YARRANLEA SOLAR FARM

GLARE IMPACT ASSESSMENT REPORT

Prepared For
Yarranlea Solar Pty Ltd

October 2016

Prepared By Environmental Ethos on behalf of
Yarranlea Solar Pty Ltd

REF NO. 16003

FINAL ISSUE: 06 OCTOBER 2016

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1. INTRODUCTION

This report has been prepared by Environmental Ethos on behalf of the proponent Yarranlea Solar Pty Ltd to assess the potential glare impact of the Yarranlea Solar Farm (the Project). The Project comprises of the installation and operation of a 100 MW solar farm that will utilise photovoltaic (PV) modules to generate electricity.

The Project site is part of a freehold rural property located at 538 and 752 Yarranlea Road, Yarranlea (Lots 3347 on A341649, 2 on RP18249, 2 on A34925, 2 on RP7475) within the Toowoomba Regional Council area. The total footprint of the proposed development will cover an area of approximately 300 hectares (ha) and will be completed in up to four (4) stages.

1.1. Location

The Project site is located approximately 44 kilometres south-west of the town of Toowoomba and 10 kilometres west of Pittsworth township, within the Darling Downs region of Queensland, *refer Figure 1.* The study area is bounded by Yarranlea Road to the west and rural properties to the north, east and south. An Ergon Substation is located on the corner of Yarranlea Road and Millmerran Branch Rail Line to the south of the project site, connection to the substation is required as part of the Project. The site is currently used for cropping, which is the primary land use within the Project surrounds.

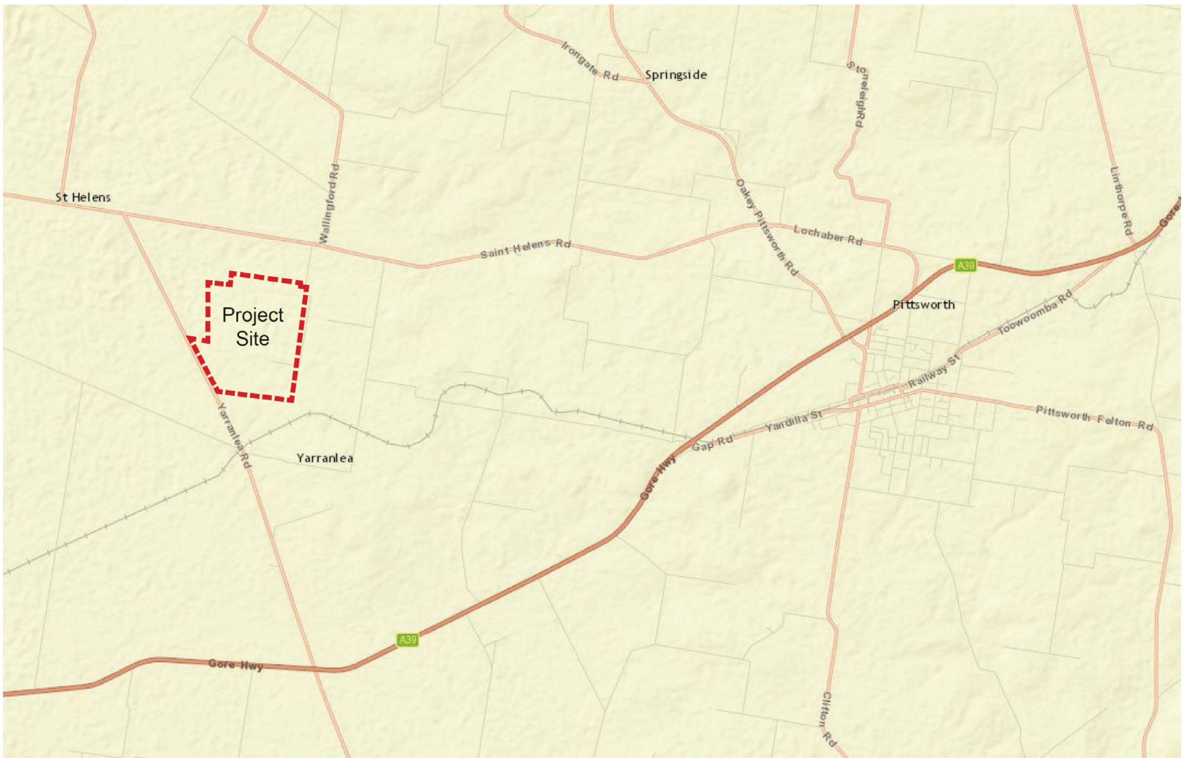


Figure 1. Location Plan

The Project site is predominantly flat land with few landscape constraints to the development of a solar farm.

2. SCOPE OF THE ASSESSMENT

The scope of this Glare Assessment includes the following:

- Description of the methodology used to undertake the study;
- Description of the elements of the Project with the potential to influence glare including size, height, and angle of PV modules, and type and operation of the tracking system;
- Identification of the viewshed and potential visibility of the Project;
- Desktop mapping of potential glare at the location of sensitive receptors within the viewshed, based on Solar Glare Hazard Analysis and viewshed analysis,
- Assessment of the baseline conditions; and
- Assessment of the potential risk of glare on sensitive receptors during operation of the Project.

