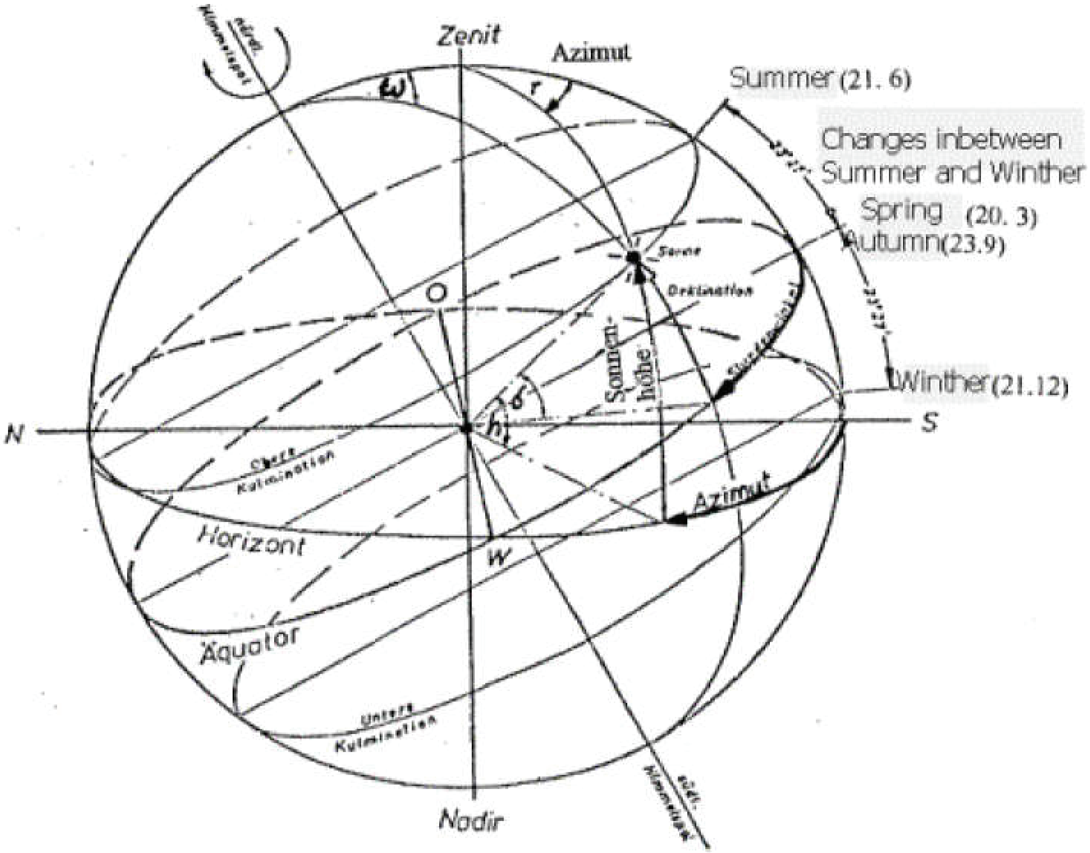
In the shadow flicker calculation model used by WindPRO the following parameters defines the shadow flicker propagation angle behind the rotor disk:

- The diameter of the sun, D: 1,390,000 km
- The distance to the sun, d: 150,000,000 km
- Angle of attack: 0.531 degrees

Theoretically, this would lead to shadow flicker impacts in up to 4.8 km behind a 45 m diameter rotor disk. In reality, however, the shadows never reach the theoretical maximum due to the optic conditions of the atmosphere. When the sun gets too low on the horizon and the distance becomes too long the shadow dissipates before it reaches the ground (or the receptor). How far away from the wind turbine the shadow will be visible is not well documented and so far only the German guidelines set up limits for this. The default distance of WindPRO is calculated based on blade width or maximum distance and the default minimum angle is 3° above the horizon. If the German guidelines are used, the maximum distance from each wind turbine can be calculated using the formula.

— Max. distance = (5*w*d) / 1,097,780

Where w is the average width of the blade. The value of 1,097,780 is derived from the diameter of the sun, reduced by a compensation factor for the fact that the sun disk is a circle and not a square.



The wind direction reduction factor is calculated by WindPRO based on the geographic location of each receptor, turbine and the site specific wind rose. The following tables are based on detailed WindPRO output for the shadow flicker simulation. Receptor ID is across the left and turbine number on the top. Reduction values have only been calculated for turbine-receptor pairs with at least one minute of recorded shadow flicker. Empty rows and columns have been removed.

