Northern Valley Wind Project

Shadow Flicker Assessment

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Executive Summary

Northern Valley Wind Limited Partnership (Northern Valley Wind LP) propose to install the Northern Valley Wind Project (the Project), located approximately 9km southeast of the town of Elk Point, Alberta, within the municipalities of St. Paul County No. 19, Two Hills County No. 21, and Vermillion River County No. 24. The proposed Project will consist of up to 17 Vestas V163-4.5 MW wind turbine generators, which have a rotor diameter of 163m, and a hub height of 125m, for a total generating capacity of up to 76.5 megawatts (MW). Northern Valley Wind LP retained Green Cat Renewables Canada Corporation (GCR) to conduct a shadow flicker assessment to evaluate impacts of the proposed Project.

GCR followed the guidelines in the Alberta Utilities Commission (AUC) Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines*[1] (Rule 007) to assess a total of 22 dwellings, identified by Northern Valley Wind LP and field verified by GCR, within 1.5km of the potential turbine locations. An additional two potentially habitable structures were identified, but they were not assessed as they were determined to be non-residential.

Rule 007 does not mention acceptable shadow flicker thresholds, so the commonly cited German guidelines have been referenced. These guidelines limit shadow flicker to a maximum of 30 hours per year and 30 minutes per day at a receptor.[2] When considering scenarios modelled with representative environmental factors, multiple jurisdictions in North America have historically adopted a maximum limit of 30 hours of annual shadow flicker (e.g., Nova Scotia[3]), without any limits on daily exposure. GCR have considered these guidelines in this shadow flicker assessment, focussing on common practices and local regulations in North America.

WindPRO modelling software was used to predict shadow flicker levels caused by the Project turbines at these receptors in both a worst-case scenario and an adjusted-case scenario, which incorporates statistical wind and sunshine data.

In the worst-case scenario:

- Five receptors are not expected to observe any shadow flicker;
- Ten receptors are expected to observe shadow flicker for less than 30 hours per year; and
- Seven receptors are expected to observe shadow flicker for more than 30 hours per year.

In the adjusted-case scenario:

- Five receptors are not expected to observe any shadow flicker;
- Sixteen receptors are expected to observe shadow flicker for less than 30 hours per year; and
- One receptor is expected to observe shadow flicker for more than 30 hours per year.

The adjusted-case alterations reduce the annual shadow flicker at each receptor by 57-81% (67% on average). This is more representative of what receptors may see in practice than the worst-case scenario, but it is still a conservative prediction of the potential shadow flicker. The receptors expected to observe over 30 hours per year in the adjusted-

[1] AUC Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines*, (April 2022), subsection 4.3.2 WP14.

[2] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

[3] *Guide to Preparing an EA Registration Document for Wind Power Projects in Nova Scotia.* (Nova Scotia, Policy Division, Environmental Assessment Branch, October 2021).

case are likely to observe less than the predicted shadow flicker due surrounding topographic features such as tree screening and other buildings. As such, the results of the adjusted-case is also a conservative prediction of potential shadow flicker.

Maximum daily flicker predictions ranged between 28 to 56 minutes in a single day in the worst-case, though these maximum daily durations are predicted to occur on very few days in a given year. These maximum daily durations are possible if all meteorological and operational conditions align, but this is not guaranteed to happen every year.

If shadow flicker is a concern for receptors, mitigation measures may be considered. Vestas' Shadow Flicker Control System can be utilized to intelligently reduce annual shadow flicker predictions while minimizing potential curtailment. With mitigation via this system, a scenario exists where a single turbine can be flagged for potential curtailment to ensure annual flicker at R01 and all other evaluated receptors does not exceed 30 hours per year in the adjusted-case. If further mitigation is deemed necessary, specific measures can be determined in consultation with the concerned occupant.

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1 Introduction

Northern Valley Wind Limited Partnership (Northern Valley Wind LP) proposes to construct and operate the Northern Valley Wind Project (the Project) in St. Paul County No. 19, Two Hills County No. 21, and Vermillion River County No. 24 in east-central Alberta, approximately 9km southeast of the town of Elk Point. The proposed Project will consist of up to 17 Vestas V163-4.5 MW wind turbine generators, sited across 19 quarter sections of land, with a total generating capacity of up to 76.5 megawatts (MW). Northern Valley Wind LP retained Green Cat Renewables Canada Corporation (GCR) to conduct a shadow flicker assessment to evaluate the proposed Project.

Alberta Utilities Commission (AUC) Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines*[4] (Rule 007) provides guidelines for the receptors to be included in a shadow flicker assessment, but specific modelling parameters, software, and thresholds are not identified. GCR has followed the Rule 007 guidelines in the preparation of this shadow flicker assessment. The impact at each receptor within 1.5km of the centre of each turbine has been assessed using WindPRO software, modelling a "worst-case scenario" and an "adjusted-case scenario".

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, suggested:

"*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.*"[5]

Modern wind turbine rotors rotate at relatively low speeds of up to approximately 20 rotations per minute (60 blade shadows per minute or one shadow per second). This means that, instead of a rapid strobing phenomenon, the moving shadows can cause a brief moment of dimming in the affected room, followed by a longer bright period between blade passes. This is also well below the lower flash frequency threshold of three flashes per second that commonly triggers epilepsy symptoms.[6]

Whilst the moving shadow can occur outdoors, the shadow flicker effect is experienced inside buildings where the shadow passes over a narrow window opening.[7] 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 A: WindPRO**

[4] AUC Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines*, (April 2022), subsection 4.3.2 WP14.

