Glare Hazard Analysis

Saratoga Solar Project
Wood County, Wisconsin

February 22, 2022

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Saratoga Solar Project, LLC

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Sign-off Sheet

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Executive Summary

Stantec Consulting Services Inc. (Stantec) utilized the web-based ForgeSolar glare hazard analysis program to analyze the potential for glare from the proposed Saratoga Solar Project, LLC (Saratoga Solar) for the Saratoga Solar Project (Project), a 150.5-megawatt (MW), utility-scale, photovoltaic (PV) electric generating facility located in Wood County, Wisconsin, and depicted in **Figure 1**. The Project will include photovoltaic solar panels mounted on a racking system to maximize solar energy capture and electric generation of the array. The Project area encompasses approximately 1,900 acres in a rural area located approximately 5 miles south of the City of Wisconsin Rapids, in central Wisconsin. The ForgeSolar program visually depicts glare effects using the following classification scheme on a series of project area maps (no color indicates no glare predicted):

GREEN - Low potential for temporary after-image.
YELLOW - Potential for temporary after-image.
RED - Potential for permanent eye damage.

Based on the solar array parameters provided and the current site design, glare is **not** predicted from the Project for pilots landing at four airports within a 10-mile radius of the Project, including Jennie's Field Airport, Gottschalk Field Airport, Cranmoor Airstrip Airport, Alexander Field - South Wood County Airport. The results of the ForgeSolar analysis determined that glare from the Project is **not** predicted to occur for drivers of vehicles on 10 roadways adjacent to the Project (**Table 1**). The analysis was completed at two viewing heights for roadways: 5 feet (cars and small trucks) and 9 feet (semi-trucks). Glare is also **not** predicted for the total of approximately 537 structures, primarily residences, that were analyzed within proximity to the Project area. All routes and structures were analyzed using 9-foot and 12-foot panel heights.

It should be noted that a 'resting angle' of 60 degrees was used for the panels in the analysis. If a resting angle of 0 degrees (panels facing straight up) is used in the analysis, the program moves the panels to 0 degrees instantly once the sun drops below 60 degrees in either direction. This results in the panels facing straight up during sunrise and sunset, under which conditions the program predicts extensive green and yellow glare. Analyses conducted using the new 'backtracking' tools in Forgesolar that model backtracking during daylight hours also resulted in significant glare. <u>Panels should therefore not be returned to a 0-degree position prior to sunset and should be in place at 60 degrees to the east prior to sunrise</u> (See Figure 2 - Incidence Angle diagram).

Please Note – Topography provided by Google Earth was adjusted in forested areas where LiDAR apparently measured treetops instead of the ground. The area is known to be flat and therefore elevations in forested areas with significantly higher than surrounding areas were manually adjusted to match neighboring non-forested points. The final site plan will be flat or nearly so and therefore this adjustment should provide more accurate results.

Abbreviations

AGL	above ground level
Deg	degrees (0 is due north, 180 is due south)
DNI	direct normal irradiance
FAA	Federal Aviation Administration
FP	flight path (landing path from threshold to two miles out)
ft	foot
kW	kilowatt
kWh	kilowatt hour
m	meters
mi	mile
min	minutes
mrad	milliradian
MW	megawatt
MSL	mean sea level
OP	observation point (e.g., control tower, vehicle location)
PV	photovoltaic
W/m^2	Watts per square meter

Glossary

Correlate Slope Error with Surface Type?	Correlates the slope error value based on the surface material type; default value is 8.43 milliradians (mrads).
Eye Focal Length [meter (m)]	Typical distance between the cornea and the retina of the human eye, default is 0.017, though some sources indicate that the typical length is 0.022.
Glide Slope [degrees (deg)]	Angle at which the plane approaches the runway during landing (default is 3 deg from horizontal).
Maximum Tracking Angle (deg)	Rotation limit of panels in either direction. Full rotation is 2*maximum tracking angle. E.g., maximum tracking angle of 60 deg indicates full panel rotation range of 120 deg.
Resting Angle (deg)	Angle modules return to after maximum angle is reached.
Observation Point	A specific location, such as a control tower or vehicle, from which an observer might experience glare.
Ocular Transmission Coefficient	Related to the ability of the eye to transmit light, set by at 0.5 by ForgeSolar.
Offset angle of module (deg)	Additional tilt/elevation angle between the tracking axis and the panel.
Orientation of Tracking Axis (deg)	Azimuthal position of tracking axis measured clockwise from true north. Tracking systems in the northern hemisphere are typically oriented near 180 deg. Tracking systems in the southern hemisphere are typically oriented near 0 deg.
Peak DNI (W/m^2)**	This value is set at 1,000 by ForgeSolar and is the amount of solar radiation per unit surface area by a surface perpendicular to the sun's rays in a straight line from the direction of the sun at its current position in the sky.
Pupil Diameter (m)	Typical pupil diameter for observer, default is 0.002 m.
PV Array Axis Tracking	Panel tracking mode, if any. Panel can be set to track along one (single) or two (dual) axis tracking. This parameter affects the positioning of the panels at every time step when the sun is up.
PV Array Panel Material	Surface material of panels, including use of anti-reflective coating (ARC). Options include: smooth glass without ARC, smooth glass with ARC, light-textured glass without ARC, light-textured glass with ARC, and deeply textured glass.
Rated Power (kilowatts)	Power rating of the solar array - used to estimate the energy output per year of the array (optional).
Slope Error (mrad)	Accounts for beam scatter of sunlight on the array. Default is 8.43 mrads but the value may be adjusted based on the panel material type.
Subtended Angle of Sun (mrad)	The angle above horizontal at which the viewer observes the sun, default value is 9.3 mrad.
Threshold	The physical beginning of the runway. Aircraft are typically expected to be 50 feet above ground at this point.

Time Interval (minutes)	Time step intervals used by the program for analyses. Default is set to analyze for glare at every one-minute interval throughout the year.
Time zone	Time zone difference from Greenwich Mean Time at the location of the analysis.
Tilt of Tracking Axis (deg)	The elevation angle of the tracking axis upon which panels rotate (e.g., torque tube), measured from flat ground. 0 deg implies the axis is on level, flat ground. Values between 0 and 30 deg are typical.
Vary Reflectivity	Varies panel reflectivity with sun position at each time step.
Maximum Downward Viewing Angle (deg)	The angle extending downward from the horizon indicating the maximum downward viewing angle from the cockpit. Used to determine whether glare is visible by the pilot along the flight path. Default is 30 degrees.

Sources:
Ho, Clifford, K., Cianan A. Sims, Julius E. Yellowhair. 2015. Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 2H. Sandia National Laboratories.

ForgeSolar – PV Planning & Glare Analysis. https://www.forgesolar.com/

**Source: http://www.3tier.com/en/support/solar-prospecting-tools/what-direct-normal-irradiance-solar-prospecting/

1.0 INTRODUCTION

On behalf of Saratoga Solar, Stantec Consulting Services Inc. utilized the web based ForgeSolar glare hazard analysis program to complete a glare analysis for the Project to determine the potential for glint/glare from the photovoltaic solar panels to affect pilots and airport operations, residents in the area, and drivers passing through. The Project is located approximately 5 miles south of the Wisconsin Rapids in Wood County, central Wisconsin (**Figure 1**).

ForgeSolar is an interactive tool that provides a quantified assessment of (1) when and where glare will occur throughout the year for a prescribed solar project and (2) potential effects on the human eye at locations where glare occurs. Glare can occur from the reflection of sunlight on the PV solar panels of utility-scale solar-powered electric generating facilities. While PV solar panels absorb direct sunlight, some reflection can occur when the panels are directed close to horizontal, which predominately occurs during sunset and sunrise when the incidence angle of the panels is highest, as depicted in **Figure 2** below.

ForgeSolar employs an interactive Google map for site location, mapping the proposed PV array(s), and specifying observer locations, vehicular travel routes, or flight paths. Latitude, longitude, and elevation are automatically recorded through the Google interface, providing necessary information for sun position and vector calculations. Additional information regarding the orientation and tilt of the PV solar panels, reflectance, environment, and ocular factors are entered by the user.

If glare is found, the tool calculates the retinal irradiance and subtended angle (size/distance) of the glare source to predict potential ocular hazards ranging from temporary after-image to retinal burn. The results are presented in a plot that specifies when glare will occur throughout the year, with color codes indicating the potential ocular hazard.

