High River Solar Project

Solar Glare Hazard Analysis Report

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Executive Summary

High River Solar Limited Partnership (High River Solar LP) is developing a solar photovoltaic (PV) project called the High River Solar Project (the Project). The Project is proposed to cover approximately 129 acres of land in the Municipal District of Foothills, Alberta, adjacent to the Town of High River's northwestern municipal boundary. The Project is proposed to use a single-axis tracking (SAT) system with a total generating capacity of 18.5 megawatts (MW_{AC}). High River Solar LP has retained Green Cat Renewables Canada Corporation (GCR) to conduct a solar glare hazard analysis for the potential of glare at dwellings and along transportation routes near the Project.

GCR utilizes ForgeSolar's GlareGauge software to assess user-input PV arrays for potential glare on identified roadways and aviation assets. The software evaluates the occurrence of glare on a minute-by-minute basis. If glare is predicted, each minute of glare as a function of retinal irradiance and subtended angle is plotted on a hazard plot. Retinal irradiance and subtended angle predict the ocular hazard associated with the glare as either green (low potential for after-image), yellow (potential for temporary after-image), or red (potential for retinal damage). The software does not consider obstacles such as trees, hills, buildings, etc. between the PV array and glare receptor.

GCR followed (and in some cases, went beyond) the guidelines provided in Alberta Utilities Commission (AUC) Rule 007 for the receptors to be included in a solar glare assessment, but Rule 007 does not specify any modelling parameters or glare threshold limits.[1] GCR also referred to the information provided in Zehndorfer Engineering's Solar Glare and Glint Project Report,[2] which was written to inform the AUC's update to Rule 007, Alberta Transportation guidelines,[3] and other relevant literature.

GCR evaluated the area within 4,000m of the Project for aerodromes and within 800m for any other receptors. The assessment considered the following receptors near the Project:

- Six dwellings;
- Two highways and two local roads; and
- High River (Hospital) Heliport.

The glare analysis indicates that the Project is not likely to have the potential to create hazardous glare conditions for the dwellings or transportation routes assessed. Any glare predicted to affect the evaluated receptors can be eliminated by utilizing a minimum backtracking angle of 3° or higher.

If a resting angle lower than 3° is used in operation, the actual glare impacts that will be experienced in the field are anticipated to be only a fraction of the results presented in this report. The impact of glare on dwellings and routes are expected to be reduced by sun-masking as the glare occurs at sunset or sunrise when the sun aligns with the glare spot and observer, and the sunlight glances across the nearly horizontal arrays at a shallow angle. The actual impacts along transportation routes are expected to be less because vehicle operators will be travelling past the affected areas, not standing still while looking at the solar PV arrays. In line with Alberta Transportation guidelines, glare within the ±15° FOV of drivers on provincial highways can be mitigated using a minimum backtracking angle of 3° or by installing an appropriately sized and designed barrier to obstruct drivers' views of glare-producing parts of the Project.

[1] AUC Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines* (March 2021), subsection 4.3.2 SP14.

[2] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).

[3] *Application Requirements for Solar Generation Development near Provincial Highways (*Alberta Transportation, June 2021).

Based on the assessment results, the High River Solar Project is not expected to present a significant hazard to drivers and pilots near the Project, and the glare is not expected to have a significant adverse effect on a resident's use of their home.

Table of Contents

1 Introduction

High River Solar Limited Partnership (High River Solar LP) retained Green Cat Renewables Canada Corporation (GCR) to conduct a solar glare hazard analysis for the High River Solar Project (the Project). The solar photovoltaic (PV) project is located in the Municipal District of Foothills, Alberta, adjacent to the Town of High River's northwestern municipal boundary. The Project will utilize a single-axis tracker (SAT) system with a total capacity of 18.5 megawatts (MW_{AC}).

The assessment considers the glare impact of the Project on dwellings and transportation routes within 800 metres of the site. The evaluated roads include Highway 2A, Highway 543, and two local roads. GCR conducted a search for registered and unregistered aerodromes within 4,000m of the Project using aerial imagery and publicly available data. The High River (Hospital) Heliport was the only registered aerodrome found located approximately 3.1km southeast of the Project. No unregistered aerodromes were identified.

Glint and glare refer to light reflected off smooth surfaces, either momentarily and intense (glint) or less intense for a more sustained period (glare). Solar PV technology is specifically designed to absorb as much sunlight as possible and modules are generally coated in an anti-reflective coating. Solar PV sites have been developed alongside major transport routes and airports around the world, including adjacent to road infrastructure. This suggests that solar PV technology, such as that proposed for the Project, can safely coexist with roads and aerodromes.

It is considered that a developer, in this case High River Solar LP, should provide safety assurances regarding the full potential impact of the installation on receptors, routes, and roads in the form of a glare assessment.

2 Background Information

The potential for glint and glare from solar PV modules on the surrounding roads, residential properties and nearby aerodromes should be fully considered when planning a solar project.

Glint and glare are both caused by the reflection of light from a surface, in this case sunlight from a solar module. Glare is caused by a continuous but less intense reflection of a bright light, whereas glint is caused by a strong, momentary reflection of sunlight. Reflections from smooth surfaces produce more direct "specular" reflections, and rougher surfaces disperse the light in multiple directions, creating "diffuse" reflections. Figure 2-1 shows these two types of reflections from a solar PV module.

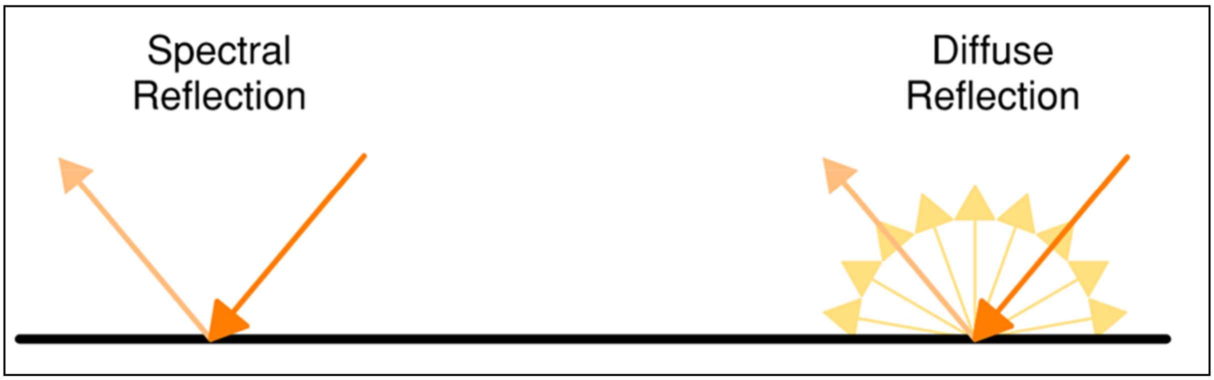

Figure 2-1 – Types of Light Reflection from Solar Modules

Calculation of potential glare requires the azimuth and elevation angle of the sun, and the consequent angles of incidence and reflection at the array, at all times throughout the year.

The angle of incidence is the angle at which the sun strikes the module (measured from normal/perpendicular to the surface). The angle of reflection is equal and opposite the angle of incidence. Light transmission through the glass and absorption by the PV module is greatest when the light is normal to the glass surface, while more light is reflected at shallower angles. As shown in Figure 2-2 a low incidence angle in a fixed tilt system is associated with the sun being high in the sky such that the sun's rays are shining at close to a right angle with the module surface. The highest incidence angles will occur in the early morning and late evening when the sun is low in the sky.

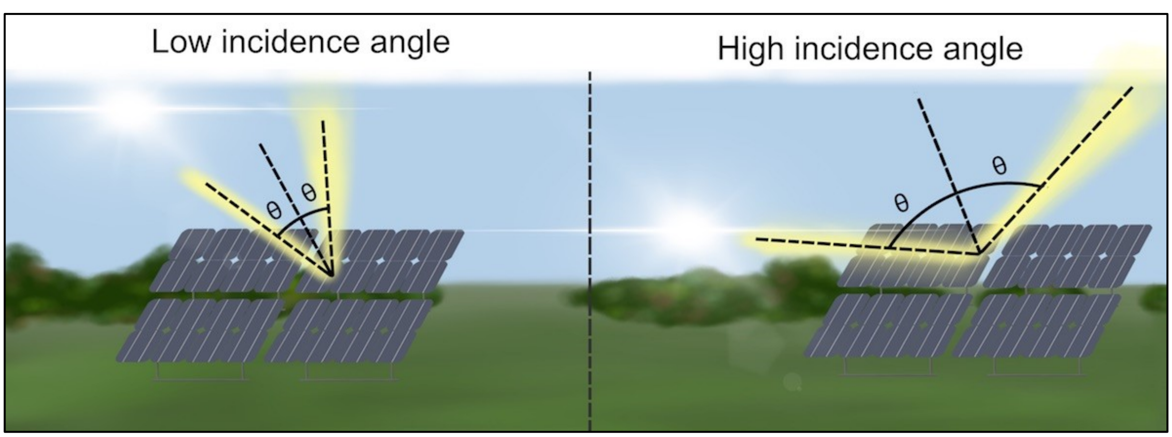

Figure 2-2 – Angles of Incidence relative to the Sun's Position

Throughout the day the sun will track across the sky; therefore, the angle at which the light is incident on the module will vary. Figure 2-3 shows the two angles (azimuth and elevation/zenith) required to define the orientation of the sun with respect to the solar module.

