Glare Impact Study of Lake Herman Solar Facility

Thomas Cleveland, PE
Raleigh, NC
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Executive Summary

Photovoltaic (PV) modules (aka solar panels) are designed to absorb, and thus not reflect, close to 100% of the solar energy that strikes them. However, when sunlight strikes the glass front of a solar panel at a glancing angle a significant portion of the solar radiation is reflected, which can potentially lead to solar glint or glare impacting a person's vision, including pilots landing aircraft. Thankfully, the conditions required for a PV project to create hazardous glare rarely occur. Also, it is possible to use specialized 3-D modeling software to predict when and where glare may be produced, which allows adjustment of solar project designs before they are constructed in order to avoid the potential for glare hazards.

To avoid construction of solar PV projects that could create a solar glare hazard for aircraft, the Federal Aviation Administration (FAA) and the US Department of Energy's Sandia National Laboratories partnered to develop a software to calculate the potential for a PV project to create glare intense enough to be a hazard to nearby aviation. The software, called Solar Glare Hazard Analysis Tool (SGHAT), may also be used to assess the potential for a PV project to cause solar glare for other viewers, such as vehicle drivers on nearby roads and neighbors looking out of their windows.

The analysis presented in this report used a privately licensed version of the SGHAT software, called ForgeSolar, to conduct a detailed site-specific PV solar glare analysis of the proposed Lake Herman Solar project (Project). The software from ForgeSolar has been validated as effective for this type of solar glare analysis. The software analysis checks for the potential for low or high intensity solar glare for every minute of the year at many user-defined observation points and/or routes. Specifically, the analysis of the Lake Herman Solar project included the final approach flight paths for the six runways at Travis Air Force Base, the air traffic control tower at Travis Air Force Base, the 2-mile section of Lake Herman Road immediately south of the PV project, and buildings within about 1 mile of the site (see figure to the right for locations as modeled in ForgeSolar).

Observation Locations Analyzed in ForgeSolar: Flight Paths at Travis Air Force Base in upper right (red lines); Lake Herman Road 2-way route (aqua lines), and buildings (red OP# markers) [Cover image shows Lake Herman Road and building locations in detail]

The analysis predicts **no glare** of any intensity at any time during the year at any of the analyzed observation locations.

Background

At the request of RPCA Solar 4, LLC, I conducted an analysis of the potential for solar glare impacts by the proposed 5 MW_{AC} Lake Herman solar facility located on the northern city limits of Benicia, California. The study analyzed the potential for glare impacts to drivers on Lake Herman Road, pilots approaching the runways at Travis Air Force Base, the air traffic control tower at Travis Air Force Base, and residential and commercial neighbors within one mile.

Glare Impact Analysis

Figure 1: Glare coming directly from the Sun

Intense glare can create a visual hazard. Every experienced driver is familiar with the type of glare shown in the photo to the right that occurs when an auto driver is heading directly into the rising or setting sun. Similarly, airplane and helicopter pilots often fly in the direction of the sun and thus experience very intense glare directly from the sun itself. Pilots also experience glare from reflections off a variety of objects on the ground, such as metal roofs, bodies of water, and car windshields. Consequently, pilots fly with sunglasses and tinted visors to minimize this hazard. The reflected glare produced by these objects is not nearly as intense as direct sunlight. Like many other objects on or near the ground, reflections off solar panels (aka PV modules) can also cause glare visible to pilots. There is also the potential for solar panels on or very near the airport to cause distracting glare for air traffic controllers. Due to these potential hazards, the Federal Aviation Administration (FAA) and the US Department of Energy's Sandia National Laboratories collaborated to create an online software tool, known as the Solar Glare Hazard Analysis Tool, or SGHAT, to analyze solar photovoltaic projects for their potential to create hazardous solar glare. After multiple years of free public availability, access to the SGHAT tool was ended in 2017 and the SGHAT technology was licensed to a private company, ForgeSolar. ForgeSolar improved upon the original SGHAT technology and offers a private solar glare hazard analysis tool, which is the only such tool available today. The analysis presented in this report used the current professional ForgeSolar software.

The software calculates the potential for glare at each modeled observer (e.g approaching pilot, passing motorist, neighbor) for every minute of the year. The model knows the position of the sun each minute, assumes a cloud-free sky, and calculates the potential for glare from each section of the proposed solar facility. The software can calculate not only whether there is a possibility for glare each minute, but also the intensity of the glare. Thus, it can assess the degree of hazard any glare may present to pilots and motorists.

Modeling the Lake Herman Solar Facility

The models presented in this report use the default SGHAT values for model variables that are not site specific, such as the sun subtended angle of 9.3 milliradians and 0.017 meter eye focal length. All the model variables are visible in the ForgeSolar results reports included in the appendix of this report.

Figure 2 shows the location of the PV array in the ForgeSolar model. The array layout from a Lake Herman site plan containing satellite imagery was overlaid over the ForgeSolar software so that the PV array location in the model accurately represents the location of the array in the actual project. To be conservative the array in ForgeSolar extends all the way to the site's perimeter fence.

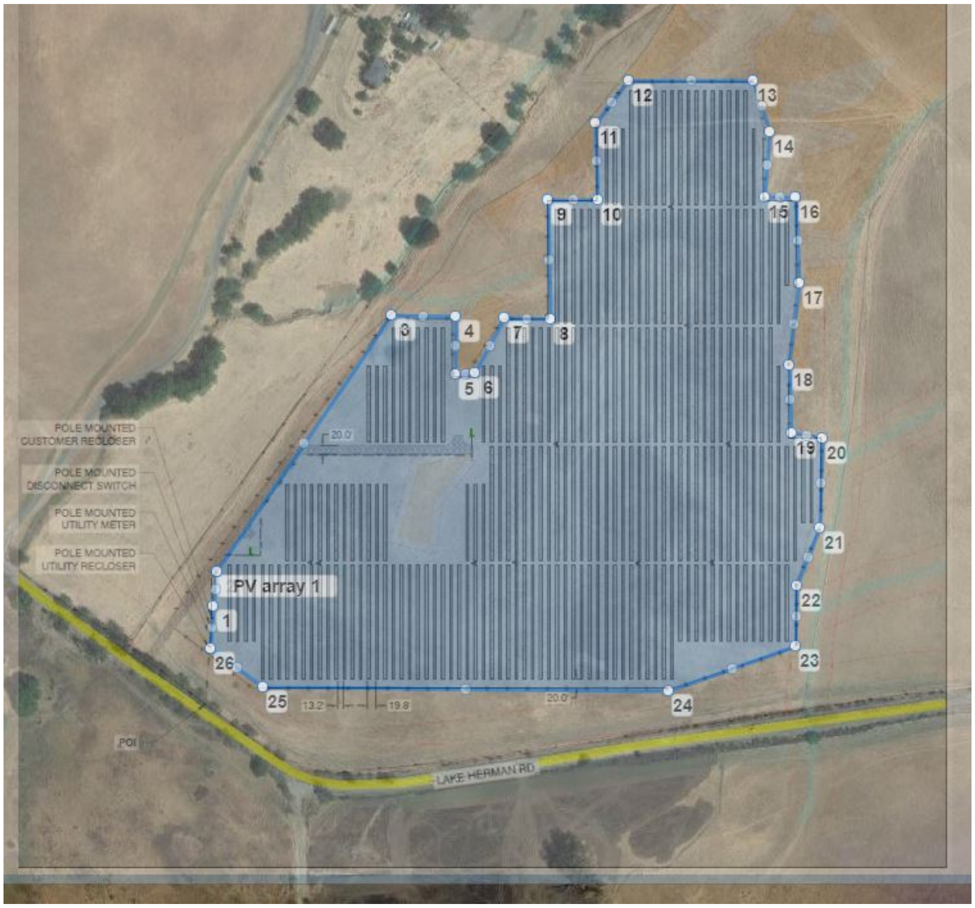

Figure 2. Lake Herman PV Array in ForgeSolar (blue area with numbered vertices) with Overlay of Lake Herman Site Plan Showing the Array Layout, Site Fence, and Satellite Imagery

The entire project uses single-axis tracking racking to mount the PV modules. As is typical for this type of PV module racking, the array at the Lake Herman site consists of 1-module-wide rows that are each oriented along a North-South line. This North-South line is also the axis of rotation of each row. The basic motion is that each row slowly rotates over the course of every day from a 60-degree tilt toward the east at sunrise to a 60-degree tilt toward the west by sunset. Around midday when the sun is at its highest position in the sky the rows of modules are horizontal, with each module facing straight up. The ForgeSolar analysis assumes that the rows remain tilted 60 degrees (from horizontal) to the west from the time of sunset each day until the time of sunrise the next day. In actuality the tracking system is likely to be more sophisticated and implement automatic backtracking, which means that near sunrise and sunset the rows will tilt less than the full 60 degrees in order to avoid each row partially shading the row behind it. Solar module electricity production is very sensitive to partial shading, so the system can produce more power by facing the modules a little more horizontal than otherwise optimal if it means avoiding one row shading another. This backtracking will increase the incidence angle of the sunlight on the modules which increases the reflectivity of the modules and thus the potential for glare impacts.

