APPENDIX L

SOLAR GLARE HAZARD ANALYSIS

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Seville Solar Farm Complex: Solar Glare Hazard Analysis

Date: November 20, 2014
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Key Findings

- **Fixed-tilt photovoltaic (PV)** arrays *do present glare issues to the residences due west of the project site* for short intervals (15-30 minutes) of potential after-image glare at sunrise in non-winter months (mid-March through October). The arrays *do not* present glare issues to other surrounding ground-level observation points.
- **Horizontal Single-axis tracking PV arrays** *do not* present glare issues to surrounding ground-level observation points.
- **Dual-axis tracking concentrated PV (CPV) arrays** *do not* present glare issues to surrounding ground-level observation points.

Project Description

Environmental Management Associates (EMA) contracted with Good Company to evaluate the potential for glare from the proposed Seville Solar Farm Complex to surrounding ground-level observation points. The observation points assessed include roads, residences and the Ocotillo Wells State Vehicular Recreation Area.

The proposed Seville Solar Farm Complex, if built, would be a ground-mounted photovoltaic (PV) array with a total capacity of approximately 135 MW. The final design and specifications for the PV array has not been selected as of this writing, but three design alternatives are being considered.

- Fixed-tilt PV array
- Horizontal single-axis tracking PV array that partially tracks the path of the sun from east to west
- Dual-axis tracking concentrated PV array that tracks and directly faces the sun at all times

The 1,181-acre site for the proposed Seville Solar Farm Complex is located on the 2,440-acre Allegretti Farms property in west-central Imperial County, California, approximately 8 miles west of the junction of State Highway 78 and State Highway 86, and approximately 3 miles east of the San Diego County line. The elevation of the site is at its highest in the northwest corner and slopes downward to the southeast by roughly 35 feet.

Methodology

The purpose of a glare analysis is to assess the potential impact of glare from PV modules and other components as a potential hazard or distraction for motorists and nearby residents. Glare is a common phenomenon that originates from the reflection of a light source (usually the sun) off any reflective service (e.g., windows, chrome automobile bumpers, water, solar panels, etc.).

The methodology for the analysis consists of 2 parts: 1) identifying the observational points of concern around the project site, and 2) conducting the calculations necessary to determine if the observational points of concern intersect with the angles of light reflection, resulting in glare.

The points of concern for this glare analysis were identified through information provided by EMA and through the use of Google Earth and Google Maps. EMA identified the *Ocotillo Wells State Vehicular Recreation Area* as a site of particular concern. A radius of ~11 miles around the project site was reviewed for major traffic corridors, residential and commercial structures. The points identified are described in the *Analysis* section of this report in Figure 3.

The calculations in this analysis are based on the Solar Glare Hazard Analysis Tool (SGHAT) methodology and tool, developed by Sandia National Laboratory for the U.S. Department of Energy. This free, publically available, online tool is built on a Google Earth platform and allows assessment for potential solar glare hazard based on multiple variables including: elevation of panels and observation points, panel tilt, panel orientation, reflectivity, peak direct normal irradiance and ocular measurements. The following points highlight and describe the variables within SGHAT adjusted for this analysis.

- **Elevation:** height of the panel. We ran multiple scenarios to gauge differences between glare potential from the bottom to the top of the panels, depending on design and panel size.
- **Orientation:** direction that the panel is facing. Depending on the type of panel (fixed, single-axis, dual-axis) we used different orientations in degrees off of due north to signal orientation. For example, 90° represents due east, whereas 180° is due south and 270° is due west.
- **Tilt**: angle of the panels. For example, fixed-tilt panels are set at 25° off the horizon.
- **Reflectivity:** amount of light reflected. SGHAT uses 10% reflectivity as a default. This variable can be reduced to 2% to demonstrate the effects of using the proposed anti-reflective coatings or textured glass.

The output of the tool is a finding of whether or not the potential for glare exists as a result of the angle of reflected light reaching a particular observation point and the related intensity of the glare. The tool calculates the angle reflection for all hours of the day and all days of the year based on the changing azimuth[1] of the sun. See Figure 2 for an example of the tool's results.

One particular benefit of SGHAT for this analysis is its capability of calculating solar glare potential given different elevations and topography. The proposed solar farm site is located just below sea level and there are potential observation points in the surrounding area that are between 100 and 225 feet in elevation, which makes elevation and impact on solar reflection very important.

One of SGHAT's limitations is its current inability to measure single or dual-axis tracking. This element will be added in forthcoming versions of SGHAT. However, according to the SGHAT user manual, dual-axis tracking will not significantly contribute to stray light reflections unless the technology is not operating properly because the array is constantly pointed toward the sun.[2] To overcome this limitation, the horizontal single-axis and dual-axis alternatives were assessed in this analysis by adjusting the panel orientation and tilt in the SGHAT tool to the direction that the panels would be pointed at various times throughout the day.