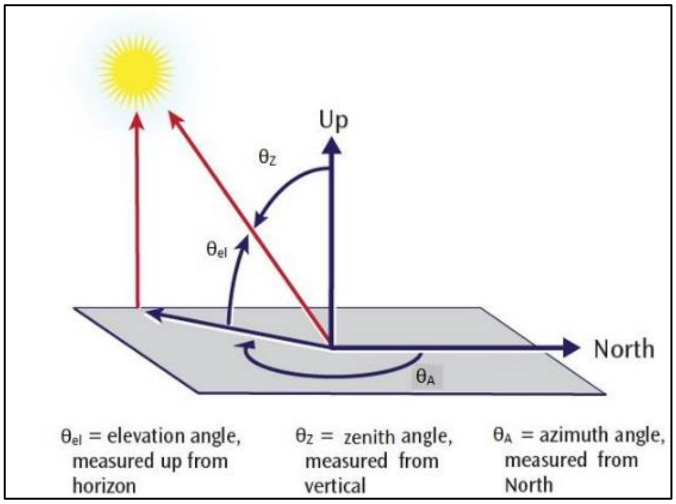

Figure 2-3 – Sun's Position relative to Solar Module

There are many factors that affect the glare level. These include but are not limited to:

- The type of solar module
- The module's tilt angle and orientation
- Size of solar development
- Shape of solar development
- Location of solar development
- Distance between solar development and observer
- Angle to observer
- Relative height of observer

Single-axis tracking systems will often include a backtracking function. At low sun elevation angles, high array tilt angles will result in shading from rows nearer the sun on those behind them. To mitigate consequent production losses, the trackers will gradually tilt away from the sun back toward horizontal.

The following section describes the proposed development and the associated infrastructure in detail.

3 Project Description

The proposed Project site is located in the Municipal District of Foothills, Alberta, adjacent to the northwestern municipal boundary of the Town of High River. The Project location is shown in Figure 3-1.

The Project covers approximately 129 acres of land with a total generating capacity of 18.5 MW_{AC}. The PV modules will be mounted on single-axis trackers secured to the ground with pile foundations.

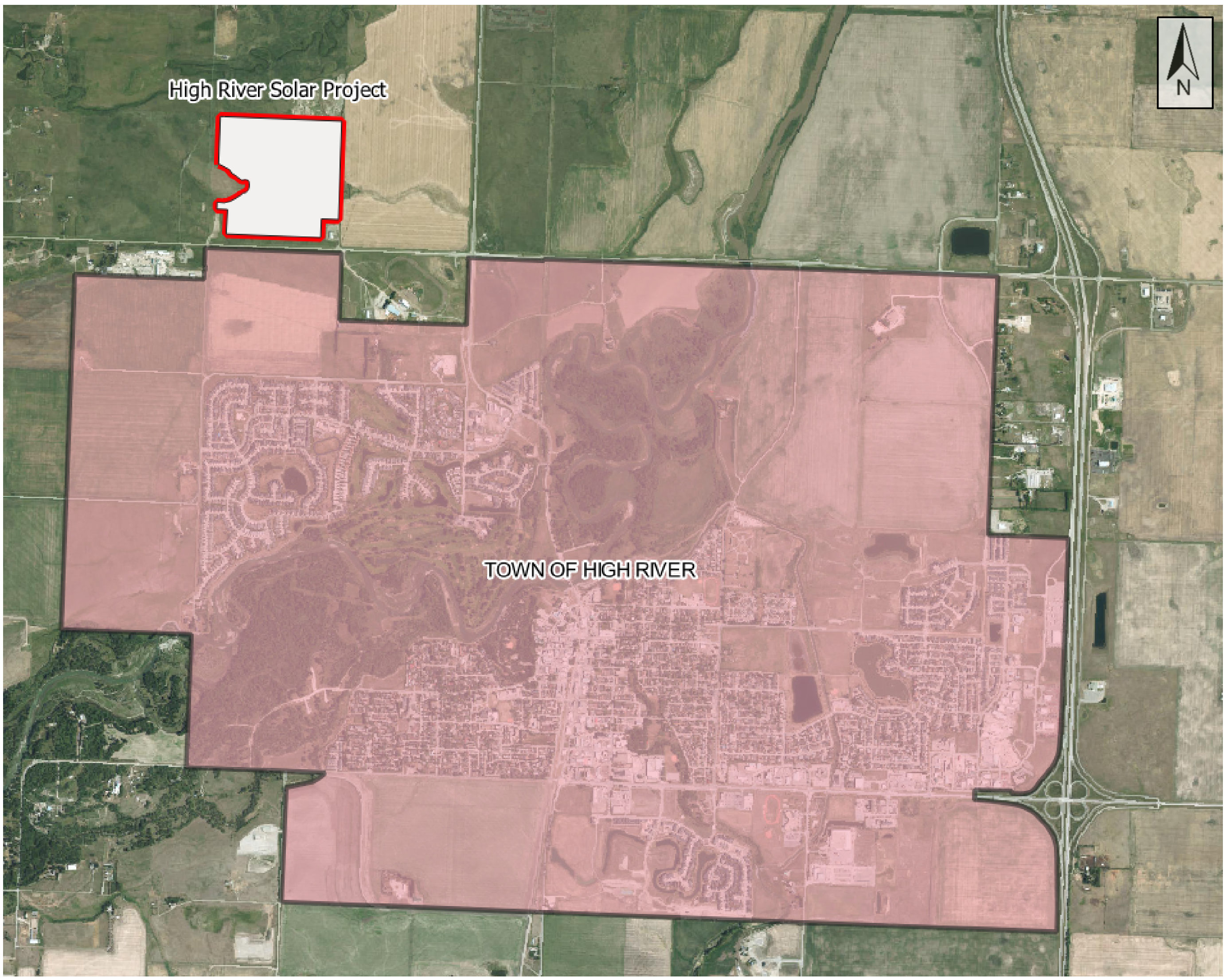

Figure 3-1 – High River Solar Project Location

4 Legislation and Guidelines

There is currently no adopted legislation for assessing the impacts of glare for solar energy development in Alberta or Canada, and standardized guidance only specify what receptors to include in an assessment without specifying acceptable thresholds. Transport Canada publication TP1247E indicates that glare from solar arrays should be evaluated when proposed near aerodromes, but does not provide additional specifications.[4]

The Alberta Utilities Commission's (AUC's) Rule 007 states that solar glare assessment reports must include receptors within 800m from the boundary of the project and aerodromes within 4,000m from the boundary of the project.[5] It continues to state the following requirements:

- Describe the time, location, duration, and intensity of solar glare predicted to be caused by the project.
- Describe the software or tools used in the assessment, the assumptions, and the input parameters (equipment-specific and environmental) utilized.
- Describe the qualification of the individual(s) performing the assessment.
- Identify the potential solar glare at critical points along highways, major roadways, and railways.
- Identify the potential solar glare at any aerodrome within 4,000 metres from the boundary of the project, including the potential effect on runways, flight paths and air traffic control towers.
- Include a map (or maps) identifying the solar glare receptors, critical points along highways, major roadways and railways, and aerodromes that were assessed.
- Include a table that provides the expected intensity of the solar glare (e.g., green, yellow, or red) and the expected duration of solar glare at each identified receptor, critical points along highways, major roadways and railways, and any registered and known unregistered aerodromes that were assessed.

Alberta Transportation developed requirements for the assessment of solar PV projects being proposed near provincial highways. The guideline is based on AUC Rule 007 with additional specifications for the assessment of roads. This includes vehicle heights, consideration of potential shading and sun-masking, and mitigation for glare predicted within ±15° of a driver's heading.[6]

This report will abide by: requirements in AUC Rule 007; suggestions made in Zehndorfer Engineering's Solar Glare and Glint Project Report from September 2019;[7] Alberta Transportation guidelines; and other relevant literature.

As observed in the Zehndorfer document, solar glare assessments in Canada typically utilize Sandia National Laboratories' Solar Glare Hazard Analysis Tool (SGHAT) through ForgeSolar's software called GlareGauge. The Zehndorfer report notes that: "*the typical Solar Glare Assessment in Canada consists of more than just the plain SGHAT report. It describes the geometric situation, highlights glare duration and suggests glare-reducing measures.*"[8] This approach has been adopted for this assessment.

[4] *Aviation – Land Use in the Vicinity of Aerodromes – TP1247E* (Transport Canada, 2013/14).

[5] AUC Rule 007: *Applications for Power Plants, Substations, Transmission Lines, Industrial System Designations, Hydro Developments and Gas Utility Pipelines* (September 2021), subsection 4.3.2 SP14.