Unfortunately, the ForgeSolar software is not currently able to model automatic backtracking; however, additional ForgeSolar simulations were conducted to assess the glare impact of backtracking. Four additional systems were analyzed, two with the PV array facing west and with a fixed-tilt 45 degrees and 30 degrees from horizontal and another two facing east also with tilts of 45 and 30 degrees. The west-facing models represent a backtracked array near sunset and the east-facing models represent a backtracked array near sunrise.

For all SGHAT models in this report, the solar array is modeled at a height of 5 feet, representing a typical height for the center of each PV module. Models were also run with array heights of 2 feet and 8 feet, representing the bottom and top of the array, as recommended in the SGHAT user manual. The results of the 2-ft and 8-ft height models were the same as the model with a 5-foot array height, so for simplicity only the 5-foot array data is presented in this report.

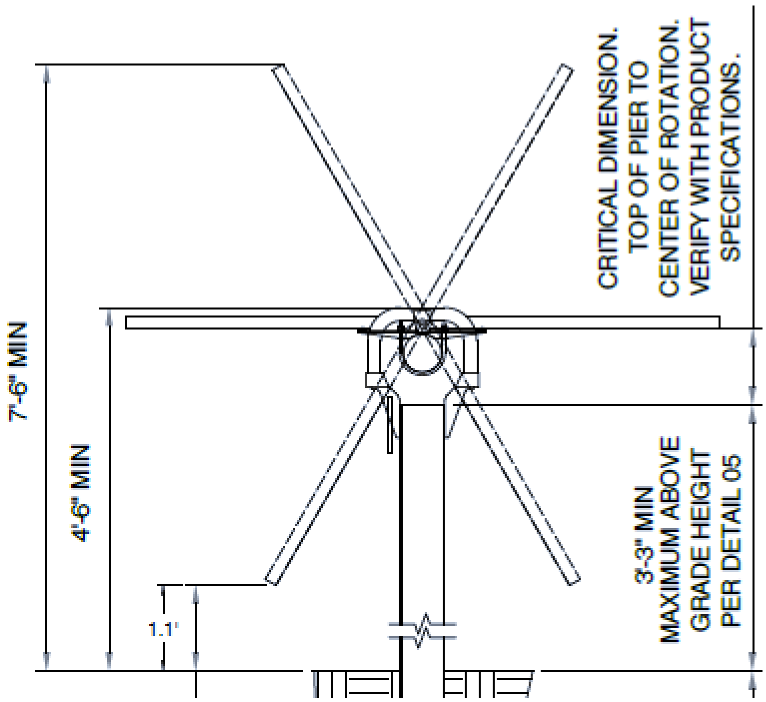

Figure 3. Diagram of PV Module Racking from the Lake Herman Solar Site Plan, Including Minimum Height Above Grade for Horizontal and Extreme Angles of Rotation

It is vital to realize that the software does _not_ take into account visual obstructions between the solar array and the observer. This includes both topographical barriers, such as a hill, and living or man-made barriers such as a forest or building. A comprehensive analysis of the visibility of the solar array from each observation route or point is not included in this report, although aerial 3D surface models clearly show that several of the nearby buildings and the air traffic control tower at Travis Air Force Bases have their view of the solar array, and thus any glare it may produce, blocked by elevated topography between the observation point and every part of the array. For simplicity no potential relevant observation points were omitted from the ForgeSolar analysis due to having no line of sight to the array; however, some potential residential observation points were omitted from the ForgeSolar analysis due to other building blocking their sight of the array and because other modeled observation points represent a closer observation point along the same line of sight.

Analysis of the Travis Air Force Base Airport (KSUU)

This analysis modeled the potential for glare hazards for Travis Air Force Base (KSUU), which is located about 14.1 miles northeast from the Lake Herman Solar project (measured from the threshold of the closest runway to the closest solar module). The Travis Air Force Base Land Use Compatibility Plan classifies all the land around the base as one of several impact zones (Zones A to E) depending on its potential to impact operations at the base with Zone A having the most potential for impact. The proposed site for the Lake Herman Solar project is in Zone D, which requires that any commercial-scale solar facility not create a glare hazard at the base. To comply the solar project must not create glare along any final approach path that is more intense than glare that has a “low potential for after-image”. Travis Air Force Base has six runways, Runway 3L/21R, Runway 03R/21L, and a shorter assault strip Runway 32/212. Each set of runways share the same physical runway but represent approaches from opposite ends. The specifics of the typical approach for each runway were set based on FAA data for Travis Air Force Base[1]. The airport also has an air traffic control tower located just to the northwest of the runways that was included in the solar glare analysis as Observation Point 20.

Figure 4. Location of Travis Air Force Base Airport in Relation to the Lake Herman Solar Project Site; 14.1 Miles Between Them Along the Red Line (Image is Oriented with North Toward the Top)

[1] Sourced from https://maps.avnwx.com/airport/KSUU which presents the current airport data provided by FAA (https://aeronav.faa.gov/afd/20jun2019/sw_233_20JUN2019.pdf) in a user-friendly format

Figure 5. Approach Flight Paths (Red Lines) to Travis Air Force Base's Six Runways and the Airports Air Traffic Control Tower ("20 – ATCT" slightly to the left of the center of the image), as Modeled in ForgeSolar

As specified in the Interim Policy for the FAA Review of Solar Energy System Projects on Federally Obligated Airports[2], the ForgeSolar software examines the last two miles of the landing approach to each runway. The analysis is limited to this portion of the flight path because severe glare during the final approach has the potential to create a hazard for the pilot, whereas severe glare earlier in the flight is generally a not hazard.

The SGHAT results for the Project were **no glare** of any intensity during any minute of the year for any of the flight paths and for the air traffic control tower. The four additional ForgeSolar models representing intelligent backtracking of the array near sunrise and sunset predicted **no glare** from a backtracking array.

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[2] "Interim Policy for the FAA Review of Solar Energy System Projects on Federally Obligated Airports.", http://www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf

Analysis of Potential Glare Impacts to Nearby Motorists

The proposed project is just to the north of Lake Herman Road, which is a small rural roadway, and was analyzed in ForgeSolar for any potential glare impacts from the proposed solar facility. The other nearby roads are small private roads with very limited traffic volume and slow traffic speeds, so these roads were not included in the ForgeSolar glare analysis. There are some rolling hills in the area, but the proposed solar facility is generally at the same elevation as Lake Herman Road. The rolling hills block view of the solar project along several portions of the road but there is limited vegetation to block motorists' views of the solar modules where there is no hill to impede view. Therefore, there are sections of Lake Herman road where the proposed solar project will be visible within 45 degrees of the automobile's direction of travel. The following two images from a 3D model of the site in Google Earth use elevated views from above the area to provide a sense of the views of the site for both the eastbound and westbound motorists on Lake Herman Road. The yellow area seen in these images show the location of the site footprint within the project's perimeter fence.

Figure 6. View from Southeast of the Solar Site from an Elevated Viewpoint across Lake Herman Road. Lake Herman is Visible in the Upper Left Corner of the Image. The Yellow Area is the site footprint within the perimeter fence.

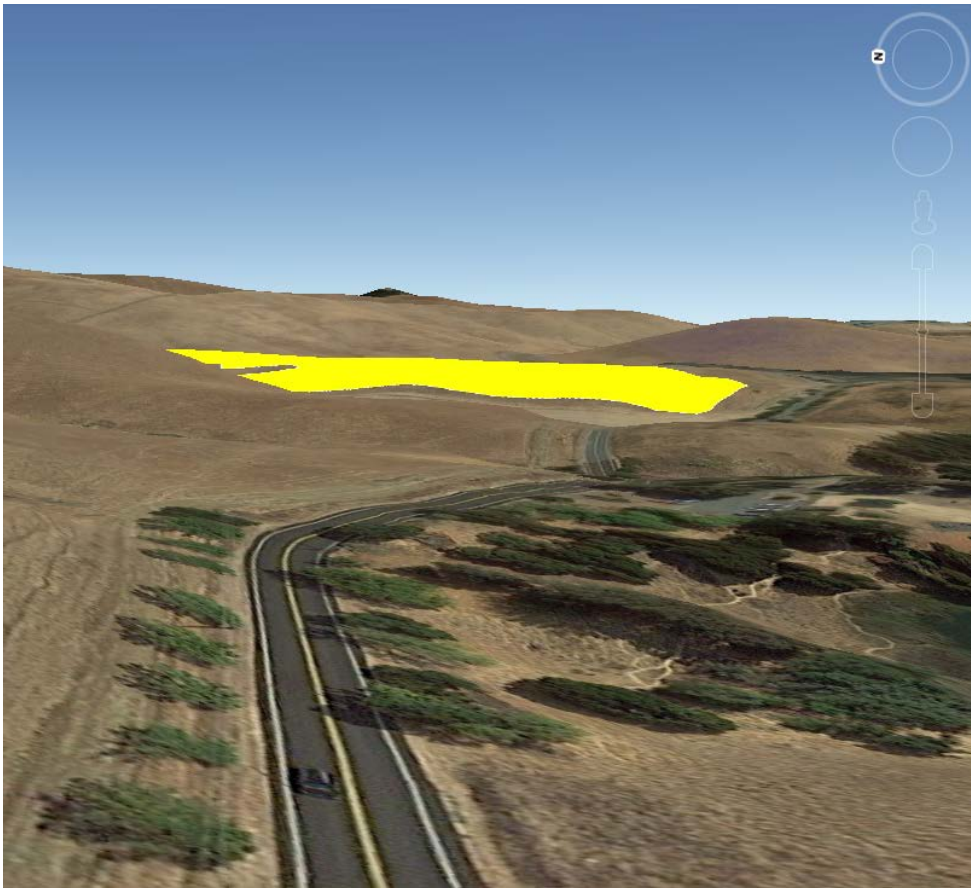

Figure 7. View Facing East from above Lake Herman Road to the West of the Solar Site from an Elevated Viewpoint

ForgeSolar provides a “route” type of observation location that is designed to model the potential for glare hazards along roads and other routes. One route was modeled in ForgeSolar as shown in Figure 8, which is analyzed by ForgeSolar as both an eastbound route and a westbound route. The route was modeled at 3.5 feet above the ground, to represent the height of a driver, per the American Association of State Highway and Transportation Officials (AASHTO) eye height of a driver of a passenger vehicle[3]. The software checks for glare from up to 50 degrees from the direction of travel. Studies of pilots have shown that glare from beyond 45 degrees from their direction of travel does not present any glare hazard, and it is reasonable to assume that the same holds true for motor vehicle drivers as well.