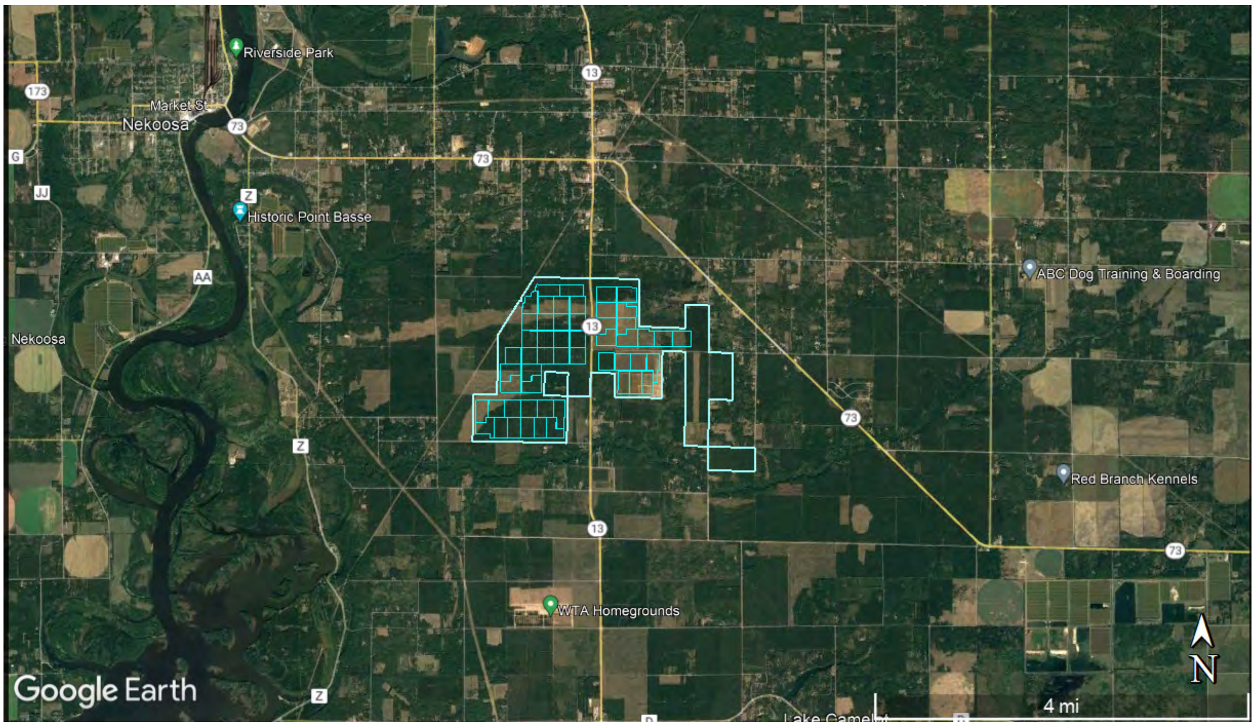
This glare study analyzes potential glare for pilots of planes landing at four airports in the vicinity of the Project area (**Figure 3**). Glare analyses were also conducted for drivers of vehicles at 5-foot (ft) above ground level (AGL) (cars and small trucks) and 9-ft AGL (semi-truck) viewing heights on 10 roadways adjacent to the PV panels (**Figures A.1 to A.8, Appendix A, Table 1**). Roadways were analyzed for glare from arrays within proximity to each panel block, and therefore not every roadway was analyzed for all three panel blocks.

The analysis also included a determination of potential glare to viewers at approximately 537 unique structures, primarily residences, in the vicinity of the Project using a 25-ft AGL viewing height which is a conservative viewing height for one- and two-story structures (**Figures A.1 to A.8, Appendix A**). The analyses were separated into three blocks of arrays due to program limitations on the size of subarrays[1] and the analyses conducted for each block considered the structures most likely to see glare from the array.

[1] Subarrays, as shown in Figures 1 and 3, can be no larger than 25 acres in size to allow ForgeSolar to produce the most accurate results.

Not all structures were analyzed for all three panel blocks[2], but all structures most likely to see each set of panel blocks were analyzed with the nearest block. All airports, roadways, and structures were analyzed using 9-ft and 12-ft AGL panel heights. **Table 1** indicates which roadways were analyzed within each block. Many additional analyses including structures only were conducted to accommodate analysis of all structures because ForgeSolar will only allow analysis of up to 40 structures at a time.

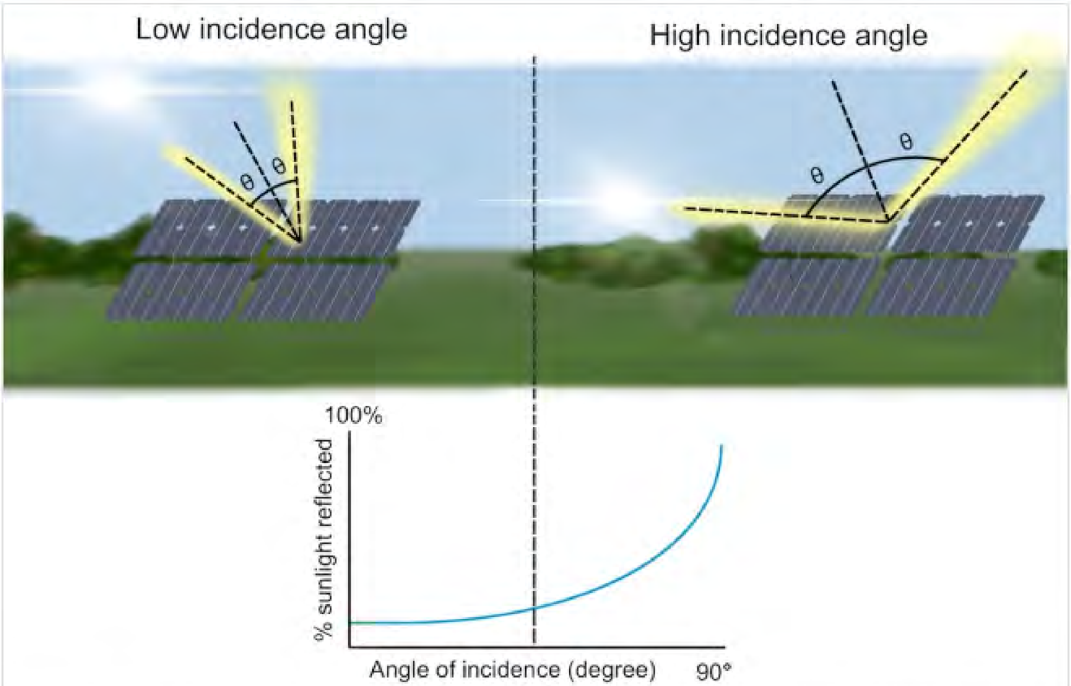
Figure 1. Saratoga Solar Project Location Map*



Source: Google Earth Imagery, June 2021
*Blue lines indicate the Project boundary, purple indicates planned array locations.

[2] ForgeSolar only allows 40 structures (Observation Points) to be included in each analysis.

Figure 2. Reflectivity Differences Between Low and High Incidence Angles



PV panel reflectance depends on incidence angle between panel normal (i.e. facing) and sun position. Large incidence angle yields more reflected sunlight.