[6] *Application Requirements for Solar Generation Development near Provincial Highways* (Alberta Transportation, June 2021).

[7] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).

[8] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019), PDF page 8.

The Zehndorfer report also comments that: "*with respect to dwellings, geometrical considerations can be useful. The inclination angle towards a window makes a difference, because light rays perpendicular towards the glass will penetrate the window, while window recesses will shade flat-angled rays of light.*"[9]

In addition to Zehndorfer's report, the US Federal Aviation Administration (FAA) have provided the Technical Guidance for Evaluating Selected Solar Technologies on Airports.[10] This document, last updated in April 2018, states that potential for glare might vary depending on site specifics such as existing land uses, location, and size of the project.

A geometric analysis may be required to assess any reflectivity issues coming from the solar modules. FAA guidelines have also been informed by the 2015 study, Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach, by Rogers, et al. This study concludes that glare of sufficient size and intensity in an airplane pilot's view, within ±25° of heading, may have an adverse impact on the pilot's ability to read their instruments or land their plane. The study also indicates that glare beyond ±50° of heading is not likely to impair a pilot.[11]

4.1 Geometric Analysis – Use of the Solar Glare Hazard Analysis Tool

The SGHAT is a validated tool specifically designed to estimate potential glare according to a Solar Glare Hazard Analysis Plot at a certain module height, tilt, type, and observer location. ForgeSolar's GlareGauge/SGHAT software allows for the analysis of potential glare on flight paths, routes, and stationary observation points. It is widely accepted as the most comprehensive tool to assess potential glare impacts on receptors near solar power projects. The Zehndorfer report reviewed several glare software packages that may be used to assess solar PV glare, including ForgeSolar's GlareGauge/SGHAT. The report does not make a specific recommendation, but the findings suggest that the SGHAT is the most accessible tool of those evaluated, and the most robust with respect to the output information.[12]

[9] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019), PDF page 6.
[10] *Technical Guidance for Evaluating Selected Solar Technologies on Airports* (FAA, April 2018), pg. 40.
[11] *Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach* (Rogers, J. A., et al., July 2015).
[12] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).

5 Assessment Methodology

The SGHAT is configured to enable an analysis on flight paths using a 2-mile approach to a runway when landing. No airports were reported within 4,000m of the Project, so no airplane flight paths were included in this assessment. An airport is located approximately seven kilometres from the Project, so it was not assessed due to the distance. A heliport is located within 4,000m of the Project and was assessed, using straight line flight paths and information about approach path directions from the Canada Flight Supplement.

The decision for Proceeding 25296 set out the AUC's understanding of the viewing angles relevant to pilots: *"The Commission understands the FAA study to conclude that yellow-grade glare between 25 and 50 degrees has the potential to adversely affect pilots".*[13] This suggests that flight paths approaching a runway should model a pilot's perspective looking straight out the cockpit windshield with a peripheral range of ±50° and downward up to 30° below the approach vector to provide context on potential glare during final descent. Further analysis of a narrower ±25° field of view (FOV) encompasses the region where a pilot's vision is more susceptible to glare impacts. Glare occurring outside of this range is less likely or not expected to adversely impact a pilot.[14]

For ground-based routes, the Zehndorfer report recommends modelling the FOV within ±15° from the vehicle operator's heading.[15] This covers the region where a person's vision will be most focussed, which is the critical area of concern. A more conservative ±25° FOV can also be modelled to identify routes that may be peripherally impacted by glare. This wider FOV is based on the information presented in the Rogers FAA report for airplane pilots, adapted to suit vehicle operators using ground-based routes. In line with Alberta Transportation guidelines,[16] passenger, truck, and commercial vehicle heights are considered in the analysis.

In line with AUC Rule 007's guidelines for choosing receptors to include in a solar glare analysis, the assessment evaluated:

- Six dwellings;
- Two highways and two local roads; and
- High River (Hospital) Heliport.

Note, if the modules are not visible to the individual receptor, then no glare can be observed at that receptor.

5.1 Assessment Input Parameters

The solar arrays, observation points, and transportation routes were plotted using an interactive Google map, and site-specific data was entered into the software prior to modelling. The following sections provide details of the parameters specified for the analysis calculations in the GlareGauge software.

[13] Decision 25296-D01-2021 (*AUC, February 11, 2021), para. 53.*
[14] *Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach (Rogers, J.A., et al., July 2015).*
[15] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).
[16] *Application Requirements for Solar Generation Development near Provincial Highways (*Alberta Transportation, June 2021).

5.1.1 PV Array

The general PV array areas were plotted on the interactive Google map as shown in Figure 5-1. The Project was split into two sub-arrays to avoid conflict between complex array geometry and software calculations, while also providing additional detail in areas with greater topographical variation. The modelled sub-arrays include more land than the proposed PV array coverage, which results in a more conservative analysis.

Figure 5-1 – General PV Array Areas Plotted in GlareGauge Software

The Project details in Table 5-1 were specified in the model.

Table 5-1 – PV Array Specified Parameters

Required Inputs	Specified Parameters	Description
Axis Tracking	Single	Modules are mounted on single-axis trackers
Tilt of Tracking Axis	0°	Elevation angle of tracking axis with 0° being faced up (flat) parallel to the ground
Orientation	180° (south)	Azimuthal position measured from true north
Maximum Tracking Angle	52°	Rotation limit of the arrays in each direction
Resting Angle, Backtracking	0°, 1°, 2°, 3°, 4°, 5°, 10°	Minimum rotation angle of modules outside of the normal tracking range (during backtracking)
Ground Coverage Ratio	0.30	Ratio between the PV module area and total ground area
Module Surface Material	Smooth glass with anti-reflective coating	Surface material of modules
Module Height Above Ground	1.45m	Array centroid height

Solar PV modules are designed to maximize light absorption and conversion to electricity. Specifying different types of glass and coatings used on the modules can affect a system's energy production and glare potential. Smooth glass with anti-reflective coatings (typical of solar PV modules) will generally reflect less light, i.e., create less glare, than uncoated or conventional glass.

The backtracking operation of the single-axis tracking system has been considered in this analysis. The GlareGauge backtracking algorithms account for the geometry between arrays and the sun, as well as the slope of the plotted sub-arrays. In the morning and evening when the sun is outside of the normal tracking range, the rotation angle in the model will adjust to shallower angles to avoid inter-row shading. The user-specified resting angle sets the lower limit for backtracking rotation.

The elevation variation across the site is minor, ranging from approximately 1,039m to 1,045m above mean sea level (AMSL). Further review of Google elevation data shows that the land is slightly higher toward the west end of the Project.

5.1.2 Route Paths

Four route paths were evaluated for glare impacts from the Project in this assessment, including two highways and two local roads. The routes include sections of Highway 2A, Highway 543, Longview Trail, and 64 Street E. Figure 5-2 shows the routes in relation to the Project.

All road routes were modelled as two-way routes to represent vehicles travelling in both possible directions. Two horizontal viewing angles were evaluated for motorists: ±15° and ±25° (30° and 50° total FOV). The ±15° range encompasses the region where a person's vision will be most focussed, which is the critical area of concern.[17,18] The ±25° range is a more conservative view representing a person's extended visual range that may be impacted by glare. The road routes were set at an elevation of 1.08m to represent the height of a typical passenger vehicle, 1.8m to represent the height of a typical truck or bus, and 2.3m to represent the height of a commercial truck in accordance with Alberta Transportation guidelines. Commercial vehicles are typically more susceptible to glare than passenger vehicles due to their increased height.