[3] A Policy on Geometric Design of Highways and Streets. American Association of State Highway and Transportation Officials, Washington, D. C., 2004 edition

Figure 8. Observation Route on Lake Herman Road (Aqua Line) as Modeled in ForgeSolar, Approximately 2 Miles End-to-End

The SGHAT results for the Project were **no glare** of any intensity during any minute of the year for motorists on Lake Herman Road. The four additional ForgeSolar models representing intelligent backtracking of the array near sunrise and sunset predicted **no glare** from a backtracking array for motorists on Lake Herman Road.

Analysis of Residential and Commercial Neighbors

There is only one occupied building closer than ½ mile from the proposed solar facility, which is a home about 1/10 of a mile to the northwest of the project. There are numerous residential, industrial, and commercial buildings between about ½ and 1 mile from the PV site. Twenty of these buildings were included in the ForgeSolar model (Observation Points 2 through 19, 21, and 22. Observation Point 20 is the air traffic control tower at Travis Air Force Base). There are additional buildings within a 1-mile radius of the solar facility, but these buildings are either unoccupied, have their view blocked by a building included in the analysis, or are represented by the analysis results of a nearby building included in the analysis. All but four of the buildings within 1 mile of the proposed site are in an area of development to the south of the project. Most of the buildings have their view of the Project at least partially blocked by higher ground between the building and the site, and some of the buildings have their view fully blocked by a hill. Rather than include a line-of-site to justify not modeling some buildings all appropriate buildings were simply included in the ForgeSolar analysis.

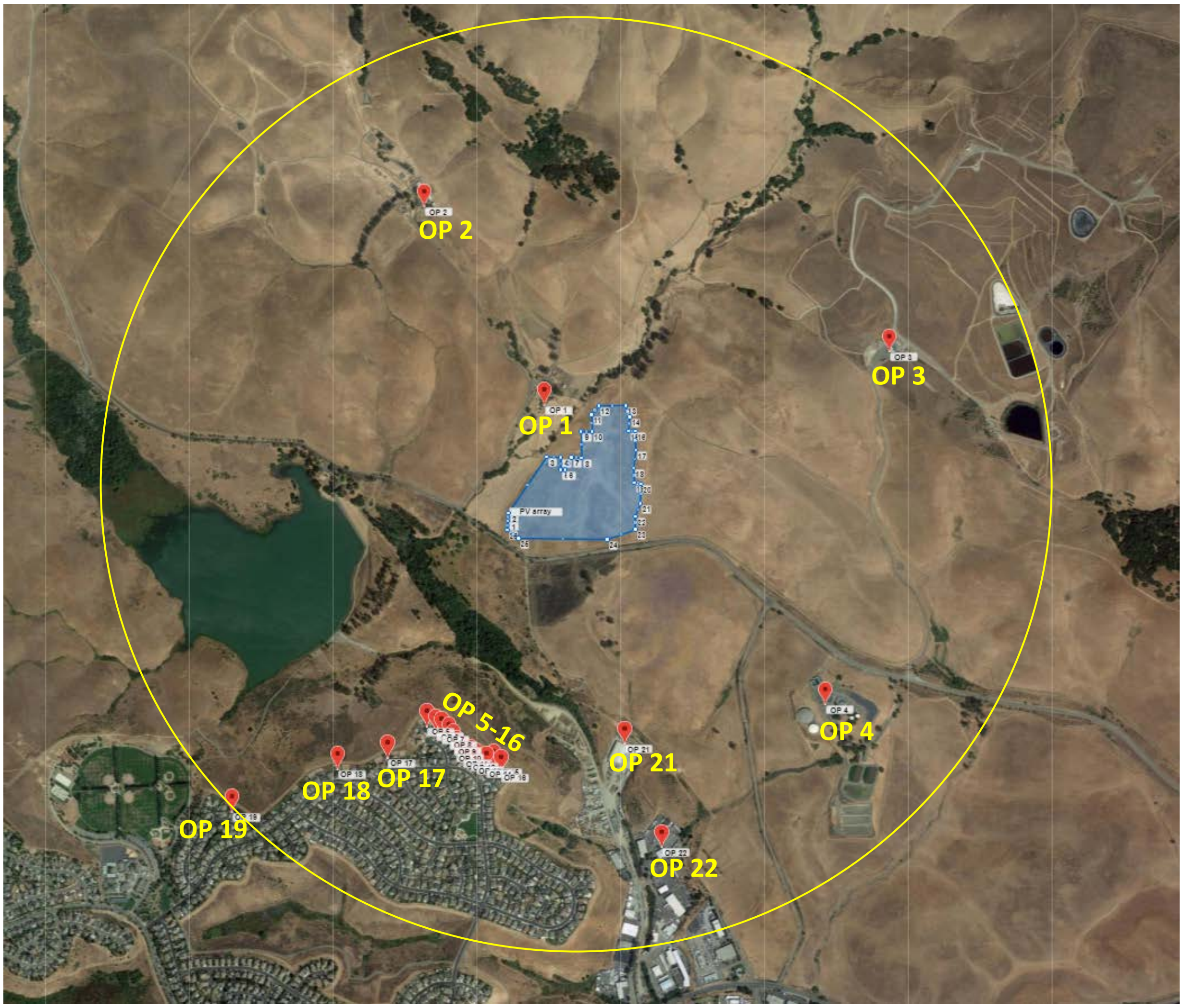

Figure 9. Residential and Non-Residential Buildings within 1 Mile Radius (Yellow Circle) of the Center of the Proposed Solar Facility Modeled in ForgeSolar (Observation Points, OP)

The SGHAT results for the Project were **no glare** of any intensity during any minute of the year for any of the observation points located at buildings. The four additional ForgeSolar models representing intelligent backtracking of the array near sunrise and sunset predicted **no glare** from a backtracking array for any of the observation points located at buildings.

SGHAT Results

As described above, the ForgeSolar SGHAT software was used to conduct a glare hazard analysis of pilots landing at Travis Air Force Base, air traffic controllers at Travis Air Force Base, motorists on Lake Herman Road, and people at nearby buildings. A summary of results is presented in this section of the report and the full ForgeSolar-generated report in provided in Appendix A.

The ForgeSolar SGHAT defines two intensities of glare, “green” and “yellow”. Green glare represents a “Low Potential for Temporary After-Image” and is about 1/1000th the intensity of looking directly into the sun (based on Hazards Plot in the SGHAT User's Manual)[4]. According to the FAA Interim solar policy[5], which defines the requirements for solar projects constructed on airport property, glare visible to pilots on their final landing approach that is classified in this green range is acceptable. In other words, any amount of green glare is considered non-hazardous. Yellow glare has a "Potential for Temporary After-Image"; such glare could affect the pilot's ability so see clearly even after looking away from the glare. The FAA Interim solar policy (which only has authority for solar built on airports) does not allow solar arrays that produce yellow glare visible to pilots on final approach to be built on airport property. The ForgeSolar results use the same green and yellow glare classifications for glare visible at other types of observation points as well, such as to motorists and pedestrians.

The ForgeSolar SGHAT results for the Project were **no glare** of any intensity during any minute of the year for every flight path, air traffic control tower, roadway route, and the land-based observation point. As described in the *Modeling the Lake Herman Solar Facility* section, additional ForgeSolar models were constructed to simulate intelligent backtracking by the tracking system early and late in the day to avoid inter-row shading. When backtracking the modules are turned away from the sun and thus have more potential to create a glare hazard. The results of these simulations showed that backtracked rows (45 and 30 degrees from horizontal) did not produce any glare during the hours near sunrise and sunset in which backtracking may be used. The models did predict some glare near noon, but this glare result is meaningless because the array will be tracking the sun at this time of day and not in a backtracked position at that time. The ForgeSolar-generated reports for the 30-tilt east-facing and west-facing are provided in Appendix B and Appendix C respectively.