3. METHODOLOGY

3.1. Glare Assessment Parameters

Glare assessment modelling for solar farms is based on the following factors:

- the tilt, orientation, and optical properties of the PV modules in the solar array;
- sun position over time, taking into account geographic location;
- the location of sensitive receptors (viewers); and
- Screening potential of surrounding topography and vegetation.

3.2. Glare Intensity Categories

Glare refers to the human experience of reflected light. The potential hazard from solar glare is a function of retinal irradiance (power of electromagnetic radiation per unit area produced by the sun) and the subtended angle (size and distance) of the glare source. [1]

Glare can be broadly classified into three categories: low potential for after-image, potential for after-image, and potential for permanent eye damage, *Figure 2* illustrates the glare intensity categories.

[1] HO, C.K., C.M. Ghanbari, and R.B. Diver, 2011, Methodology to Assess Potential Glint and Glare hazards from Concentrated Solar Power Plants

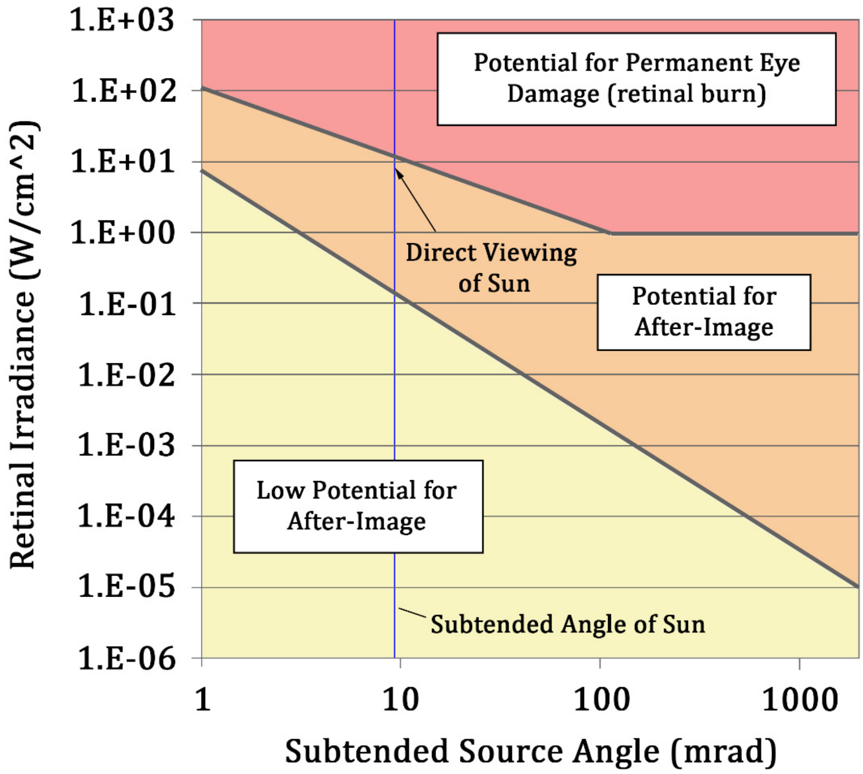


Figure 2. Ocular impacts and Hazard Ranges[2]

The amount of light reflected from a PV module depends on the amount of sunlight hitting the surface, as well as the surface reflectivity. The amount of sunlight interacting with the PV module will vary based on geographic location, time of year, cloud cover, and PV module orientation. 1000W/m^2 is generally used in most counties as an estimate of the solar energy interacting with a PV module when no other information is available. This study modelled scenarios using 2000 W/m^2 in order to cover potentially higher solar energy levels in Australia as compared to other parts of the world. Flash blindness for a period of 4-12 seconds (i.e. time to recovery of vision) occurs when 7-11 W/m^2 (or 650-1,100 lumens/m^2) reaches the eye[3].

3.3. Reflection and Angle of Incidence

PV modules are designed to maximise the absorption of solar energy and therefore minimise the extent of solar energy reflected. PV modules have low levels of reflectivity between 0.03 and 0.20 depending on the specific materials, anti-reflective coatings, and angle of incidence.[4]

The higher reflectivity values of 0.20, that is 20% of incident light being reflected, can occur when the angle of incidence is greater than 50^o. *Figure 3 and 4* show the relationship between increased angles of incidence and increased levels of reflected light. Where the angle of incidence remains below 50° the amount of reflected light remains below 10%. The angle of incident is particularly

[2] Source: Solar Glare Hazard Analysis Tool (SGHAT) Presentation (2013) https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Ho.pdf
[3] Sandia National Laboratory, SGHAT Technical Manual
[4] *Ho, C. 2013 Relieving a Glare Problem*

relevant to specular reflection (light reflection from a smooth surface). Diffuse reflection (light reflection from a rough surface) may also occur in PV modules, however this is typically a result of dust or similar materials building up on the PV module surface, which would potentially reduce the reflection.