[5] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*. Retrieved May 31, 2023, from UK 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.

[6] Epilepsy Society. *Photosensitive Epilepsy.* Retrieved November 7, 2023: https://epilepsysociety.org.uk/about-epilepsy/epileptic-seizures/seizure-triggers/photosensitive-epilepsy

[7] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*, pg. 51-52. Retrieved May 31, 2023, from UK 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.

Shadow Flicker, Figure A-1. A single window in a single building may 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 receptor 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.*"[8]

[8] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*. Retrieved May 31, 2023, from UK 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

2.1 Identification of Potential Shadow Flicker Zone

The Project is located in St. Paul County No. 19, Two Hills County No. 21, and Vermillion River County No. 24, Alberta. The Project location is rural and industrial, consisting primarily of cultivated fields, varying watercourses and waterbodies, and oil/gas facilities and is located approximately 9km southeast of the town of Elk Point. GCR have considered 22 occupied receptors within 1.5km of the proposed turbine locations, identified by Northern Valley Wind LP and field verified by GCR in May 2023, to satisfy the requirements of Rule 007. An additional two potentially habitable structures were identified, but they were not assessed as they were determined to be non-residential structures used by operators in the area.[9] The proponent has confirmed with the owners and lessees of the properties, that the structures will not be used for habitation or human rest.

2.2 Turbine Specifications

The Project will consist of 17 Vestas V163-4.5 MW wind turbine generators, specified with a rotor diameter of 163m and a hub height of 125m. The turbine locations are provided in **Appendix B: Turbine Locations**.

2.3 Modelling of Windows

Each receptor has been modelled using WindPRO's "green house" mode, which assumes receptors near the Project have windows oriented in every direction; therefore, receptors are always susceptible to flicker from every direction. This "green house" window model represents a conservative approach to ensure that annual variations in shadow flicker event timing are captured in the model.[10] Each receptor has been modelled as a 1m-by-1m window facing each turbine, with a receptor eye level at 1.5m above ground. Changes in window size have been shown to have a negligible effect on shadow flicker results, especially with increasing distance from the turbines.[11]

2.4 Model Conditions

Calculations have been carried out using WindPRO software. This program uses the "SHADOW" calculation method that accounts for simple geometric considerations including: the position of the sun at a given date and time; a green house model for receptors; and the size of the turbine that may cast the shadows.

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 Area.[12] WindPRO has been set to calculate the shadow propagation up to a fixed distance of 1.5km from each wind turbine to match the assessment radius and the theoretical maximum impact area. The minimum sun height of influence was set at WindPRO's default of 3° over the horizon. A minimum sun angle

[9] AUC Rule 007 defines receptors as "permanently or seasonally occupied (minimum use of six weeks per year or more) dwellings used for the purpose of human rest".

[10] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

[11] Ibid.

[12] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

threshold is set because sunlight at low sun angles becomes too diffuse to produce coherent shadows; thus, flicker is unlikely to be observed.[13]

Topographical data was considered in the WindPRO model. The Altalis 20K Digital Elevation Model (DEM) dataset was selected for this assessment. The absolute accuracy of the data is determined by Alberta Survey Control Markers, and relative accuracy is ±5m.[14] This indicates that small undulations in the land may not be captured, but it is insignificant compared with the turbine heights and distances between receptors and turbine locations. The resolution of the topographical data is considered sufficient for the shadow flicker analysis.

No vegetative or building screening between the turbines and the receptors was assumed for all model runs, which may have been a conservative assumption at some receptors.

The effects of shadow flicker are typically predicted to be worst at lower elevations of dwellings in the absence of screening, so this assessment used a receptor height of 1.5m for all dwellings to provide a conservative estimate of potential shadow flicker impacts.

2.4.1 Worst-Case Model

The worst-case model adopted a conservative approach by assuming that:

- The turbine is facing the sun at all times of the day;
- Sunlight is present from sunrise to sunset, 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.

2.4.2 Adjusted-Case Model

The adjusted-case model utilized statistical weather data to produce more representative shadow flicker predictions. The additional data included:

- **Wind Direction:** Wind turbines will face the wind direction rather than always being perpendicular to the receptor/sun. This reduces the amount of the sun disc that is covered by wind turbine blades at times, resulting in smaller/weaker shadows and less flicker. The wind direction distribution shown in **Table 2-1** is based on ERA5 reanalysis data (ECMWF, 2021) for the nearest location (53.75°, -110.75°) at 100m above ground level (AGL), obtained via Windographer's data downloader (AWS Truepower, LLC, 2015).[15]
- **Monthly Sunshine Probability:** The model incorporates the percentage of daytime hours with sunlight for each month. The average monthly sunshine hours per day reported by the Edmonton/Stony Plain weather station was used since it is the nearest station available in WindPRO.

[13] EMD International A/S. (September 2022). *WindPRO 3.6 User Manual*, section 6. Retrieved May 31, 2023: https://help.emd.dk/knowledgebase/content/windPRO3.6/c6-UK_WindPRO3.6-Environment.pdf.

[14] *20K Digital Elevation Model* (Altalis Ltd., November 20, 2017).

[15] Wind direction frequencies used in the model only considered data with wind speeds of at least 2.5m/s to account for turbine cut-in speeds. Below this wind speed, the turbine blades will not be rotating and therefore will not produce shadow flicker.