Conclusion

The solar glare hazard analysis of the proposed Lake Herman solar facility finds that the PV system will not produce any glare hazards. ForgeSolar, a detailed, proven solar glare hazard analysis software, was used to model the potential for the proposed solar array to cause glare for approaching motorists, people at nearby buildings, and pilots and air traffic controllers at Travis Air Force Base. In fact, the software analysis found **no glare of any intensity at any time during the year at any of the analyzed locations**. The proposed PV project uses a single-axis tracking racking system to support the solar modules/panels which keeps the solar modules generally facing toward the sun. This design avoids situations where the sunlight hits the solar panels with a glancing angle, which is when the glass of a solar panel is reflective and thus has a potential to cause visible glare to an observer.

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[4] *Solar Glare Hazard Analysis Tool Users Manual version 2.0*, https://share.sandia.gov/phlux/static/references/glint-glare/SGHAT_Users_Manual_v2-0_final.pdf

[5] *Interim Policy for the FAA Review of Solar Energy System Projects on Federally Obligated Airports*, http://www.gpo.gov/fdsys/pkg/FR-2013-10-23/pdf/2013-24729.pdf

Appendix A: SGHAT/ForgeSolar Results Report

ForgeSolar Glare Analysis Report – Page 1 of 13

FORGESOLAR GLARE ANALYSIS

Project: **Lake Herman**

Proposed 5 MW solar facility on Lake Herman Rd. in Benicia California near Travis Air Force Base. Will use single axis tracking array

Site configuration: **Baseline**

Analysis conducted by Tommy Cleveland (thcleveland@gmail.com) at 05:10 on 21 Jul, 2019.

U.S. FAA 2013 Policy Adherence

The following table summarizes the policy adherence of the glare analysis based on the 2013 U.S. Federal Aviation Administration Interim Policy 78 FR 63276. This policy requires the following criteria be met for solar energy systems on airport property:

- No "yellow" glare (potential for after-image) for any flight path from threshold to 2 miles
- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics (see list below)

ForgeSolar does not represent or speak officially for the FAA and cannot approve or deny projects. Results are informational only.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
Flight path(s)	PASS	Flight path receptor(s) do not receive yellow glare
ATCT(s)	PASS	Receptor(s) marked as ATCT do not receive glare

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

FAA Policy 78 FR 63276 can be read at https://www.federalregister.gov/d/2013-24729

ForgeSolar Glare Analysis Report – Page 2 of 13

SITE CONFIGURATION

Analysis Parameters

DNI: peaks at 1,000.0 W/m^2
Time interval: 1 min
Ocular transmission coefficient: 0.5
Pupil diameter: 0.002 m
Eye focal length: 0.017 m
Sun subtended angle: 9.3 mrad
Site Config ID: 29667.5349

ForgeSolar Glare Analysis Report – Page 3 of 13

PV Array(s)

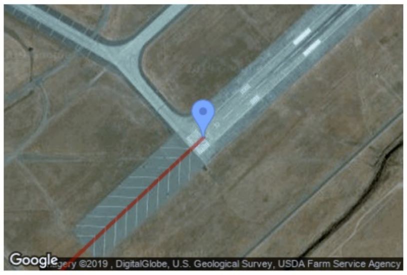
Name: PV array
Axis tracking: Single-axis rotation
Tracking axis orientation: 180.0°
Tracking axis tilt: 0.0°
Tracking axis panel offset: 0.0°
Max tracking angle: 60.0°
Resting angle: 60.0°
Rated power: 5000.0 kW
Panel material: Smooth glass without AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.096105	-122.144826	106.95	5.00	111.95
2	38.096333	-122.144794	108.88	5.00	113.88
3	38.098021	-122.143334	116.12	5.00	121.12
4	38.098013	-122.142798	130.51	5.00	135.51
5	38.097633	-122.142798	145.05	5.00	150.05
6	38.097641	-122.142637	150.85	5.00	155.85
7	38.098004	-122.142390	142.65	5.00	147.65
8	38.097996	-122.142004	150.95	5.00	155.95
9	38.098781	-122.142026	154.44	5.00	159.44
10	38.098781	-122.141607	158.77	5.00	163.77
11	38.099288	-122.141629	142.58	5.00	147.58
12	38.099566	-122.141350	161.93	5.00	166.93
13	38.099566	-122.140309	188.83	5.00	193.83
14	38.099229	-122.140169	193.00	5.00	198.00
15	38.098798	-122.140212	183.89	5.00	188.89
16	38.098798	-122.139955	182.04	5.00	187.04
17	38.098232	-122.139923	168.46	5.00	173.46
18	38.097692	-122.140008	160.23	5.00	165.23
19	38.097244	-122.139987	146.89	5.00	151.89
20	38.097211	-122.139730	139.04	5.00	144.04
21	38.096620	-122.139751	131.05	5.00	136.05
22	38.096240	-122.139944	121.39	5.00	126.39
23	38.095843	-122.139955	115.49	5.00	120.50
24	38.095547	-122.141017	145.56	5.00	150.56
25	38.095573	-122.144407	128.45	5.00	133.45
26	38.095826	-122.144847	104.06	5.00	109.06

ForgeSolar Glare Analysis Report – Page 4 of 13

Flight Path Receptor(s)

Name: Runway 03L
Description:
Threshold height: 75 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.243510	-121.956684	32.62	75.00	107.63
Two-mile	38.223792	-121.983639	3.64	657.44	661.08

Name: Runway 03R
Description:
Threshold height: 69 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.261684	-121.926204	52.29	69.00	121.29
Two-mile	38.241965	-121.953166	19.57	655.17	674.75

Name: Runway 212 (assault strip)
Description:
Threshold height: 50 ft
Direction: 226.9°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.280787	-121.897193	52.14	50.00	102.14
Two-mile	38.300545	-121.870272	37.97	617.63	655.60

ForgeSolar Glare Analysis Report – Page 5 of 13

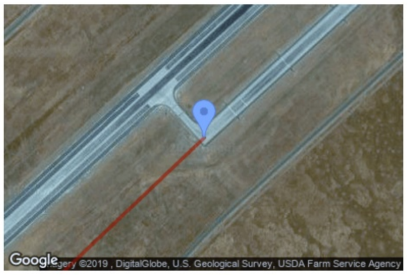
Name: Runway 21L
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.281560	-121.898514	53.07	75.00	128.08
Two-mile	38.301279	-121.871545	37.42	644.11	681.53

Name: Runway 21R
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.263417	-121.928980	48.70	75.00	123.70
Two-mile	38.283136	-121.902017	46.98	630.18	677.15

Name: Runway 32 (assault strip)
Description:
Threshold height: 50 ft
Direction: 46.4°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



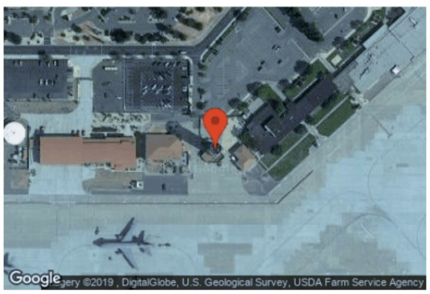
Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.273315	-121.907571	58.49	50.00	108.49
Two-mile	38.253380	-121.934277	39.73	622.21	661.94

ForgeSolar Glare Analysis Report – Page 6 of 13

Discrete Observation Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	38.099556	-122.143422	116.45	6.00
OP 2	2	38.105524	-122.148023	186.99	6.00
OP 3	3	38.101159	-122.130236	392.05	6.00
OP 4	4	38.090553	-122.132693	254.76	6.00
OP 5	5	38.089899	-122.147898	204.10	6.00
OP 6	6	38.089743	-122.147560	202.99	6.00
OP 7	7	38.089662	-122.147346	201.52	6.00
OP 8	8	38.089502	-122.147077	198.72	6.00
OP 9	9	38.089316	-122.146900	198.50	6.00
OP 10	10	38.089109	-122.146788	196.28	6.00
OP 11	11	38.088932	-122.146535	191.32	6.00
OP 12	12	38.088835	-122.146262	189.79	6.00
OP 13	13	38.088733	-122.146037	187.96	6.00
OP 14	14	38.088641	-122.145629	188.97	6.00
OP 15	15	38.088691	-122.145345	190.06	6.00
OP 16	16	38.088522	-122.145076	189.01	6.00
OP 17	17	38.088964	-122.149402	220.54	6.00
OP 18	18	38.088617	-122.151312	249.51	6.00
OP 19	19	38.087342	-122.155356	248.27	6.00
20-ATCT	20	38.265538	-121.933272	51.83	100.00
OP 21	21	38.089387	-122.140280	42.90	6.00
OP 22	22	38.086251	-122.139004	41.33	6.00

Map image of 20-ATCT



ForgeSolar Glare Analysis Report – Page 7 of 13

Route Receptor(s)