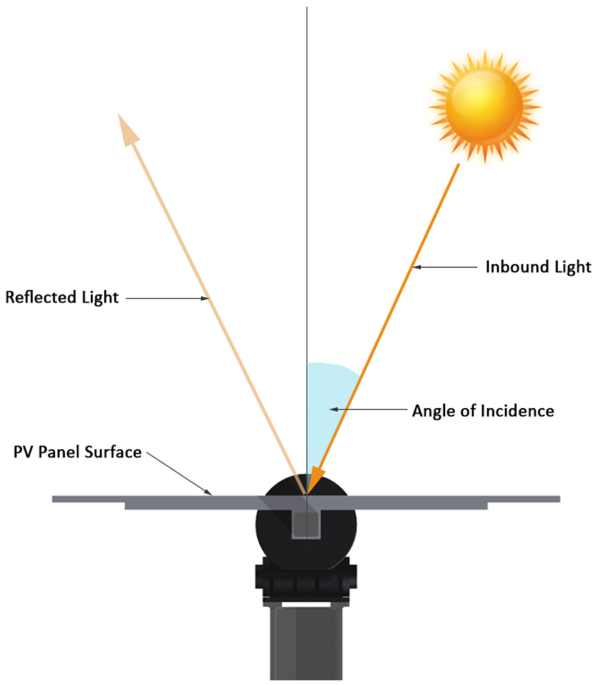


Figure 3. Angle of Incidence Relative to PV Panel Surface

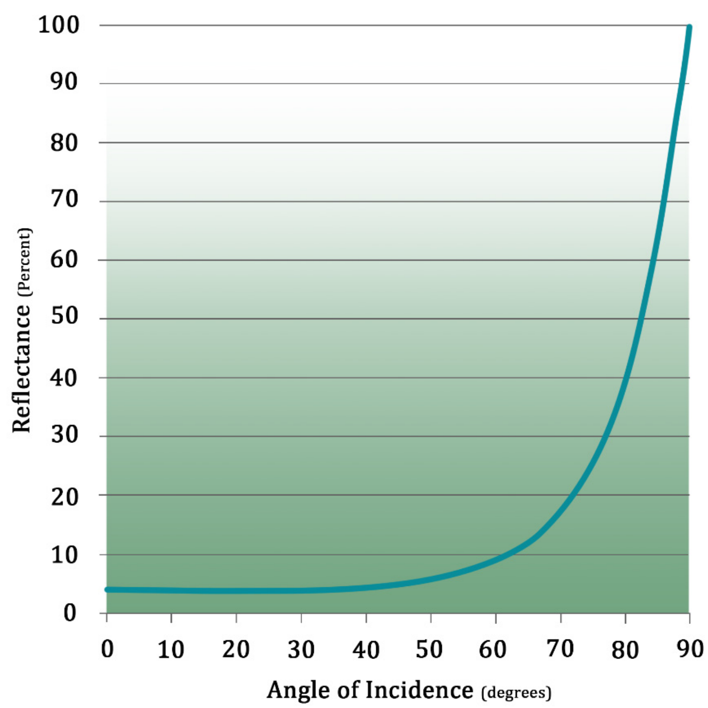


Figure 4. Angles of Incidence and Increased Levels of Reflected Light (Glass (n-1.5))

The sun changes its east-west orientation throughout the day, and the sun's north-south position in the sky changes throughout the year. The sun reaches its highest position at noon on the Summer

Solstice (21 December in the Southern Hemisphere) and its lowest position at sunrise and sunset on the Winter Solstice (21 June in the Southern Hemisphere).

In a fixed PV solar array, the angle of incidence varies as the sun moves across the sky, that is the angle of incidence are at their lowest around noon where the sun is directly overhead, and increase in the early mornings and late evenings as the incidence angles increase. If the PV array is mounted on a tracking system, this variation is reduced because the panel is rotated to remain perpendicular to the sun. Therefore a PV modular array using a tracking system has less potential to cause glare whilst it tracks the sun. *Figure 5* illustrates a PV module mounted horizontal single axis tracking system following the east to west path of the sun.

A single axis tracking system has a fixed maximum angle of rotation, once the tracking mechanism reaches this maximum angle, the PV modules position relative to the sun becomes fixed and therefore the angle of incidence increases and the potential for glare increases. Some tracking systems utilise 'backtracking' to avoid PV modules over shadowing each other. During the backtracking procedure (early morning and late afternoon) the tracking system begins to rotate away from the sun to reduce shadow casting to adjoining PV panels. During the backtracking phase, higher angles of incidence will occur in comparison to the tracking phase, and this may increase the potential for glare.