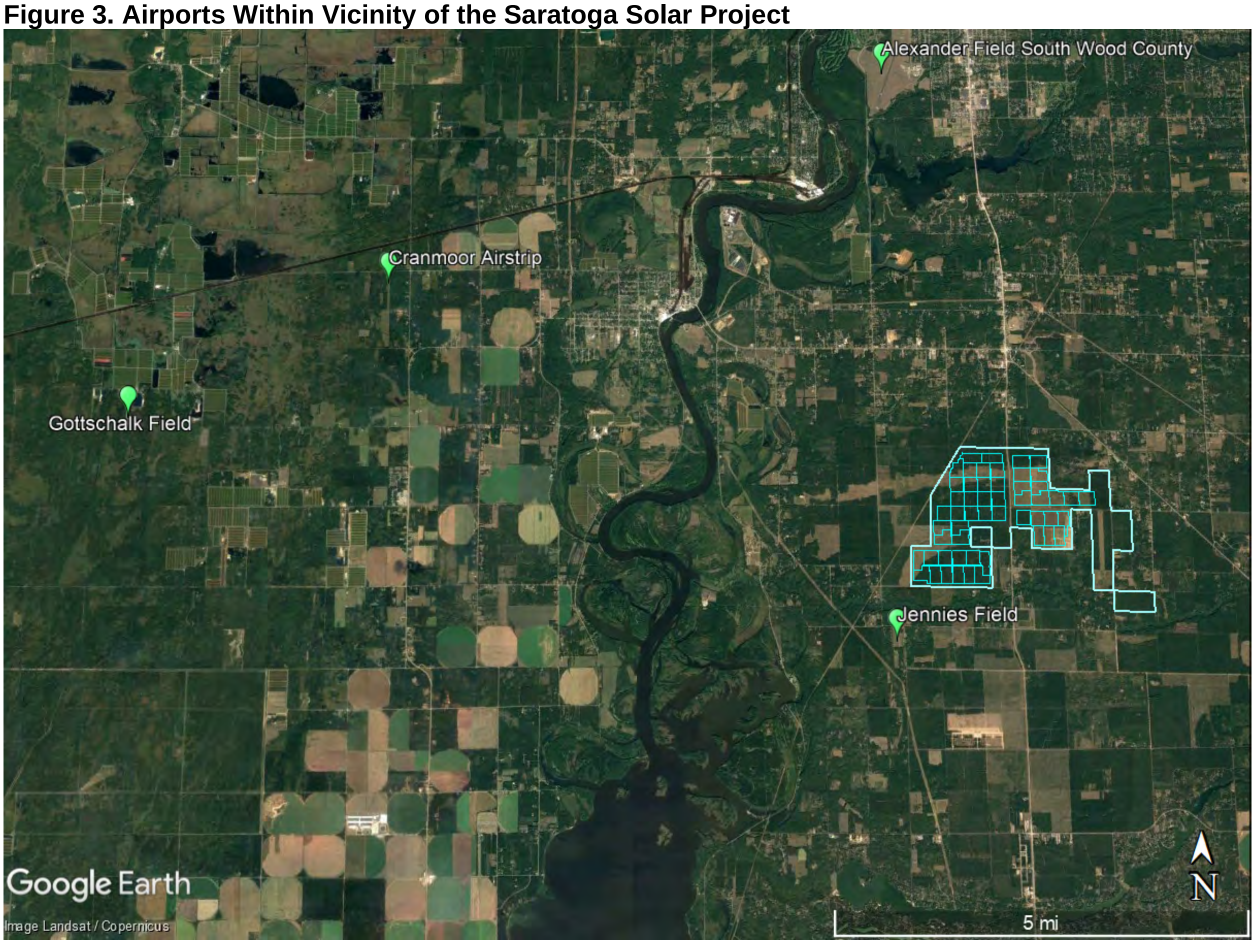
Source: ForgeSolar 2022

The arrays used in the analysis program were drawn to encompass all array areas shown in purple in **Figure 1.** In order to be conservative in the glare analysis, most arrays were drawn slightly larger areas than the panels will actually occupy.

Table 1: Roadways Included in ForgeSolar Analysis

Route Name	Blocks Including Route in Analysis
Majestic Trail	1,2
Young Street	1
Lexus Lane	1
Highway 13	1,2,3
Blue Ridge Lane	1,2
Tower Road	1,2,3
Rangeline Road	1,2
Bell Road	3
Highway 73	3
Evergreen Avenue	3

Figure 3. Airports Within Vicinity of the Saratoga Solar Project



Source: Google Earth Imagery, June 2021

2.0 DATA INPUT SUMMARY

The parameters used for the analyses are listed in **Table 2** below. “Default” indicates the default parameter value set by ForgeSolar and is considered the most conservative value for the parameter. “Chosen” parameters were selected to perform the most conservative analysis with respect to glare potential. “Provided” parameters are Project specific information provided by the client.

2.1 SOLAR ARRAY

The location of the solar array and array parameters used for the analyses are based on information provided by Saratoga Solar. The analyses described below were conducted using 9-ft and 12-ft panel AGL heights. A detailed description of each parameter is provided in the Glossary.

Table 2: Solar Panel Parameters Used for Glare Analysis

Parameter	Value Used	Default, Chosen or Provided?
Axis tracking	Single	Provided
Tracking Axis Tilt (deg)	0.0	Provided
Tracking Axis Orientation (deg)	180.0	Provided
Tracking Axis Panel Offset (deg)	0.0	Default
Maximum Tracking Angle (deg)	60.0	Provided
Resting Angle (deg)	60.0	Provided
Rated Power (kW)	Not Used	NA
Vary reflectivity?	Yes	Default
Panel material	Smooth glass with Anti-Reflective Coating	Provided
Time zone offset	-6	Based on site location
Subtended angle of sun (mrad)	9.3	Default
Peak DNI (W/m^2)	1,000	Default
Ocular transmission coefficient	0.5	Default
Pupil diameter (m)	0.002	Default
Eye focal length (m)	0.017	Default
Time interval (min)	1	Default
Correlate slope error with surface type?	Yes	Default
Slope error (mrad)	8.43	Default

2.2 AIRPORT APPROACH PATHS AND AIR TRAFFIC CONTROL TOWER

Four airports were included in the glare analyses for this Project: Jennie’s Field Airport, Gottschalk Field Airport, Cranmoor Airstrip Airport, and Alexander Field –South Wood County Airport. Approach paths were analyzed for runways in all directions available to pilots at each of the airports.

There are no Air Traffic Control Towers (ATCTs) identified for any of the airports included in this glare analysis.

2.3 ROADWAYS AND PROPERTIES LOCATED ADJACENT TO THE SOLAR ARRAYS

This analysis included potential glare to vehicles travelling on 10 roads in the vicinity of the Project area (**Table 1**). The ForgeSolar program sets the default viewing angle of the array at 50 degrees from the driver’s direct line of sight (when looking forward). The Federal Aviation Administration (FAA) has determined that glare beyond 50 degrees from the line of sight will have no impact on the viewer[3].

Potential glare to drivers was evaluated for both passenger vehicles and semi-trucks, where the passenger vehicles were assumed to have a maximum viewing height of 5-ft AGL while the viewing height for drivers of semi-trucks was assumed to be a maximum of 9-ft AGL. The location of the roadway routes analyzed are shown as blue-green route lines in the figures included in **Appendix A.**

The analyses for each of the three array blocks were run multiple times, once for 5-ft car heights and once for 9-ft truck heights, and a once each again for each of the panel heights (9-ft and 12-ft AGL). Blocks 1 was run an additional 10 times and Blocks 2, and 3 were run twice more each in order to analyze all of the 537 structures. Potential glare to viewers from approximately 537 unique structures in the vicinity of the Project was also analyzed at 25-ft AGL viewing heights.

[3] Rogers, J. A., et al. (2015). Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach, Federal Aviation Administration (link)

3.0 GLARE ANALYSES RESULTS

The web-based ForgeSolar program was used to analyze glare potential in one-minute increments throughout the year. The program visually depicts glare effects using the following classification scheme on a series of project area maps (no color indicates no glare predicted):

GREEN - Low potential for temporary after-image.
YELLOW - Potential for temporary after-image.
RED - Potential for permanent eye damage.

3.1 AIRPORT APPROACH PATHS

Glare is not predicted for any of the four airports analyzed and their combined 10 approach paths for the airports depicted in **Figure 2** at any time of the day, any time throughout the year, based on the input parameters described above. Results are shown for each of the approach paths in the ForgeSolar reports in **Appendix A**.

3.2 CONTROL TOWERS

None of the airports included in this analysis have associated ATCTs and therefore adverse impacts to ATCTs are not anticipated.

3.3 ROADWAYS AND PROPERTIES LOCATED ADJACENT TO THE SOLAR ARRAYS

Glare is not predicted for drivers along the 10 roadways analyzed (**Table 1**) that are adjacent to the Project area. The potential for glare for a range of driver conditions was evaluated for viewing heights of 5-ft (cars and small trucks) and 9-ft (semi-trucks). Glare is also not predicted for approximately 537 unique structures analyzed at 25-ft viewing heights as shown in figures included in **Appendix A.**