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.098603	-122.156958	147.86	3.50	151.36
2	38.098464	-122.154163	151.17	3.50	154.67
3	38.098411	-122.152891	146.38	3.50	149.88
4	38.098283	-122.152460	145.63	3.50	149.13
5	38.097681	-122.151210	127.57	3.50	131.07
6	38.097535	-122.150708	114.88	3.50	118.38
7	38.097267	-122.148975	103.07	3.50	106.57
8	38.097105	-122.148418	117.17	3.50	120.67
9	38.096507	-122.146875	85.81	3.50	89.31
10	38.095543	-122.145159	100.36	3.50	103.86
11	38.095207	-122.144547	120.38	3.50	123.88
12	38.095026	-122.144196	127.21	3.50	130.71
13	38.094924	-122.143858	131.01	3.50	134.51
14	38.094922	-122.143316	134.99	3.50	138.49
15	38.095232	-122.140725	137.78	3.50	141.28
16	38.095517	-122.138239	136.33	3.50	139.83
17	38.095431	-122.137447	148.37	3.50	151.87
18	38.095277	-122.137005	148.82	3.50	152.32
19	38.095045	-122.136624	145.33	3.50	148.83
20	38.094711	-122.136243	139.69	3.50	143.19
21	38.093616	-122.134698	130.76	3.50	134.26
22	38.092566	-122.132939	153.79	3.50	157.29
23	38.091918	-122.131833	176.45	3.50	179.95
24	38.091621	-122.130903	182.10	3.50	185.60
25	38.091015	-122.128041	180.03	3.50	183.53
26	38.090618	-122.125619	197.60	3.50	201.10

ForgeSolar Glare Analysis Report – Page 8 of 13

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt (°)	Orient (°)	"Green" Glare min	"Yellow" Glare min	Energy kWh
PV array	SA tracking	SA tracking	0	0	15,490,000.0

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	0	0
OP 21	0	0

ForgeSolar Glare Analysis Report – Page 9 of 13

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
OP 22	0	0
Route 1	0	0

Results for: PV array

Receptor	Green Glare (min)	Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	0	0
OP 2	0	0
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	0	0
OP 21	0	0
OP 22	0	0
Route 1	0	0

Flight Path: Runway 03L

0 minutes of yellow glare
0 minutes of green glare

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Flight Path: Runway 03R

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 212 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21L

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21R

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 32 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 1

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare

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0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 13

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 14

0 minutes of yellow glare
0 minutes of green glare

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Point Receptor: OP 15

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 16

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 17

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 18

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 19

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: 20-ATCT

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 21

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 22

0 minutes of yellow glare
0 minutes of green glare

Route: Route 1

0 minutes of yellow glare
0 minutes of green glare

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Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
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. This includes buildings, tree cover and geographic obstructions.
Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare.
The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual results and glare occurrence may differ.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.

Appendix B: SGHAT/ForgeSolar Results Report for Sunrise Backtrack Simulation

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 1 of 13

FORGESOLAR GLARE ANALYSIS

Project: **Lake Herman**
Proposed 5 MW solar facility on Lake Herman Rd. in Benicia California near Travis Air Force Base. Will use single axis tracking array

Site configuration: **East facing fixed 30-tilt to simulate backtracking**
Analysis conducted by Tommy Cleveland (thcleveland@gmail.com) at 03:12 on 21 Jul, 2019.

U.S. FAA 2013 Policy Adherence

The following table summarizes the policy adherence of the glare analysis based on the 2013 U.S. Federal Aviation Administration Interim Policy 78 FR 63276. This policy requires the following criteria be met for solar energy systems on airport property:

- No "yellow" glare (potential for after-image) for any flight path from threshold to 2 miles
- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics (see list below)

ForgeSolar does not represent or speak officially for the FAA and cannot approve or deny projects. Results are informational only.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
Flight path(s)	PASS	Flight path receptor(s) do not receive yellow glare
ATCT(s)	FAIL	Receptor(s) marked as ATCT receive green and/or yellow glare

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

FAA Policy 78 FR 63276 can be read at https://www.federalregister.gov/d/2013-24729

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 2 of 13

SITE CONFIGURATION

Analysis Parameters

DNI: peaks at 1,000.0 W/m^2
Time interval: 1 min
Ocular transmission coefficient: 0.5
Pupil diameter: 0.002 m
Eye focal length: 0.017 m
Sun subtended angle: 9.3 mrad
Site Config ID: 29690.5349

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 3 of 13

PV Array(s)

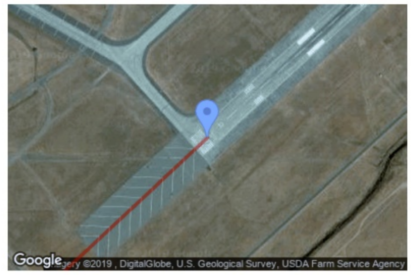
Name: PV array
Axis tracking: Fixed (no rotation)
Tilt: 30.0°
Orientation: 90.0°
Rated power: 5000.0 kW
Panel material: Smooth glass without AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.096105	-122.144826	106.95	5.00	111.95
2	38.096333	-122.144794	108.88	5.00	113.88
3	38.098021	-122.143334	116.12	5.00	121.12
4	38.098013	-122.142798	130.51	5.00	135.51
5	38.097633	-122.142798	145.05	5.00	150.05
6	38.097641	-122.142637	150.85	5.00	155.85
7	38.098004	-122.142390	142.65	5.00	147.65
8	38.097996	-122.142004	150.95	5.00	155.95
9	38.098781	-122.142026	154.44	5.00	159.44
10	38.098781	-122.141607	158.77	5.00	163.77
11	38.099288	-122.141629	142.58	5.00	147.58
12	38.099566	-122.141350	161.93	5.00	166.93
13	38.099566	-122.140309	188.83	5.00	193.83
14	38.099229	-122.140169	193.00	5.00	198.00
15	38.098798	-122.140212	183.89	5.00	188.89
16	38.098798	-122.139955	182.04	5.00	187.04
17	38.098232	-122.139923	168.46	5.00	173.46
18	38.097692	-122.140008	160.23	5.00	165.23
19	38.097244	-122.139987	146.89	5.00	151.89
20	38.097211	-122.139730	139.04	5.00	144.04
21	38.096620	-122.139751	131.05	5.00	136.05
22	38.096240	-122.139944	121.39	5.00	126.39
23	38.095843	-122.139955	115.49	5.00	120.50
24	38.095547	-122.141017	145.56	5.00	150.56
25	38.095573	-122.144407	128.45	5.00	133.45
26	38.095826	-122.144847	104.06	5.00	109.06

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 4 of 13

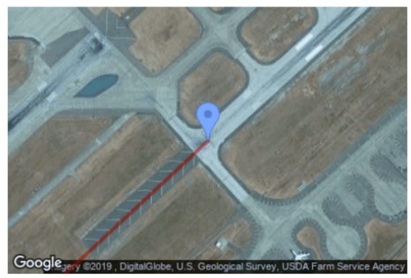
Flight Path Receptor(s)

Name: Runway 03L
Description:
Threshold height: 75 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.243510	-121.956684	32.62	75.00	107.63
Two-mile	38.223792	-121.983639	3.64	657.44	661.08

Name: Runway 03R
Description:
Threshold height: 69 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.261684	-121.926204	52.29	69.00	121.29
Two-mile	38.241965	-121.953166	19.57	655.17	674.75

Name: Runway 212 (assault strip)
Description:
Threshold height: 50 ft
Direction: 226.9°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.280787	-121.897193	52.14	50.00	102.14
Two-mile	38.300545	-121.870272	37.97	617.63	655.60

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 5 of 13

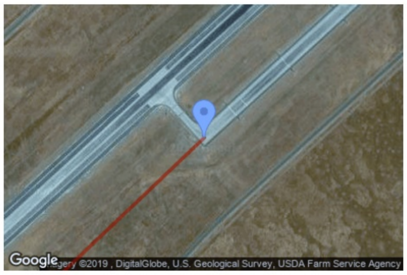
Name: Runway 21L
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.281560	-121.898514	53.07	75.00	128.08
Two-mile	38.301279	-121.871545	37.42	644.11	681.53

Name: Runway 21R
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.263417	-121.928980	48.70	75.00	123.70
Two-mile	38.283136	-121.902017	46.98	630.18	677.15

Name: Runway 32 (assault strip)
Description:
Threshold height: 50 ft
Direction: 46.4°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



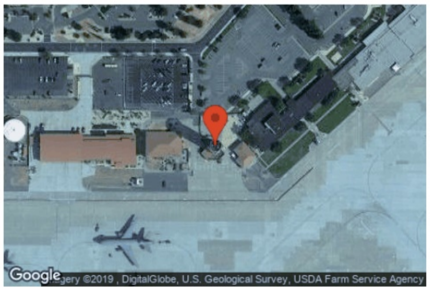
Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.273315	-121.907571	58.49	50.00	108.49
Two-mile	38.253380	-121.934277	39.73	622.21	661.94

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 6 of 13

Discrete Observation Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	38.099556	-122.143422	116.45	6.00
OP 2	2	38.105524	-122.148023	186.99	6.00
OP 3	3	38.101159	-122.130236	392.05	6.00
OP 4	4	38.090553	-122.132693	254.76	6.00
OP 5	5	38.089899	-122.147898	204.10	6.00
OP 6	6	38.089743	-122.147560	202.99	6.00
OP 7	7	38.089662	-122.147346	201.52	6.00
OP 8	8	38.089502	-122.147077	198.72	6.00
OP 9	9	38.089316	-122.146900	198.50	6.00
OP 10	10	38.089109	-122.146788	196.28	6.00
OP 11	11	38.088932	-122.146535	191.32	6.00
OP 12	12	38.088835	-122.146262	189.79	6.00
OP 13	13	38.088733	-122.146037	187.96	6.00
OP 14	14	38.088641	-122.145629	188.97	6.00
OP 15	15	38.088691	-122.145345	190.06	6.00
OP 16	16	38.088522	-122.145076	189.01	6.00
OP 17	17	38.088964	-122.149402	220.54	6.00
OP 18	18	38.088617	-122.151312	249.51	6.00
OP 19	19	38.087342	-122.155356	248.27	6.00
20-ATCT	20	38.265538	-121.933272	51.83	100.00