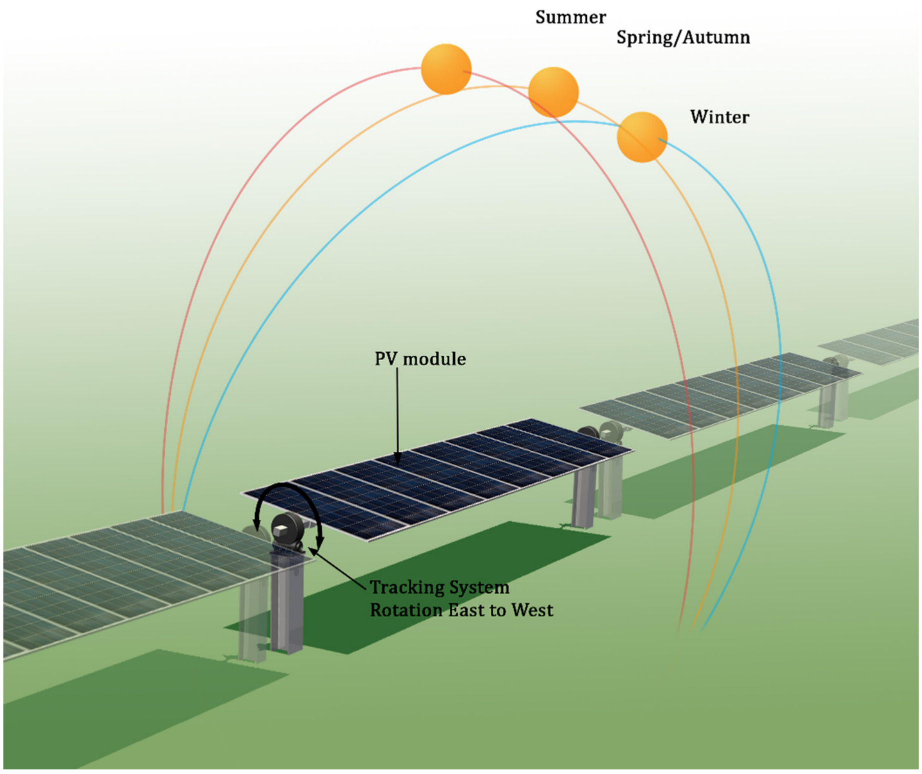


Figure 5. Diagrammatic illustration of sun position relative to PV module mounted on a horizontal single axis tracking system.

3.4. View shed Analysis

The viewshed analysis is generated in GIS by positioning a 3D model of the solar farm into a Digital Terrain Model (DTM). The DTM used in this study is based on a contour interval of 1 metre. The location of sensitive receptors (dwellings, roads, etc) are located relative to the location of the solar farm and view lines between the two assessed taken into consideration intervening topography. The result is a map showing the extent of the viewshed, potential visibility of the solar farm and therefore the potential for glare. The viewshed analysis is used in conjunction with solar hazard assessment software to assess the potential for solar glare hazard.

3.5. Solar Glare Hazard Analysis

This assessment has utilised the Solar Glare Hazard Analysis Tool (SGHAT 2.0) developed by Sandi National Laboratory [5] to assess potential glare utilising latitude and longitudinal coordinates, elevation, sun position, and vector calculations. The PV module orientation, reflectance environment and ocular factors are also considered by the software. If potential glare is identified by the model, the tool calculates the retinal irradiance and subtended angle (size/distance) of the glare source to predict potential ocular hazards according to the glare intensity categories (refer *Section 3.2*).

The sun position algorithm used by SGHAT calculates the sun position in two forms: first as a unit vector extending from the Cartesian origin toward the sun, and second as azimuthal and altitudinal angles. The algorithm enables determination of the sun position at one (1) minute intervals throughout the year.

The SGHAT is a high level tool and does not take into consideration the following factors:

- Backtracking or the effect of shading in relation to the PV array tracking system
- Gaps between PV modules
- Atmospheric conditions
- Topography and vegetation between the solar panels and the viewer (sensitive receptor)

SGHAT has been used extensively in the United States to assess the potential impact of solar arrays located in close proximity to airports. The US Federal Aviation Administration requires the use of SGHAT to demonstrated compliance with the safety requirements of all proposed solar energy systems located at federally obligated airports. Used in conjunction with a viewshed analysis, the two tools represent a conservative assessment.

3.6. Baseline Conditions

The baseline is a statement of the characteristics which currently exist in the Project area. The baseline glare condition assessment takes into consideration the following:

- Characteristics of the environment that may affect the potential for glare;
- Land use and human modifications to the landscape such as roads, buildings and existing infrastructure which may influence glare and sensitivity to glare.

[5] https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Technical_Reference-v5.pdf

3.7. Risk Assessment Approach

Once the potential for glare has been identified through the viewshed analysis and SGHAT, the potential magnitude of the glare hazard is considered relative to background conditions. A risk assessment approach is then used to identify the potential significance of the risk based on the magnitude of the glare hazard generated and the sensitivity of the receptors (viewers).