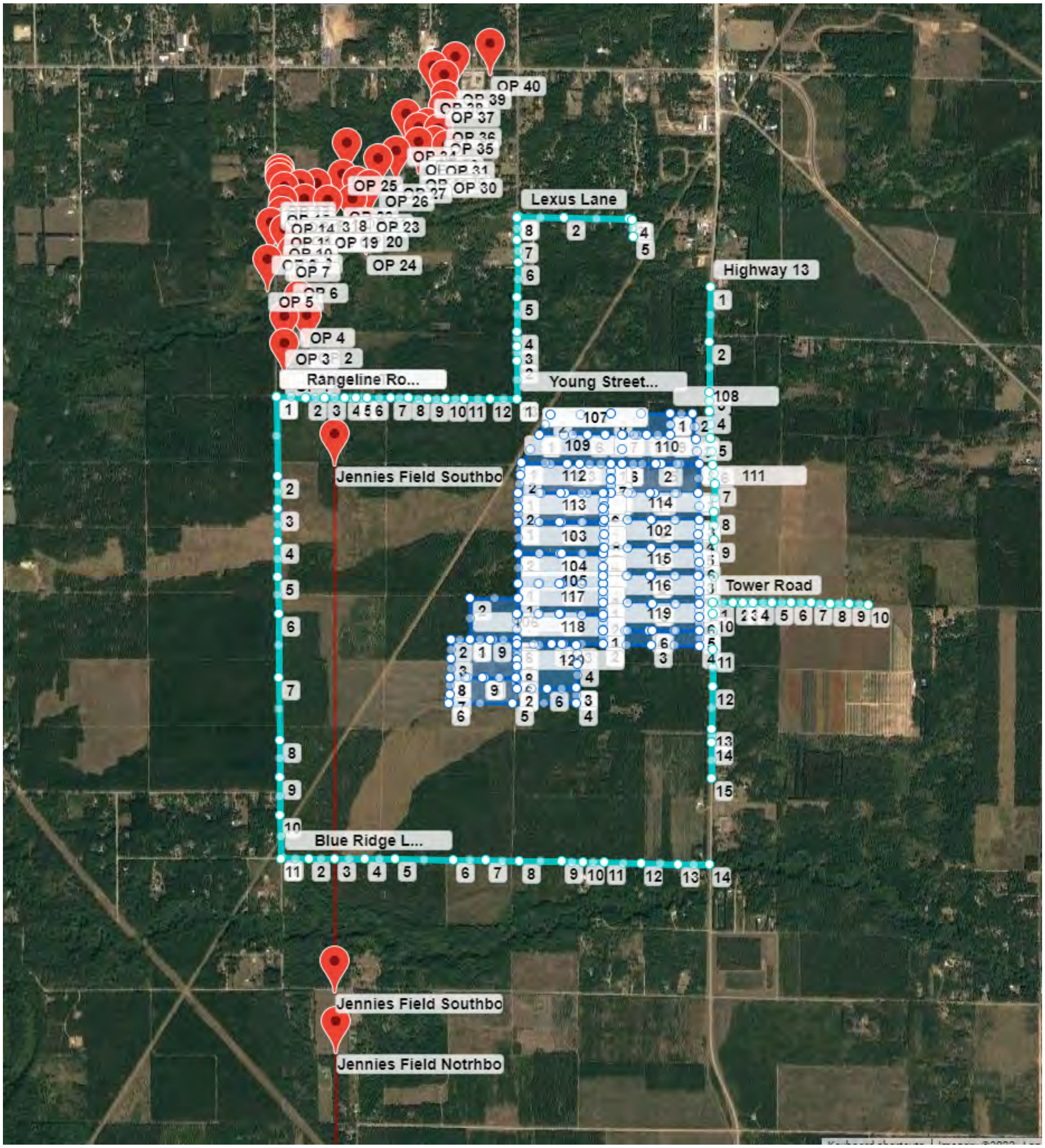
4.0 CONCLUSIONS

Based on the solar array parameters provided, glare is not predicted for planes landing in all available directions at each of the four airports analyzed located within 10 miles of the Project area (**Figure 3**), including: Jennies Field, Gottschalk Field, Cranmoor Airstrip and Alexander Field South Wood County Airport. Glare is not predicted for drivers of vehicles on 10 roadways adjacent to the Project area (**Table 1**), at 5-ft (cars and small trucks), 9-ft (semi-trucks) viewing heights. Glare is also not predicted for approximately 537 unique structures with 25-ft viewing heights (**Appendix A**). All receptors were analyzed using both 9-ft and 12-ft AGL panel heights.

APPENDIX A

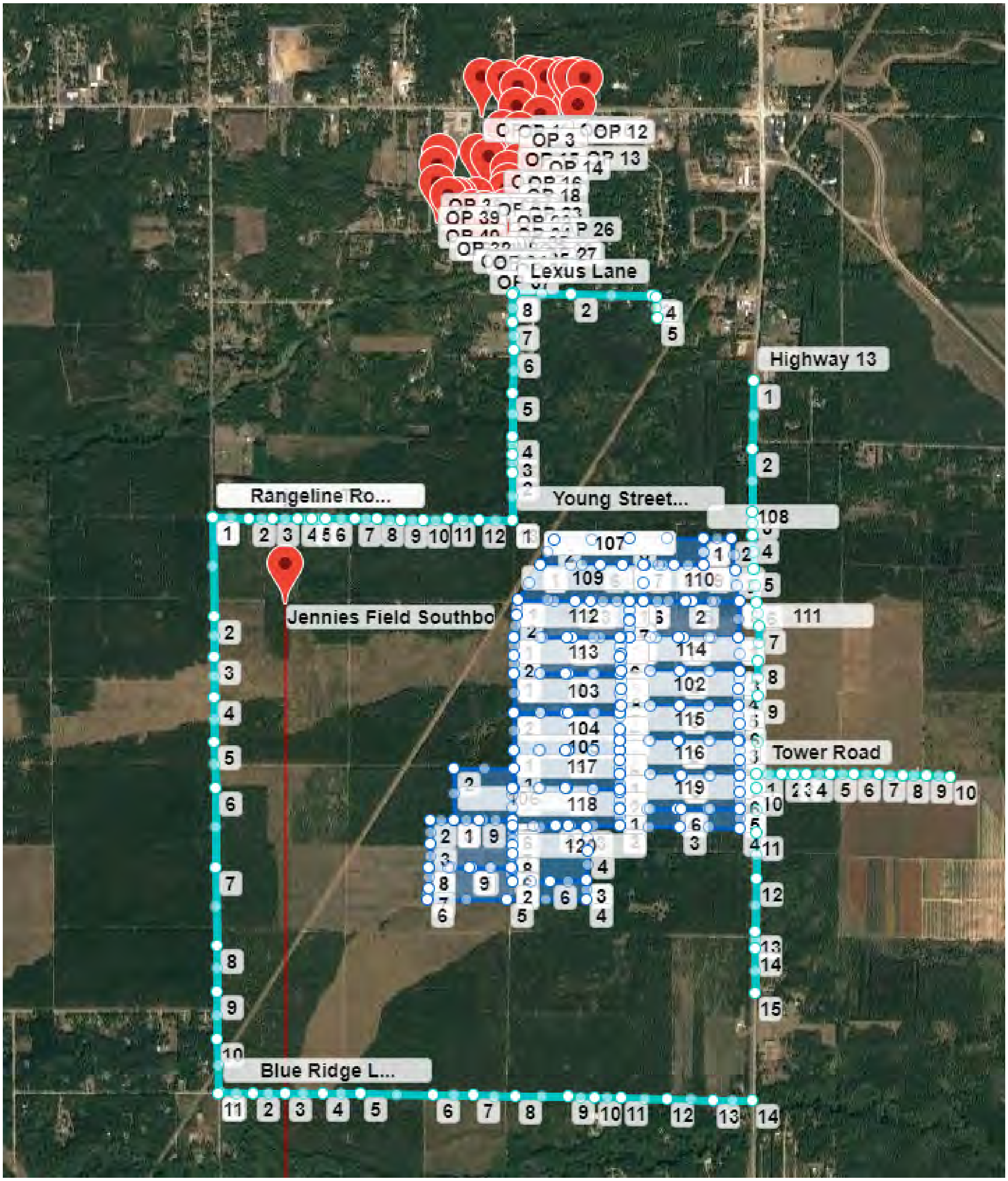
Glare Analysis Layout Figures

Figure A.1: Block 1 Analysis Area, Structure Group 1, and Roads



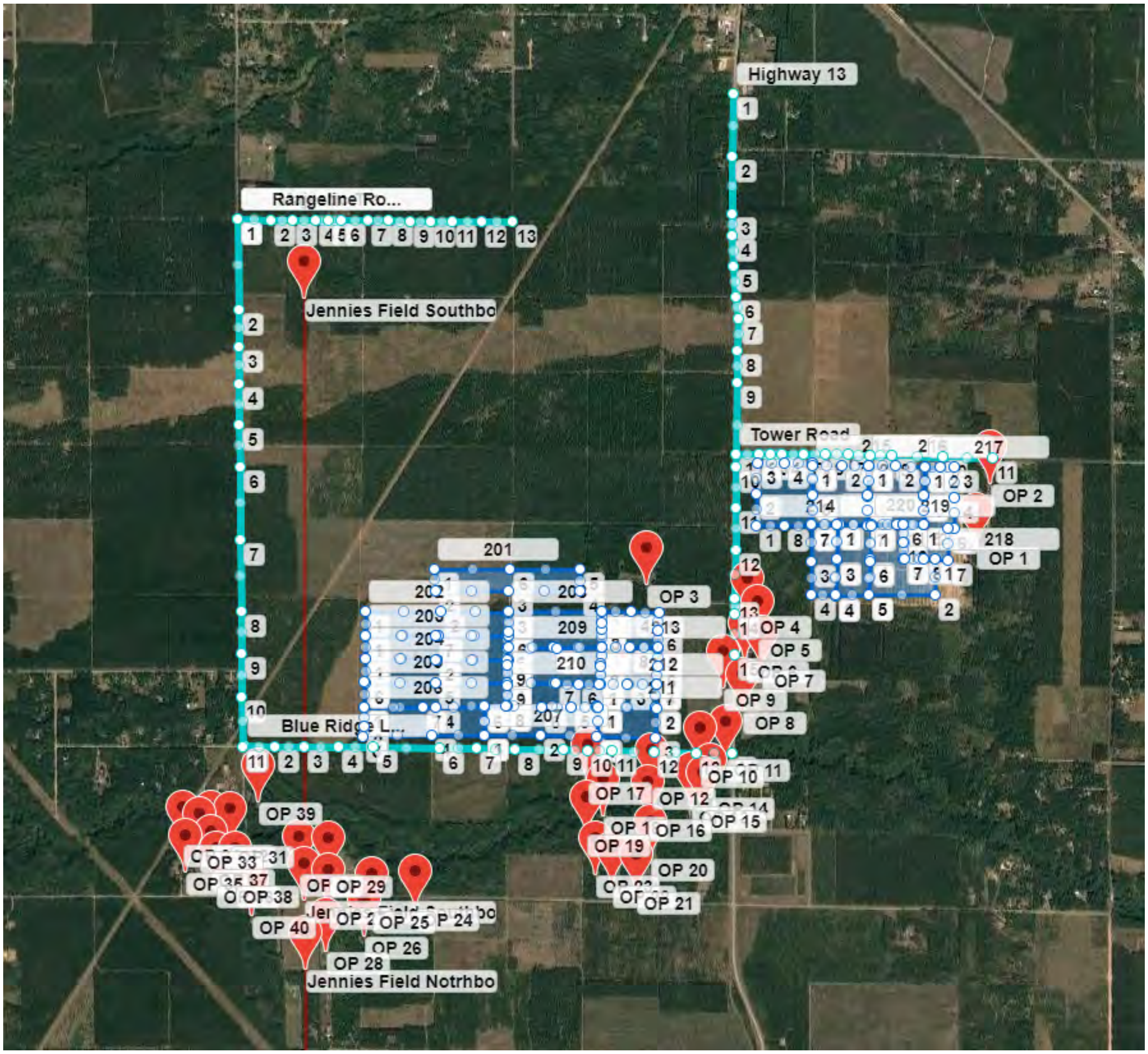
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.2: Block 1 Analysis Area, Structure Group 2, and Roads