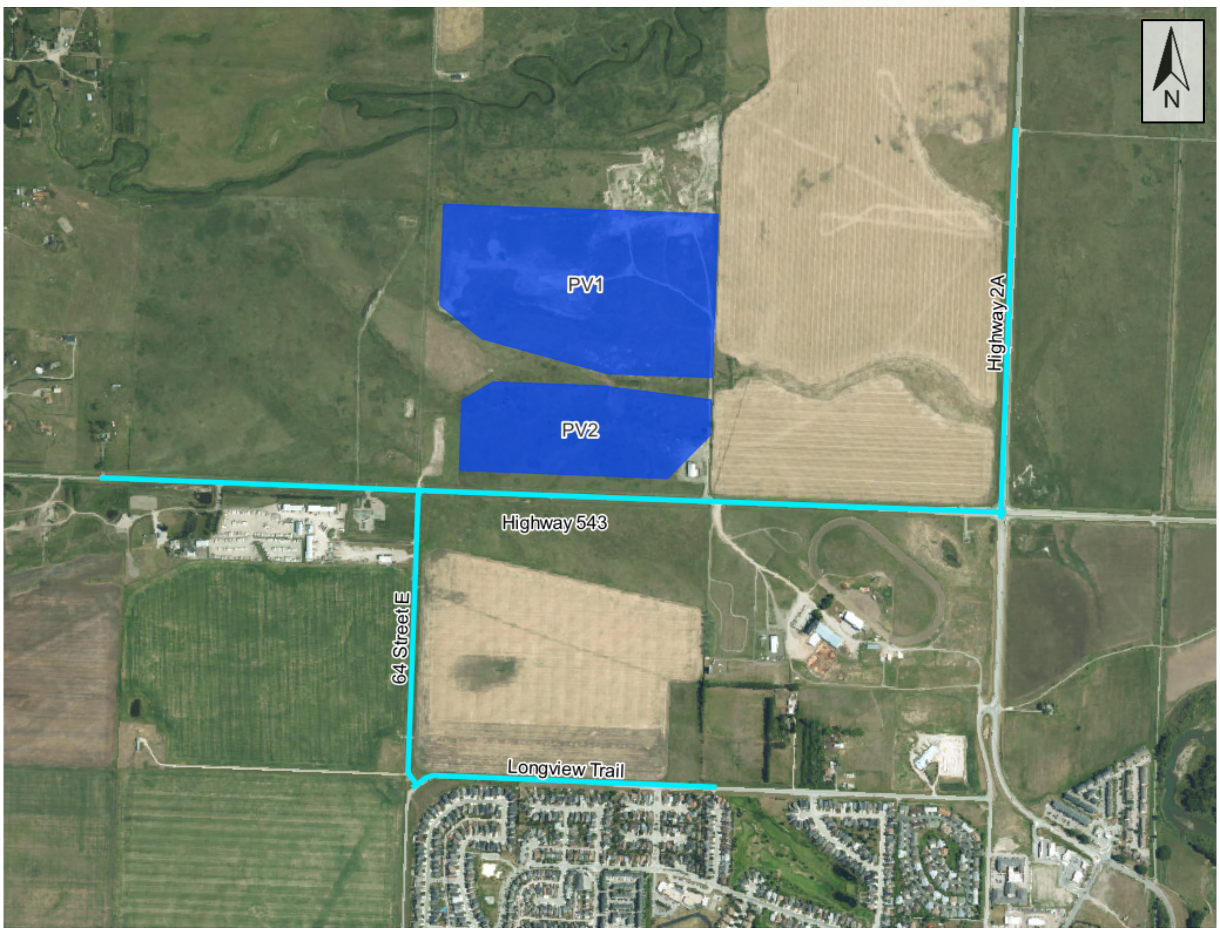

Figure 5-2 – Roads near the Project

[17] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).
[18] *Application Requirements for Solar Generation Development near Provincial Highways (*Alberta Transportation, June 2021).

5.1.3 Dwellings

Six dwellings were assessed within approximately 800m of the Project. High River Solar LP conducted a site visit on March 24, 2022, noting the number of storeys at the nearby residences. The dwellings included a mix of two-storey buildings and single-storey buildings with raised ground floors. All of the residences were modelled at 4.5m above ground to represent two-storey dwellings for a conservative approach. The model assumes the receptor has an unobstructed view of the arrays, i.e., the view is not affected by any part of the building being evaluated. Figure 5-3 shows the dwellings in relation to the Project.[19]

Figure 5-3 – Dwellings near the Project

[19] Receptors are not numbered consecutively and follow the numbering scheme used in *High River Solar Project – Noise Impact Assessment* (Green Cat Renewables, November 2022). Receptors are numbered to R24, but only 6 receptors were evaluated in this assessment.

5.1.4 High River (Hospital) Heliport

The High River (Hospital) Heliport is approximately 3.1km southeast of the Project. Figure 5-4 shows the location of the heliport relative to the Project.

Figure 5-4 – Location of the High River (Hospital) Heliport

There is currently no clear, standardized guidance for assessing the impacts of glare on heliports. However, the FAA guideline AC 150/5390-2C discusses heliports (general, transport, and hospital) and states that a helicopter's final approach commences at a distance of 4,000 feet (1.2km) from the heliport, and a height of 500 feet (152m) above the elevation of the heliport.[20] Helicopters are theoretically able to carry out their final approach from any direction,

[20] *2012, FAA — AC 150/5390-2C*

rather than following a specific approach flight path. However, the Canada Flight Supplement[21] (CFS) provides recommendations and restrictions on paths that pilots can take when departing/approaching a heliport. The image for the High River (Hospital) Heliport from the CFS is shown in Figure 5-5.

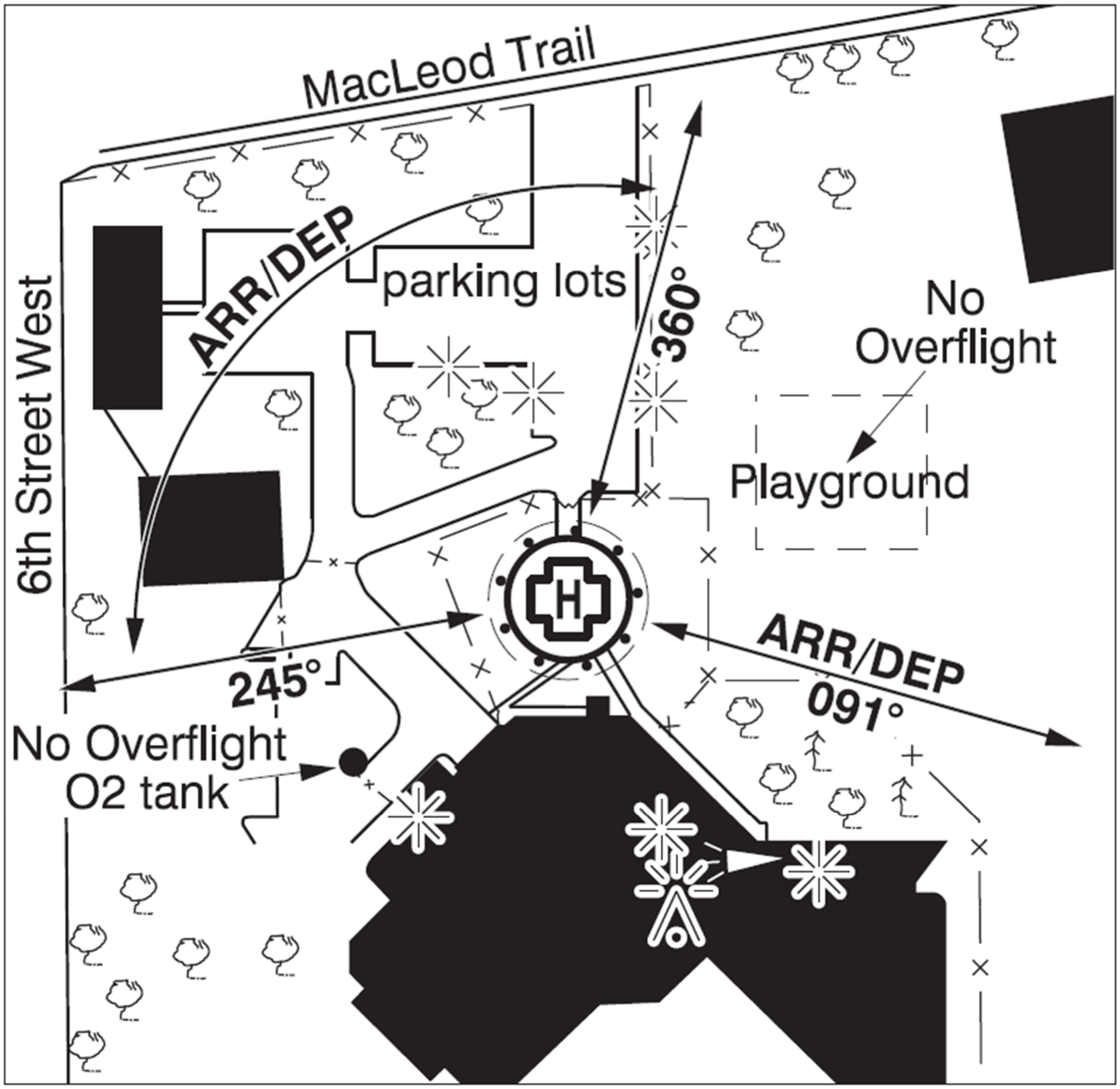

Figure 5-5 – Canada Flight Supplement Approaches/Departures for the High River (Hospital) Heliport[22]

GCR assessed specific flight paths at 106° and between 260° and 15° (360° + 15°), which are respectively shown as 091°, 245°, and 360° in Figure 5-5. Additional flight paths at 285°, 315°, and 345° were assessed to better represent the range of approaches possible from the northwest. This analysis has set the horizontal viewing angle to ±50° from

[21] *Canada Flight Supplement effective 24 March 2022 to 19 May 2022* (NAV CANADA, 2022).
[22] A 15° magnetic adjustment has been applied, so the angles shown will be referred to as (from left to right) 260°, 15°, and 106°.

center, encompassing a conservative region where glare may affect a pilot, and a ±25° FOV for the region where yellow-grade glare is expected to adversely impact pilots. Glare occurring outside of this range is not expected to adversely impact the pilot. Figure 5-6 shows the helicopter paths that were assessed.