While SGHAT is a relatively new tool (released in 2013), it will likely become the *de facto* option for solar glare hazard analysis due to its ease of use, powerful analytical abilities and design pedigree.

Defining Solar Glare Hazard

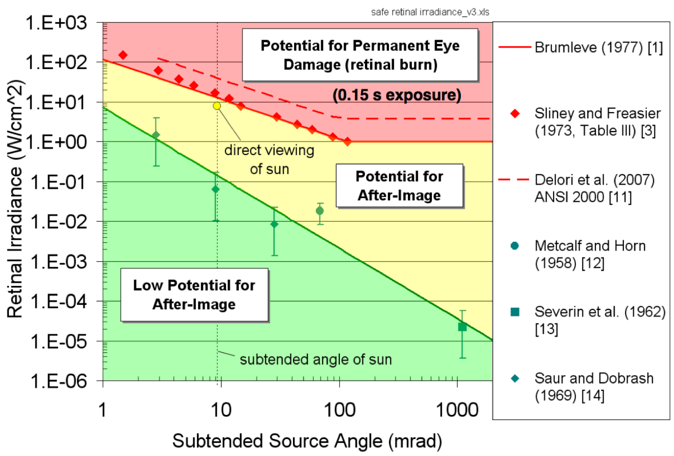
Glare can be described as a continuous source of excessive brightness.[3] Glare, and its effect on vision, is not a simple measurement because the effect of glare depends on a number of factors including the source radiance, source angle, duration of exposure, wavelength, pupil diameter and eye focal length.

Retinal irradiance (W/cm^2 – watts per cm^2) and subtended source angle (mrad) are the two main factors used to assess impact on the human eye. Retinal irradiance calculates the total power of the light entering the pupil and the retinal image area. Subtended source angle is calculated using the light source size, distance and focal length. These two factors are shown as axes of Figure 1, which maps the

[1] Azimuth is the horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object. This word is being used here to describe the arc of the sun in the sky as it changes with the seasons (i.e. higher arc in the summer and lower in winter).
[2] Ho. August 2013. Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 2.0 https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf
[3] Ho and Khalsa. 2011. *Summary of Impact Analyses of Renewable Energy Technologies on Aviation and Airports.* Sandia National Laboratories. Retrieved October 30, 2013 at https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Ho.pdf

potential ocular impacts and thresholds for each of the three bands of potential hazard from available research on the subject.

Figure 1: Ocular Impacts and Hazard Ranges

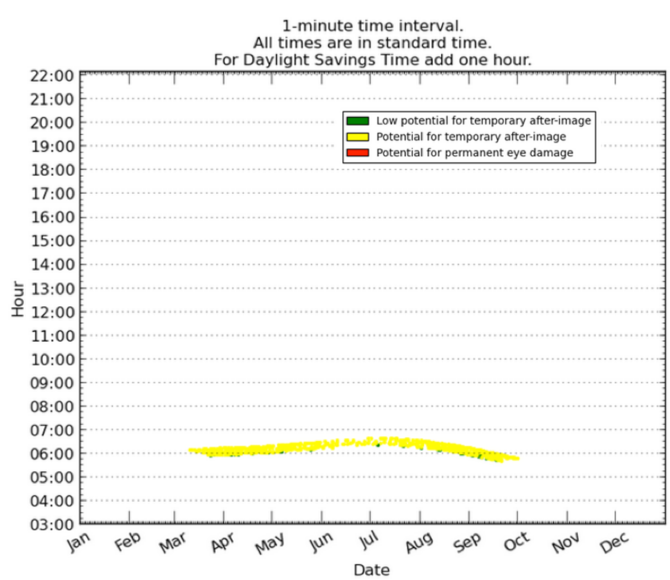


Source: Solar Glare Hazard Analysis Tool (SGHAT) Presentation (2013)
https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Ho.pdf

After-image experiences (green and yellow bands in Figure 1 above) vary broadly and are commonly described as flash blindness, which results from bright sources of light bleaching retinal visual pigments. Commonly yellow, can mean caution, and in some instances potential for after-image can infer caution such as when directly viewing the sun (a point labeled in Figure 1). However, when considering the results of the SGHAT tool, it is important to remember that the yellow band describes a range of effects, not a single point or single effect. Experiencing after-image potential is common. Examples of after-image potential include the eye's reaction to a flash bulb or a light being turned on in a dark room. The red band is not applicable to this analysis, as PV or CPV panels are not capable of creating the conditions that would cause permanent eye damage.

This technical definition of glare is provided to the reader as background information because the SGHAT tool uses calculated values for retinal irradiance and subtended source angle, and the same colors used in Figure 1, to describe the intensity of glare in the results. Figure 2 provides an example of the one output from the SGHAT tool. The yellow line shoes the timing, duration and intensity of glare (yellow = potential for temporary after image). Data from the tool may also be downloaded as a text file.