Table 2-1 – Wind Direction Frequency

Wind Direction	Frequency (%)
N	4.2
NNE	2.9
NE	2.6
ENE	2.8
E	3.6
ESE	5.8
SE	8.9
SSE	8.3
S	6.3
SSW	4.9
SW	4.4
WSW	5.4
W	9.1
WNW	12.7
NW	10.8
NNW	7.3
Total	**100.0**

Although this adjusted-case is more representative than the purely theoretical, the conditions specified for the adjusted-case are still more conservative than a truly realistic representation of shadow flicker. Additional elements that are likely to reduce the hours of potential flicker and lead to a more realistic estimate of flicker include:

- Vegetation and structures that block the view of turbines from receptor windows, which will reduce or eliminate shadow flicker occurrence;
- Orientation of receptor windows, which will dictate whether turbines and shadows can be seen from the property in practice;
- Height of windows above ground is likely to be higher than the conservative 1.5m in this assessment, which may reduce the probability of flicker; and
- Other human factors such as typical activities and times of use for each property.

2.5 Assessment of Potential Impacts

The AUC's Rule 007 requires a shadow flicker assessment to be included in a wind power plant application. The assessment must describe the shadow flicker model results. Observers that are predicted to see shadow flicker within their homes or offices may perceive a subjective nuisance reaction from the flickering light, especially if it occurs for prolonged daily durations and annual periods.

Rule 007 does not state specific shadow flicker thresholds, and so guidance in other jurisdictions was considered. German guidance limits annual theoretical shadow flicker at a receptor to a maximum of 30 hours per year or 30 minutes per day.[16] When considering scenarios modelled with representative environmental factors, multiple jurisdictions in North America, such as Nova Scotia, have historically adopted a maximum limit of 30 hours of annual shadow flicker, without any limits on daily exposure.[17,18] GCR have considered these guidelines in this shadow flicker assessment, focussing on common practices and local regulations in North America.

[16] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

[17] *Guide to Preparing an EA Registration Document for Wind Power Projects in Nova Scotia.* (Nova Scotia, Policy Division, Environmental Assessment Branch. October 2021).

[18] Ollson Environmental Health Management. (February 14, 2019). *Scientific Basis for 30-hour Shadow Flicker Standard used by Crowned Ridge Wind Farm*. Retrieved October 25, 2023: https://puc.sd.gov/commission/dockets/Civil/2019/batenumber/14179-14522.pdf.

3 Study Area

The Study Area lies east of Highway 41, in northern Alberta. The proposed Project infrastructure is distributed throughout the following townships: 56-6-W4M and 55-6-W4M. The Study Area follows the Rule 007 guidelines to include the area within 1.5km of the centre point of each turbine. GCR identified 22 of the receptors provided by the Proponent that fall within a 1.5km radius of at least one potential turbine location. The effects of shadow flicker are typically predicted to be worst at lower elevations of receptors in the absence of screening, so this assessment used a height of 1.5m at all receptors to provide a conservative estimate of potential shadow flicker impacts.

Figure 3-1 shows the wind turbine locations and the receptors within 1.5 km of a turbine, forming the baseline of the study area of the assessment. Details of the identified receptors are listed in Table 3-1.