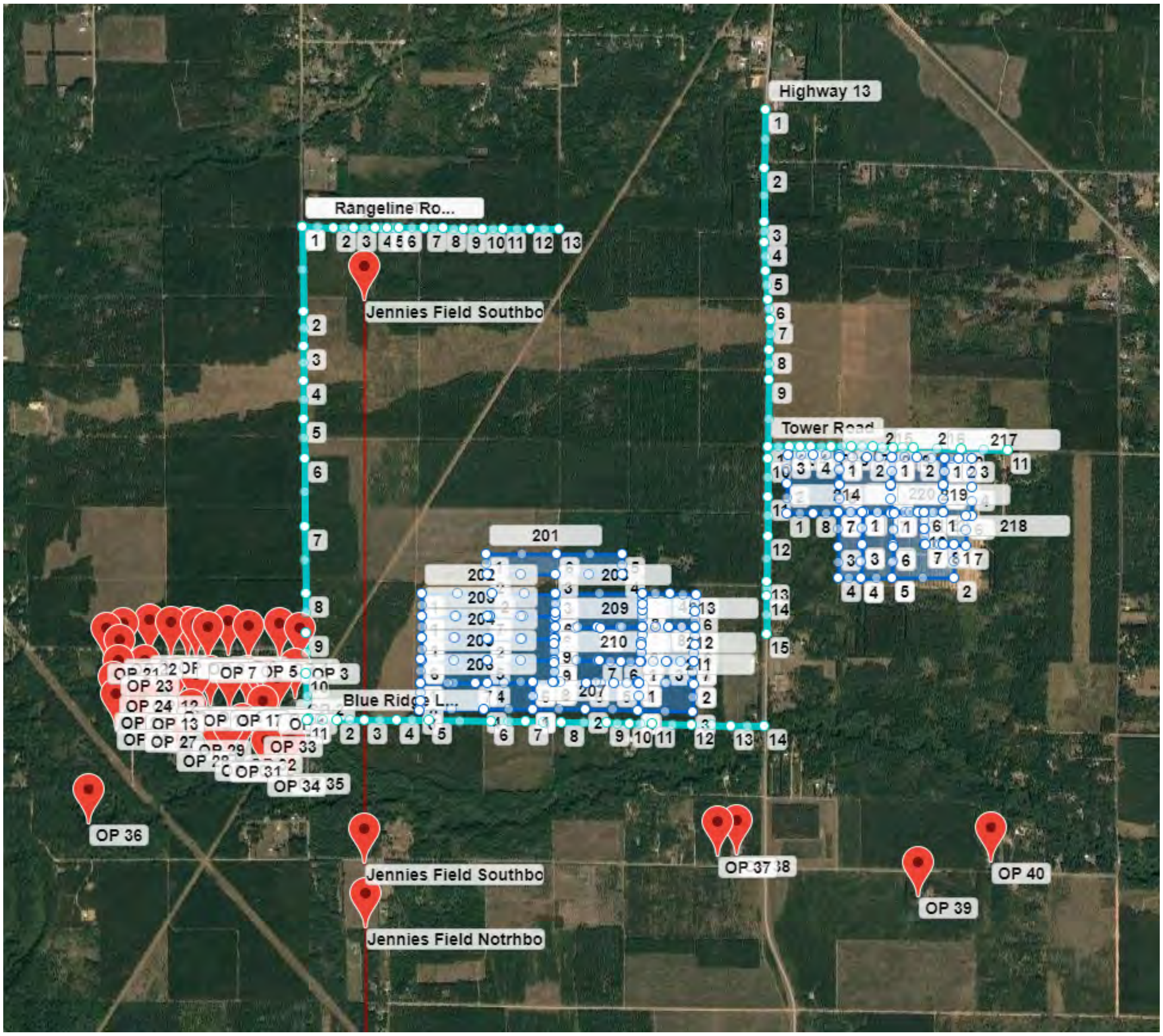
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.3: Block 2 Analysis Area, Structure Group 3, and Roads



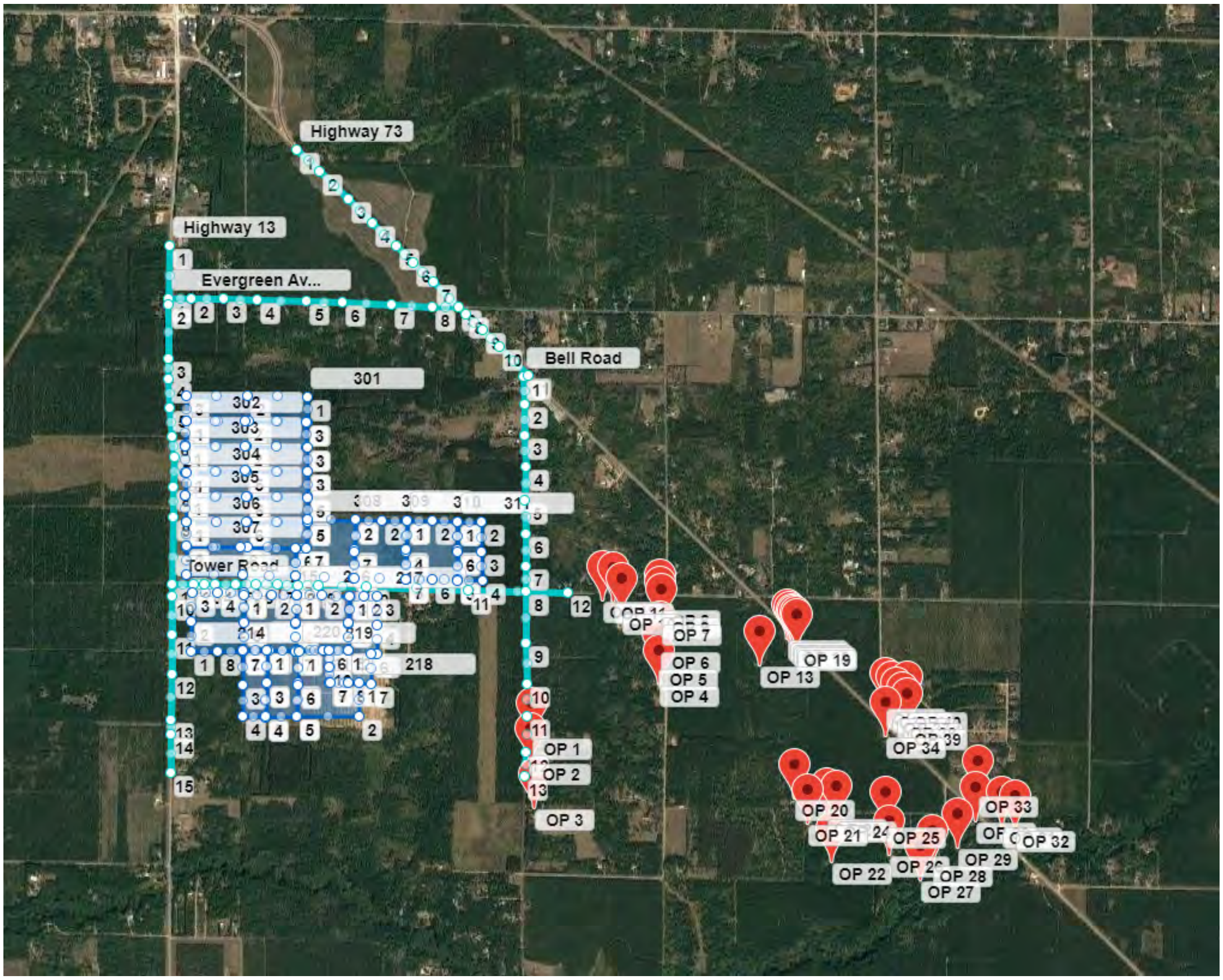
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.4: Block 2 Analysis Area, Structure Group 4, and Roads



