Coaldale Renewable Energy Project

Shadow Flicker Assessment

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Coaldale Renewables GP Inc.

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This document has been prepared by Green Cat Renewables Canada Corporation. The material and data in this report were prepared under the supervision and direction of the undersigned.

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RM APEGA ID#: 250600
DATE: August 23, 2024
PERMIT NUMBER: P14302
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

Stephanie Wood, P.Eng.

The shadow flicker assessment is being issued with professional engineering authentication. The information contained in this report, to which the engineering authentication is applied, is deemed complete for the intended purpose.

Disclaimer

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Executive Summary

Coaldale Renewables GP Inc. (Coaldale Renewables) propose to install the Coaldale Renewable Energy Project (the Project), located approximately 10km northeast of the Town of Coaldale, Alberta, within Lethbridge County and the Municipal District of Taber. The proposed Project will consist of up to 5 wind turbine generators and a 5-megawatt (MW_{AC}) solar photovoltaic (PV) development. The Project turbines will have a rotor diameter of up to 175m, and a hub height of up to 125m, with a total generating capacity of up to 35 MW_{AC}. Coaldale Renewables 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 24 representative dwellings, identified from desktop verification by GCR and field verified by GCR, within approximately 1.5km of the proposed turbine locations.

Rule 007 does not mention acceptable shadow flicker thresholds. 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[2]), 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 measured wind and statistical sunshine data.

In the worst-case scenario:

- Four 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
- Ten receptors are expected to observe shadow flicker for more than 30 hours per year.

Maximum daily flicker predictions ranged between 10 to 54 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.

In the adjusted-case scenario:

- Four receptors are not expected to observe any shadow flicker;
- Twenty receptors are expected to observe shadow flicker for less than 30 hours per year; and
- No receptors are expected to observe shadow flicker for more than 30 hours per year.

In the adjusted-case scenario, none of the receptors were predicted to receive over 30 hours of flicker per year, with the highest annual prediction of 22 hours and 25 minutes. The adjusted-case alterations reduce the annual shadow

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

flicker at each receptor by 55-72% (64% 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. Additional conditions that may yield further reductions but were not evaluated include actual window sizes, building and window orientations, the presence of additional obstructions, typical activities at each receptor, and times of use for each property. As a result, potential shadow flicker from the Coaldale Renewable Energy Project is concluded to be of low significance, and mitigation is not being recommended at this time.

Table of Contents

1 Introduction

Coaldale Renewables GP Inc. (Coaldale Renewables) proposes to install the Coaldale Renewable Energy Project (the Project), in Lethbridge County and the Municipal District of Taber, located approximately 10km northeast of the Town of Coaldale, Alberta. The proposed Project will consist of up to 5 wind turbine generators, with a total generating capacity of up to 35 megawatts (MW_{AC}) and a 5 MW_{AC} solar photovoltaic (PV) development. Coaldale Renewables 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* [3] (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, 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.*"[4]

Whilst the moving shadow can occur outdoors, the shadow flicker effect is experienced inside buildings where the shadow passes over a narrow window opening.[5] 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 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;

[3] 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.

[4] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*. Retrieved July 29, 2024, 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.

[5] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*, pg. 51-52. Retrieved July 29, 2024, 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.

- 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.*"[6]

[6] Brinckerhoff, P. (n.d.). *Update of UK Shadow Flicker Evidence Base: Final Report*. Retrieved June 11, 2024, 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 Lethbridge County and Municipal District of Taber, Alberta. The Project location is rural and industrial, consisting primarily of cultivated fields, varying watercourses and waterbodies, and oil/gas facilities and is located around the Hamlet of Chin that is approximately 10km northeast of the Town of Coaldale.

The Study Area follows the Rule 007 guidelines to include the area within 1.5km of the centre point of each Project turbine. To allow for potential turbine micrositing, an additional 50m beyond the 1.5km radius (total of 1.55km) was considered.