Figure 2: Example of SGHAT results graphic



Analysis

The proposed Seville Solar Complex site is located just south of Highway 78 and the Ocotillo Wells State Vehicular Recreation Area (OWSVRA). OWSVRA is an extensive park offering off-road motor vehicle trails and covers an area of roughly 85,000 acres. EMA requested that special attention be given in the analysis to highway traffic and the motorists using the OWSVRA. Three points along Highway 78 were considered and multiple points throughout the park, including those at the highest elevations. Also considered were the residences and commercial buildings located directly to the west and northwest and farms and residences due east of the project site. The nearest residence is approximately one mile to the west of the solar farm facility. Figure 3 lists all observation points considered.

In total, 19 observation points were considered including:

- Nearby residences and commercial buildings (9 observation points)
- Ocotillo Wells State Vehicular Recreation Area – OWSVRA (7 observation points)
- Highway 78 (3 observation points)

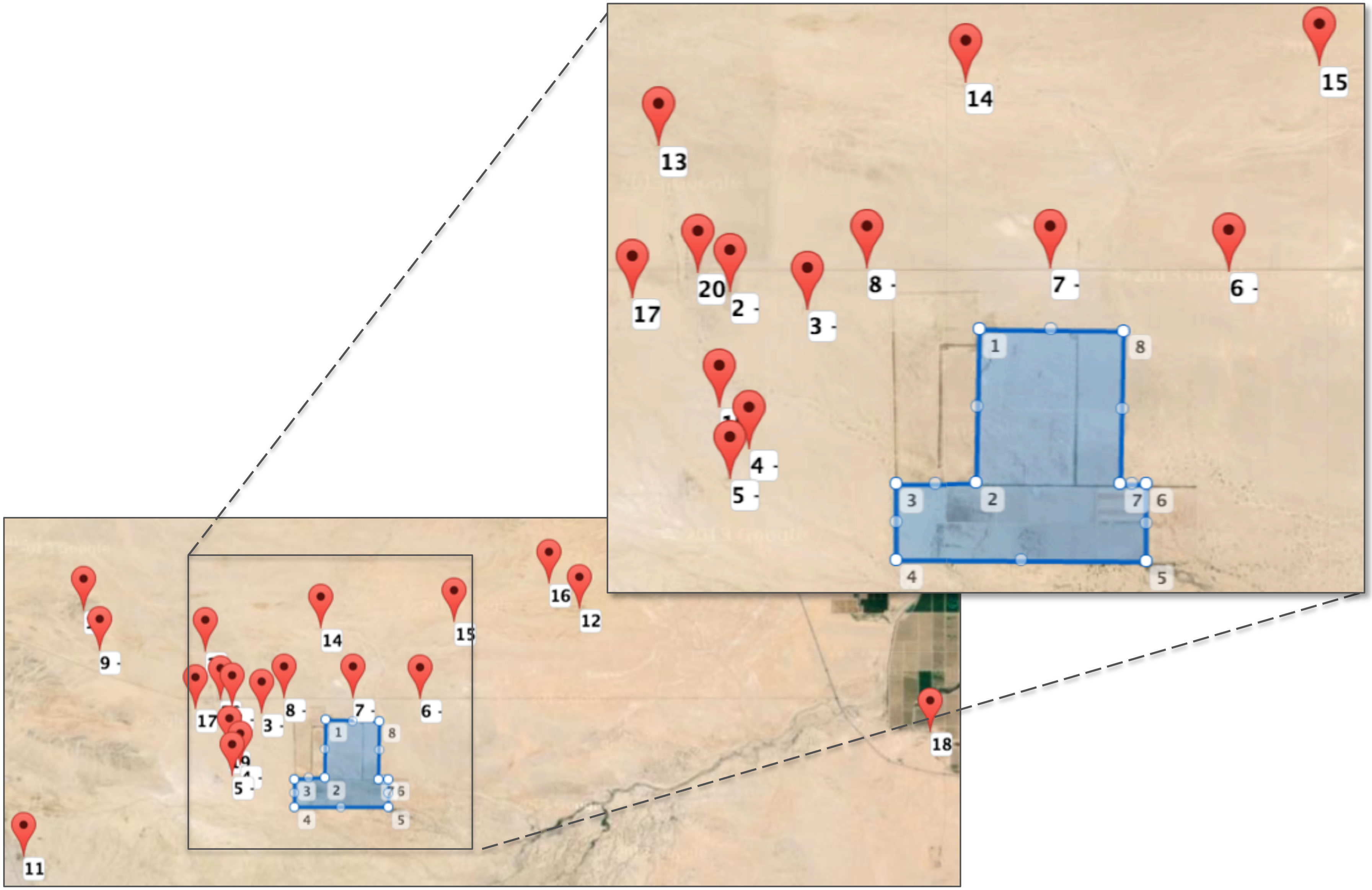
Figure 3: Observation Points Near Seville Solar Farm Complex