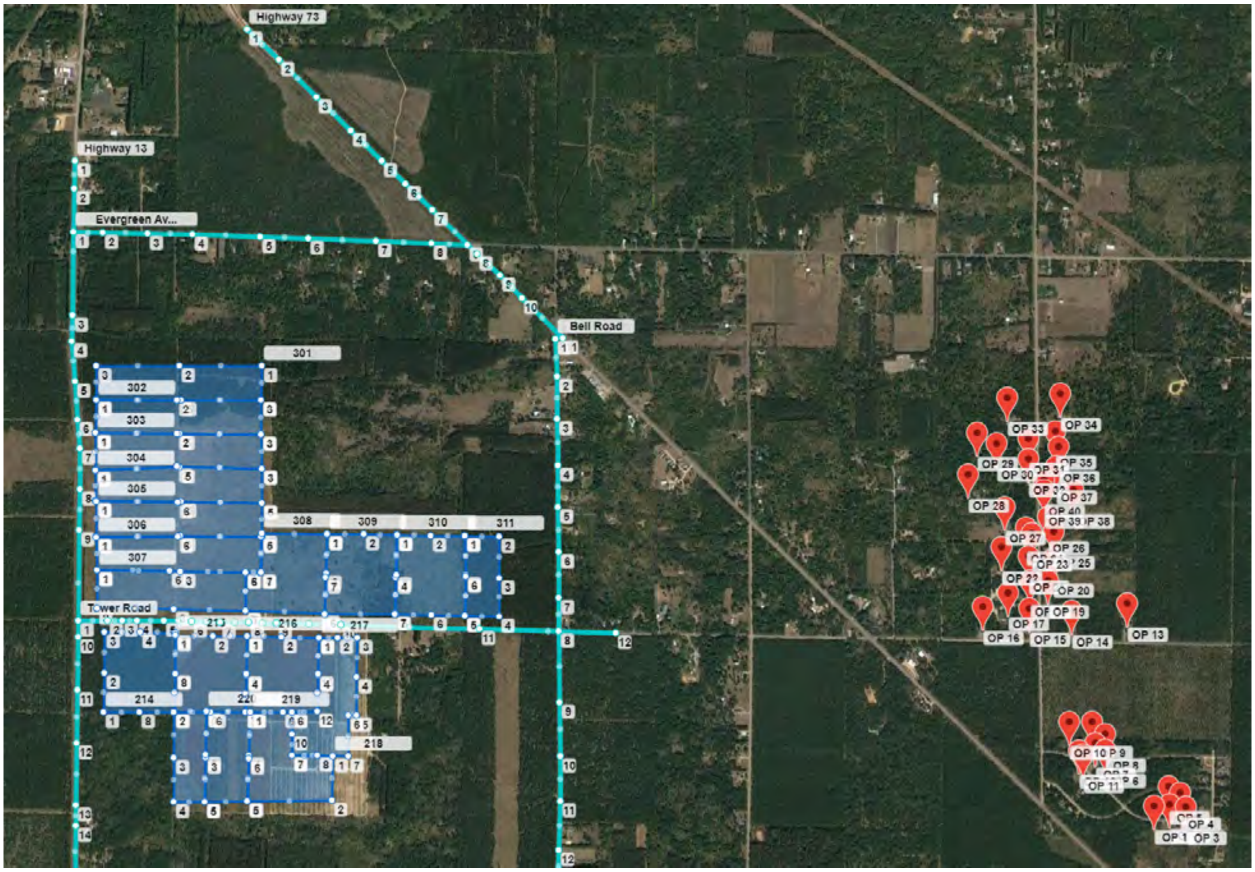
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays.
Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.5: Block 3 Analysis Area, Structure Group 6, and Roads



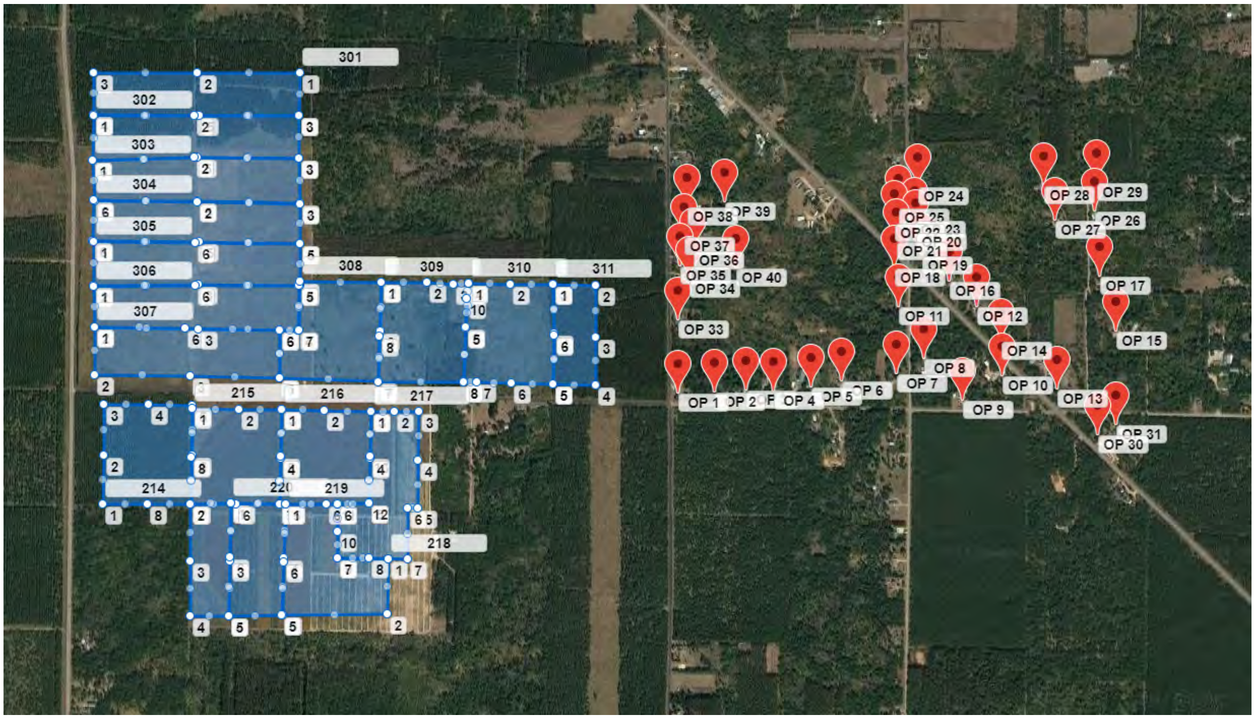
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.6: Block 3 Analysis Area, Structure Group 7, and Roads



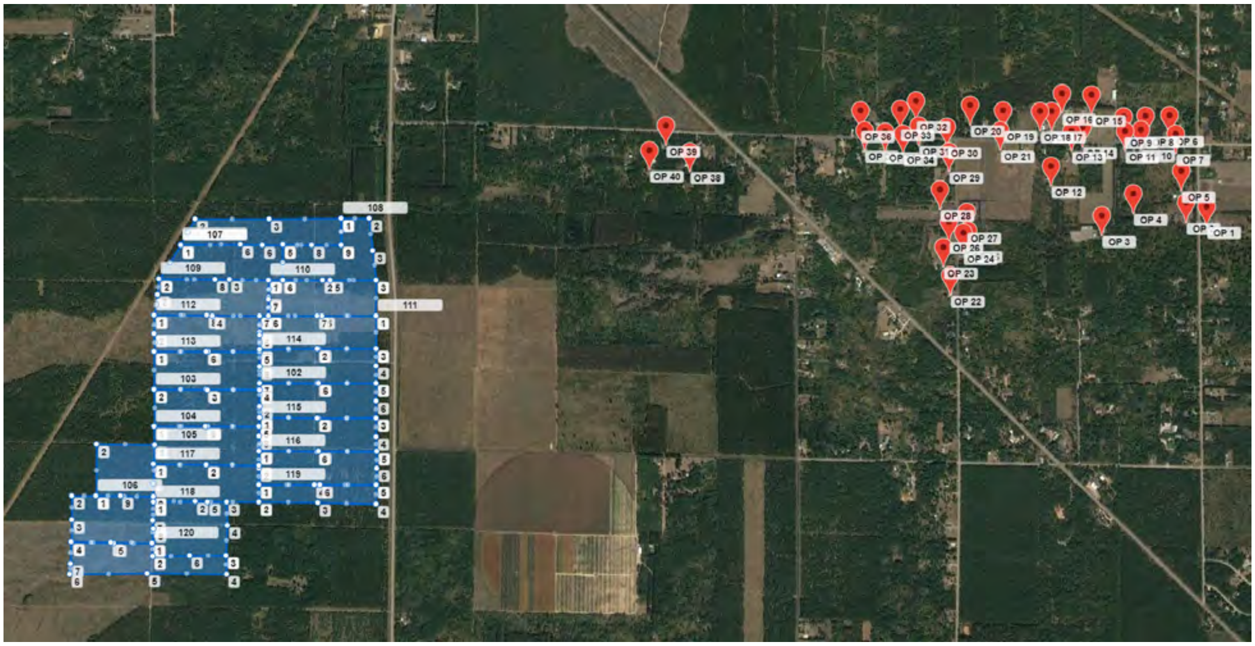
*Red markers indicate structures, turquoise lines indicate roads, and blue polygons indicate PV arrays.
Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.7: Block 1 Analysis Area and Structure Group 9