2.2 Turbine Specifications

The Project will consist of 5 wind turbine generators. Coaldale Renewables has not finalized the Project's turbine model at this time, so the largest turbine dimensions being considered have been modelled, which includes a rotor diameter of up to 175m and a hub height of 125m. Assessment of these dimensions represents the most predicted potential impact at the receptors. 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" model represents a conservative approach to ensure that annual variations in shadow flicker event timing are captured in the model.[7] Changes in window size have been shown to have a negligible effect on shadow flicker results, especially with increasing distance from the turbines.[8] Therefore, each receptor has been modelled as a 1m-by-1m window facing each turbine, with a receptor eye level at 1.5m above ground.

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. WindPRO calculates 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. Any potential flicker predicted for receptors farther than 1.5km from a turbine is expected to be far less impactful than for receptors closer to a turbine due to the decreased shadow definition at longer distances. The minimum sun height of influence was set at WindPRO's default of 3° over the horizon. A minimum sun angle threshold is set because sunlight at low sun angles becomes too diffuse to produce coherent shadows; thus, significant shadows are unlikely to be observed.[9]

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

[8] Ibid.

[9] EMD International A/S. (September 2022). *WindPRO 3.6 User Manual*, section 6. Retrieved July 29, 2024: https://help.emd.dk/knowledgebase/content/windPRO3.6/c6-UK_WindPRO3.6-Environment.pdf.

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.[10] The stated accuracies indicate that small undulations in the land may not be captured, but these are insignificant compared with the turbine heights and distances between receptors and turbine locations. The resolution of the topographical data is 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 scenario adopted a very conservative approach by assuming that:

- Each 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; and
- Each turbine is always operating.

2.4.2 Adjusted-Case Model

The adjusted-case scenario utilized measured and 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, resulting in smaller/weaker shadows and less flicker. The measured wind data from the Project site was used to obtain the wind direction distribution shown in **Table 2-1.**[11]
- **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 Suffield weather station was used since it is the nearest station available in WindPRO.

[10] *20K Digital Elevation Model* (Altalis Ltd., November 20, 2017).

[11] Wind direction frequencies used in the model do not consider the turbine cut-in or cut-out wind speeds. The turbine is assumed to be operating at all wind speeds, therefore adding conservatism to the model.

Table 2-1 – Wind Direction Frequency

Wind Direction	Frequency (%)
N	5.1
NNE	4.4
NE	3.2
ENE	3.1
E	3.8
ESE	3.0
SE	3.0
SSE	3.7
S	3.8
SSW	5.2
SW	11.2
WSW	22.5
W	11.4
WNW	5.3
NW	5.0
NNW	6.3
Total	**100.0**

Although this adjusted-case scenario is more representative than the purely theoretical scenario, the conditions specified for the adjusted-case scenario 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 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 reviewed. 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.[12,13] GCR have considered these guidelines in this shadow flicker assessment, focussing on common practices and local regulations in North America.

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

[13] Ollson Environmental Health Management. (February 14, 2019). *Scientific Basis for 30-hour Shadow Flicker Standard used by Crowned Ridge Wind Farm*. Retrieved June 21, 2024: https://puc.sd.gov/commission/dockets/Civil/2019/batenumber/14179-14522.pdf.

3 Study Area

The Study Area straddles Highway 3 in southern Alberta, including the Hamlet of Chin. The proposed Project infrastructure is distributed throughout the following townships: 09-18-W4M and 09-19-W4M. The Study Area follows the Rule 007 guidelines to include the area within 1.5km of the centre point of each Project turbine. GCR identified 22 representative receptors that fall within a 1.5km radius of at least one potential turbine location. An additional 50m beyond the 1.5km radius (total of 1.55km) was considered to account for potential turbine micrositing, leading to the inclusion of two additional receptors (total of 24 receptors). These additional receptors were field verified by GCR in June 2024 to be dwellings according to the requirements of Rule 007.

The effects of shadow flicker are typically predicted to be worse 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 1.5km of a turbine, forming the baseline of the study area of the assessment. Details of the identified receptors are listed in Table 3-1.