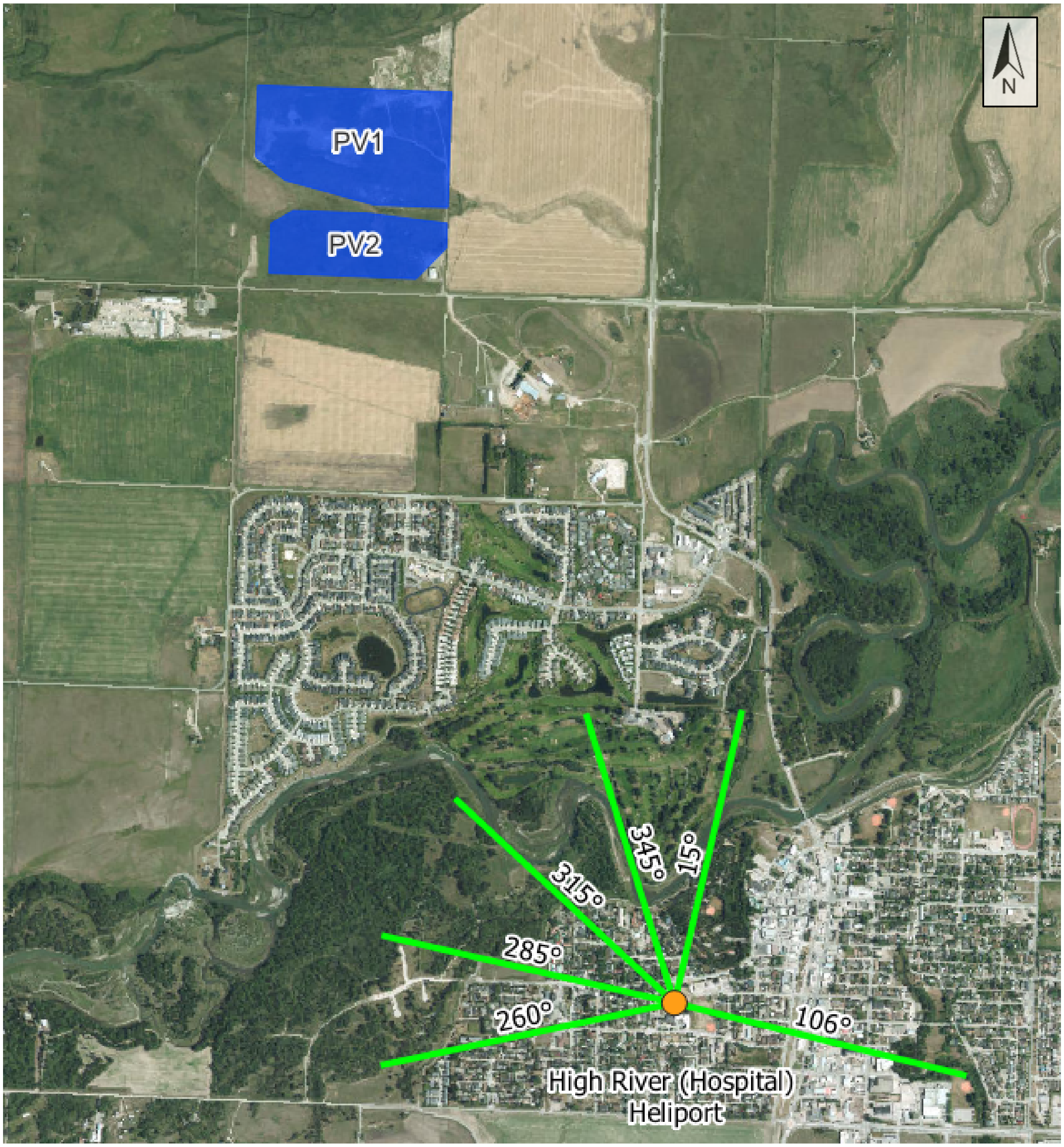

Figure 5-6 – Helicopter Paths assessed for the High River (Hospital) Heliport

GCR understands that helicopters may fly in many different directions (straight, "J"-turn, etc.), however, there are limitations in the GlareGauge software that require flight paths to be assessed as straight-line approaches to a point, following a specified descent angle. As such, it was assumed that the helicopter will only fly in a straight line approaching the heliport.

5.1.5 Other Assumptions

The following assumptions have been made in setting the parameters for this analysis:

- Times associated with glare are denoted in Standard time. For Daylight Savings, add one hour.
- Glare analyses do not account for physical obstructions between reflectors and receptors that may mitigate impacts. This includes buildings, tree cover and geographic obstructions.
- The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual values may differ.
- Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.
- Glare analysis does not account for change in weather patterns. It is assessed as clear sunny skies throughout the year.
- To increase accuracy of modelling results, parts of the array may be divided into sub-sections if the footprint covers a large surface area with drastic elevation changes, or to avoid concave outlines.
- Default parameters, as alluded to in the following section, highlight ocular metrics used in this assessment as has been acceptable according to the Sandia National Laboratories methodology on assessing potential glint and glare hazards.[23] These are shown below in Table 5-2.

Table 5-2 – Default Parameters

GlareGauge Parameters	
Direct Normal Irradiance, DNI (amount of solar radiation received in a collimated beam on a surface normal to the sun during a 60-minute period)	Varies and peaks at 1000 W/m^2
Ocular Transmission Coefficient (absorption of radiation within the eye before it reaches the retina)	0.5
Pupil Diameter (Typical daylight adjusted length)	0.002m
Eye Focal Length (distance where rays intersect in the eye)	0.017m
Sun Subtended Angle	9.3 mrad

[23] *Methodology to Assess Potential Glint and Glare Hazards from Concentrating Solar Power Plants: Analytical Models and Experimental Validation* (Ho, C.K., C.M. Ghanbari and R.B. Diver, Journal of Solar Energy Engineering-Transactions of the ASME, 133 (3), 2011).

5.2 Glare Analysis Procedure

GCR calculated the potential glare for observation points and route receptors using the SGHAT. Although effects from glare are subjective, depending on variables such as a person's ocular parameters and size/distance from the glare source, the SGHAT has a generalized approach to specify the hazard that glare may produce. GCR's commentary on the levels of glare found and related sources of mitigation, if required, are intended to help decision makers evaluate potential impacts.

The SGHAT User's Manual v3.0 states that: *"If glare is found, the tool calculates the retinal irradiance and subtended source angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a simple, easy-to-interpret plot that specifies when glare will occur throughout the year, with color codes indicating the potential ocular hazard."*[24]

The colour codes are based on a red, yellow, and green structure to categorize the level of risk to a person's eyes. Glare classification is dependent on the glare intensity and the apparent size of the glare area as viewed from the eye. The severity of glare is proportional to the effects of an after-image, which can be described as a lingering image of glare in the field-of-view, or a flash blindness when observed prior to a typical blink response time. The descriptions for each category are as follows:

- Green: Glare is present but there is a low potential for temporary after-image;
- Yellow: Glare is present with the potential for temporary after-image; and
- Red: Glare is present with the potential for permanent eye damage.

The level of glare is derived using the graph below that plots the level of irradiance against the angle that is occupied by the glare in the field-of-view.

ForgeSolar have developed a plot to categorize glare based on its intensity at the eye and its size in the observer's field-of-view. The plot is divided into the red, yellow, and green regions described above. The hazard associated with directly viewing the sun unfiltered is also plotted for comparison. Figure 5-7 shows an example of the hazard plot.

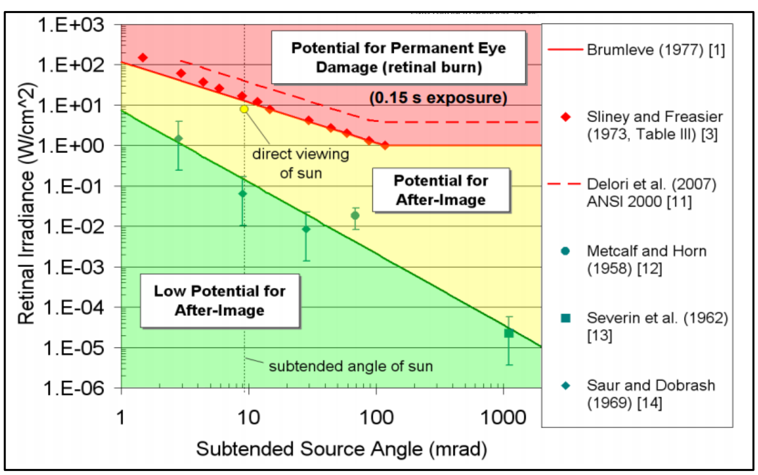

Figure 5-7 – Hazard Plot depicting the Retinal Effects of Light

[24] *Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v 3.0* (Ho and Sims, Sandia National Laboratories, 2016).

Ho et al. developed a model to estimate potential impacts to eyesight with regards to retinal irradiance (amount of light entering the eye and reaching the retina) and subtended source angle (the size of the glare divided by the distance from the emitting source). Significant damage, including retinal burn, may occur at high retinal irradiances and large subtended angles. This is highlighted in the red region. The yellow section denotes the potential for a temporary after-image. The size and impact of the after-image is dependent upon the subtended source angle.[25] At a low retinal irradiance and small subtended angle, the hazard will be in the green section where there is very low potential for after-image.