Observation Point	Description	Latitude	Longitude
1	Blu Inn Café	33.12527	-116.04442
2	Blu Inn RV Park	33.12345	-116.04075
3	Residence # 1	33.12176	-116.03177
4	Residence # 8	33.10838	-116.03842
5	Residence # 7	33.10551	-116.04063
6	Highway 78 - NE	33.12555	115.98314
7	Highway 78 - N	33.12576	-116.00374
8	Highway 78 - NW	33.12584	-116.02485
9	OWSVRA - County Line Rd. Bluff	33.13791	-116.08162
10	OWSVRA - County Line Rd. Hills	33.14822	-116.08633
11	Residence #9	33.08485	-116.10472
12	OWSVRA - South of Oil Well Wash	33.14891	-115.93434
13	OWSVRA - San Felipe Wash	33.13763	-116.04899
14	OWSVRA - Tarantula Wash	33.14368	-116.01355
15	OWSVRA - Pole Line Road	33.14528	-115.9728
16	OWSVRA - Gas Dome Trail	33.15505	-115.94344
17	Residence #2, 3, 5	33.12291	-116.05204
18	Residence #10	33.11698	-115.82655
19	Residence #4	33.11237	-116.04188

Note: The description for Residence 1 – XX follows a naming system used by EMA in a file (*Selville Noise Receptors.kmz)* provided to Good Company on Oct. 28th to direct selection of observation points.

Figure 4 is a screenshot from the SGHAT tool showing both the boundaries of the proposed solar farm (blue shaded section) and the location of the observation points.

Figure 4: Seville Solar Farm Complex and Adjacent Observation Points



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As part of our analysis we assessed three alternative solar PV systems, which each have their own characteristics and specifications for panel tilt, height, orientation and reflectivity.

- **Fixed-tilt PV array.** Flat-plate fixed-axis PV modules (or panels) are fixed tilt (25°)[4] at a height of between 0.5 feet and 8 feet and oriented to face due south (180°) in order to capture the greatest amount of light from the sun over the course of a year. A fixed-axis solar panel will reflect light based on the angle of the sun relative to the panel. SGHAT's default panel reflectivity setting is 10% and was used for all designs in this analysis, but it is important to note that the application of anti-reflective coatings and textured glass can reduce reflectivity to as low as 2%. When the sun is closer to the horizon during sunrise and sunset, it will be reflected in the opposite direction at glancing angles (angles greater than 60%). Because the sun is so low in the sky during these times of the day, it's at these times that the likelihood for glare to be an issue at ground level is the greatest. At large glancing angles, reflectivity for PV modules can be 20% or more, even with texturing and anti-glare coatings.[5]

- **Horizontal single-axis tracking PV array.** Instead of being fixed south, a horizontal single-axis tracking (HSAT) system allows the PV modules to follow the sun from east to west. The purpose of PV tracking systems is to optimize solar energy collection by pointing the face of the module towards the sun throughout the day. For the purpose of this analysis we assume that the maximum panel tilt angle is 45° for both east and west directions at sunrise and sunset respectively, regardless of the time of the year. At mid-day the panel angle is assumed to be 90° regardless of the time of the year. The panels were considered over a range of heights relative to the ground, from 0.5 feet to 8 feet. As stated earlier, the primarily limitation of the SGHAT tool is that it currently does not include the analytical capabilities to assess single- or dual-axis panels. To overcome this limitation, the tool was set for different panel orientations and tilts based on the known operating specifications at different points during the day to assess glare for that particular time of day.

- **Dual-axis tracking concentrated PV array.** Before sunrise, the CPV modules go into their "wake cycle" where they rotate into a position facing east and wait for the sun to rise. The operational limits of the system dictate that the minimum tilt angle of the modules is 85°. As the sun rises and first strikes the modules the light will be reflected back at a 10° angle above the sun, which reduces the occurrence of glare by keeping reflection above the horizon. The modules will remain at this minimum angle until the sun is in line with the module. At this point the modules begin tracking the sun. It is also at this point that the angle of reflection is the lowest, or 5° above the horizon. As with the single-axis design, we set up and ran the tool at different panel orientations and tilts based on the known operating specifications at different points during the day to assess glare impacts for that particular time of day.

[4] Data for panel orientation, tilts and heights for all designs were provided by EMA staff.
[5] Ho, C. April 2013. Relieving a Glaring Problem, Solar Today https://share.sandia.gov/phlux/static/references/glint-glare/Ho-SolarToday-April13_v2.pdf

Results

Of the three alternative designs, *the fixed-axis array was the only option that presented potential for after-image glare*. The glare from the fixed-axis array would impact only those residences to the west and east of the array (observation points 4, 5, 11,19 as shown in Figure 5). The glare would be experienced from mid-March through October for 15-30 minutes just after sunrise or just before sunset. Glare would affect observation points to the west during sunrise and to the east during sunset. The SGHAT graphic results showing the exact times of day and times of the year when glare will be experienced by these observation points are presented in Appendix A of this report. The SGHAT results also found low potential for after image glare for point 18, but this finding was determined to be incomplete. The tool isn't currently able to account for natural or man-made obstacles that would prevent the occurrence or observation of glare.[6] The mountains to the west of the array provide an obstacle to the occurrence of sunset glare for observation points to the east of the array, reducing and likely eliminating glare potential at point 18.