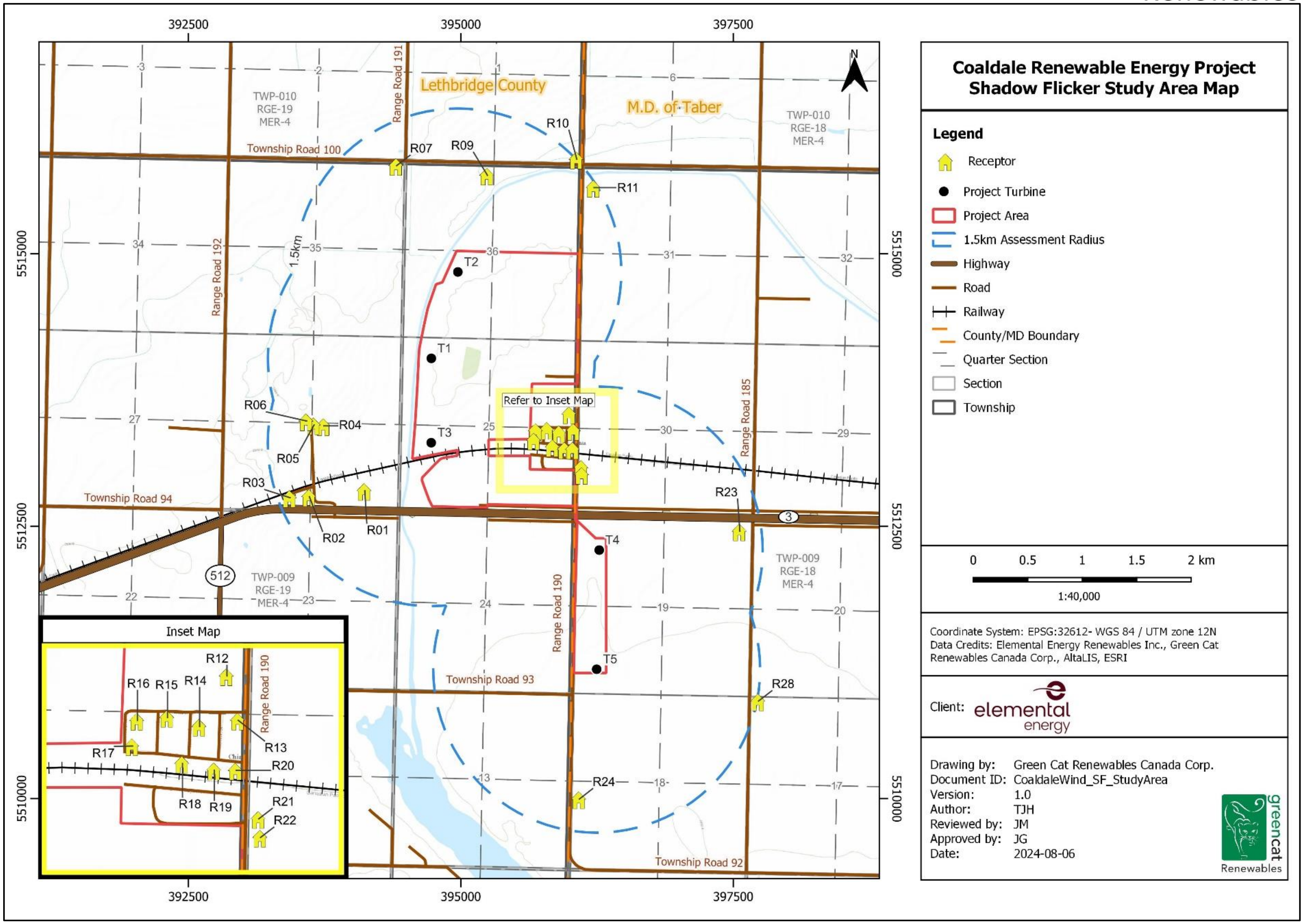


Figure 3-1 – Coaldale Renewable Energy Project Shadow Flicker Study Area Map

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	394119	5512826	843	1.5	T3	750
R02	393611	5512771	844	1.5	T3	1220
R03	393433	5512761	847	1.5	T3	1390
R04	393744	5513421	846	1.5	T3	1000
R05	393653	5513429	847	1.5	T3	1090
R06	393585	5513465	849	1.5	T3	1160
R07	394411	5515809	849	1.5	T2	1130
R09	395245	5515720	838	1.5	T2	930
R10**	396065	5515868	840	1.5	T2	1505
R11	396223	5515608	842	1.5	T2	1470
R12	395999	5513529	844	1.5	T4	1280
R13	396038	5513376	846	1.5	T4	1120
R14	395905	5513355	846	1.5	T4	1130
R15	395795	5513386	846	1.5	T3	1070
R16	395691	5513376	845	1.5	T3	970
R17	395674	5513288	843	1.5	T3	950
R18	395846	5513228	845	1.5	T4	1040
R19	395956	5513205	846	1.5	T4	980
R20	395999	5513206	848	1.5	T4	960
R21	396109	5513037	847	1.5	T4	770
R22	396115	5512973	846	1.5	T4	710
R23	397561	5512454	847	1.5	T4	1300
R24	396088	5509996	858	1.5	T5	1200
R28**	397732	5510895	854	1.5	T5	1510

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

**Receptor is slightly outside the 1.5km Study Area, so no significant shadows are expected. However, the receptor has been assessed for shadow flicker in case of micrositing.

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	0:00	0:00	0:00	-
R02	42:04	0:36	19:02	WTG3
R03	20:31	0:30	9:14	WTG3
R04	40:34	0:40	15:04	WTG3, WTG1
R05	48:41	0:37	19:21	WTG1, WTG3
R06	54:39	0:35	22:25	WTG1, WTG3
R07	0:00	0:00	0:00	-
R09	0:00	0:00	0:00	-
R10	27:17	0:29	7:33	WTG2
R11	14:25	0:29	4:34	WTG2
R12	34:13	0:31	12:36	WTG1, WTG3
R13	41:02	0:30	14:47	WTG1, WTG3
R14	48:02	0:34	16:58	WTG1, WTG3
R15	49:47	0:38	17:25	WTG1, WTG3
R16	40:20	0:42	13:57	WTG3, WTG1
R17	30:42	0:43	10:33	WTG3, WTG4
R18	24:59	0:36	8:47	WTG3, WTG1
R19	27:33	0:33	9:38	WTG3, WTG1
R20	14:35	0:31	5:06	WTG2
R21	12:28	0:29	4:41	WTG3
R22	29:56	0:37	8:18	WTG4, WTG3
R23	13:48	0:31	4:46	WTG3
R24	0:00	0:00	0:00	-
R28	10:38	0:27	4:02	WTG5

4.2 Discussion

No shadow flicker impacts from Project turbines are expected at R1, R7, R9 or R24 in either scenario due to their location relative to the turbines.

4.2.1 Worst-Case Discussion

In the worst-case, ten receptors are expected to observe shadow flicker for less than 30 hours per year, and four 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.