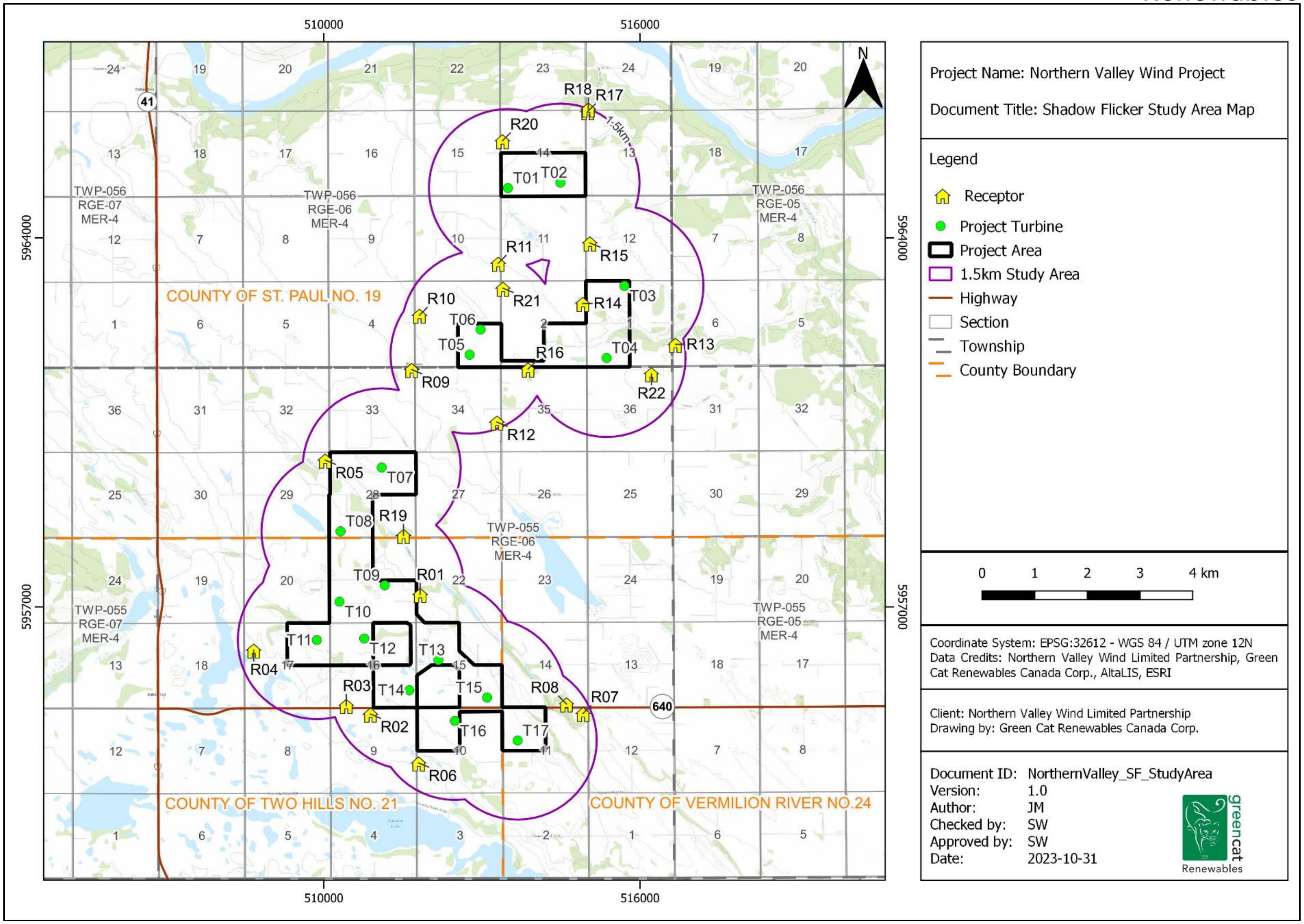

Figure 3-1 – Northern Valley Wind Project Shadow Flicker Study Area Map

Table 3-1 – Potentially Sensitive Shadow Receptors

Receptor ID	UTM Coordinates (NAD83, Zone 12N) (m)			Modelled Receptor Height (m)	ID of Nearest Turbine	Distance from Nearest Turbine (to nearest 10m)
	Easting	Northing	Elevation			
R01	511831	5957236	673	1.5	T01	700m E
R02	510887	5954965	645	1.5	T02	870m SW
R03	510428	5955129	649	1.5	T02	1,230m W
R04	508671	5956179	634	1.5	T03	1,210m W
R05	510028	5959784	656	1.5	T03	1,090m W
R06	511801	5954038	640	1.5	T04	1,050m SW
R07	514922	5954977	635	1.5	T04	1,340m NE
R08	514607	5955158	637	1.5	T05	1,160m NE
R09	511667	5961503	631	1.5	T05	1,130m SW
R10	511817	5962532	644	1.5	T05	1,190m NW
R11	513312	5963518	671	1.5	T06	1,300m N
R12	513288	5960505	649	1.5	T06	1,380m SE
R13	516675	5961980	671	1.5	T06	1,330m E
R14	514918	5962757	674	1.5	T07	860m SW
R15	515051	5963904	683	1.5	T09	1,050m NW
R16	513878	5961511	669	1.5	T09	1,140m SE
R17	515009	5966394	637	1.5	T11	1,440m NE
R18	515023	5966446	634	1.5	T14	1,490m NE
R19	511514	5958355	653	1.5	T14	1,010m NE
R20	513393	5965843	662	1.5	T16	910m N
R21	513402	5963045	664	1.5	T17	890m NE
R22	516218	5961422	678	1.5	T17	900m SE

*All receptors were assessed at 1.5m, as potential shadow flicker impacts are greatest near the ground.

4 Modelling Results and Discussion

4.1 Shadow Flicker Results

The detailed results of the WindPRO shadow flicker model are presented in Table 4-1. The table includes the annual and maximum daily shadow flicker results in the worst-case scenario, and the annual shadow flicker in the adjusted-case scenario. The table also lists the turbines affecting each receptor in descending order of impact. The turbines contributing shadow flicker to each receptor may be separate instances occurring at different parts of the building or overlapping shadows through a single window, depending on the relative locations of the receptors and turbines.

Appendix C: Shadow Flicker Maps presents the iso-contour maps of the annual shadow flicker results in the worst-case and adjusted-case scenarios.

Table 4-1 – Shadow Flicker Results Identifying Turbines with the Largest Contributions

Receptor ID	Worst-Case Shadow Hours (hh:mm)		Adjusted-Case Shadow Hours (hh:mm)	Contributing Turbines (descending order of impact)
	Annual	Max Daily	Annual	
R01	103:37	0:56	39:49	T9, T12
R02	25:33	0:38	8:21	T14
R03	19:39	0:32	7:26	T14
R04	18:40	0:32	7:14	T11
R05	19:48	0:35	6:28	T07
R06	0:00	0:00	0:00	-
R07	13:25	0:28	3:58	T17
R08	21:27	0:34	5:28	T17
R09	23:50	0:34	8:57	T05
R10	37:47	0:32	12:19	T05, T06
R11	0:00	0:00	0:00	-
R12	0:00	0:00	0:00	-
R13	11:02	0:28	3:18	T04
R14	72:36	0:47	25:05	T03, T04
R15	46:53	0:39	12:28	T03
R16	19:38	0:34	8:21	T05
R17	0:00	0:00	0:00	-
R18	0:00	0:00	0:00	-
R19	44:11	0:37	11:23	T09, T08
R20	28:30	0:29	7:45	T02, T01
R21	46:24	0:46	8:53	T06
R22	44:03	0:44	18:34	T04

4.2 Worst-Case Discussion

In the worst-case, ten receptors are expected to observe shadow flicker for less than 30 hours per year, and five receptors are expected to observe no shadow flicker. Due to the limited amount of shadow flicker and the conservative nature of the model, these receptors are not expected to be significantly impacted.