Figure 5 shows the results for the fixed-axis array based on panel orientation, panel tilt, panel elevation relative to the ground, panel reflectivity and the glare findings that include observation points affected and a measure of glare intensity. This design was analyzed for a number of panel elevations, 0.5, 5 and 8 feet, to determine the affect of panel elevation on glare. Glare was detected at all height settings.

Based on these findings, the SGHAT reflectivity setting was also adjusted from 10% (default) to 2% to represent panels with anti-reflective coatings and/or textured glass to reduce reflectance to as low as 2% to determine if this modification would significantly change the glare findings. As can be seen in Figure 5, it does not eliminate the occurrence of glare, but it does reduce the intensity from potential for after-image to low potential for after-image. It's important to note that this analysis did not take into account the potential for the water diversion berm and tamarisk tree wind break on the western edge of the property to obscure the glare from the fixed-axis array to these off-property Ops. As previously mentioned the SGHAT tool does not have the ability to account for on the ground obstacles that could obscure glare by specific observation points.

Figure 5: Glare Results for Fixed-tilt PV Design

Alternative 1: Fixed (south facing fixed-axis array)							
Panel Design	Panel Orientation	Panel Tilt	Panel Elevation	Reflectivity	Glare Hazard	Observation Point	Glare Description
	degrees from due North	degrees from the horizon	feet from the ground	%			
Fixed tilt							
	180°	25°	5	10%	Potential for After-Image	OP: 4, 5, 11, 19	Up to 15-30 min in morning hours (6:00 to 7:00)
	180°	25°	0.5	10%	Potential for After-Image	OP: 4, 5, 11, 19	
	180°	25°	8	10%	Potential for After-Image	OP: 4, 5, 11	
Fixed with anti-reflective coating (ARC) and 2% reflectivity							
	180°	25°	5	2%	Low Potential for After-Image	OP: 4, 5, 11	Up to 15-30 min in morning hours (6:00 to 7:00)
	180°	25°	0.5	2%	Low Potential for After-Image	OP: 4, 5, 11	
	180°	25°	8	2%	Low Potential for After-Image	OP: 4, 5, 11	

As was stated previously, the yellow band that represents the potential for after-image describes a range of ocular effects. By plotting the raw SGHAT data for observation point 4, it was determined that the effect for this observation point is located near the bottom edge of the range of potential for after-image effects (see Figure 6). Therefore, the ocular effects will be closer to turning on a light as opposed to staring at the sun.

Single-axis tracking PV arrays and dual-axis tracking CPV arrays do not present glare issues. Figures 7 and 8 list each of the alternatives and no glare was identified by SGHAT. For the horizontal single-axis tracking system the angle of reflections are well above any ground level observational points of concern. There are similar findings for the dual-axis CPV system. For this system the moments of greatest concern are at sunrise and sunset, when the angles of reflection are lowest relative to the ground. In

[6] Ho. August 2013. Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 2.0

these moments the observational points of concern are at a great enough distance from the site making these low angles a non-issue.