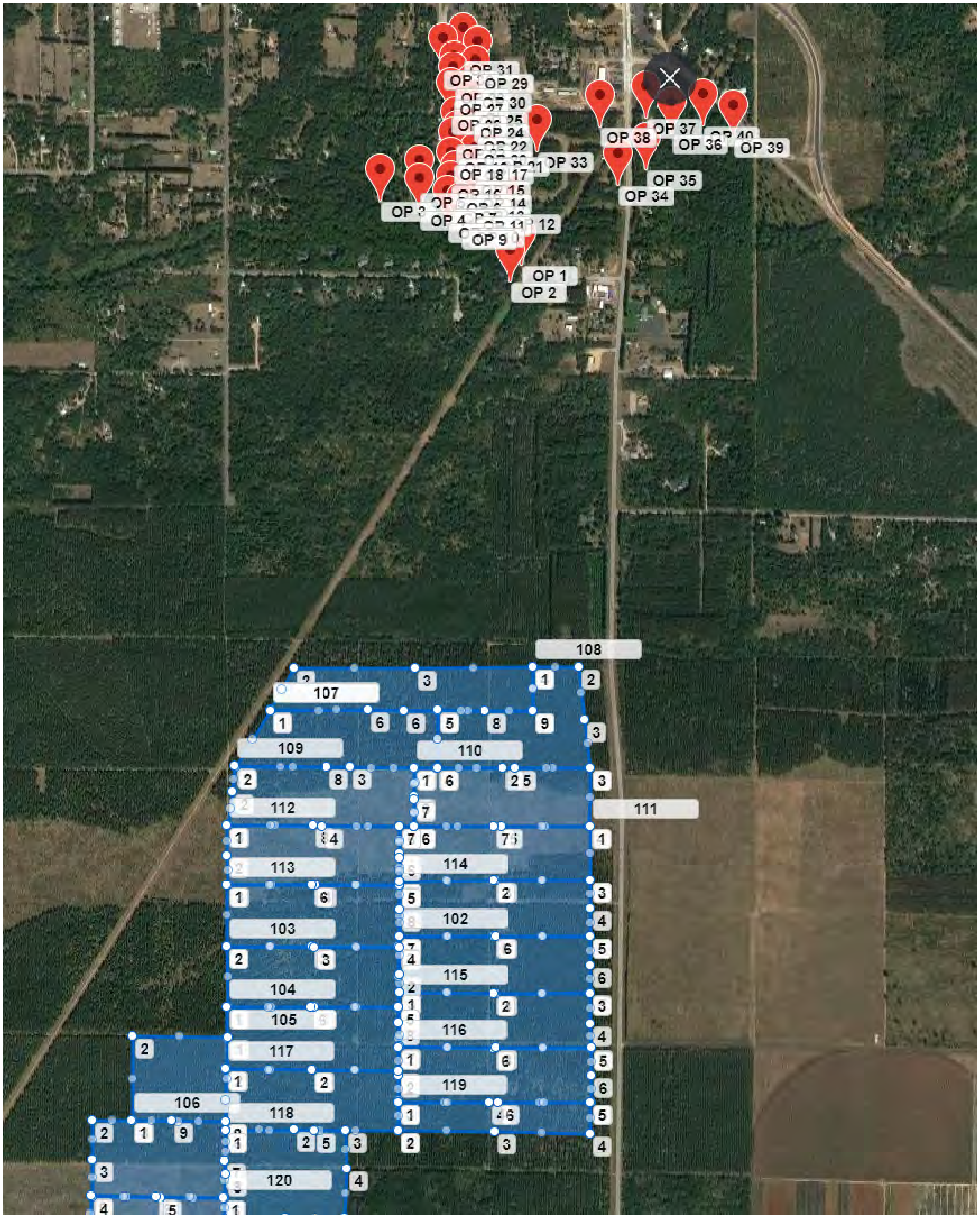
*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.8: Block 1 Analysis Area and Structure Group 10



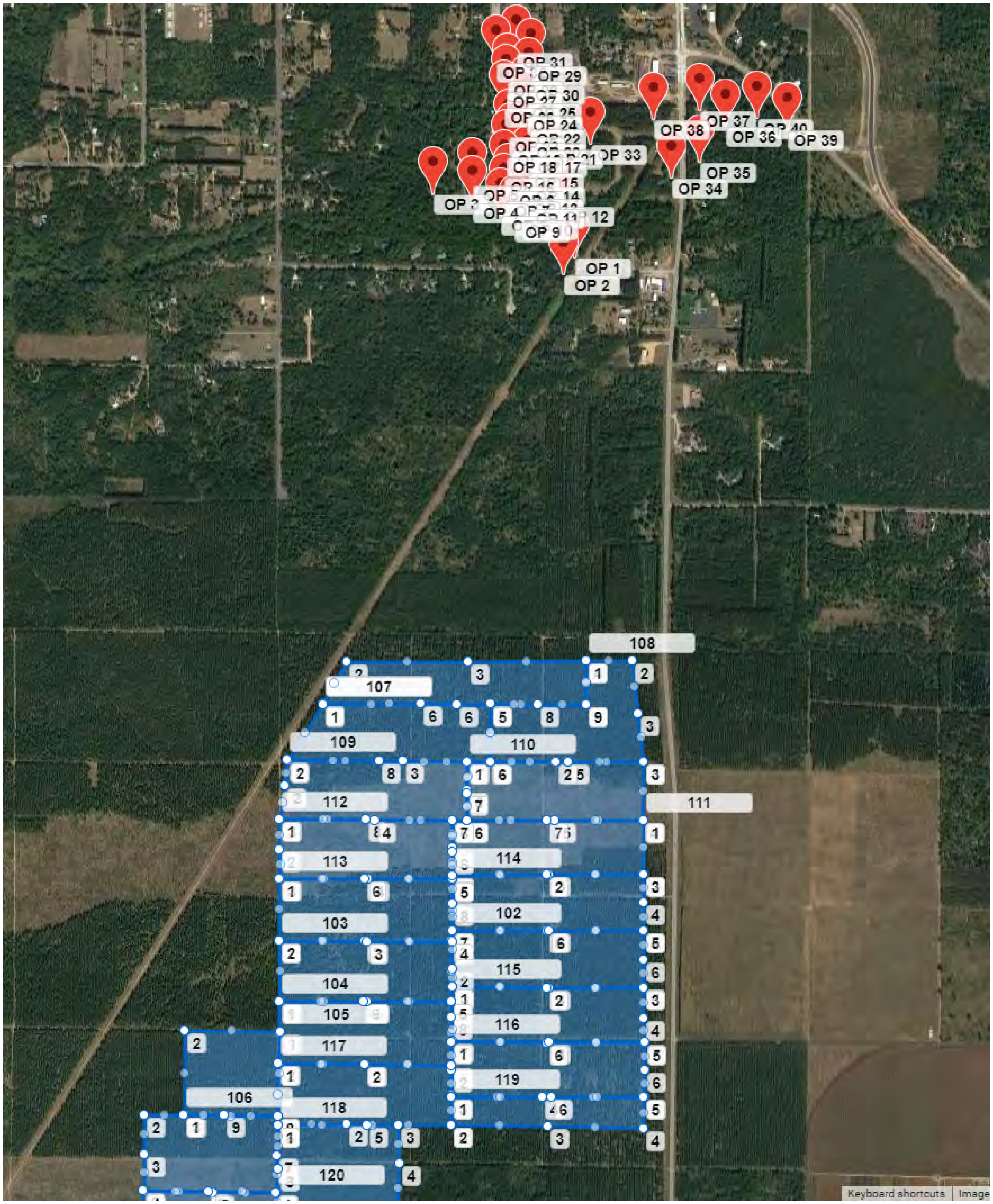
*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.9: Block 1 Analysis Area and Structure Group 11