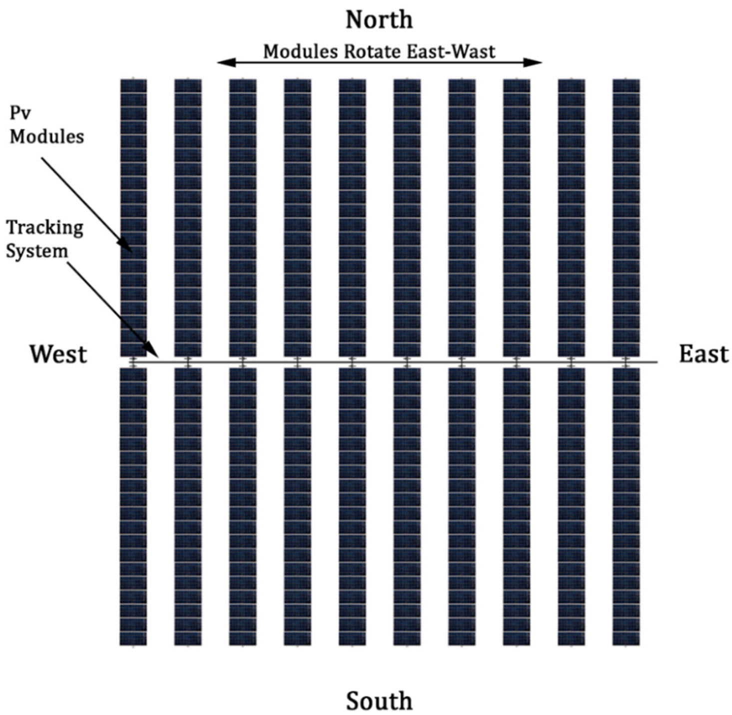
4. PROJECT DESCRIPTION

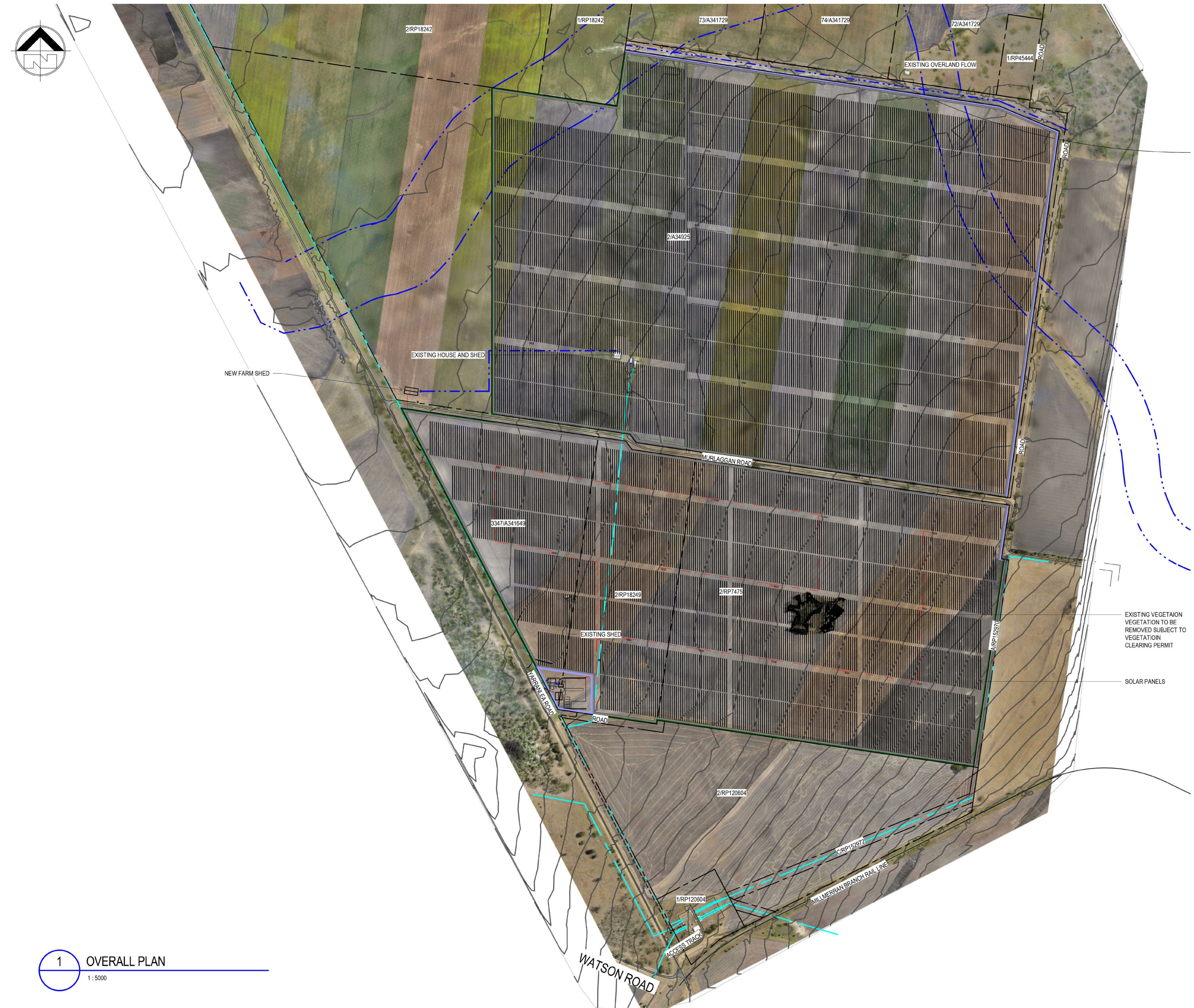
The general layout of the solar farm is as show in *Figure 6.* The main elements of the Solar Farm with the potential to influence glare are the tilt, orientation, and optical properties of the PV modules in the solar array, and the rotational capabilities of the tracking system. Whilst specific products are yet to be determined for the Project, the general technical properties of the main elements influencing glare are described below.