Seven receptors are expected to see shadow flicker for more than 30 hours per year in this scenario. These receptors include: R01, R10, R14, R15, R19, R21, R22. These receptors require further consideration beyond the worst-case results.

The maximum daily flicker in the worst-case scenario assumes all meteorological and operational conditions align to have the potential to produce flicker for the entire prediction period. In the worst-case, potentially affected receptors were predicted to observe maximum daily flicker between 28 to 56 minutes in a single day, but the maximum daily duration at each receptor is predicted to occur on very few days in a given year. Furthermore, weather and operational conditions may align to produce the maximum daily flicker at a receptor in one year, but not necessarily in another year.

4.3 Adjusted-Case Discussion

In the adjusted-case, the annual shadow flicker at each receptor is reduced by 57-81% (67% on average) when the analysis is modelled with statistical wind and sunshine data. Under these conditions, 16 receptors predicted to see shadow flicker are expected to observe less than 30 hours of flicker per year and five receptors are predicted to observe no shadow flicker. Due to the limited amount of shadow flicker, these receptors are not expected to be impacted.

The only receptor predicted to observe over 30 hours of flicker per year in this scenario is R01. As such, further consideration of the potential for flicker at this property is required.

Although the adjusted-case model presents results that are closer to what can be expected to be seen once the Project is operating, it is still considered conservative since additional elements may further reduce impacts.

Obstructions that block an observer's view of the Project infrastructure will decrease shadow flicker impacts. Aerial imagery suggests that shadow flicker may be further reduced for receptors that have obstructions between the receptor and the turbines. R01 is surrounded by trees and other buildings that may at least partially obstruct views of the proposed turbines from the receptor. These trees and structures may reduce shadow flicker impacts experienced by the receptor seasonally or year-round. As a result, it is considered that R01 would not experience more than 30 hours of actual flicker in a typical year.

Since the shadow receptors were modelled using the green house mode, actual window locations and orientation relative to the turbines will likely reduce the actual flicker seen inside receptor buildings. This analysis can be refined if the orientation of the property, number of windows and their dimensions, and presence of other obstacles are known.

The adjusted-case shadow flicker results may differ if more local sunshine data can be included in the model. The current analysis incorporates sunshine data from the Edmonton/Stony Plain weather station, which is the closest station to the Project available in WindPRO at a distance of approximately 218km. Environment and Climate Change Canada's climate normals data from weather stations within similar proximity to the Project Area were compared to the modelled values.[19] The comparison revealed that the average daily bright sunshine hours varied by less than one hour on a monthly basis between stations, and less than four hours on an annual basis. This variation implies that long-term, site-specific sunshine data will have a minor impact on the shadow flicker results.

4.4 Mitigation

If shadow flicker is a concern for receptors during Project operations, mitigation measures can be employed to reduce or eliminate the flicker. In the event of a concern, specific mitigation measures can be developed in consultation with affected stakeholders on a case-by-case basis.

Vestas offers a "Shadow Flicker Control System" that can be programmed to reduce the impact of shadow flicker on nearby receptors. The system uses light sensors on the turbines in combination with modelled shadow flicker predictions to determine when there is the potential for flicker to occur between specific turbines and receptors, pausing the wind turbine(s) when set curtailment criteria are met. If one or more curtailment criteria are not met, the wind turbine(s) can continue operating as normal.

Another mitigation measure could be to install vegetative screening close enough to the affected window(s) to mitigate the worst effects without unduly preventing light reaching the property. Adding shutters or external shading elements to affected windows may be a further consideration on a case-by-case basis. Shutters and other window coverings allow occupants to flexibly control the amount of light entering a building if they determine that mitigation is necessary.

The Shadow Flicker Control System may be utilized to reduce potential shadow flicker impacts while minimizing curtailment. Targeted turbines would only be curtailed during predicted periods of flicker when incoming sunlight is intense enough to produce strong shadows.

As an example of a mitigation strategy, turbine T09 could be set for curtailment in May every year, leading to mitigation of flicker at receptor R01 under 30 hours per year in the adjusted-case scenario. If this example of mitigation is implemented, no receptor would be predicted to observe more than 30 hours of shadow flicker per year in the adjusted-case. Variations of this mitigation plan exist that achieve the same results.

[19] Including weather stations near Cold Lake, AB, Meadow Lake, AB, and Edmonton, AB.

5 Summary and Conclusion

Northern Valley Wind LP proposes to construct and operate the Project in St. Paul County No. 19, Two Hills County No. 21, and Vermillion River County No. 24 in east-central Alberta, approximately 9km southeast of the town of Elk Point. The Project will use up to 17 Vestas V163-4.5 MW wind turbine generators, which have a rotor diameter of 163m and a hub height of 125m and a total generating capacity of up to 76.5MW.

AUC Rule 007 provides guidelines to determine receptors to include in a shadow flicker assessment, but it does not state acceptable shadow flicker thresholds. German guidance limits annual theoretical shadow flicker at a receptor to a maximum of 30 hours per year or 30 minutes per day, whereas North American jurisdictions, such as Nova Scotia, have historically limited annual shadow flicker to a maximum of 30 hours without daily exposure limits when incorporating representative environmental factors. GCR considered both guidelines in this assessment, focussing on common practices and local regulations in North America.