Figure 6: Fixed Tilt - Ocular Impact Potential from Glare

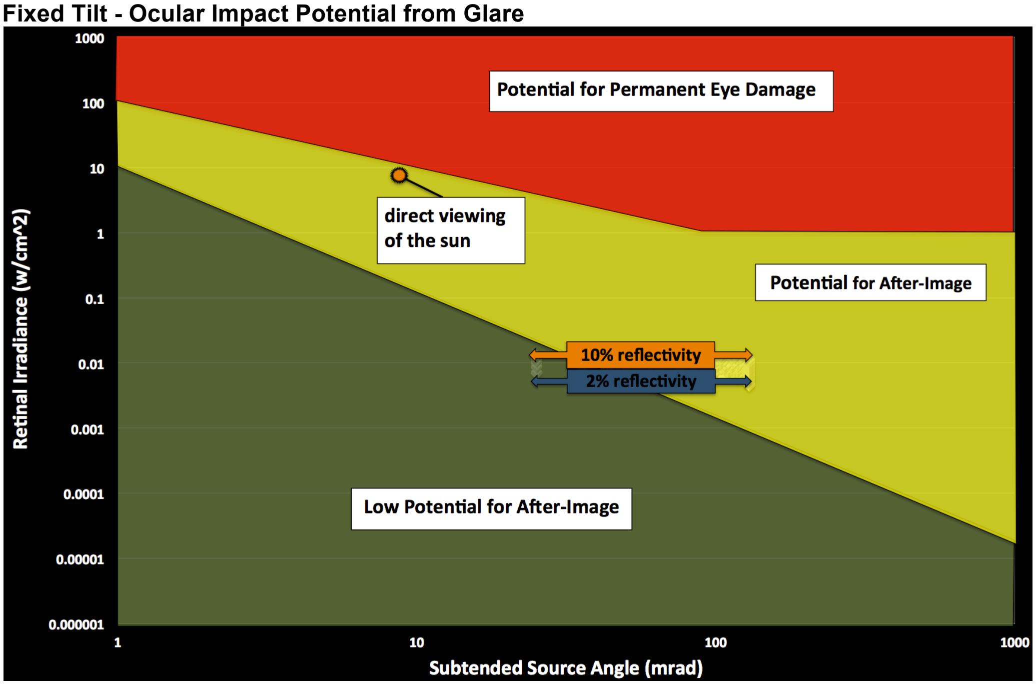


Figure 7: Glare Results for Horizontal Single-axis Design

Time of Day	Panel Orientation	Panel Tilt	Panel Elevation	Reflectivity	Glare Hazard	Observation Point	Glare Description
	degrees from due North	degrees from the horizon	feet from the ground	%			
Sunrise							
	90°	45°	0.5	10%	No Glare	N/A	
	90°	45°	5	10%	No Glare	N/A	no glare at sunrise
	90°	45°	8	10%	No Glare	N/A	
Midday							
	90°	0	0.5	10%	No Glare	N/A	
	90°	0	5	10%	No Glare	N/A	no glare at 12pm +/- 3 hours
	90°	0	8	10%	No Glare	N/A	
Sunset							
	270°	45°	0.5	10%	No Glare	N/A	
	270°	45°	5	10%	No Glare	N/A	no glare at sunset
	270°	45°	8	10%	No Glare	N/A	

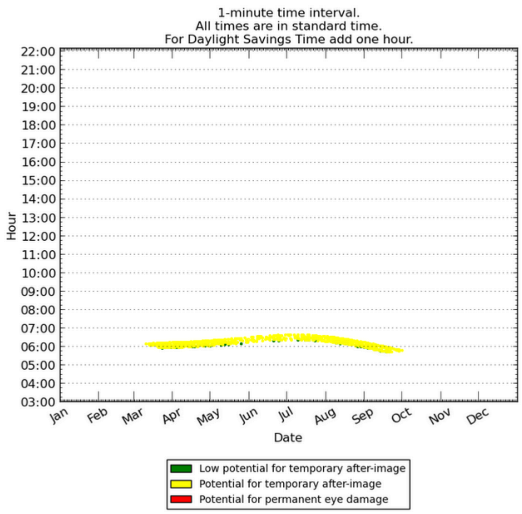
Figure 8: Glare Results for CPV Dual-axis Design

Alternative 3: Concentrated PV dual-axis tracking array							
Time of Day	**Panel Orientation**	**Panel Tilt**	**Panel Elevation**	**Reflectivity**	**Glare Hazard**	**Observation Point**	**Glare Description**
	degrees from due North	degrees from the horizon	feet from the ground	%			
Sunrise							
	90°	85°	1.6	10%	No Glare	N/A	no glare at sunrise
	90°	85°	27	10%	No Glare	N/A	no glare at sunrise
Sunset							
	270°	85°	1.6	10%	No Glare	N/A	no glare at sunset
	270°	85°	27	10%	No Glare	N/A	no glare at sunset

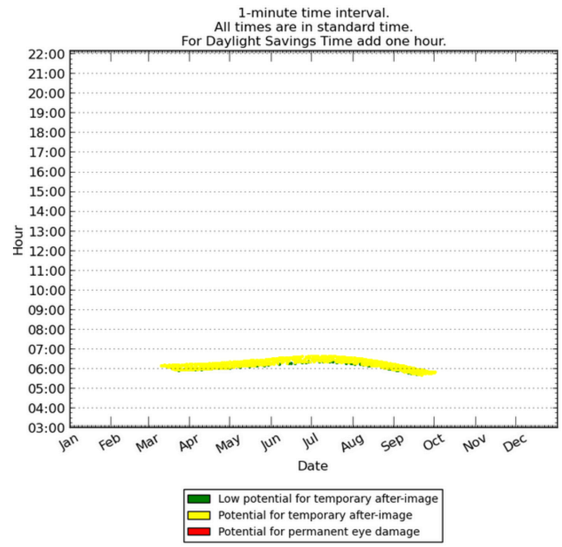
Appendix A: SGHAT Glare Hazard Output: Individual Observation Points