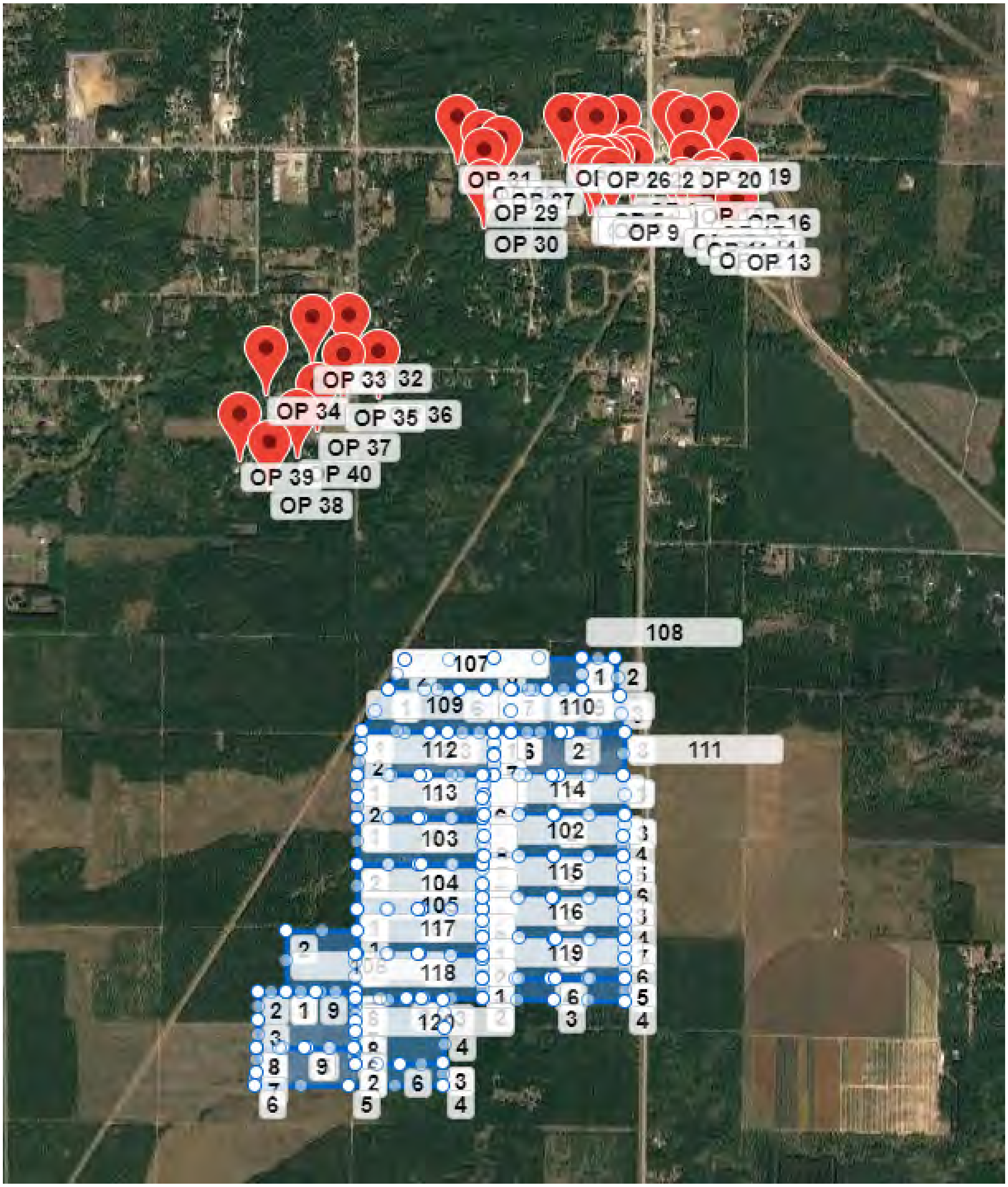
*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.10: Block 1 Analysis Area and Structure Group 12



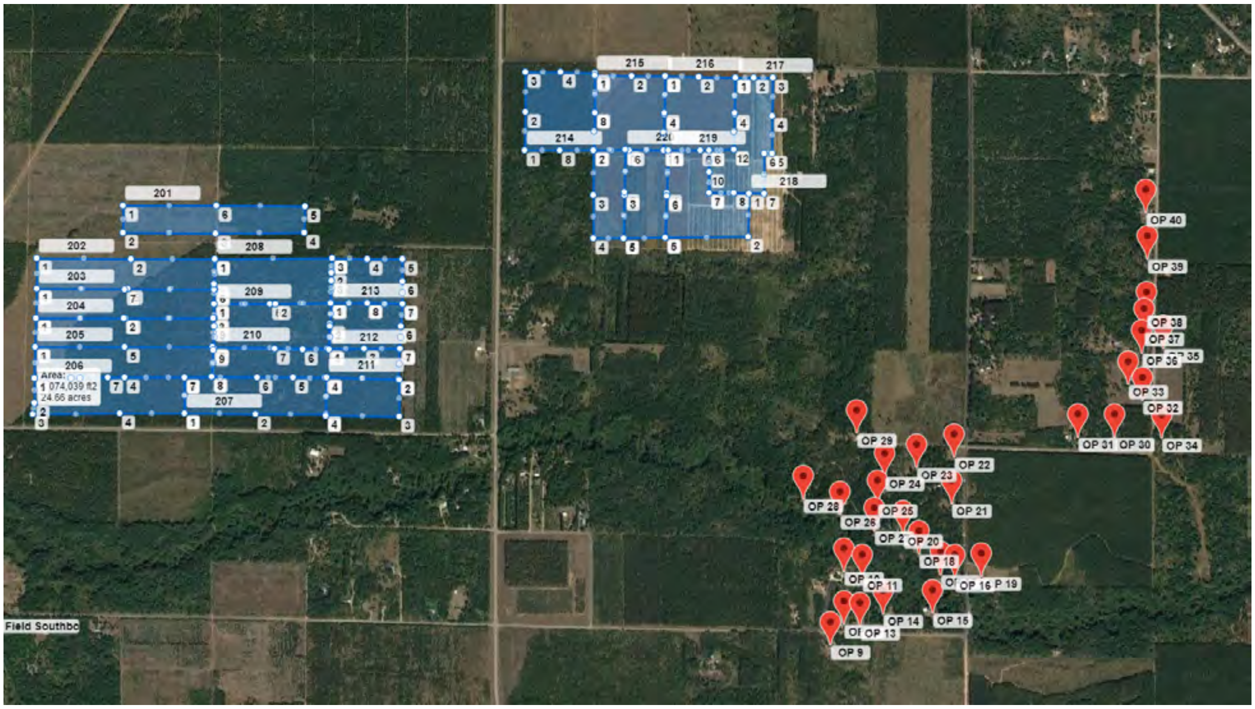
*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.11: Block 1 Analysis Area and Structure Group 13



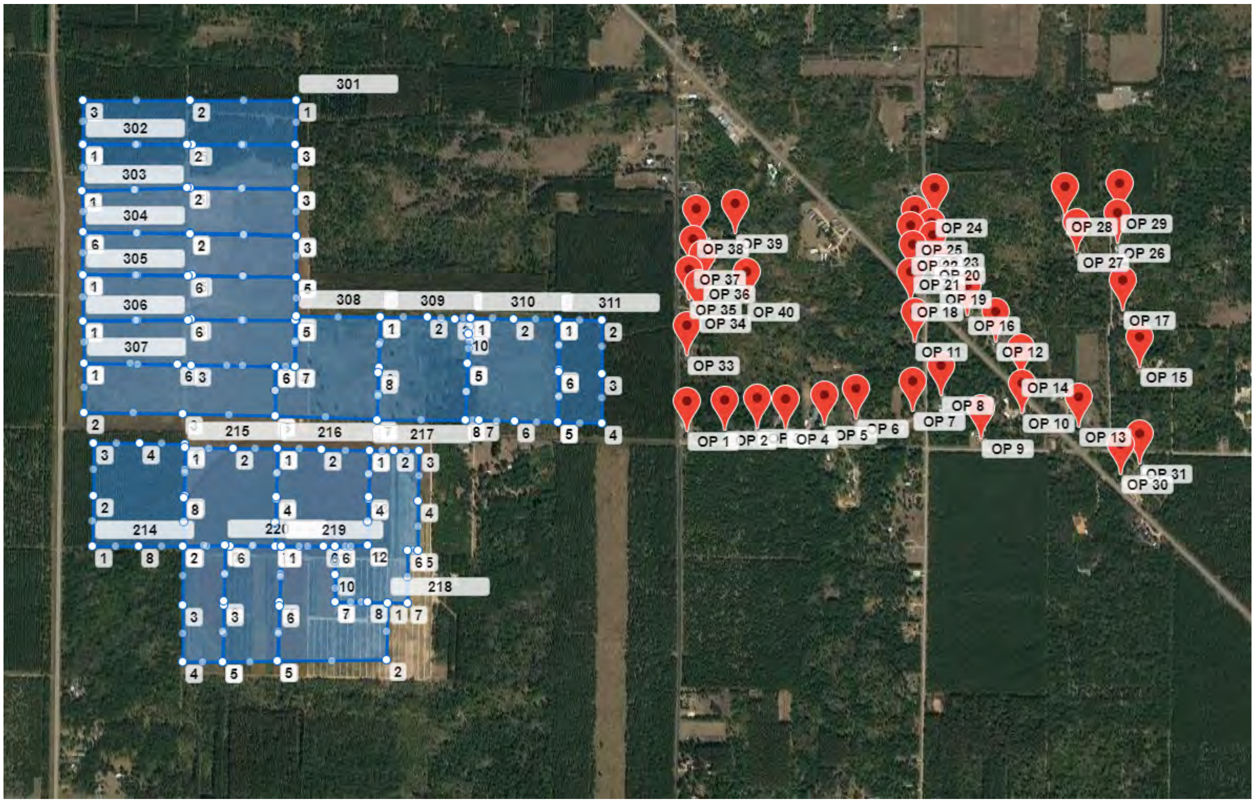
*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.12: Block 2 Analysis Area and Structure Group 5



*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.

Figure A.13: Block 3 Analysis Area and Structure Group 8



*Red markers indicate structures and blue polygons indicate PV arrays. Source: ForgeSolar, Google Earth Imagery, June 2021.