BLUEBIRD Solar Project

REFLECTIVITY AND VISIBILITY ANALYSIS

REVISION INDEX

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Executive Summary

This report analyzes the potential glare events caused by the Bluebird Solar Project (Harrison County, KY) on adjacent dwelling units and land traffic in roads near the project.

Solar plants are based on flat photovoltaic modules with low reflectivity characteristics. However, the fraction of the incident light that is reflected increases with the incidence angle, being higher when solar elevation is low (sunrise and sunset), thus potentially causing glare/glint events to observers when geometrically aligned with the reflected image of the photovoltaic plant and the sun.

To evaluate the glare hazard from the Bluebird Solar Project, a geometric analysis is done to evaluate the occurrences of geometric alignment of the PV plant reflected solar beams with observers (*Key Observation Points* or KOPs, also called *Sensitive Receptors*) located at existing dwelling units or driving in roads adjacent to the project site. Because of the rural environment and the terrain orography, the KOPs are dispersed around the project boundaries and in most of the cases without any direct visual on the solar modules, thus reflectivity event are unlikely to happen at ground level. In addition, the existence of dense vegetation plus the additionally proposed landscaping tree barriers are in most cases sufficient to fully mitigate any potential reflectivity events. However, because of the complex terrain topography, some KOPs without a near dense wooden mass do show enough visibility on the solar modules, therefore potentially subjected to glare.

The procedure followed in this report to identify reflectivity events at KOPs consists in a 3D geometric analysis resolving the reflection equations for solar beams onto the surface of the modules. This geometric analysis does not consider vegetation or topographic visual screens, which are evaluated in a second step in this report. The geometric analysis is completed for a complete year in 1-minute intervals. All mathematical expressions for sun position, KOP's position, orientation of PV modules and reflected sun beams are described and implemented in a computer routine to evaluate the risk of reflected sunlight reaching the observers.

In addition to this purely geometric analysis, a visibility analysis is conducted to determine whether the Key Observation Points (KOPs) are protected by existing vegetation or topographic visual barriers. A 3D model including visual barriers of 20' height (visual walls) at existing and proposed dense vegetation areas is built in Google Earth to determine whether the solar modules are visible from KOPs. It shall be noted that some existing tree masses around the project consist of trees taller than 20'. A third step consist a combination of the previous results to define the proposed mitigation where potentially needed.

The KOPs potentially requiring mitigation in the form of added visual barriers are: R9, R10, R15, R17, R18, R19, R20, R23, R25 and R26. The same type of analysis is conducted for land traffic at Russell Cave Road (also known as KY 353) and Leesburg Pike Road (also known as KY 62), with some additional landscaping visual barriers proposed at the West curve of KY 353.

Finally, an alternative mitigation strategy consisting in altering the orientation of the solar modules is proposed in case the wooden visual barriers (existing and added) prove to be insufficient for certain KOPs and season of the year. Potential events can only accurately be determined through observation during the first 12 months of plant operation. In this period, and as soon as an event would be detected, it would be mitigated with adequate adjustments to the control system of the plant. After these first 12 months of operation and adjustments, no future events would ever occur.

Contents

1 Introduction

AZTEC Engineering has been engaged by BayWa Renewable Energy to evaluate the potential of glare from the Bluebird Solar project towards the neighbor dwelling units and land traffic in the adjacent Rusell Cave Road/KY-353 and Leesburg Pike Road/KY-62.

The Bluebird Solar photovoltaic project is located southwest of Harrison County (KY), approximately 8 miles southwest of Cynthiana. The project sits within a cluster of parcels that make up approximately 1,345 acres of which 1,000 will be included in the CUP request. The parcels are surrounded by some scattered farming and dwelling units. The Project is divided into two areas located East and West of Russell Cave Road (also known as KY 353), with the eastern portion representing about 15% of the total project area. The western boundary of the project is limited by the Leesburg Pike Road (also known as KY 62), although the closest project boundary is more than 1700 feet from Leesburg Pike (also known as KY 62). Figure 1 show the project location, with the cluster parcels (buildable areas) highlighted in orange color. Not all these parcels are planned to hold solar modules, as shown if Figure 2.