Ten receptors are expected to see shadow flicker for more than 30 hours per year in this scenario. These receptors include: R02, R04-R06, and R12-R17. 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 10 to 55 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.

4.2.2 Adjusted-Case Discussion

The adjusted-case scenario presents results that are closer to what can be expected to be seen once the Project is operating; however, these are still considered conservative since additional elements may further reduce impacts.

In this scenario, the annual shadow flicker at each receptor is reduced by 55-72% (64% on average) when the analysis is modelled with measured wind and statistical sunshine data. Under these conditions, 20 receptors predicted to see shadow flicker are expected to observe less than 30 hours of flicker per year and four receptors are predicted to observe no shadow flicker. Due to the limited amount of shadow flicker, these receptors are not expected to be significantly impacted.

There are no receptors predicted to observe over 30 hours of flicker per year in this scenario.

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 Suffield weather station, which is the closest station to the Project available in WindPRO at a distance of approximately 106km. 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.[14] The comparison revealed that the average daily bright sunshine hours varied by less than one hour on a monthly basis between stations, and approximately 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.

4.2.3 General Observations

Obstructions that block an observer's view of the Project infrastructure will decrease shadow flicker impacts relative to the results presented. Aerial imagery suggests that shadow flicker may be further reduced for receptors that have

[14] Including weather stations near Suffield, AB, Medicine Hat, AB, and Calgary, AB.

obstructions between the receptor and the turbines. For example, multiple receptors have trees and/or other structures near the dwelling and in the direction of turbines that are predicted to produce shadow flicker that may block the line-of-sight.

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.

Overall, it is considered highly likely that shadow flicker potential has been over-estimated by both worst-case and adjusted-case models.