5.2.1 Limitations

The SGHAT will convert the footprint of a concave polygon to a convex polygon.[26] For example, an array that is in the shape of a 'C' has a concave section and GlareGauge will modify the 'C' shape into a semi-circle. By closing the 'C' shape, the size of the PV array is increased thus potentially over-estimating the size of the array, and consequently over-predicting the glare effects. This change in geometry is required by the glare-check algorithm during analysis. PV arrays with significant concavities should be modelled as multiple arrays to avoid over-estimating the size of the PV array and the resultant glare. The limitations of the software have been carefully considered to ensure the PV array is not concave in order to represent the glare impacts as accurately as possible.

An unavoidable limitation of the SGHAT is that "*random number computations are utilized by various steps of the annual hazard analysis algorithm. Predicted minutes of glare can vary between runs as a result. This limitation primarily affects analyses of Observation Point receptors, including [air traffic control towers].*"[27]

Wind probabilities are also not considered by the SGHAT, so special operations that change the tilt of a SAT system are not modelled by the software. This includes functions like "stow mode" where arrays will be tilted closer to horizontal to reduce wind loading during high wind events. Special SAT system operations will utilize different tilt angles than standard operations, causing glare results to deviate from the values predicted by the SGHAT; however, non-standard operations are expected to occur so infrequently that it is unreasonable to include them in a general glare assessment.

[25] *Evaluation of glare at the Ivanpah Solar Electric Generating System* (C.K. Ho et al., Elsevier Ltd., 2015).
[26] *ForgeSolar "Help" page*. Retrieved March 24, 2022.
[27] *ForgeSolar "Help" page*. Retrieved March 24, 2022.

6 Assessment of Impact

This section presents the findings of the glare assessment. The results are factual based on the model parameters used, which are considered to be conservative and as reasonable as possible. AUC Rule 007 provides guidelines for the receptors to be included in a solar glare assessment, but modelling parameters and glare threshold limits are not specified. Therefore, this analysis also considers the principles laid out in the Zehndorfer Engineering Report,[28] Alberta Transportation guidelines,[29] and other relevant literature.

The GlareGauge software considers the glare potential for a full one-year period in one-minute intervals to account for the variations between seasons, DNI, and sun angle.

The results showed that glare may be seen by the evaluated receptors if the resting angle is set between 0° to 2°, with the greatest potential impact from a 1° resting angle. Models with resting angles steeper than 2° did not predict any glare for the evaluated receptors. The following results come from the worst-case model using a 1° resting angle.

6.1 Route Path Results

The following tables present the glare results for the route paths assessed from the array centroid height. Results are shown for passenger, trucks, and commercial road vehicles at 1.08m, 1.8m, and 2.3m, respectively. Results in Table 6-1 used a ±15° FOV, which was modelled to capture potential glare within a vehicle operator's critical visual range. Results in Table 6-2 were evaluated with a ±25° horizontal FOV to highlight routes that may experience glare from an extended visual range. Equivalent levels of glare within ±15° will have a greater impact on the observer than glare outside that range.

Table 6-1 – Annual Route Path Glare Levels for Passenger, Truck/Bus, and Commercial Vehicles (±15° FOV, 1° Resting Angle)

Receptor	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
Highway 2A (Passenger)	0	0	0	0
Highway 2A (Truck/Bus)	0	0	0	0
Highway 2A (Commercial)	0	0	0	0
Highway 543 (Passenger)	0	321	0	7
Highway 543 (Truck/Bus)	0	355	0	9
Highway 543 (Commercial)	0	383	0	9
Longview Trail (Passenger)	0	0	0	0
Longview Trail (Truck/Bus)	0	0	0	0
Longview Trail (Commercial)	0	0	0	0

[28] *Solar Glare and Glint Project* (Zehndorfer Engineering, September 2019).
[29] *Application Requirements for Solar Generation Development near Provincial Highways* (Alberta Transportation, June 2021).

Receptor	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
64 Street E (Passenger)	0	0	0	0
64 Street E (Truck/Bus)	0	0	0	0
64 Street E (Commercial)	0	0	0	0

Table 6-2 – Annual Route Path Glare Levels for Passenger, Truck/Bus, and Commercial Vehicles (±25° FOV, 1° Resting Angle)

Receptor	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
Highway 2A (Passenger)	0	0	0	0
Highway 2A (Truck/Bus)	0	0	0	0
Highway 2A (Commercial)	0	0	0	0
Highway 543 (Passenger)	0	737	0	12
Highway 543 (Truck/Bus)	0	796	0	12
Highway 543 (Commercial)	0	842	0	13
Longview Trail (Passenger)	0	0	0	0
Longview Trail (Truck/Bus)	0	0	0	0
Longview Trail (Commercial)	0	0	0	0
64 Street E (Passenger)	0	0	0	0
64 Street E (Truck/Bus)	0	0	0	0
64 Street E (Commercial)	0	0	0	0

Drivers using Highway 2A, Longview Trail, and 64 Street E are not predicted to observe glare from the Project with any resting angle. Highway 543 is predicted to receive minimal annual durations of yellow glare when a 1° resting angle is specified. Drivers of commercial vehicles using Highway 543 are expected to be the most impacted by the Project.

Considering the more critical ±15° FOV, drivers of commercial vehicles travelling along Highway 543 are expected to see yellow glare for a maximum of 383 minutes/year. The glare is predicted in the shoulder seasons of mid March to May and mid August to October, occurring in the morning and in the evening between 05:35 and 06:45 MST (around sunrise) and between 18:35 and 19:40 MST (around sunset) for up to 9 minutes per day.[30] When travelling eastbound in the morning or westbound in the evening, the glare will originate from the same general direction as the sun. This

[30] These results apply to a portion of the route, not just a single point along the road. The results describe a time period during which a vehicle operator may see glare from the Project, but it is highly unlikely that an observer will be affected by the glare for the full duration. A vehicle operator will only see a fraction of the glare since they will be travelling past the affected area, not standing still while looking at the solar PV arrays.

is an example of sun-masking, where the glare impact is likely to be eclipsed by the direct effects of the sun when both can be seen simultaneously by the observer.

The following figures represent the predicted glare within the ±15° FOV of drivers travelling along Highway 543. Figure 6-1 shows the daily time periods during which glare is predicted, and Figure 6-2 shows the daily duration of predicted glare.

Figure 6-3 presents the hazard plot for glare expected to affect the ±15° FOV of commercial drivers on Highway 543. The hazard plot shows that the glare seen from the route path will have approximately 10 times the subtended angle of the sun, but it will be around 510 times dimmer than the sun. The glare is also more than two orders of magnitude below the threshold for glare that has the potential to cause permanent eye damage at the same subtended angle. Glare at this level may temporarily affect an operator's vision, but it is not expected to create a hazardous situation.

Alberta Transportation guidelines indicate that potential mitigation measures should be explored if glare is predicted within the ±15° FOV of drivers using provincial highways. This assessment shows that utilizing a minimum resting/backtracking angle of 3° or higher is expected to eliminate glare impacts for all evaluated receptors. Another mitigation measure includes the installation and design of visual screening (e.g., fencing, foliage/vegetation, berms, etc.) that will partially or completely obstruct an observer's view of the glare-producing parts of the Project. A sufficiently tall and opaque barrier installed between the affected receptors and source arrays is expected to obstruct the view of the glare-producing parts of the Project.

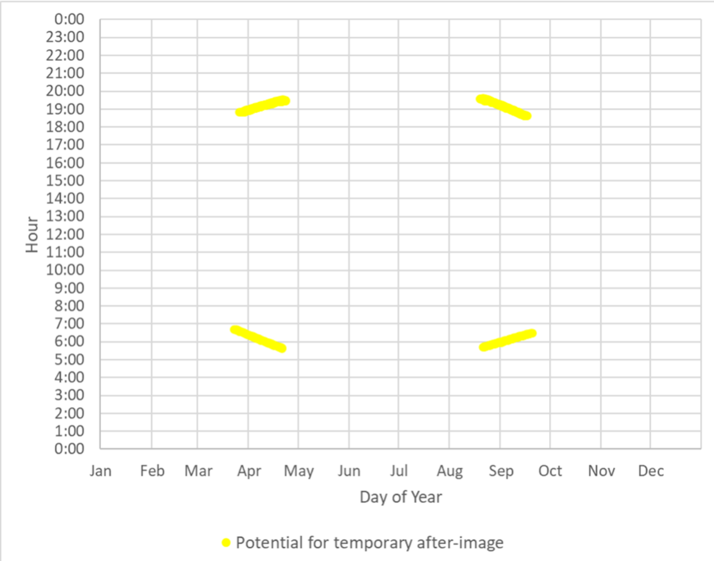

Figure 6-1 – Annual Predicted Glare Occurrence for Highway 543 (±15° FOV, 1° Resting Angle)