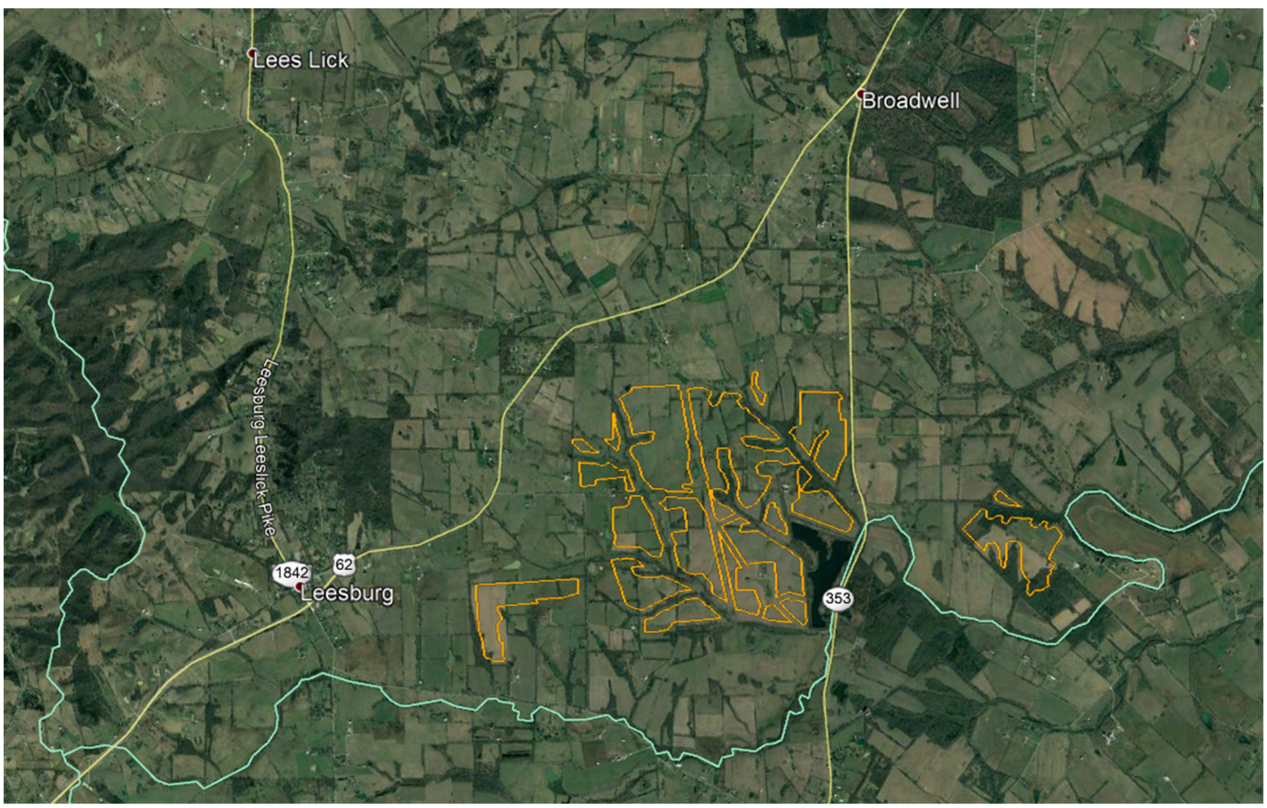


Figure 1 – Project site location and buildable areas.

The solar modules will be mounted on horizontal single axis solar tracking structures to provide them with the best possible orientation towards the sun's disk instantaneous location (i.e., modules rotating from East to West daily). The modules will be arranged in some of the depicted buildable areas. Figure 3 below shows the relative location of the buildable areas with respect to the potential KOPs, numbered as R1 to R26:

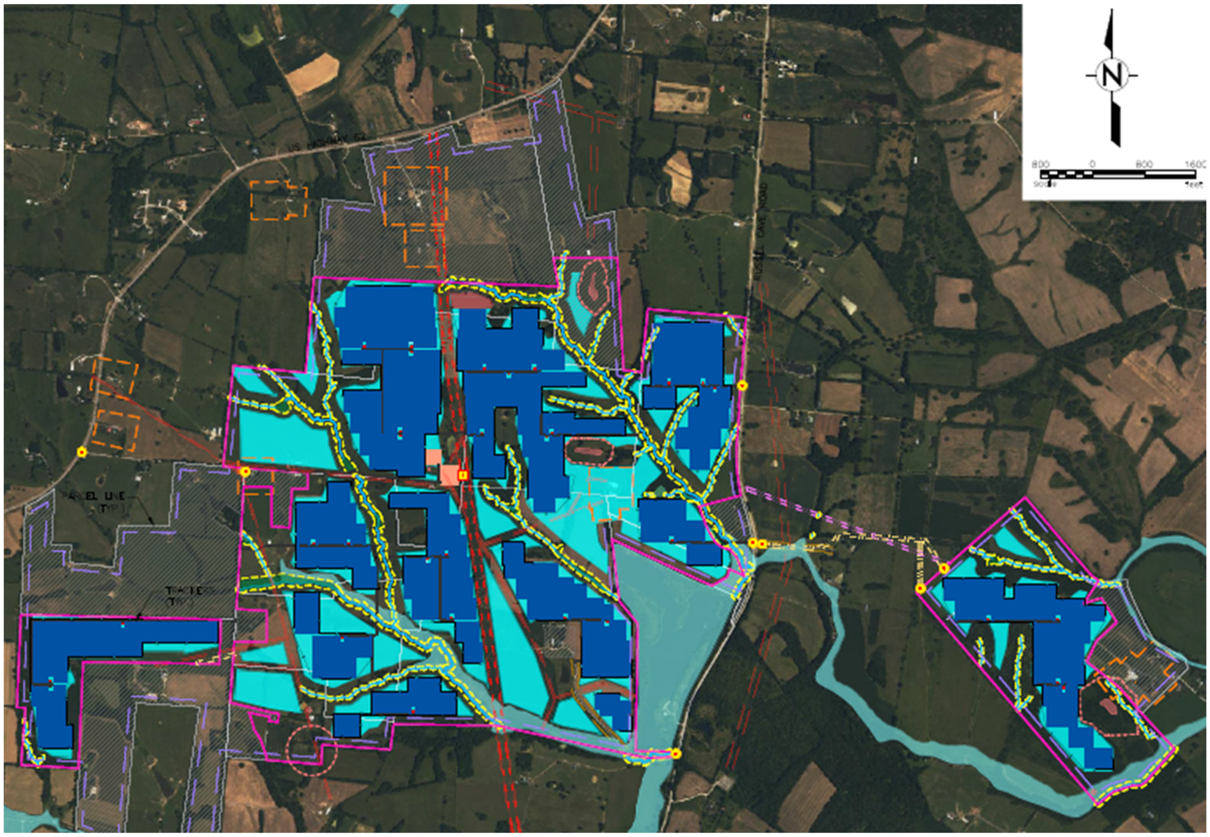


Figure 2 – Location of solar modules within buildable areas.