Fixed-tilt PV design: 25° tilt, 5 foot panel elevation

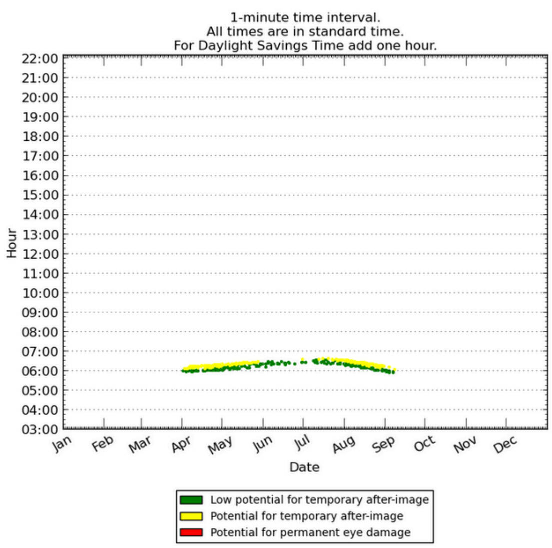
Observation Point: 4 - Residence #8



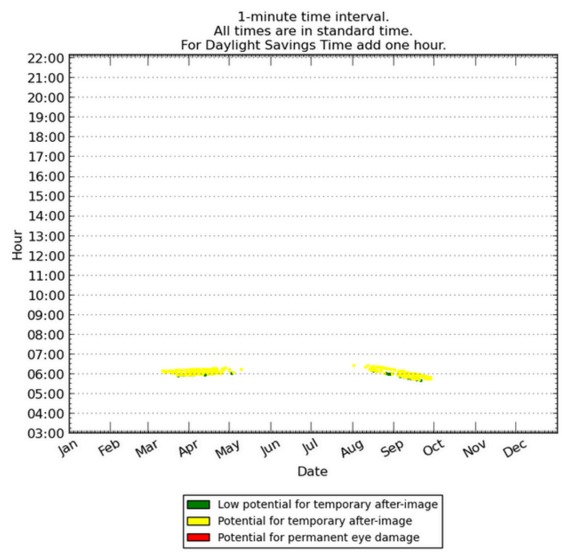
Observation Point: 5 - Residence #7



Observation Point: 11 - Residence #9

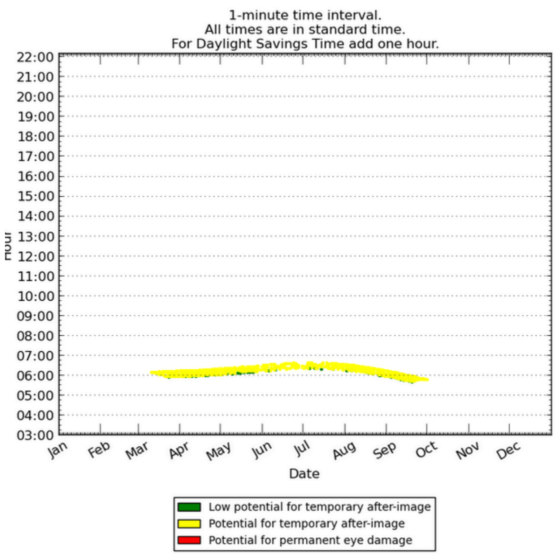


Observation Point: 19 - Residence #4

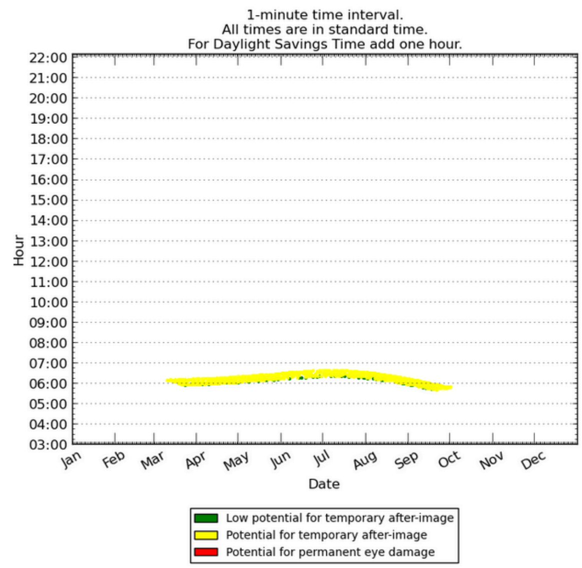


Fixed-tilt PV design: 25° tilt, 0.5 foot panel elevation

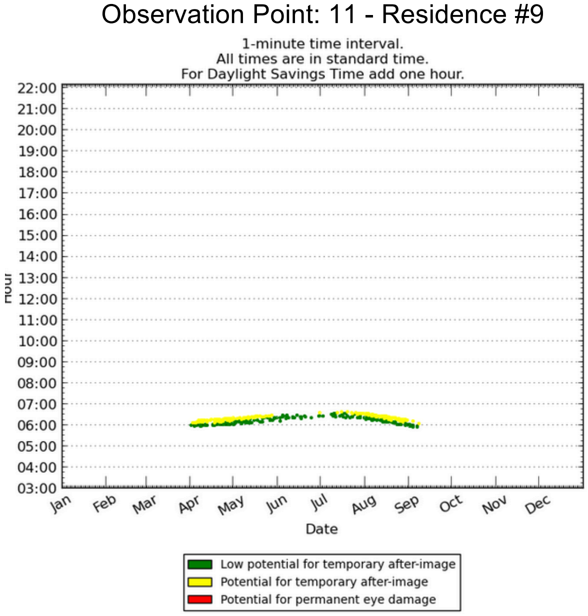
Observation Point: 4 - Residence #8