4.1. PV modules

The specific type of PV module utilised in the Project has yet to be determined and will not be finalised until around the time of construction commencing. However PV modules are generally consistent in form and function, and an illustrative example is provided below. As a general principle, PV modules are designed to absorb solar radiation, not reflect it, and the solar radiation is converted into electricity.

Each PV panel comprises of approximately 72 polycrystalline silicon solar cell overlayed by a 3.2 to 4.0 mm tempered glass front and held in an anodised aluminium alloy frame. The approximate dimensions for each solar array are 7 metres x 2 metres, being made up of 7 individual solar panels of approximately 2 metres x 1 metre. The PV modules are mounted on a horizontal single axis tracking system with rows aligned north-south, refer *Figure 7.*





1 OVERALL PLAN
1 : 5000

PROJECT TEAM

Consulting Engineer:

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YARRANLEA SOLAR

- LANDSCAPING BUFFER (3m)
- LANDSCAPING BUFFER (5m)
- EXISTING HOUSE
- ACCESS TRACK
- LEASE BOUNDARY / PROPERTY LINE
- BOUNDARY

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PROJECT
YARRANLEA SOLAR FARM

CLIENT
YARRANLEA SOLAR PTY LTD

ISSUE	DESCRIPTION	DATE
	DRAFT	04/10/16
A	FINAL FOR SUBMISSION	06/10/16

DESIGNED BY S CRAWFORD
APPROVED BY S CRAWFORD
DATE OF FIRST ISSUE 04/10/2016
NORTH

DRAWING NAME: **LAYOUT PLAN**
DRAWING NUMBER: **16003-FIGURE 6**
ISSUE: A

Figure 7. Illustration of PV Module Row Alignment

4.2. Horizontal single axis tracking system

The horizontal single axis tracking system rotates the PV panels across an east to west arc, following the sun's trajectory across the sky. The purpose of the tracking system is to optimize solar energy collection by holding the PV module perpendicular to the sun. The tracking system is capable of a maximum rotation range of 90^o (+/- 45^o) or 120^o (+/- 60^o) depending on the system used. For the purpose of this study a rotation range of 120^o (+/- 60^o) has been used, refer *Figure 8.*

This study has assumed the tracking system will utilise a 'backtracking' procedure to reduce the potential for over shadowing between panels.

The zenith tilt angle of the panels are assumed to be set at zero, that is, the panels are not tilted on a north – south alignment but remain horizontal along the plane of the tracker. This enables the height of the panel to remain consistent relative to each other and avoids potential over shadowing.

The maximum height of the PV modules above natural ground is approximately 2 to 3 metres, a height of 3 metres was used in the modelling.

The configuration of the tracking system rows may vary slightly dependent on the type of system used, in general the rows will be a minimum 5 metres apart.

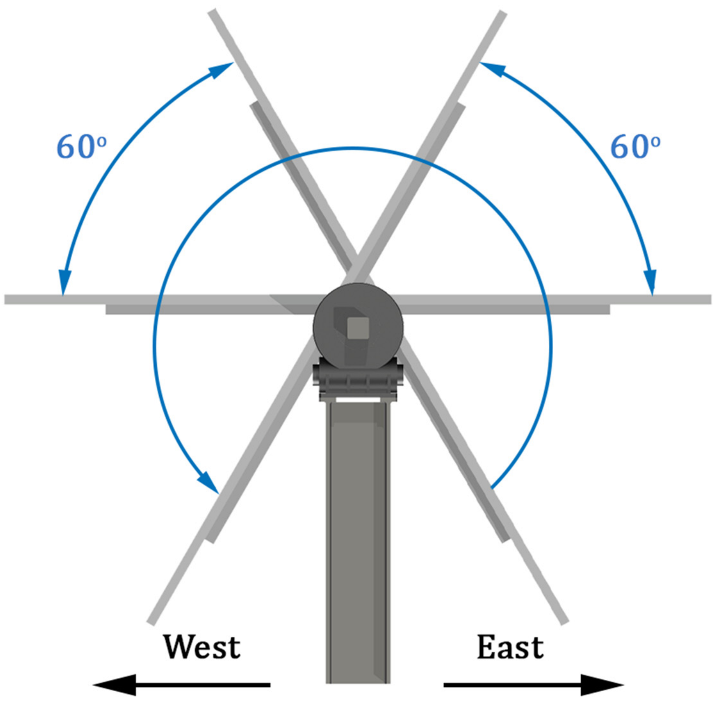

Figure 8. Illustration of PV Module Rotation Angles

5. DESKTOP GLARE ASSESSMENT

The aim of the desktop glare assessment is to identify if any sensitive receptors have the potential to be impacted by glare. The software modelling systems used in the desktop assessment include GIS viewshed modelling to identify the location of sensitive receptors with line of sight to the solar farm, and the SGHAT to identify the potential and ocular significance of glare.