Map image of 20-ATCT



ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page7 of 13

Route Receptor(s)

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.098603	-122.156958	147.86	3.50	151.36
2	38.098464	-122.154163	151.17	3.50	154.67
3	38.098411	-122.152891	146.38	3.50	149.88
4	38.098283	-122.152460	145.63	3.50	149.13
5	38.097681	-122.151210	127.57	3.50	131.07
6	38.097535	-122.150708	114.88	3.50	118.38
7	38.097267	-122.148975	103.07	3.50	106.57
8	38.097105	-122.148418	117.17	3.50	120.67
9	38.096507	-122.146875	85.81	3.50	89.31
10	38.095543	-122.145159	100.36	3.50	103.86
11	38.095207	-122.144547	120.38	3.50	123.88
12	38.095026	-122.144196	127.21	3.50	130.71
13	38.094924	-122.143858	131.01	3.50	134.51
14	38.094922	-122.143316	134.99	3.50	138.49
15	38.095232	-122.140725	137.78	3.50	141.28
16	38.095517	-122.138239	136.33	3.50	139.83
17	38.095431	-122.137447	148.37	3.50	151.87
18	38.095277	-122.137005	148.82	3.50	152.32
19	38.095045	-122.136624	145.33	3.50	148.83
20	38.094711	-122.136243	139.69	3.50	143.19
21	38.093616	-122.134698	130.76	3.50	134.26
22	38.092566	-122.132939	153.79	3.50	157.29
23	38.091918	-122.131833	176.45	3.50	179.95
24	38.091621	-122.130903	182.10	3.50	185.60
25	38.091015	-122.128041	180.03	3.50	183.53
26	38.090618	-122.125619	197.60	3.50	201.10

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 8 of 13

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt	Orient	"Green" Glare	"Yellow" Glare	Energy
	(°)	(°)	min	min	kWh
PV array	30.0	90.0	3,743	0	9,191,000.0

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	0	0
OP 2	0	0
OP 3	3697	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	46	0
Route 1	0	0

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 9 of 13

Results for: PV array

Receptor	Green Glare (min)	Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	0	0
OP 2	0	0
OP 3	3697	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	46	0
Route 1	0	0

Flight Path: Runway 03L

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 03R

0 minutes of yellow glare
0 minutes of green glare

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 10 of 13

Flight Path: Runway 212 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21L

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21R

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 32 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 1

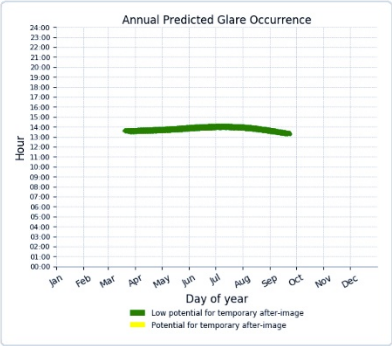
0 minutes of yellow glare
0 minutes of green glare

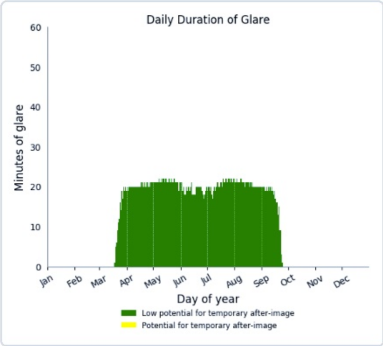
Point Receptor: OP 2

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 3

0 minutes of yellow glare
3697 minutes of green glare





ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 11 of 13

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 13

0 minutes of yellow glare

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 12 of 13

0 minutes of green glare

Point Receptor: OP 14

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 15

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 16

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 17

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 18

0 minutes of yellow glare
0 minutes of green glare

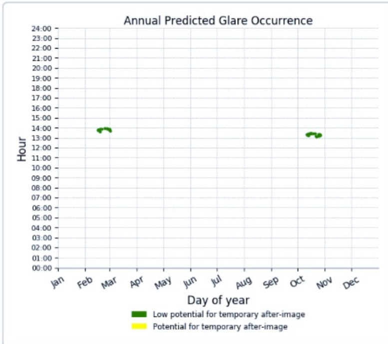
Point Receptor: OP 19

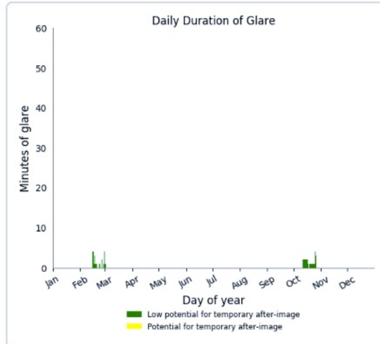
0 minutes of yellow glare
0 minutes of green glare

Point Receptor: 20-ATCT

0 minutes of yellow glare
46 minutes of green glare

ForgeSolar Glare Analysis Report (Sunrise Backtrack Simulation) – Page 13 of 13





Route: Route 1

0 minutes of yellow glare
0 minutes of green glare

Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
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. This includes buildings, tree cover and geographic obstructions.
Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare.
The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual results and glare occurrence may differ.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.

Appendix C: SGHAT/ForgeSolar Results Report for Sunset Backtrack Simulation

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 1 of 13

ForgeSolar
PV planning & glare analysis

FORGESOLAR GLARE ANALYSIS

Project: **Lake Herman**

Proposed 5 MW solar facility on Lake Herman Rd. in Benicia California near Travis Air Force Base. Will use single axis tracking array

Site configuration: **west facing 30 fixed tilt to simulate backtracking**

Analysis conducted by Tommy Cleveland (thcleveland@gmail.com) at 02:28 on 21 Jul, 2019.

U.S. FAA 2013 Policy Adherence

The following table summarizes the policy adherence of the glare analysis based on the 2013 U.S. Federal Aviation Administration Interim Policy 78 FR 63276. This policy requires the following criteria be met for solar energy systems on airport property:

- No "yellow" glare (potential for after-image) for any flight path from threshold to 2 miles
- No glare of any kind for Air Traffic Control Tower(s) ("ATCT") at cab height.
- Default analysis and observer characteristics (see list below)

ForgeSolar does not represent or speak officially for the FAA and cannot approve or deny projects. Results are informational only.

COMPONENT	STATUS	DESCRIPTION
Analysis parameters	PASS	Analysis time interval and eye characteristics used are acceptable
Flight path(s)	PASS	Flight path receptor(s) do not receive yellow glare
ATCT(s)	PASS	Receptor(s) marked as ATCT do not receive glare

Default glare analysis parameters and observer eye characteristics (for reference only):

- Analysis time interval: 1 minute
- Ocular transmission coefficient: 0.5
- Pupil diameter: 0.002 meters
- Eye focal length: 0.017 meters
- Sun subtended angle: 9.3 milliradians

FAA Policy 78 FR 63276 can be read at https://www.federalregister.gov/d/2013-24729

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 2 of 13

SITE CONFIGURATION

Analysis Parameters

DNI: peaks at 1,000.0 W/m^2
Time interval: 1 min
Ocular transmission coefficient: 0.5
Pupil diameter: 0.002 m
Eye focal length: 0.017 m
Sun subtended angle: 9.3 mrad
Site Config ID: 29688.5349

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 3 of 13

PV Array(s)

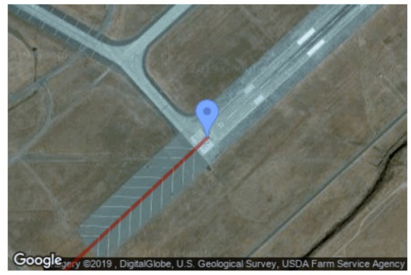
Name: PV array
Axis tracking: Fixed (no rotation)
Tilt: 30.0°
Orientation: 270.0°
Rated power: 5000.0 kW
Panel material: Smooth glass without AR coating
Reflectivity: Vary with sun
Slope error: correlate with material

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.096105	-122.144826	106.95	5.00	111.95
2	38.096333	-122.144794	108.88	5.00	113.88
3	38.098021	-122.143334	116.12	5.00	121.12
4	38.098013	-122.142798	130.51	5.00	135.51
5	38.097633	-122.142798	145.05	5.00	150.05
6	38.097641	-122.142637	150.85	5.00	155.85
7	38.098004	-122.142390	142.65	5.00	147.65
8	38.097996	-122.142004	150.95	5.00	155.95
9	38.098781	-122.142026	154.44	5.00	159.44
10	38.098781	-122.141607	158.77	5.00	163.77
11	38.099288	-122.141629	142.58	5.00	147.58
12	38.099566	-122.141350	161.93	5.00	166.93
13	38.099566	-122.140309	188.83	5.00	193.83
14	38.099229	-122.140169	193.00	5.00	198.00
15	38.098798	-122.140212	183.89	5.00	188.89
16	38.098798	-122.139955	182.04	5.00	187.04
17	38.098232	-122.139923	168.46	5.00	173.46
18	38.097692	-122.140008	160.23	5.00	165.23
19	38.097244	-122.139987	146.89	5.00	151.89
20	38.097211	-122.139730	139.04	5.00	144.04
21	38.096620	-122.139751	131.05	5.00	136.05
22	38.096240	-122.139944	121.39	5.00	126.39
23	38.095843	-122.139955	115.49	5.00	120.50
24	38.095547	-122.141017	145.56	5.00	150.56
25	38.095573	-122.144407	128.45	5.00	133.45
26	38.095826	-122.144847	104.06	5.00	109.06