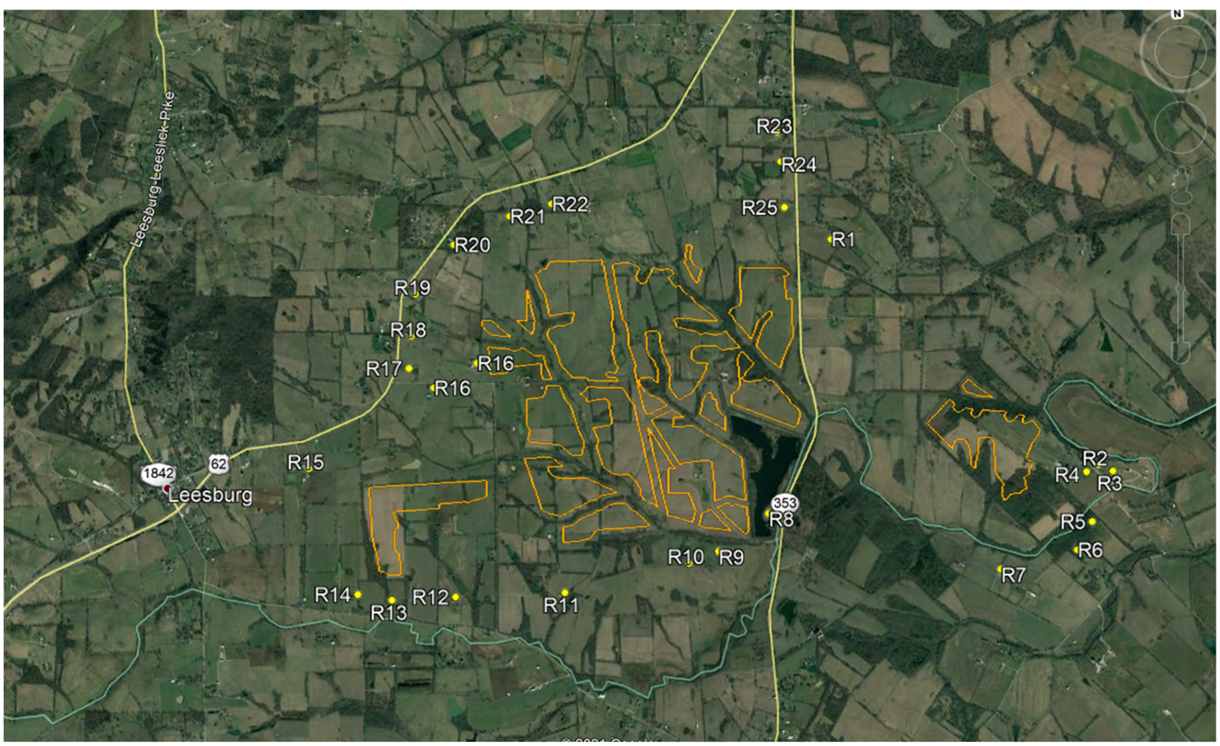


Figure 3 - Location of potential KOPs.

This document addresses the potential for glare hazard in both (i) the identified static Key Observation Points (KOPs), and (ii) Russell Cave Road also known as KY 353 and traffic at Leesburg Pike also known as KY 62, due to the future installation of the photovoltaic modules.

To evaluate the risk of direct sun light reflection events from the photovoltaic modules toward the KOPs a mathematical (geometric) model has been developed. The model predicts which times of the year there is a possibility for observers located at KOPs to experience reflection from the PV panels. The methodology is described in Section 3 of this document.

2 Definitions

The following definitions and descriptions are relevant to understanding the methodology and results of this study.

Photovoltaic System – A PV system consists of a series of flat photovoltaic modules mounted on any of the following supporting structure types:

- Fixed tilt structures
- Single axis tracker structures
- Two axis tracker structures

Depending on the supporting structure type, the modules shall be fixed tilt or moving towards the sun position with appropriate solar tracker structures. A varying orientation provides the PV modules a higher sun exposure. This project will use single horizontal axis tracker structures. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity and are furnished with anti-reflective coating for that purpose. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel and should not pose a reflectance hazard to viewers (Figure 4).

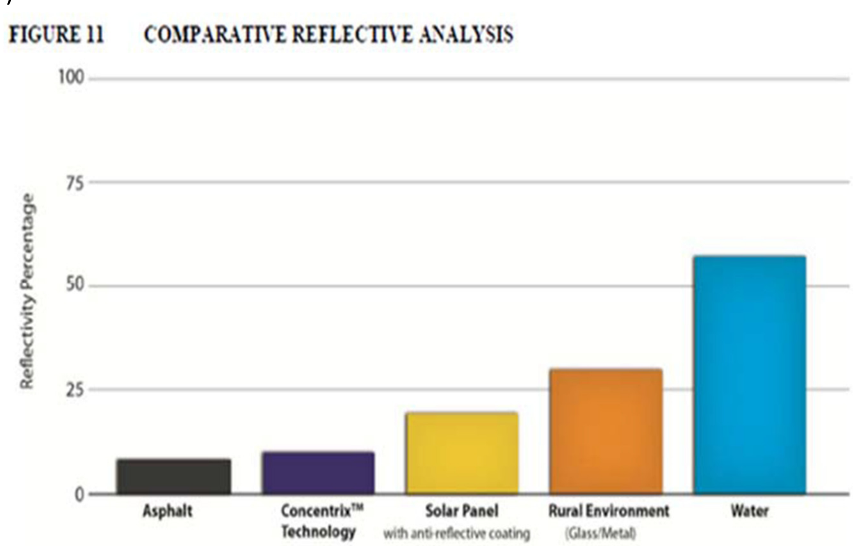


Figure 4 – Reflectivity properties of several materials

However, it shall be noted that reflectivity characteristics of solar modules vary with light incidence angle. Figure 3 shows the reflection coefficients (p.u.) of PV modules in function on the light incidence angle, which describes an increasing reflected fraction of incident light as the incident angle increases (i.e., at sunrise and sunset). For example, at an incidence angle of 70^{o}, 40% of incident light is reflected.