Following the Rule 007 guidelines, 22 properties were identified and assessed within 1.5km of the 17 proposed turbine locations. Receptors were modelled using the worst-case assumptions in WindPRO, which results in an overestimation of the actual shadow flicker that will be observed. Since WindPRO's green house model assumes receptors are susceptible to shadow flicker from all directions, the actual location and orientation of a building's windows will likely reduce the amount of flicker that occurs inside the building.

In the worst-case, the modelling results show that:

- Five receptors are not expected to observe any shadow flicker;
- Ten receptors are expected to observe shadow flicker for less than 30 hours per year; and
- Seven receptors are expected to observe shadow flicker for more than 30 hours per year.

An adjusted-case was also modelled to incorporate statistical sunshine data and measured wind data, reducing the shadow flicker by 57-81% (67% on average) relative to worst-case. The adjusted-case shows that:

- Five receptors are not expected to observe any shadow flicker;
- Sixteen receptors are expected to observe shadow flicker for less than 30 hours per year; and
- One receptor is expected to observe shadow flicker for more than 30 hours per year.

The adjusted-case scenario is still considered conservative since it can be refined if additional inputs can be modelled, including; window sizes, building and window orientations, the presence of additional obstructions, typical activities at each receptor, and times of use for each property. Moreover, vegetation and other buildings are present in the immediate vicinity of the dwelling potentially affected by more than 30 hours of flicker per year. As a result, it was concluded that this receptor was unlikely to experience more than 30 hours of flicker per year in practice.

Maximum daily flicker predictions ranged between 28 to 56 minutes in a single day in the worst-case, though these maximum daily durations are predicted to occur on very few days in a given year. These maximum daily durations are possible if all meteorological and operational conditions align, but this is not guaranteed to happen every year.

If shadow flicker is a concern for receptors, mitigation measures may be considered. Vestas' Shadow Flicker Control System can be utilized to intelligently reduce annual shadow flicker predictions while minimizing potential curtailment. With mitigation via this system, a scenario exists where a single turbine can be flagged for potential curtailment to ensure annual flicker at R01 and all other evaluated receptors does not exceed 30 hours per year in the adjusted-case.

If further mitigation is deemed necessary, specific measures can be determined in consultation with the concerned occupant.

In conclusion, receptors R01, R10, R14, R15, R19, R21, and R22 are the most likely to observe shadow flicker from the Project in the worst-case scenario, with the model predicting over 30 hours of flicker per year. In the adjusted-case scenario, R01 is the most likely receptor to observe shadow flicker for more than 30 hours per year. However, topographic factors such as tree screening and other buildings on the property observed in satellite imagery, suggest that shadow flicker may actually be less than predicted. In the adjusted-case scenario, 16 of the 22 evaluated receptors are predicted to see less than 30 hours per year, and five are predicted to see no shadow flicker. The adjusted-case scenario is more representative of what receptors may see in practice, but it is still a conservative prediction of the potential shadow flicker. Additional information would help refine the analysis, likely resulting in further reductions.

6 Shadow Flicker Practitioners' Information

Table 6-1 summarizes the information of the author and technical reviewer of the shadow flicker assessment.

Table 6-1 – Summary of Practitioners' Information

Name	Jacqueline Gallagher	Jason Mah	Cameron Sutherland
Title	Junior Project Manager	Senior Renewable Energy Engineer	Technical Director
Role	Shadow Flicker Analyst, Author	Shadow Flicker Analyst, Reviewer	Technical Reviewer and Approver
Experience	• Analyst on 15+ technical assessments for renewable energy projects in Alberta and the UK • BSc Chemistry	• Analyst on 50+ technical assessments for renewable energy projects in Alberta, BC, Nunavut, Nova Scotia, the USA, and the UK • Technical support for AUC information requests and hearings • BSc Chemical Engineering • P.Eng. (APEGA)	• Co-author of the Shadow Flicker Review report commissioned by the AUC to advise on shadow flicker assessment requirements • Expert witness experience in technical renewable energy development in Canada for multiple proceedings and hearings, including Grizzly Bear Creek Wind Power Project • Technical oversight, technical review, or authorship of GCR technical assessments for 20+ proceedings in Alberta • MSci Physics • MSc Renewable Energy Systems Technology

Appendix A: WindPRO Shadow Flicker

WindPRO is the leading 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[20]. The analysis employed is 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 receptor. WindPRO requires the following data:[21]

- 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; and
- A simulation model, which holds information about the earth's orbit and rotation relative to the sun.