5.1. Viewshed Analysis

The results of the viewshed analysis are shown in *Figure 9.*

Since the major elements of the Project, the PV models and trackers have a low horizontal profile (maximum height of 3 to 4 metres), at distances greater than 1 km these elements become visually insignificant. Therefore, the Project has the potential of being visible within 1 km of the Project site, visually insignificant at distances greater than 1 km, and barely visible at 2 km from the Project site. The north west slope of the Project site and the low hills to the south and east of the Project site, result in some topographic screening to the south east.

The results of the viewshed analysis are summarised below:

- Yarrnalea Road is located on the western boundary of the Project site. The Solar Farm will be partially screened from the road by existing vegetation.
- Pittsworth-Norwin Road is located approximately 800 metres from the Project's northern boundary.
- Roche Road is located approximately 1.7 kilometres from the Project's eastern boundary.
- Desmond Lane is located approximately 750 metres from the Project's southern boundary.
- Watson Road runs at 45 degree angle to the Project site and is approximately 500 metres from the western boundary of the Project site at its closest point.
- The Millmerran branch rail line runs along the Project site's southern boundary and is approximately 130 metres at its closest point.
- There is one (1) rural dwelling within 500 metres of the Project site which is screened from the Project by existing vegetation (OP1).
- There are four (4) rural dwellings between 500 metres and 1 kilometre from the Project (OP2, OP3, OP5 & OP7), 2 of which are screened from the Project by existing vegetation (OP2 & OP7).
- There are three (3) rural dwellings between 1 to 1.5 kilometres from the Project (OP4, OP6 & OP8), 2 of which are screened from the Project by existing vegetation and topography (OP4 & OP6).
- There are a further six (6) rural dwellings at a distance greater than 1.5 kilometres from the Project (OP 9 to OP14), 2 of which are screened from the Project by existing vegetation and topography (OP9 & OP14).

The potential glare hazard impact for identified rural dwellings, surrounding roads and the railway line has been assessed in *Section 5.2.*

YARRANLEA SOLAR

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LEGEND

- Contours (1m intervals)
- Solar Farm
- Observation Points (Rural Dwellings)
- Viewshed limits - areas screened by topography
- Viewshed - distance from solar farm

SCALE

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PROJECT
YARRANLEA SOLAR FARM

CLIENT
YARRANLEA SOLAR PTY LTD

ISSUE	DESCRIPTION	DATE
	DRAFT	04/10/16
A	FINAL FOR SUBMISSION	06/10/16

DESIGNED BY S CRAWFORD
DATE OF FIRST ISSUE 04/10/2016
APPROVED BY S CRAWFORD

NORTH

DRAWING NAME
VIEWSHED ANALYSIS

DRAWING NUMBER: **16003-FIGURE 9**
ISSUE: A

5.2. Solar Glare Hazard Analysis

The parameters used in the SGHAT model are detailed in *Table 1.*

Table 1. Input data for SGHAT Analysis

SGHAT Model Parameters	Values
Time Zone	UTC +10
Axis Tracking	Single
Tilt of tracking axis	0
Orientation of tracking axis	0
Offset angle of module	0
Module Surface material	Smooth glass with anti-reflective coating (ARC)
Maximum tracking angle	60
Height of panels above ground	3 m at rotational base

The assessment outcomes for the SGHAT are outlined in *Table 2:*

Table 2. SGHAT Assessment Results.

Sensitive Receptor	Glare Potential
Observation Point 01- Rural Dwelling	No Glare
Observation Point 02 - Rural Dwelling	No Glare
Observation Point 03 - Rural Dwelling	No Glare
Observation Point 04 – Rural Dwelling	No Glare
Observation Point 05 - Rural Dwelling	No Glare
Observation Point 06 – Rural Dwelling	No Glare
Observation Point 07 - Rural Dwelling	No Glare
Observation Point 08 - Rural Dwelling	No Glare
Observation Point 09 - Rural Dwelling	No Glare
Observation Point 10 - Rural Dwelling	No Glare
Observation Point 11 - Rural Dwelling	No Glare
Observation Point 12 - Rural Dwelling	No Glare
Observation Point 13 - Rural Dwelling	No Glare
Observation Point 14 - Rural Dwelling	No Glare
Travel Path – Pittsworth Tummaville Road	No Glare
Travel Path – Pittsworth Norwin Road	No Glare
Travel Path – Wallingford Road	No Glare
Travel Path – Roche Road	No Glare
Travel Path – Watson Road	No Glare
Travel Path – Desmond Lane	No Glare
Travel Path – Branch Railway Line	No Glare

5.3. Baseline conditions

The baseline condition within the vicinity of the Project site is characterised by flat agricultural land, predominately used for cropping and low hills used for grazing. The landscape is predominately cleared with some patches of native vegetation remaining in isolated pockets, along fence lines and roadsides. There are two large turkey dams within 1.5 kilometres of the Project site, these dams are generally shallow in profile, storing water for irrigation purposes.