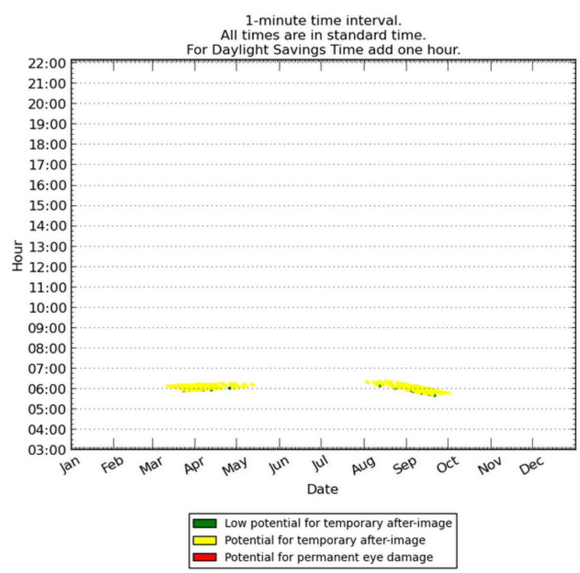
Observation Point: 5 - Residence #7



Observation Point: 11 - Residence #9

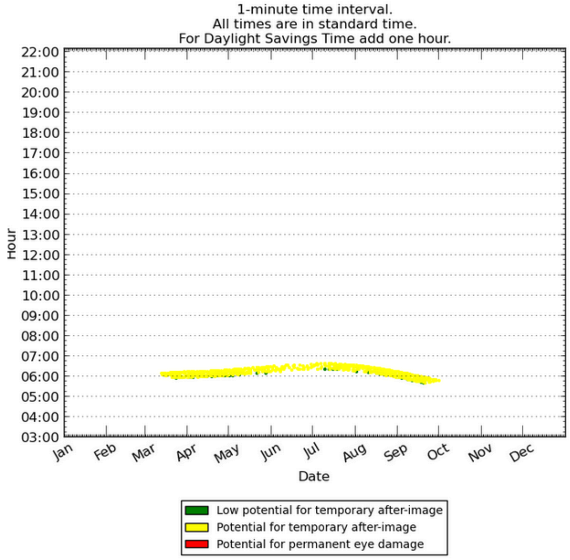


Observation Point: 19 - Residence #4

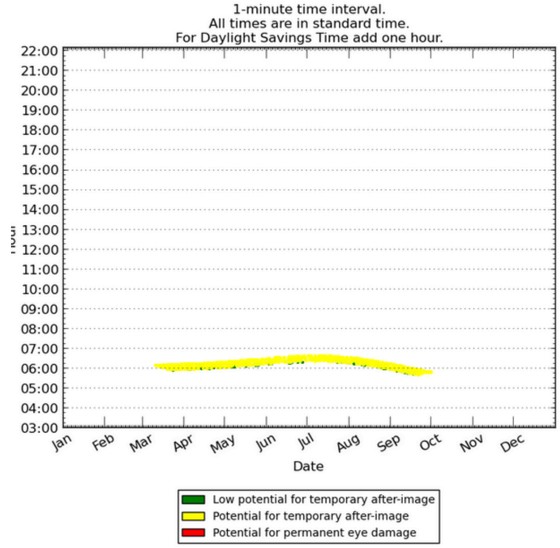


Fixed-tilt PV design: 25° tilt, 8 foot panel elevation

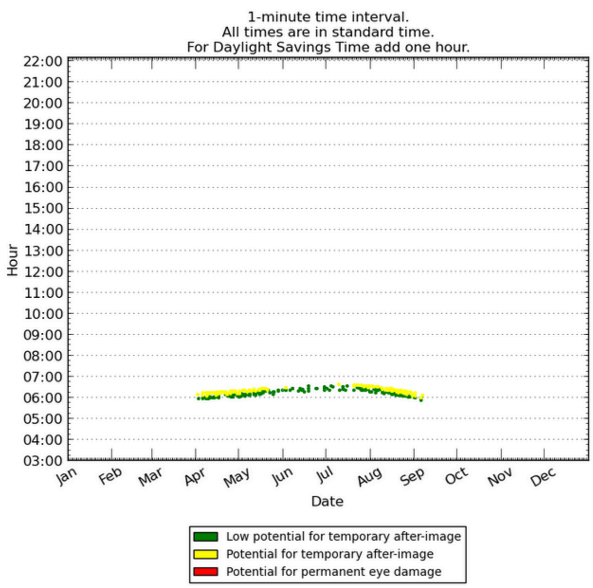
Observation Point: 4 - Residence #8



Observation Point: 5 - Residence #7



Observation Point: 11 - Residence #9



Observation Point: 19 - Residence #4