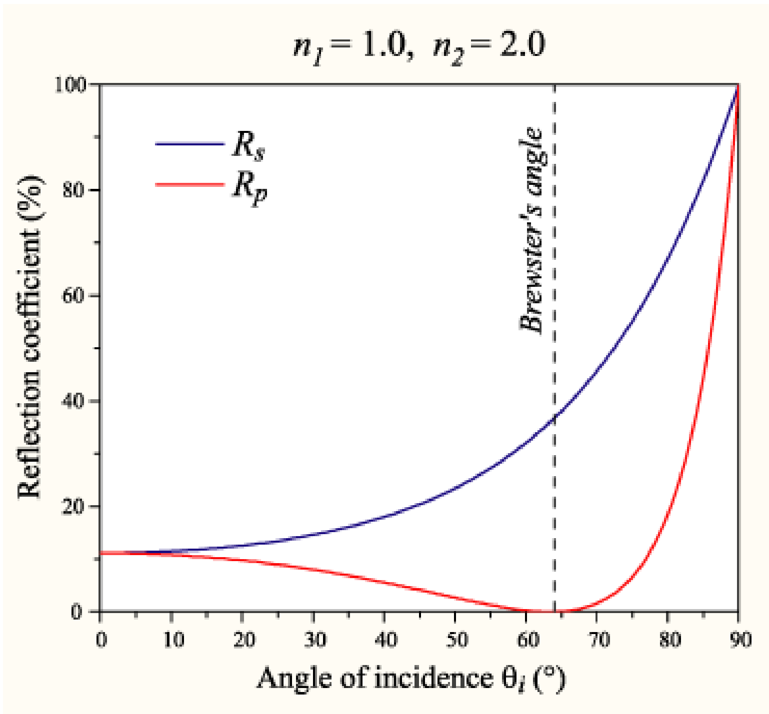


Figure 5 – Reflection coefficients for PV modules.

Glint – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the solar module. This is the potential source of the visual/reflectivity issues regarding viewer distraction. Glint is highly directional since its origin is purely reflective.

Glare – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and has negligible effects. As Glare is the reflection of diffuse irradiance, it is not a direct reflection of the sun, however still directional because of the circumsolar source for diffuse component. Diffuse fraction of reflected light is increased by reflecting plane surface roughness, which scatters the reflected beam in random directions. Other glare sources in nature (often called Albedo reflectance) can be more intense that glare from PV modules. For instance, an agricultural environment or free water surfaces have higher glare effect than PV modules at lower light incidence angles.

An example of Glint and Glare effects by a solar photovoltaic plant is shown in Figure 6 below.