4.3 Mitigation

No receptors were predicted to receive shadow flicker exceeding 30 hours annually in the adjusted-case scenario, therefore mitigation is not being recommended.

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.

5 Summary and Conclusion

Coaldale Renewables propose to install the Coaldale Renewable Energy Project around the Hamlet of Chin, Alberta, within Lethbridge County and the Municipal District of Taber. The proposed Project will consist of up to 5 wind turbine generators and a 5 MW_{AC} solar PV development. The Project turbines will have a rotor diameter of up to 175m, and a hub height of up to 125m, with a total generating capacity of up to 35 MW_{AC}.

AUC Rule 007 provides guidelines to determine receptors to include in a shadow flicker assessment, but it does not state acceptable shadow flicker thresholds. 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 focussed on common practices and local regulations in North America in this assessment.

Following the Rule 007 guidelines, 24 representative properties were identified and assessed within approximately 1.5km of the 5 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:

- Four 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
- Ten 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 55-72% (64% on average) relative to worst-case. The adjusted-case shows that:

- Four receptors are not expected to observe any shadow flicker;
- Twenty receptors are expected to observe shadow flicker for less than 30 hours per year; and
- No receptors are 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.

Maximum daily flicker predictions ranged between 10 to 55 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 observed during Project operation becomes a concern for receptors, further mitigation may be deemed necessary. Specific measures can be determined in consultation with the concerned occupant.

In conclusion, receptors R02, R04-R06, and R12-R17 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, none of the receptors were predicted to receive over 30 hours of flicker per year, with the highest annual prediction of 22 hours and 25 minutes at R06. 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. As a result, potential shadow flicker from the Coaldale Renewable Energy Project is of low significance, and mitigation is not being recommended at this time.

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	Tilda Hadley	Jason Mah	Cameron Sutherland
Title	**Renewable Energy EIT**	**Technical Lead**	**Technical Director**
Role	**Shadow Flicker Analyst, Author**	**Technical Reviewer**	**Technical Reviewer and Approver**
Experience	• Analyst on 5+ technical assessments for renewable energy projects in Alberta • BEng Chemical Engineering	• 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[15]. 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:[16]

- 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.

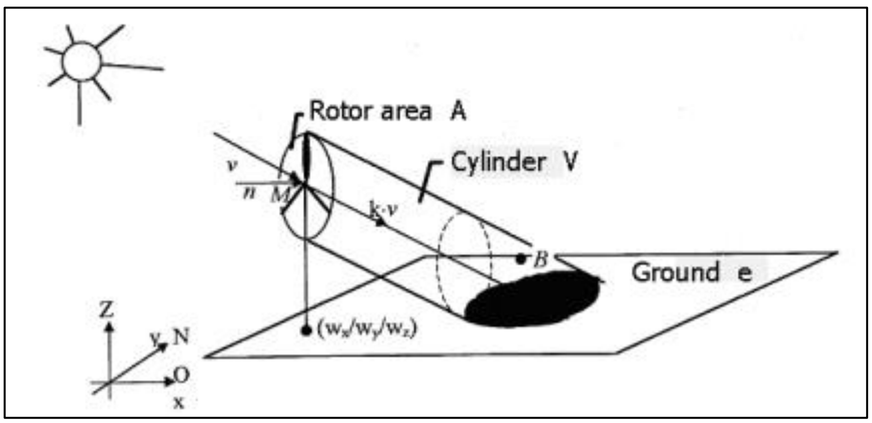


Figure A-1 – Diagram of Sun Angle Relative to the Turbine and Shadow Receptor

[15] Modules - Modular-based and covers all aspects EMD International (emd-international.com)

[16] EMD International A/S. (September 2022). *WindPRO 3.6 User Manual*, section 6. Retrieved July 20, 2024: https://help.emd.dk/knowledgebase/content/windPRO3.6/c6-UK_WindPRO3.6-Environment.pdf.

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 *1.55km for micrositing

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.[17] 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.