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 4 of 13

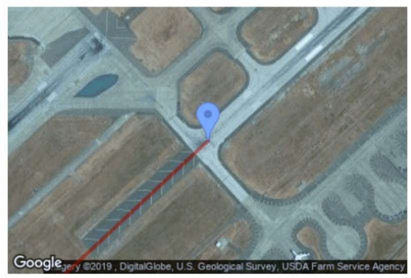
Flight Path Receptor(s)

Name: Runway 03L
Description:
Threshold height: 75 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.243510	-121.956684	32.62	75.00	107.63
Two-mile	38.223792	-121.983639	3.64	657.44	661.08

Name: Runway 03R
Description:
Threshold height: 69 ft
Direction: 47.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.261684	-121.926204	52.29	69.00	121.29
Two-mile	38.241965	-121.953166	19.57	655.17	674.75

Name: Runway 212 (assault strip)
Description:
Threshold height: 50 ft
Direction: 226.9°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.280787	-121.897193	52.14	50.00	102.14
Two-mile	38.300545	-121.870272	37.97	617.63	655.60

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 5 of 13

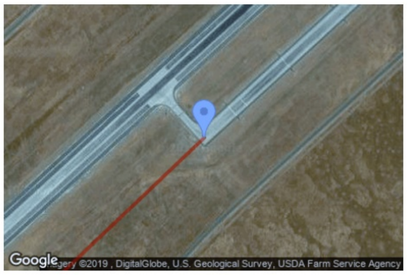
Name: Runway 21L
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.281560	-121.898514	53.07	75.00	128.08
Two-mile	38.301279	-121.871545	37.42	644.11	681.53

Name: Runway 21R
Description:
Threshold height: 75 ft
Direction: 227.0°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°

Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.263417	-121.928980	48.70	75.00	123.70
Two-mile	38.283136	-121.902017	46.98	630.18	677.15

Name: Runway 32 (assault strip)
Description:
Threshold height: 50 ft
Direction: 46.4°
Glide slope: 3.0°
Pilot view restricted? Yes
Vertical view: 30.0°
Azimuthal view: 50.0°



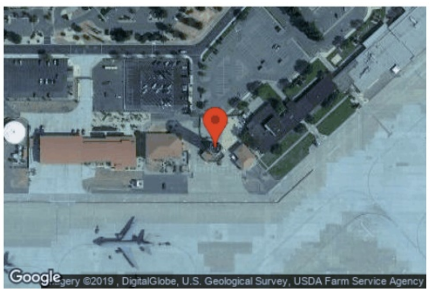
Point	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
Threshold	38.273315	-121.907571	58.49	50.00	108.49
Two-mile	38.253380	-121.934277	39.73	622.21	661.94

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 6 of 13

Discrete Observation Receptors

Name	ID	Latitude (°)	Longitude (°)	Elevation (ft)	Height (ft)
OP 1	1	38.099556	-122.143422	116.45	6.00
OP 2	2	38.105524	-122.148023	186.99	6.00
OP 3	3	38.101159	-122.130236	392.05	6.00
OP 4	4	38.090553	-122.132693	254.76	6.00
OP 5	5	38.089899	-122.147898	204.10	6.00
OP 6	6	38.089743	-122.147560	202.99	6.00
OP 7	7	38.089662	-122.147346	201.52	6.00
OP 8	8	38.089502	-122.147077	198.72	6.00
OP 9	9	38.089316	-122.146900	198.50	6.00
OP 10	10	38.089109	-122.146788	196.28	6.00
OP 11	11	38.088932	-122.146535	191.32	6.00
OP 12	12	38.088835	-122.146262	189.79	6.00
OP 13	13	38.088733	-122.146037	187.96	6.00
OP 14	14	38.088641	-122.145629	188.97	6.00
OP 15	15	38.088691	-122.145345	190.06	6.00
OP 16	16	38.088522	-122.145076	189.01	6.00
OP 17	17	38.088964	-122.149402	220.54	6.00
OP 18	18	38.088617	-122.151312	249.51	6.00
OP 19	19	38.087342	-122.155356	248.27	6.00
20-ATCT	20	38.265538	-121.933272	51.83	100.00

Map image of 20-ATCT



ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 7 of 13

Route Receptor(s)

Name: Route 1
Path type: Two-way
Observer view angle: 50.0°

Vertex	Latitude (°)	Longitude (°)	Ground elevation (ft)	Height above ground (ft)	Total elevation (ft)
1	38.098603	-122.156958	147.86	3.50	151.36
2	38.098464	-122.154163	151.17	3.50	154.67
3	38.098411	-122.152891	146.38	3.50	149.88
4	38.098283	-122.152460	145.63	3.50	149.13
5	38.097681	-122.151210	127.57	3.50	131.07
6	38.097535	-122.150708	114.88	3.50	118.38
7	38.097267	-122.148975	103.07	3.50	106.57
8	38.097105	-122.148418	117.17	3.50	120.67
9	38.096507	-122.146875	85.81	3.50	89.31
10	38.095543	-122.145159	100.36	3.50	103.86
11	38.095207	-122.144547	120.38	3.50	123.88
12	38.095026	-122.144196	127.21	3.50	130.71
13	38.094924	-122.143858	131.01	3.50	134.51
14	38.094922	-122.143316	134.99	3.50	138.49
15	38.095232	-122.140725	137.78	3.50	141.28
16	38.095517	-122.138239	136.33	3.50	139.83
17	38.095431	-122.137447	148.37	3.50	151.87
18	38.095277	-122.137005	148.82	3.50	152.32
19	38.095045	-122.136624	145.33	3.50	148.83
20	38.094711	-122.136243	139.69	3.50	143.19
21	38.093616	-122.134698	130.76	3.50	134.26
22	38.092566	-122.132939	153.79	3.50	157.29
23	38.091918	-122.131833	176.45	3.50	179.95
24	38.091621	-122.130903	182.10	3.50	185.60
25	38.091015	-122.128041	180.03	3.50	183.53
26	38.090618	-122.125619	197.60	3.50	201.10

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 8 of 13

GLARE ANALYSIS RESULTS

Summary of Glare

PV Array Name	Tilt (°)	Orient (°)	"Green" Glare min	"Yellow" Glare min	Energy kWh
PV array	30.0	270.0	122	10,281	9,190,000.0

Total annual glare received by each receptor

Receptor	Annual Green Glare (min)	Annual Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	98	8474
OP 2	0	1807
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	0	0
Route 1	24	0

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 9 of 13

Results for: PV array

Receptor	Green Glare (min)	Yellow Glare (min)
Runway 03L	0	0
Runway 03R	0	0
Runway 212 (assault strip)	0	0
Runway 21L	0	0
Runway 21R	0	0
Runway 32 (assault strip)	0	0
OP 1	98	8474
OP 2	0	1807
OP 3	0	0
OP 4	0	0
OP 5	0	0
OP 6	0	0
OP 7	0	0
OP 8	0	0
OP 9	0	0
OP 10	0	0
OP 11	0	0
OP 12	0	0
OP 13	0	0
OP 14	0	0
OP 15	0	0
OP 16	0	0
OP 17	0	0
OP 18	0	0
OP 19	0	0
20-ATCT	0	0
Route 1	24	0

Flight Path: Runway 03L

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 03R

0 minutes of yellow glare
0 minutes of green glare

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 10 of 13

Flight Path: Runway 212 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21L

0 minutes of yellow glare
0 minutes of green glare

Flight Path: Runway 21R

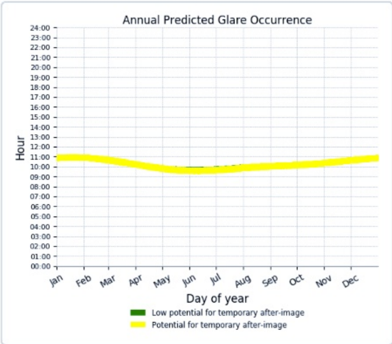
0 minutes of yellow glare
0 minutes of green glare

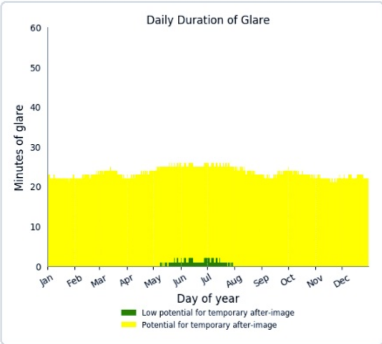
Flight Path: Runway 32 (assault strip)