Existing dwellings in the area include homesteads scattered throughout the landscape and are generally located in association with large agricultural sheds. Pittsworth is the closest town to the Project site, located approximately 10 km to the east of the Project site.

Existing features in the landscape with the potential to contribute to glare include the existing dams.

5.4. Atmospheric Conditions

Atmospheric conditions such as cloud cover, dust and haze will impact light reflection, however these factors have not been accounted for in this glare assessment. The Bureau of Meteorology statistics for Toowoomba Airport (44 km North East of the Project site) recorded 109.7 cloudy days per year (mean number over the period 1997 to 2010)[6]. Cloudy days predominately occur during the summer months, November to February. Since atmospheric conditions have not been factored into this assessment modelling, statistically the glare potential represents a conservative assessment.

6. ASSESSMENT RESULTS

The results of the desktop assessment identified no glare hazard potential is likely to be generated as a result of the operation of the Solar Farm. This assessment took into consideration the operation of the Solar Farm during daylight hours throughout the year (SGHAT modelling calculates the potential for glare at 1 minute intervals). SGHAT testing was undertaken for assumed sun energy intensity of 2000 W/m^2, which is 2x the US Federal Aviation Administration modelling requirement standards. In addition no allowance was made for atmospheric conditions.

Currently the SGHAT does not account for the 'backtracking' procedure, that is, variable angles of incidence of the sun relative to the PV module where the tracking system accounts for over shadowing potential. Therefore during the early morning and late afternoon when the backtracking procedure is operating there may occur a variation to the angle of incidence of the sun relative to the PV module to that predicted in this modelling.

In summary, based on the assumptions and parameters of this desktop assessment, the following results were identified:

- No glare potential was identified for surrounding dwellings, therefore the likely impact on these sensitive receptors within the viewshed was identified as insignificant;
- No glare potential was identified for surrounding roads, therefore the likely impact on motorists travelling in either direction along these roads was identified as insignificant; and
- No glare potential was identified for the railway line to the south of the Project site.

[6] http://www.bom.gov.au/climate/averages/tables/cw_041103_All.shtml

APPENDIX A:

SOLAR GLARE HAZARD ANALYSIS COMPILED REPORT

SOLAR GLARE HAZARD ANALYSIS REPORT

INPUTS

Analysis name	Baralaba 01
PV array axis tracking	single
Tilt of tracking axis (deg)	0.0
Orientation of tracking axis (deg)	0.0
Offset angle of module (deg)	0.0
Limit rotation angle?	True
Maximum tracking angle (deg)	60.0
Vary reflectivity	True
PV surface material	Smooth glass with ARC
Timezone offset	+10.0
Subtended angle of sun (mrad)	9.3
Peak DNI (W/m^2)	2000.0
Ocular transmission coefficient	0.5
Pupil diameter (m)	0.002
Eye focal length (m)	0.017
Time interval (min)	1
Slope error (mrad)	10.0

PV ARRAY VERTICES

ID	Latitude (deg)	Longitude (deg)	Ground Elevation (m)	Height of panels above ground (m)	Total elevation (m)
1	-27.716905982	151.527592242	417.27	3.0	420.27
2	-27.7182499082	151.538836062	431.06	3.0	434.06
3	-27.7023378027	151.541475356	421.54	3.0	424.54
4	-27.7022166899	151.540322006	419.17	3.0	422.17
5	-27.7019673396	151.540289819	419.08	3.0	422.08
6	-27.7003667342	151.529477835	413.28	3.0	416.28
7	-27.7020053359	151.529150605	412.02	3.0	415.02
8	-27.7014828858	151.525604725	411.88	3.0	414.88
9	-27.7096565673	151.525803208	412.56	3.0	415.56
10	-27.7092885036	151.523287296	410.67	3.0	413.67

OBSERVATION POINTS

ID	Latitude (deg)	Longitude (deg)	Ground Elevation (m)	Eye-level height above ground (m)	SGHAT Result
1	-27.7156095285	151.522191614	412.14	1.5	No Glare Found
2	-27.714878189	151.520351619	409.58	1.5	No Glare Found
3	-27.724788847	151.535557061	434.12	1.5	No Glare Found
4	-27.7259118715	151.524499655	416.88	1.5	No Glare Found
5	-27.705016499	151.551227868	449.57	1.5	No Glare Found
6	-27.7031048475	151.553307921	451.31	1.5	No Glare Found
7	-27.6995379249	151.548080295	422.25	1.5	No Glare Found
8	-27.6949662991	151.514289826	409.28	1.5	No Glare Found
9	-27.7155430581	151.499686539	403.78	1.5	No Glare Found
10	-27.7099510173	151.558526158	472.12	1.5	No Glare Found

11	-27.6877510528	151.543865204	423.34	1.5	No Glare Found
12	-27.6844472704	151.547971666	449.75	1.5	No Glare Found
13	-27.6822692369	151.545267999	437.52	1.5	No Glare Found
14	-27.6787823928	151.544227302	432.88	1.5	No Glare Found