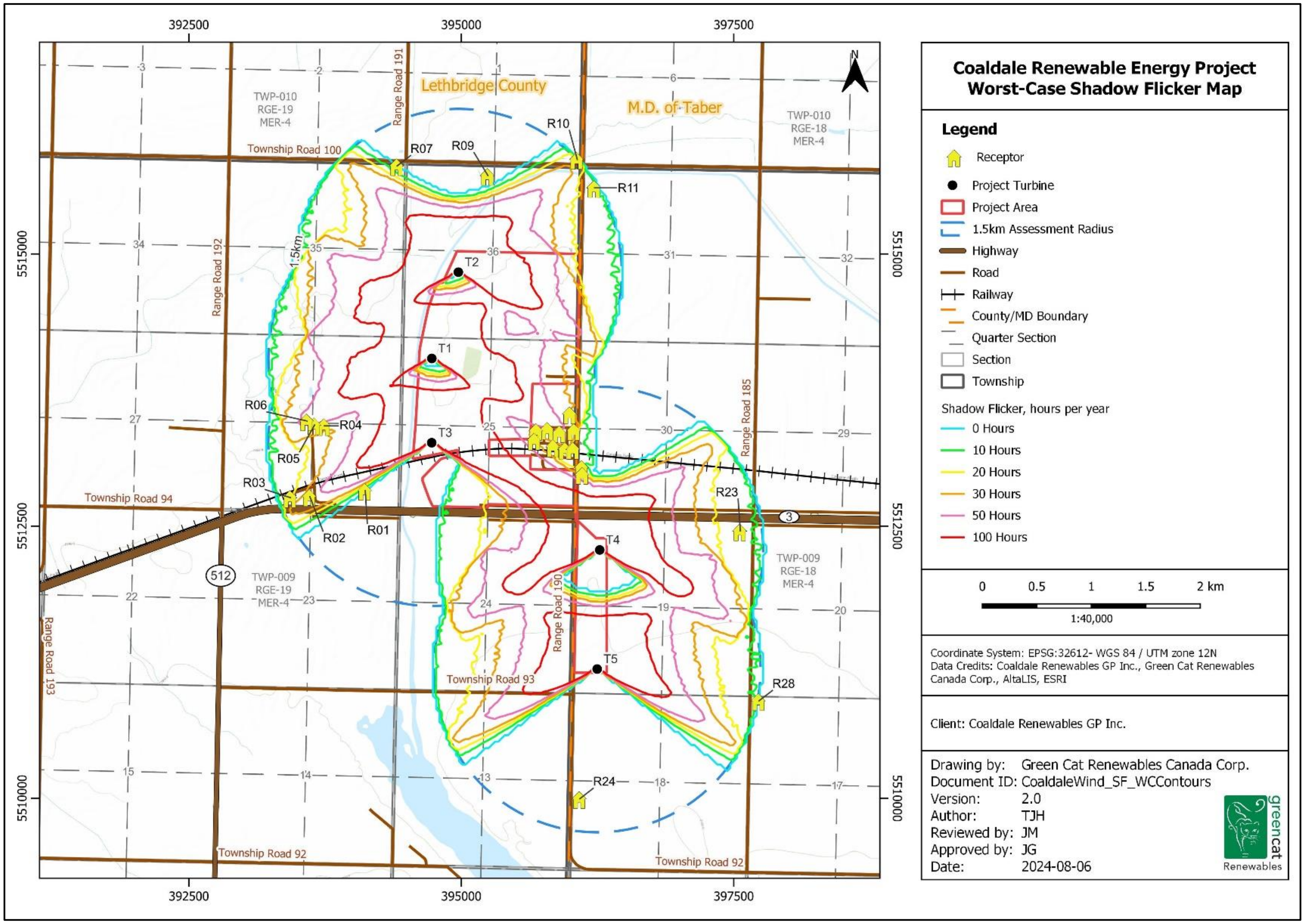
[17] EMD International A/S. (September 2022). *WindPRO 3.6 User Manual*, section 6. Retrieved July 20, 2024: https://help.emd.dk/knowledgebase/content/windPRO3.6/c6-UK_WindPRO3.6-Environment.pdf.