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 1

8474 minutes of yellow glare
98 minutes of green glare

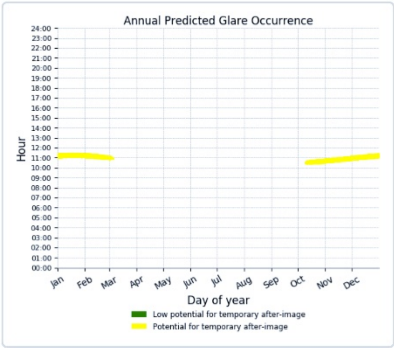


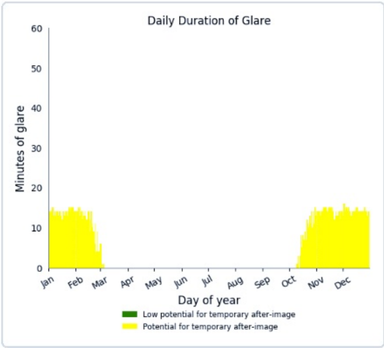


Point Receptor: OP 2

1807 minutes of yellow glare
0 minutes of green glare

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 11 of 13





Point Receptor: OP 3

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 4

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 5

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 6

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 7

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 8

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 9

0 minutes of yellow glare
0 minutes of green glare

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 12 of 13

Point Receptor: OP 10

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 11

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 12

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 13

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 14

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 15

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 16

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 17

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 18

0 minutes of yellow glare
0 minutes of green glare

Point Receptor: OP 19

0 minutes of yellow glare

ForgeSolar Glare Analysis Report (Sunset Backtrack Simulation) – Page 13 of 13

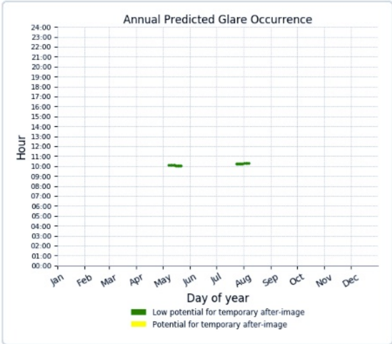
0 minutes of green glare

Point Receptor: 20-ATCT

0 minutes of yellow glare
0 minutes of green glare

Route: Route 1

0 minutes of yellow glare
24 minutes of green glare



Assumptions

"Green" glare is glare with low potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
"Yellow" glare is glare with potential to cause an after-image (flash blindness) when observed prior to a typical blink response time.
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. This includes buildings, tree cover and geographic obstructions.
Several calculations utilize the PV array centroid, rather than the actual glare spot location, due to algorithm limitations. This may affect results for large PV footprints. Additional analyses of array sub-sections can provide additional information on expected glare.
The subtended source angle (glare spot size) is constrained by the PV array footprint size. Partitioning large arrays into smaller sections will reduce the maximum potential subtended angle, potentially impacting results if actual glare spots are larger than the sub-array size. Additional analyses of the combined area of adjacent sub-arrays can provide more information on potential glare hazards. (See previous point on related limitations.)
Glare locations displayed on receptor plots are approximate. Actual glare-spot locations may differ.
Glare vector plots are simplified representations of analysis data. Actual glare emanations and results may differ.
The glare hazard determination relies on several approximations including observer eye characteristics, angle of view, and typical blink response time. Actual results and glare occurrence may differ.
Hazard zone boundaries shown in the Glare Hazard plot are an approximation and visual aid based on aggregated research data. Actual ocular impact outcomes encompass a continuous, not discrete, spectrum.

Appendix D: Thomas Cleveland's CV

Thomas (Tommy) H. Cleveland, P.E.

4141 Laurel Hills Rd. Raleigh, NC thcleveland@gmail.com 919-923-5490

Education & Training

North Carolina State University, Mechanical Engineering M.S. 2004
North Carolina State University, Mechanical Engineering B.S., Business Mgmt. minor 2001 - Summa Cum Laude
Lumberton Sr. High School, Lumberton, NC, 1997 – Valedictorian

Professional Engineer, licensed in North Carolina (#033711), 2008 - Present

Professional Experience

Solar PV Engineer, Advanced Energy, Raleigh, NC, April 2017–Present

- Evaluation of commercial and utility scale solar PV facilities to assess the quality of design, construction, and operation
- Engineering analysis and concise presentation of results to customers

Solar Energy Engineer (various progressive titles), North Carolina Solar Center/NC Clean Energy Technology Center, North Carolina State University, 2005–April, 2017

- Lead solar engineer at the Center (2008-2017)
- Conducted detailed PV + storage feasibility study for community solar project for a NC municipal utility
- Provided quality assurance and technical support to development of in-house training program of every stage of solar farm construction for a leading regional utility-scale photovoltaic EPC firm
- Guided design of prototype residential Plug and Play PV system and collected AHJ feedback (Department of Energy SunShot project)
- Co-led stakeholder process to develop Template Solar Development Ordinance for North Carolina
- Led design and development of ISO-17025 accredited solar thermal collector testing lab
- Designed and installed PV field performance monitoring system, conducted performance analysis
- Conducted renewable energy site assessments for commercial, industrial, and institutional clients
- Presented to local government officials, community leaders, and general public on solar energy
- Provided technical support to a wide variety of energy consumers and stakeholders across North Carolina

Consultant/Expert Witness, Private consultant for over 15 solar developer clients, 2012-Present

- Provides expert witness testimony at special/conditional use and re-zoning public hearings regarding the health, safety, and environmental impact of utility-scale solar photovoltaic systems. Experience in NC, SC, VA, and FL (over 60 projects to date)
- Provides respectful clear answers to sometimes ill-informed and/or hostile questions
- Conduct site-specific studies of EMF, sound, and solar glare hazard for several projects

Instructor of ET 220 Solar Photovoltaic Assessment, Department of Forestry and Environmental Resources, North Carolina State University, 2014-Present

- Developed all course content for this new three credit hour online course
- Course covers all aspects of photovoltaic site assessment including energy use, solar resource, system design, utility tariffs, estimating, economics, and more
- Course is optional course for an Environmental Technology and Management degree
- Course is required for a Renewable Energy Assessment minor

Instructor of MAE 421 Design of Solar Energy Systems, Mechanical and Aerospace Engineering Department of North Carolina State University, 2009-2014

- Instructor of the solar energy engineering course, MAE 421, in the NC State University Mechanical and Aerospace Engineering department
- The course was offered during the spring semester and typically had 30 to 50 undergraduate and up to twelve graduate engineering students
- Previously co-instructor of the course for two years (2007, 2009)

Research Assistant, North Carolina Solar Center, North Carolina State University, 2003–2005

- Developed and validated a TRNSYS simulation model of a unique solar thermal concentrating collector
- Assisted with the installation of photovoltaic systems ranging in capacity from 1 kW to 5 kW

Selected Publications

"Balancing Agricultural Productivity with Ground-Based Photovoltaic Development", NCCETC/NCSU white paper, August 2017, https://nccleantech.ncsu.edu/wp-content/uploads/Balancing-Ag-and-Solar-final-version-update.pdf

"Health and Safety Impacts of Photovoltaics", NCCETC/NCSU white paper, May 2017, https://nccleantech.ncsu.edu/wp-content/uploads/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017_white-paper-1.pdf

"Community Solar (+ Storage) Program Design for Fayetteville Public Works Commission", NCSU/NCCETC report, March 2017, (Public version) https://nccleantech.ncsu.edu/wp-content/uploads/FPWC_CommunitySolar_Public_Version.pdf

T. Cleveland, H. Tsai, "Charlotte-Mecklenburg Schools Roadmap to 100% Renewable Electricity" & "Durham Public Schools Roadmap to 100% Renewable Electricity", NCCETC, February 2016

T. Cleveland, et al, "Template Solar Energy Development Ordinance for North Carolina", NCCETC & NCSEA, December 2013, www. go.ncsu.edu/template-solar-ordinance

M. Sheehan, T. Cleveland, "*Updated Recommendations for Federal Energy Regulatory Commission Small Generator Interconnection Procedures Screens*", Solar America Board for Codes and Standards Study Report, 64 p., July 2010, www.solarabcs.org/about/publications/reports/ferc-screens/pdfs/ABCS-FERC_studyreport.pdf

T. Cleveland, et al, "*Optimizing Solar Thermal Resource Use at Commercial Buildings*", Solar 2010 – ASES National Solar Energy Conference 2010, 6 p., May 2010, www.ases.org/papers/101.pdf

T. Cleveland, "*Description and Performance of a TRNSYS Model of the Solargenix Tracking Power Roof$_{TM}$*", Solar 2005 – ASES National Solar Energy Conference, 6 p.

T. Cleveland, K. Creamer, & Dr. R. Johnson, "*Energy Metering of Solar Domestic Hot Water Systems for Inclusion in Green Power and Renewable Portfolio Standards Programs*", Solar 2004 – ASES National Solar Energy Conference 2004, 6 p.

T. Cleveland, "*Effective Energy Metering of Solar Domestic Hot Water Systems for Inclusion in Green Power and Renewable Portfolio Standards*", Master's Thesis, North Carolina State University, Raleigh, 191 p., April 2004, http://repository.lib.ncsu.edu/ir/handle/1840.16/1152

Selected Recent Presentations

T. Cleveland, A. Huang, "Plug and Play Residential PV System Innovation and Demonstration", Solar Power International Conference 2015

T. Cleveland, "*Make Solar Energy Economical*", recorded video lecture for E102: Grand Challenges of Engineering course at NC State University, January 2015

T. Cleveland, M. Clark, "*Template Solar Ordinance for North Carolina*", Solar Power International Conference 2014