APPENDIX

B

SHADOW FLICKER RESULTS

SHADOW FLICKER RESULTS

Receptor		Location NAD83, UTM Zone 20			Worst Case [HH:MM]		Real Case [HH:MM]	Largest Contribution	
ID	**Type**	**X**	**Y**	**Elevation**	**Annual**	**Max Daily**	**Annual**	**Turbine**	**Month**
Lake Shore Access (SR01)	Public Place	352379	5063236	336	30:34	0:31	7:08	T04	September
Warming Shack (SR03)	House	353106	5065628	351	0:00	0:00	0:00	-	-
Chalet/Cabin (SR02)	House	353738	5065677	329	0:00	0:00	0:00	-	-

APPENDIX

C

DIRECTION REDUCTION FACTORS FOR THE CORRECTED CASE

DIRECTION REDUCTION FACTORS

<<DIRECTION_REDUCTION_FACTORS>>

UD	T04	T05
Lake Shore Access (SR01)	0.63	0.57

APPENDIX

D

TURBINE LOCATIONS

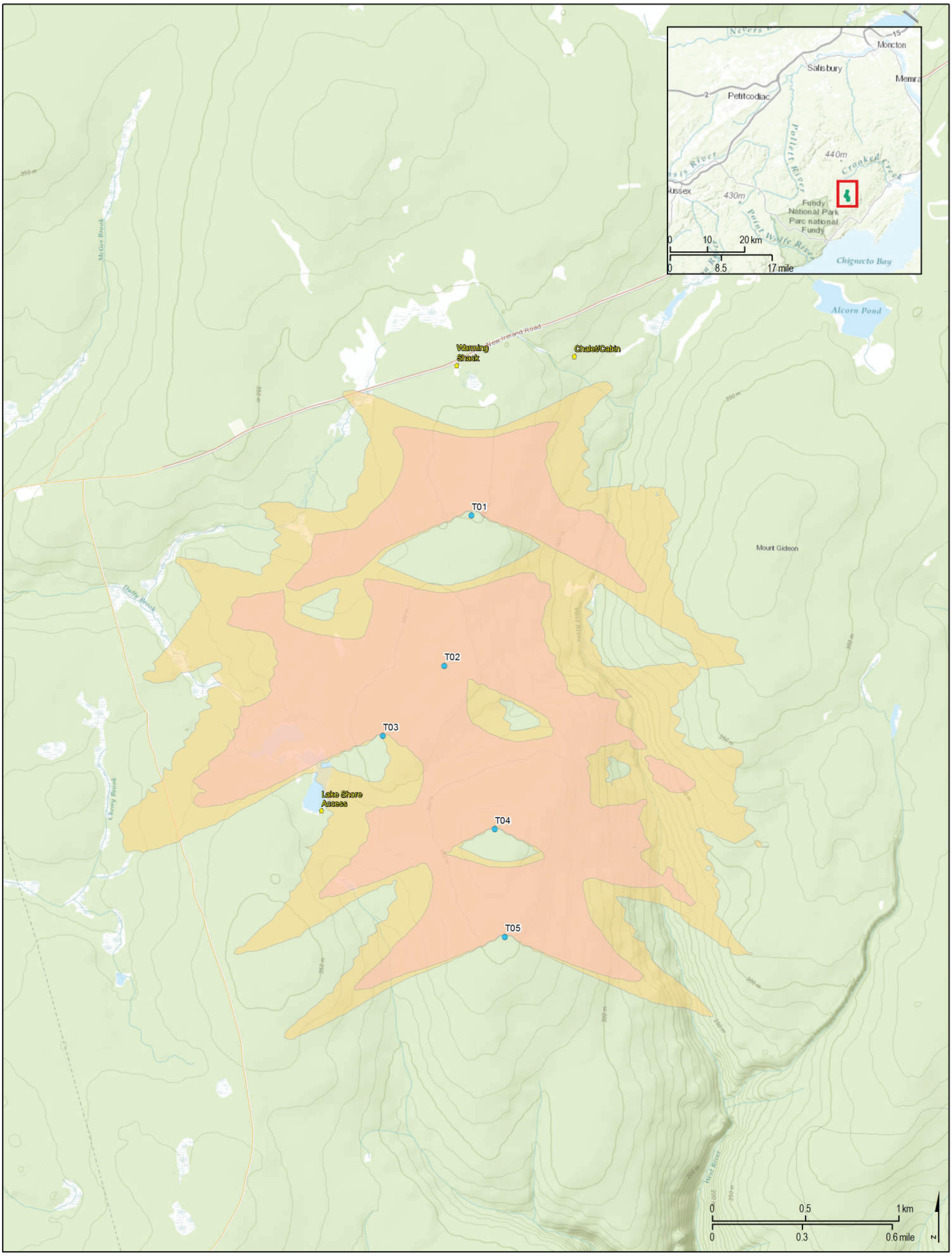
TURBINE LOCATIONS

Turbine ID	NAD 83 CSRS		Elevation [m]
	Latitude	Longitude	
T01	45° 43' 16.956" N	64° 53' 11.805" W	352
T02	45° 42' 50.646" N	64° 53' 17.636" W	358
T03	45° 42' 38.186" N	64° 53' 32.486" W	360
T04	45° 42' 22.416" N	64° 53' 4.155" W	368
T05	45° 42' 3.716" N	64° 53' 1.065" W	358