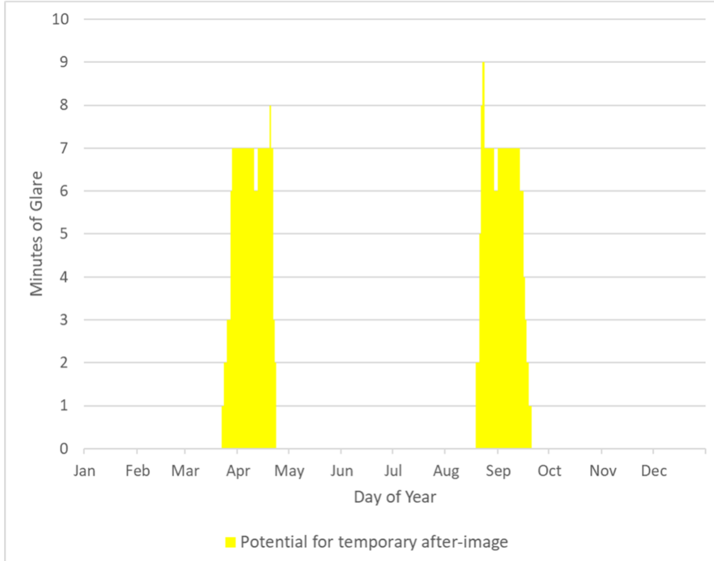

Figure 6-2 – Daily Duration of Glare for Highway 543 (±15° FOV, 1° Resting Angle)

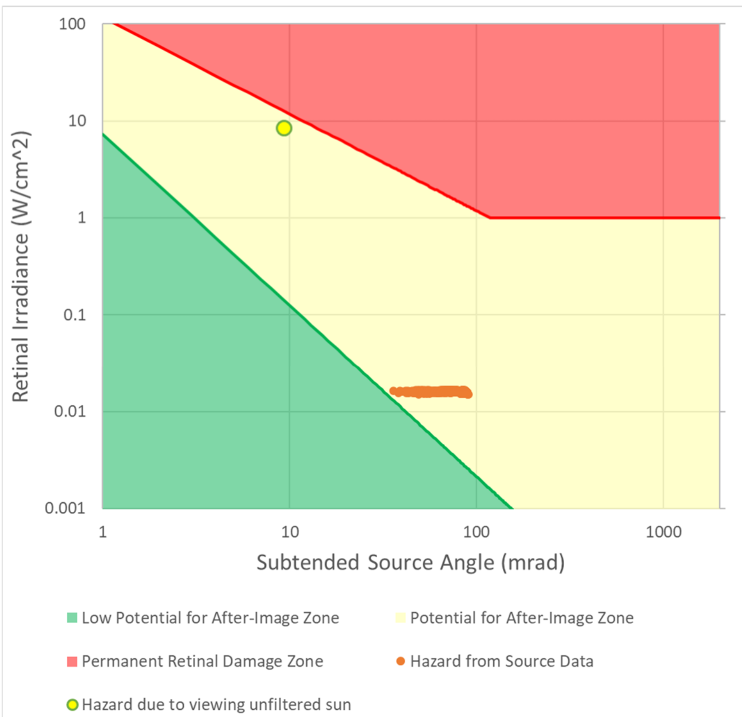

Figure 6-3 – Hazard Plot for Highway 543 (±15° FOV, 1° Resting Angle)

6.2 Dwelling Results

Six observation points were plotted to represent dwellings near the Project. All residences were assessed at 4.5m above ground to represent two-storey buildings for a conservative assessment. Table 6-3 provides the glare results for the dwellings assessed at the array centroid height.

Table 6-3 – Annual Glare Levels for Dwellings near the Project (1° Resting Angle)

Receptor	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
R3 (two-storey)	0	0	0	0
R4 (two-storey)	0	0	0	0
R5 (two-storey)	0	0	0	0
R6 (two-storey)	0	0	0	0
R15 (two-storey)	0	250	0	3
R24 (two-storey)	0	6	0	1

Dwelling R15 and dwelling R24 are the only receptors where glare is expected. Dwelling R15, which is located southeast of the Project just beyond the 800m boundary and therefore included in the analysis, is predicted to observe the most yellow glare from the Project when using a 1° resting angle. During the site visit by High River Solar LP, trees, shrubs, and buildings were observed between the dwelling and the proposed array locations, however, as noted above, the analysis assumes there are no obstructions between the receptor and the arrays. If unscreened, observers at R15 are expected to see yellow glare for a maximum of 250 minutes/year. The glare is predicted from April to mid September between 04:30 and 06:20 MST (around sunrise) for up to three minutes/day. At this time of day, the glare will originate from the same general direction as the sun. This is an example of sun-masking, where the glare impact is likely to be eclipsed by the direct effects of the sun when both can be seen simultaneously by the observer. No glare is predicted to occur at R15 from October to March.

The following figures represent the glare predicted for R15 with a resting angle of 1°. Figure 6-4 shows the daily time periods during which glare is predicted, and Figure 6-5 shows the daily duration of predicted glare.

Figure 6-6 presents the glare hazard plot for glare predicted to affect R15. The hazard plot shows that the glare seen from R15 will have approximately 6.5 times the subtended angle as the sun, but it will be around 510 times dimmer than the sun. The glare is also more than two orders of magnitude below the threshold for glare that has the potential to cause permanent eye damage at the same subtended angle. Glare at this level is not expected to create a hazardous situation or have a significant adverse impact on a resident's use of their home. Furthermore, information gathered from satellite imagery and the site visit conducted by High River Solar LP indicates that obstructions such as trees, shrubs, and buildings exist between the dwelling and the array, further reducing the potential for glare impacts of the Project.

If glare is determined to be an issue during the Project's operation, mitigation measures may be designed to reduce or eliminate its impact on an observer. Utilizing a minimum resting/backtracking angle of 3° or higher is expected to eliminate glare impacts for all evaluated receptors. Another mitigation measure includes the installation of visual screening (e.g., fencing, foliage/vegetation, berms, etc.) that will partially or completely obstruct an observer's view of the glare-producing parts of the Project.

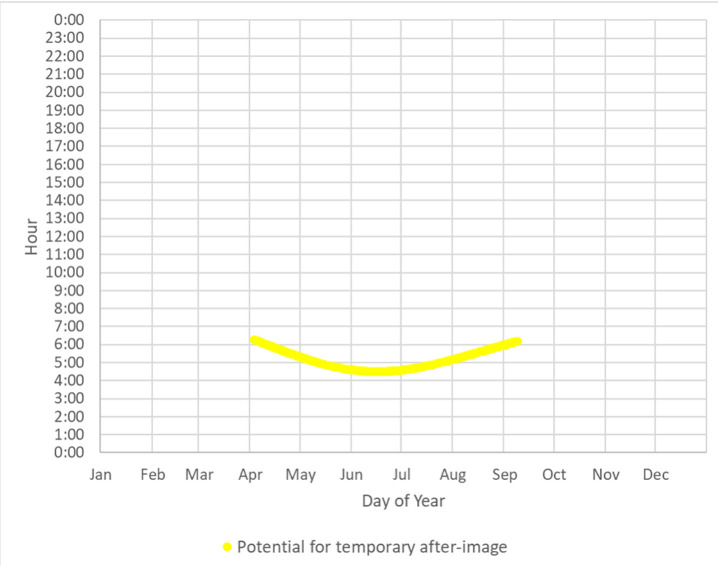

Figure 6-4 – Annual Predicted Glare Occurrence for R15 (1° Resting Angle)

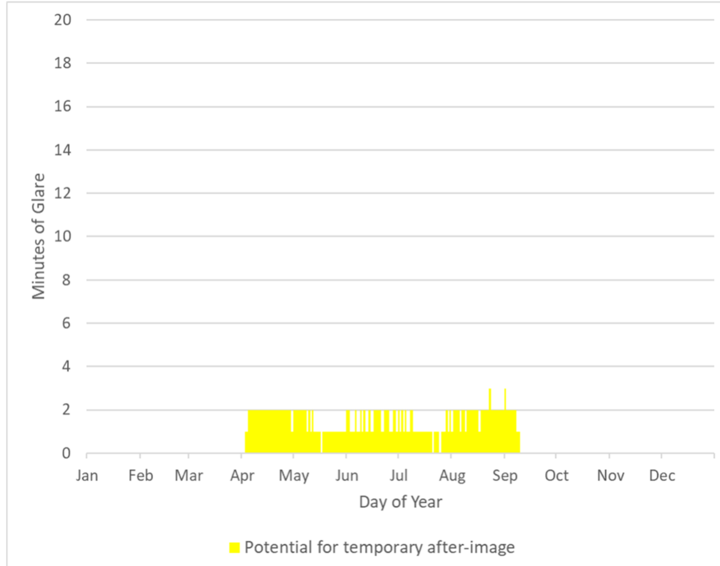

Figure 6-5 – Daily Duration of Glare for R15 (1° Resting Angle)