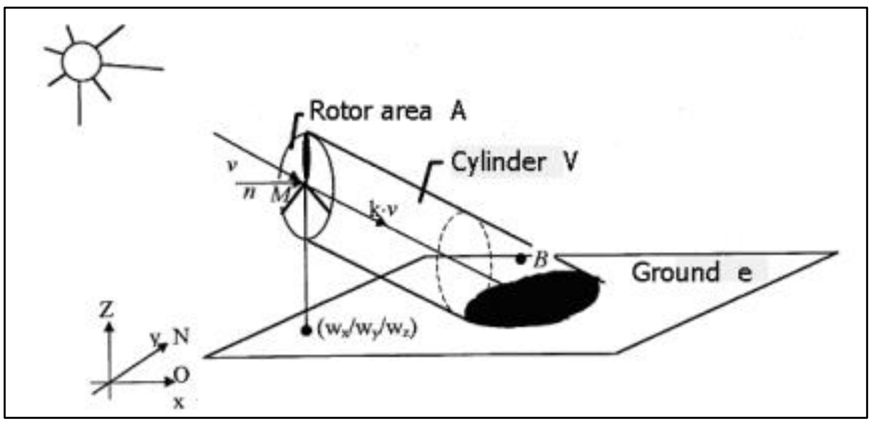

Figure A-1 – Diagram of Sun Angle Relative to the Turbine and Shadow Receptor

[20] Modules - Modular-based and covers all aspects EMD International (emd-international.com)
[21] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

Table A-1 shows the calculation parameters used in WindPRO 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	No – User override to assess 1.5km from turbines
	Icing	Optional — User defined. Not considered for this analysis.
Receptor Data	Orientation of affected window(s)	Yes – Green house mode selected
	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 & data provided by project developer
	Sunshine hours	Green house mode & nearest weather station
	Cloud cover	Green house mode
	Sun model	Disc
	Assessment distance	Input – Set to 1.5km from turbines

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.[22] This mode is useful if the actual properties of the shadow receptor are unknown, if there are wind turbines on multiple sides, or if a conservative analysis is intended.

[22] *Shadow Flicker Review for Alberta Utilities Commission* (Green Cat Renewables Canada Corporation, September 27, 2019).

Appendix B: Turbine Locations

Table C-1 – Wind Turbine Locations and Heights

Turbine ID	NAD 83, UTM Zone 12N		Latitude	Longitude	Ground Elevation (m)
	Easting	Northing			
T01	53.83286°	-110.79493°	513,496	5,964,945	673
T02	53.83375°	-110.77977°	514,493	5,965,048	685
T03	53.81612°	-110.76144°	515,706	5,963,090	677
T04	53.80384°	-110.76665°	515,367	5,961,722	665
T05	53.80447°	-110.80612°	512,768	5,961,784	658
T06	53.80874°	-110.80292°	512,977	5,962,261	663
T07	53.78527°	-110.83152°	511,100	5,959,644	666
T08	53.77439°	-110.84342°	510,319	5,958,432	676
T09	53.76517°	-110.83073°	511,158	5,957,408	681
T10	53.76240°	-110.84375°	510,300	5,957,097	694
T11	53.75586°	-110.85030°	509,870	5,956,370	679
T12	53.75612°	-110.83664°	510,770	5,956,400	687
T13	53.75241°	-110.81534°	512,176	5,955,991	684
T14	53.74727°	-110.82371°	511,626	5,955,418	680
T15	53.74599°	-110.80135°	513,101	5,955,280	676
T16	53.74203°	-110.81070°	512,485	5,954,837	681
T17	53.73865°	-110.79258°	513,681	5,954,464	672