Appendix B: Turbine Locations

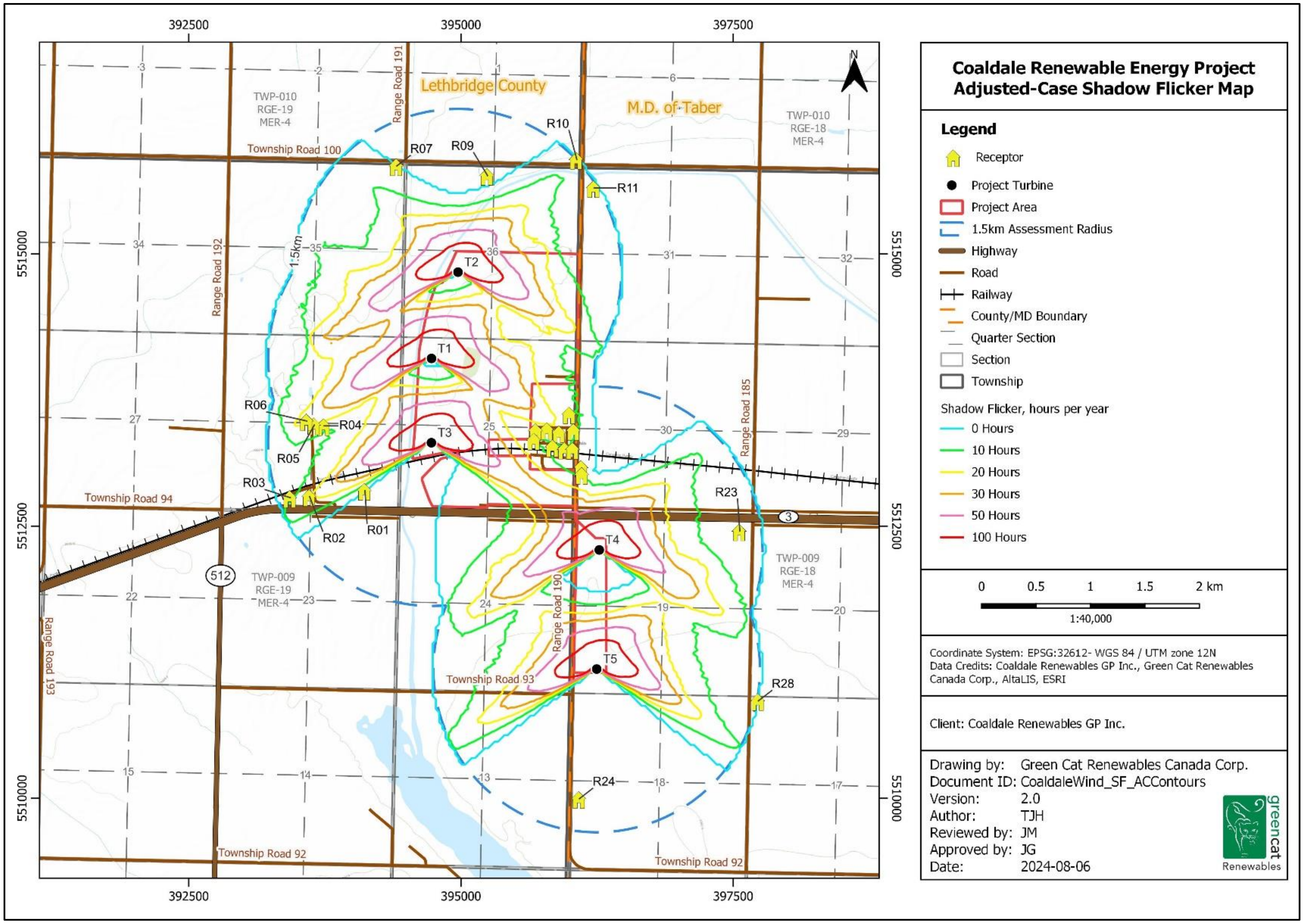
Table C-1 – Wind Turbine Locations and Heights

Turbine ID	NAD 83, UTM Zone 12N		Latitude	Longitude	Ground Elevation (m)
	Easting	Northing			
T1	394730	5514040	49.769606°	-112.461931°	847
T2	394973	5514833	49.776779°	-112.458766°	846
T3	394729	5513266	49.762645°	-112.461738°	843
T4	396268	5512293	49.754161°	-112.440104°	848
T5	396247	5511187	49.744214°	-112.440107°	853

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



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



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