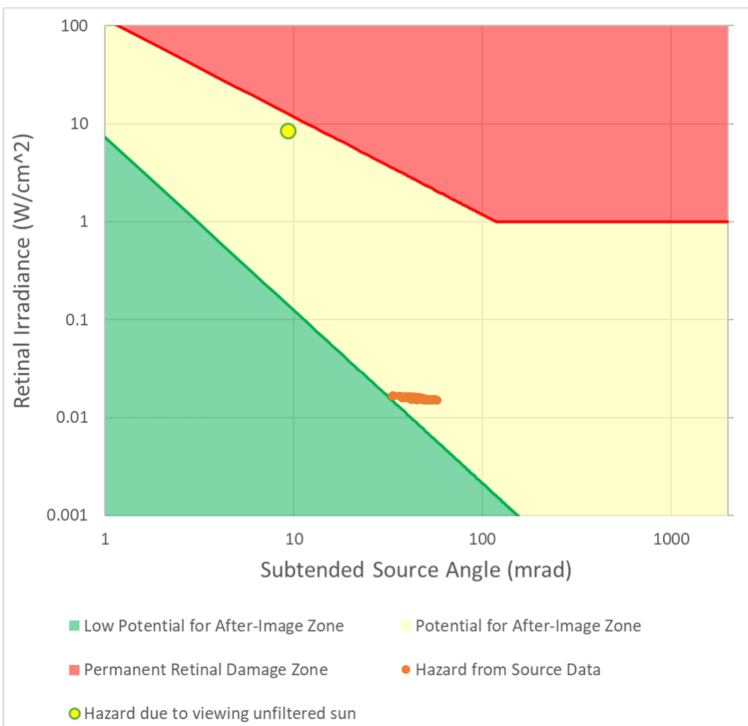

Figure 6-6 – Hazard Plot for R15 (1° Resting Angle)

6.3 High River (Hospital) Heliport Results

The potential glare impacts to the heliport were assessed by modelling possible approach paths shown in the CFS. GCR confirmed that no glare at any level is expected for flight paths with approach directions of 106° and between 260° and 15°.

Table 6-4 shows the results for the flight paths modelled with a ±25° FOV to assess glare within a pilot's critical visual range. Table 6-5 shows the results for the flight paths evaluated with a conservative ±50° FOV to highlight flight paths that may experience glare from an extended visual range. Equivalent levels of glare within ±25° will have a greater impact on the observer than glare outside that range.

Table 6-4 – Annual Glare Levels for Helicopters Landing at the High River (Hospital) Heliport (±25° FOV, 1° Resting Angle)

Helicopter Approach Direction	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
106°	0	0	0	0
260°	0	0	0	0
285°	0	0	0	0
315°	0	0	0	0
345°	0	0	0	0
15° (375°)	0	0	0	0

Table 6-5 – Annual Glare Levels for Helicopters Landing at the High River (Hospital) Heliport (±50° FOV, 1° Resting Angle)

Helicopter Approach Direction	Green Glare (min/year)	Yellow Glare (min/year)	Red Glare (min/year)	Max Daily Glare (min/day)
106°	0	0	0	0
260°	0	0	0	0
285°	0	0	0	0
315°	0	0	0	0
345°	0	0	0	0
15° (375°)	0	0	0	0

Considering the more critical ±25° FOV and conservative ±50° FOV, the results predict no glare at any level for the assessed helicopter paths at any resting angle.

7 Summary

Solar modules are specifically designed to absorb light rather than reflect it. Moreover, most modules are now manufactured with anti-reflective coatings that help further mitigate the intensity of reflections.

The assessment of the High River Solar Project was undertaken using GlareGauge software. The results are based on the assumptions and limitations set out in previous sections of this report. The SAT systems were modelled at their centroid heights with maximum tracking angles of 52°. The assessment included models using resting/minimum backtracking angles of 0°, 1°, 2°, 3°, 4°, 5°, and 10°.

The modelling results showed that glare may be seen by the evaluated receptors if the resting angle is set between 0° and 2°, with the greatest potential for impact at a 1° resting angle. Models with resting angles greater than 2° did not result in any glare at the evaluated receptors for the Project.

The ground-based route paths assessed for glare impacts included both directions of travel on Highway 2A, Highway 543, Longview Trail, and 64 Street E. The road routes were modelled at passenger, truck, and commercial vehicle heights. All ground-based routes were evaluated with a horizontal viewing angle of ±15° to capture potential glare within a vehicle operator's critical visual range, as well as ±25° to identify routes that may observe peripheral glare. Highway 2A, Longview Trail, and 65 Street E were not predicted to be affected by glare from the Project in any of the assessed cases.

In the worst-case (1° resting angle), Highway 543 was predicted to be the route most impacted by the Project. Drivers of commercial vehicles travelling along this road may observe short daily durations of yellow glare around sunrise and sunset in the shoulder seasons of mid March to May and mid August to October. It is highly unlikely that an observer will be affected by the full duration of glare in the predicted periods. Vehicle operators will only see a fraction of the predicted glare since they will be travelling past the affected area, not standing still while looking at the solar PV arrays. Since the glare occurs at sunrise and sunset when the sun aligns with the glare spot and observer, sun-masking is expected to reduce the impact of any glare that may be observed as the sunlight glances across the nearly horizontal arrays. The amount and level of glare predicted along the ground-based transportation route may temporarily affect an operator's vision, but it is not expected to create hazardous conditions, especially when compared with the simultaneous impact of the setting sun.

Six dwellings near the Project were assessed. All residences were assessed at 4.5m above ground to represent two-storey buildings for a conservative assessment. Only dwellings R15 and R24 were predicted to observe glare in the worst-case scenario using a 1° resting angle, with R15 predicted as the most impacted dwelling. The glare is expected at sunrise from April to mid September for short daily durations. Sun-masking is expected to reduce the impact of the glare as the sunlight glances across the nearly horizontal arrays at a shallow angle when the sun, glare spot, and observer align at sunset. Visual obstructions between the arrays and R15 are also expected to reduce the impact of glare on the dwelling. The amount and level of glare predicted at the residences is not expected to create hazardous conditions or have an adverse effect on a resident's use of their home, especially when compared with the simultaneous impact of the sun's position.

The High River (Hospital) Heliport is a registered aerodrome within 4,000m of the Project. The results show that no glare at any level is expected for flight paths approaching the heliport from the 106° approach and directions between 260° and 15° (360 + 15°), as stated in the Canada Flight Supplement.

If glare is determined to be an issue during the Project's operation, mitigation measures may be designed to reduce or eliminate the impact on an observer. Utilizing a minimum resting/backtracking angle of 3° or higher is expected to eliminate glare impacts for all evaluated receptors. Other mitigation measure includes the installation of visual screening (e.g., fencing, foliage/vegetation, berms, etc.) that will partially or completely obstruct an observer's view of the glare-producing parts of the Project.

8 Conclusion

In conclusion, the High River Solar Project is not likely to have the potential to create hazardous glare conditions for the roads, dwellings, or helicopter paths that were assessed. Glare predicted to affect the evaluated receptors can be eliminated by utilizing a minimum backtracking angle of 3° or higher.

If a resting angle lower than 3° is used in operation, the actual glare impacts that will be experienced in the field along transportation routes are anticipated to be only a fraction of the results presented in this report. The actual impact is expected to be less because vehicle operators will be travelling past the affected areas, not standing still while looking at the solar PV arrays. The impact of the glare on all receptors is expected to be reduced by sun-masking as the glare occurs at sunset or sunrise when the sun aligns with the glare spot and observer, and the sunlight glances across the nearly horizontal arrays at a shallow angle. In line with Alberta Transportation guidelines, potential mitigation options were considered where glare was predicted to be observed in the ±15° FOV of drivers using provincial highways. Predicted glare can be mitigated for all assessed receptors by using a minimum backtracking angle of 3° or by installing appropriately sized and designed barriers to obstruct drivers' views of glare-producing parts of the Project.

Based on the assessment results, the High River Solar Project is not expected to present a significant hazard to drivers or helicopter pilots, and the glare is not expected to have a significant adverse effect on a resident's use of their home.

9 Glare Practitioners' Information

Table 9-1 summarizes the information of the author and technical reviewer of the solar glare hazard analysis.

Table 9-1 – Summary of Practitioners' Information

Name	Jeremy Chan	Jason Mah	Cameron Sutherland
Title	Assistant Glare Analyst	Renewable Energy EIT	Technical Director
Role	Glare Analyst, Author	Technical Reviewer	Technical Reviewer
Experience	• Experience with glare modelling in ForgeSolar • Analyst on multiple assessments for solar energy projects in Alberta • BSc Mechanical Engineering	• Analyst on 40+ glare assessments in Alberta, the USA, and the UK • Technical support for AUC information requests and hearings • BSc Chemical Engineering	• Expert witness experience in technical solar development in Canada for Brooks II Solar Project, East Strathmore Solar Project, and Fox Coulee Solar Project • Technical oversight, technical review, or authorship of 40+ glare assessments for 20+ proceedings in Alberta • MSci Physics • MSc Renewable Energy Systems Technology

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