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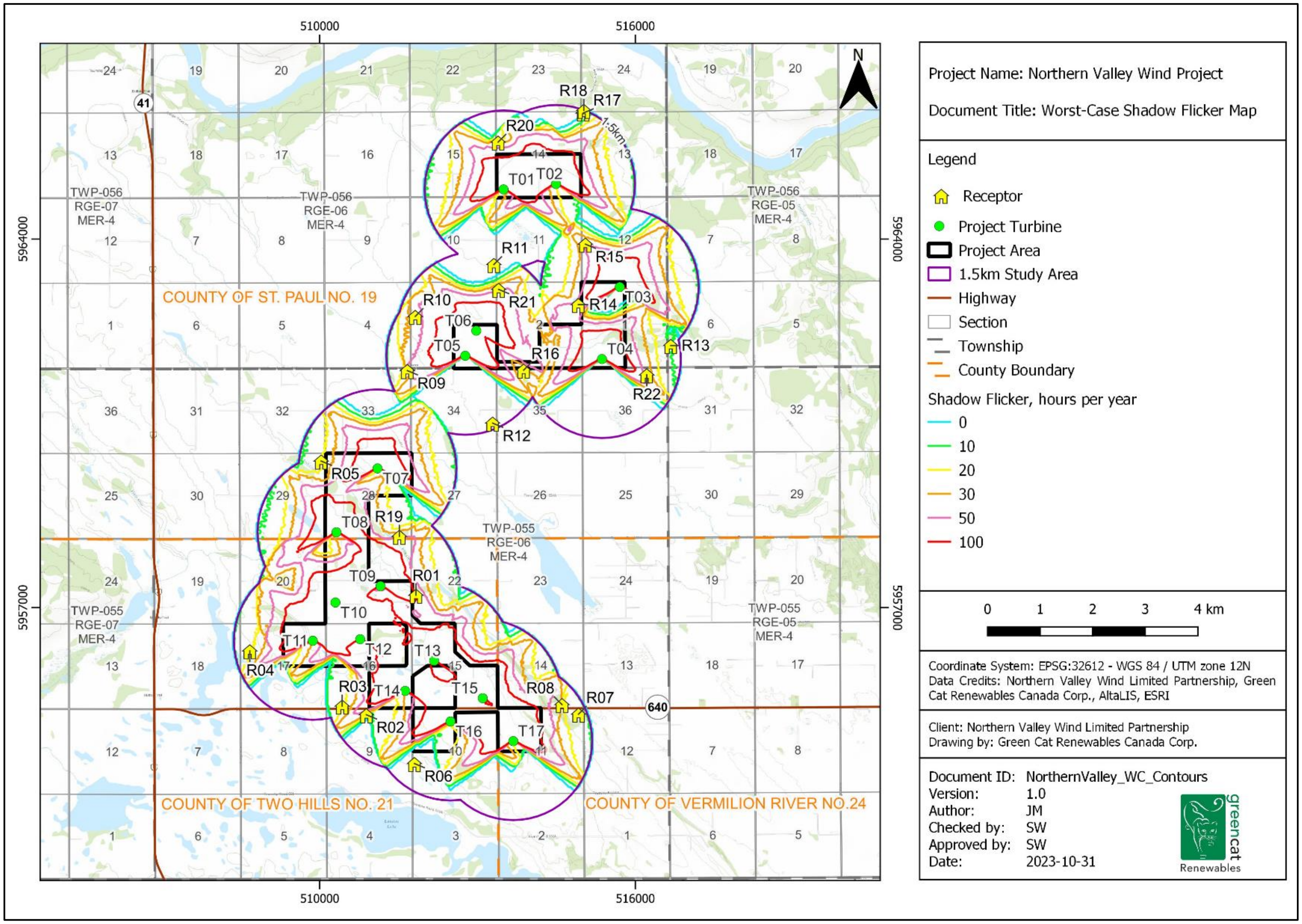
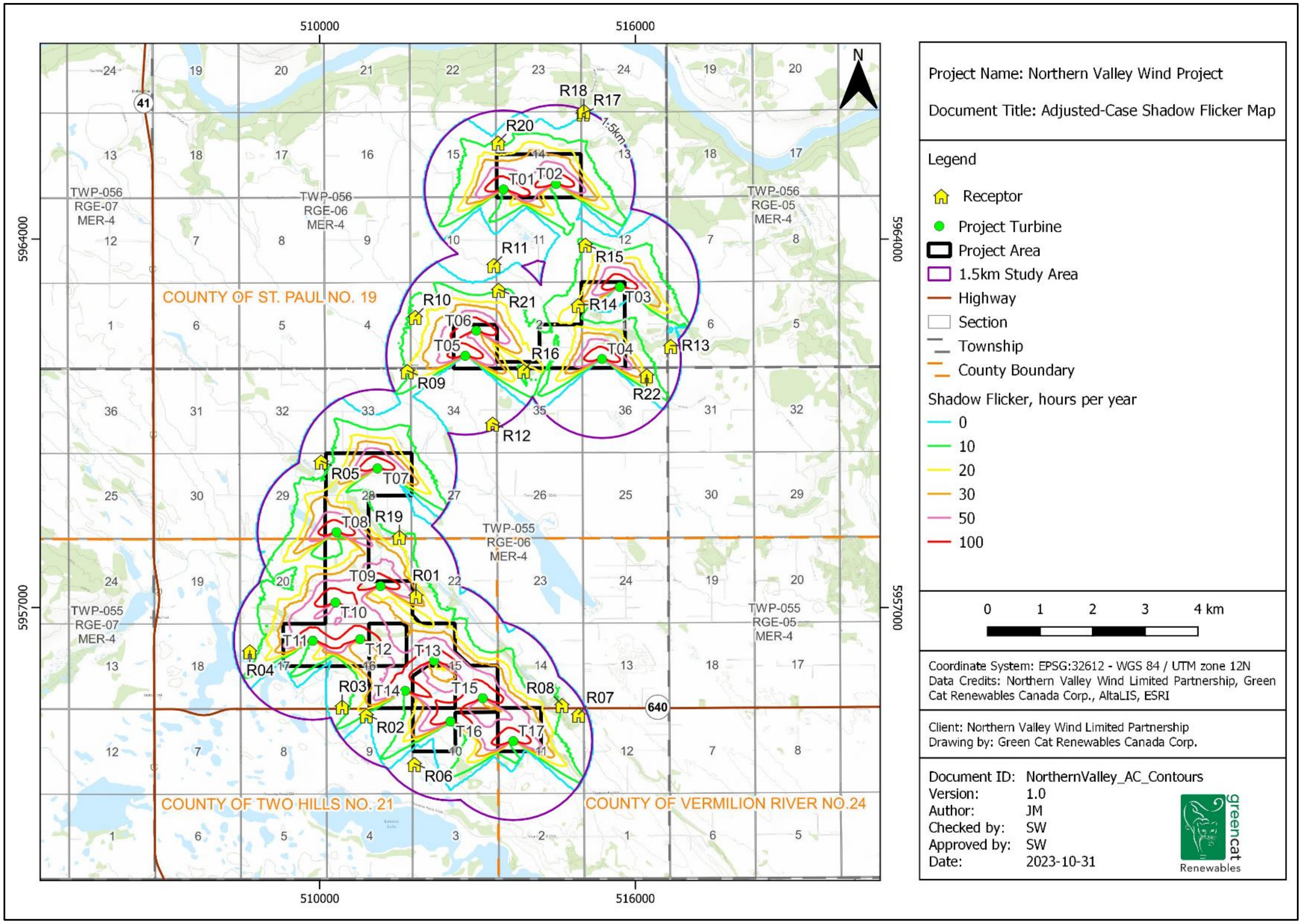
Appendix C1: Shadow Flicker Map (Worst-Case Scenario)



Appendix C2: Shadow Flicker Map (Adjusted-Case Scenario)



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