APPENDIX

E

MAPS



● V126-3.6 Wind Turbine

⬟ Receptors

🟥 Corrected Case: Exceeds 15 horus per year

🟧 Corrected Case: Exceeds 8 hours per year

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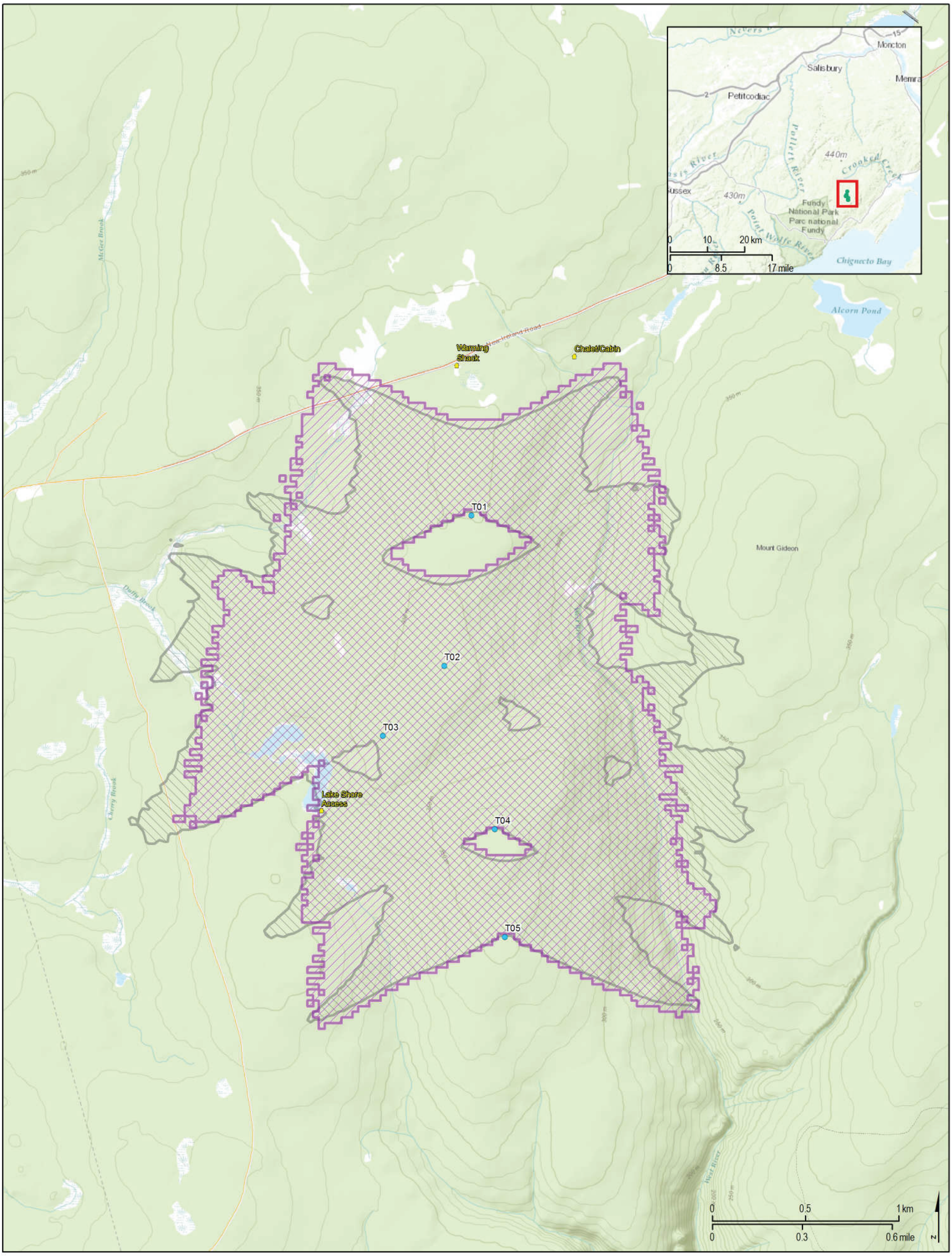
Wisokolamson Energy Project

Shadow Flicker Map

Date: 2018-04-02
Version: 2
Layout: Rev 5 2018-03-21
Datum: NAD 83
Projection: UTM Zone 20N
Scale: 1:20,000

Prepared by: WSP
Author: L. Ryan. Eng
Reviewed: E. Halberg, P. Eng
Approved: R. Istchenko, P. Eng



● V126-3.6 Wind Turbine

● Receptors

▨ Worst Case: Exceeds Maximum 30 Minutes In A Day

▨ Worst Case: Exceeds 30 hours per year

Wisokolamson Energy Project

Shadow Flicker Map

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Date: 2018-04-02
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Projection: UTM Zone 20N
Scale: 1:20,000

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