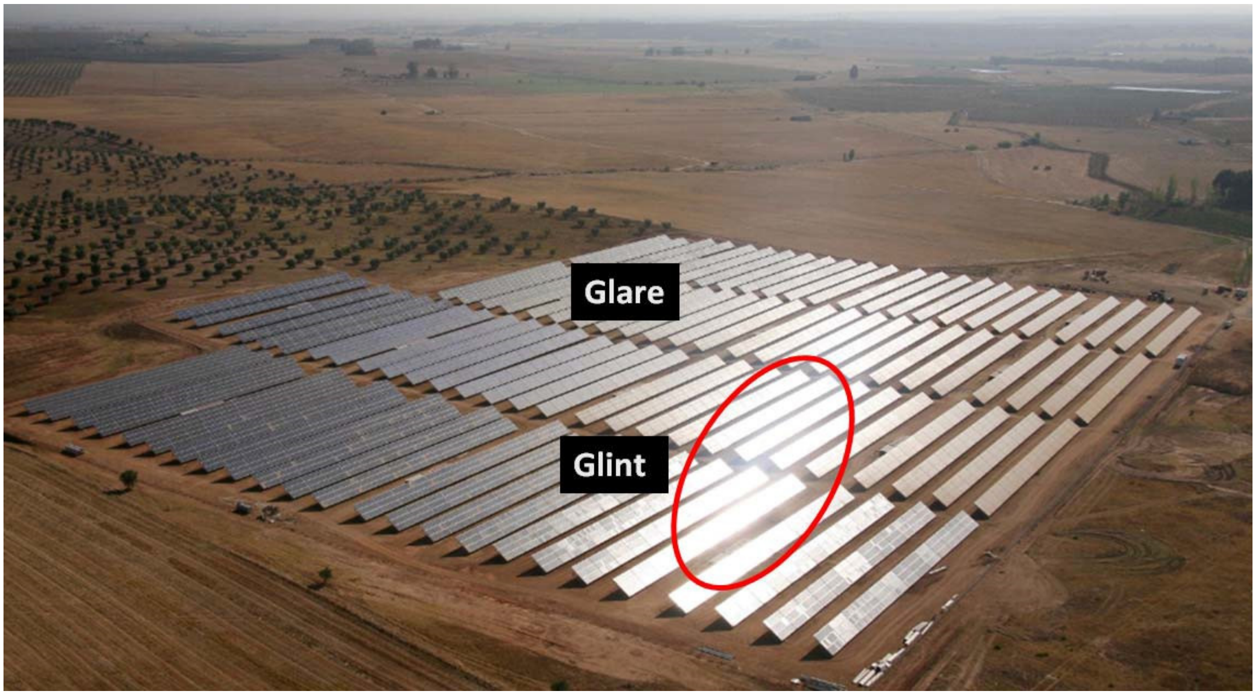


Figure 6 .- Glint and Glare appearance from a solar PV installation.

Key Observation Point (KOP) – KOPs are viewpoints used in the glint and glare study, also defined as the position of the observers. Also referred to as *Sensitive Receptors.* In this analysis, the KOPs are the dwelling/faming units located in the vicinity of the module installation areas and land traffic in Russell Cave Road (also known as KY 353).

3 Mathematical analysis

3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. To properly relate sun position, PV modules position and orientation, and the KOPs' locations, it is necessary to define a global coordinate system to which the previous locations and orientations will be referenced to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

Positive X-Axis	Pointing East
Positive Y-Axis	Pointing North
Positive Z-Axis	Pointing upwards (zenith)

The origin of the reference coordinate system is arbitrary chosen to be at the center of the buildable areas:

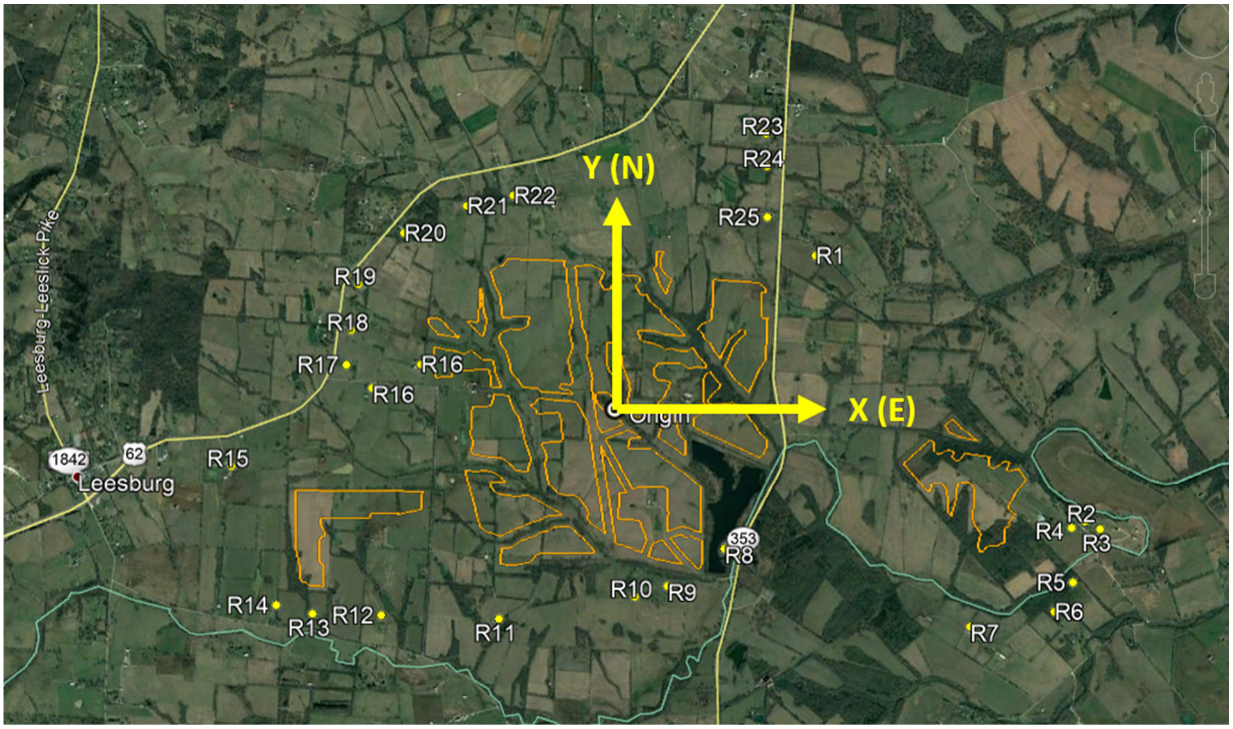


Figure 7 .- Reference coordinate system.

The absolute position of the reference coordinate system's origin is as follows:

Latitude:	38.2982° (North)
Longitude:	-84.3754° (West)
Elevation:	870ft (o.s.l)

3.2 Sun position

The instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the angular deviation of sun's horizontal projection from due South, while elevation is the vertical angle between the horizontal plane and sun's position. Figure 8 illustrates the above definitions and criteria for positive values.

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). The cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = cos\theta \; sin\varphi$$
$$B = -cos\theta \; cos\varphi$$
$$C = sin\theta$$

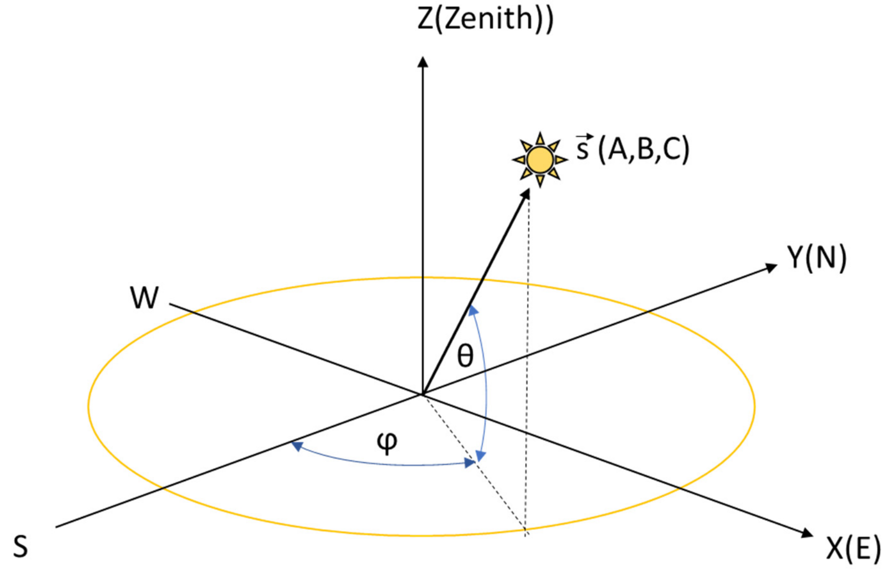


Fig 8.- Sun position coordinates.

The azimuth and elevation angular coordinates (φ, θ) are both function of:

- Latitude (L) at the origin (O)
- Time: Day of the year (i) and hour of the day (H)

and can be calculated by means of the following astronomical equations:

Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$

$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32,… until i =365). The hour of the day (H) is referred to solar noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc). As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in Fig. 9 for the selected coordinate system origin:

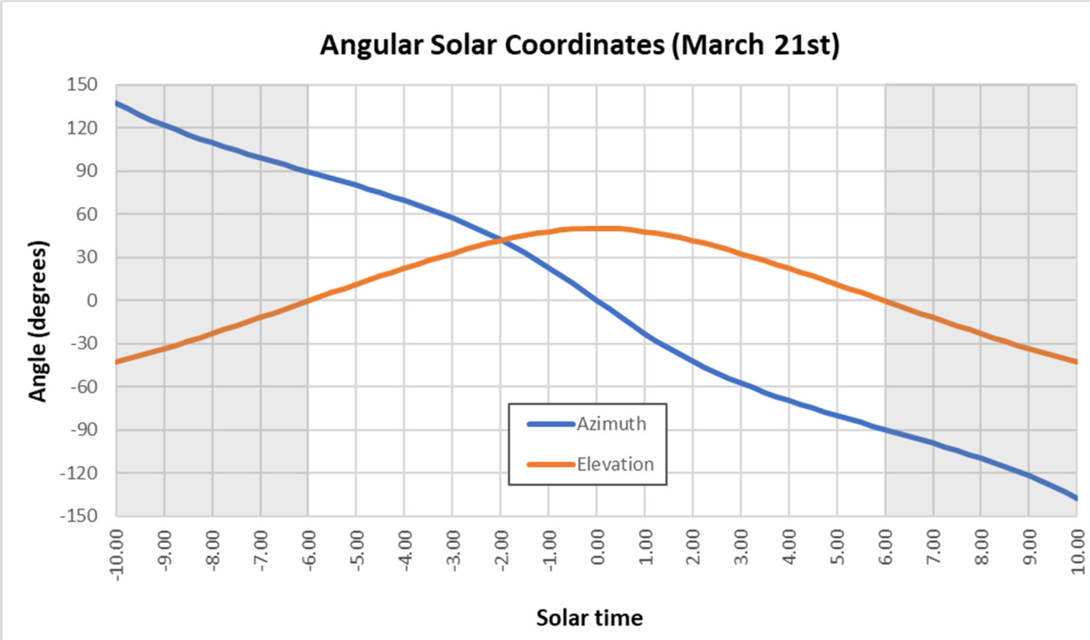


Figure 9.- Sun position angular coordinates in function of hour of the day (solar time). Shaded areas depict nighttime.

Negative values of the elevation angle mean nighttime (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is 90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 50.32° for the project's latitude and particular day. To facilitate the geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). These are plotted in Fig. 10 for the same sample day.

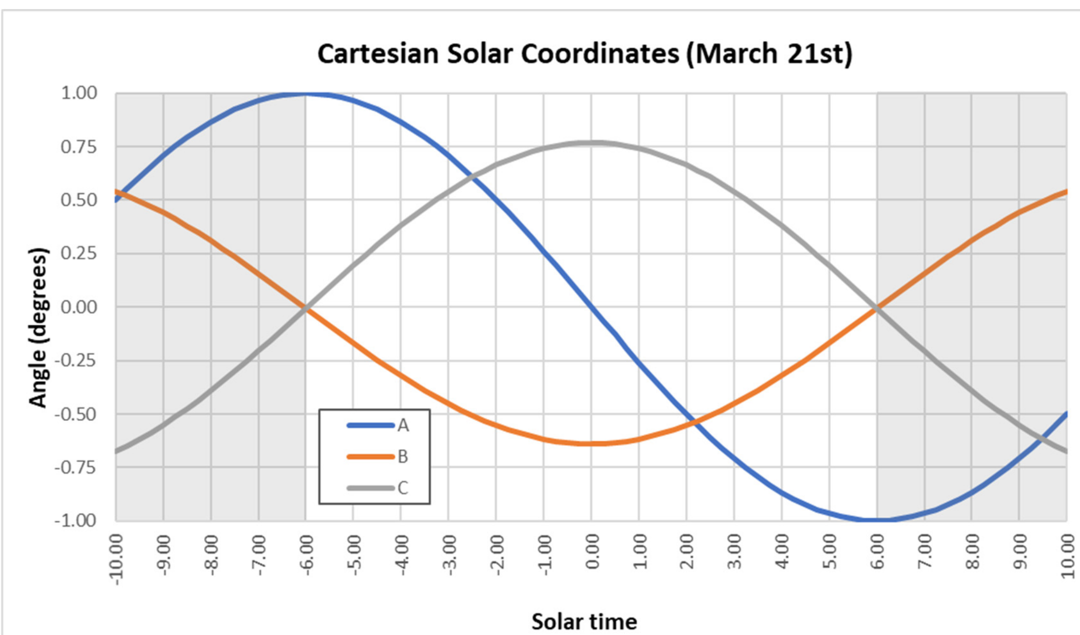


Figure 10.- Sun position vector Cartesian coordinates in function of hour of the day (solar time).

3.3 Reflection equations for horizontal axis trackers

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation vectors are known. The instantaneous solar beam direction vector s = (A, B, C) and the reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both define a plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in that plane and symmetric to the incident beam with respect to the reflecting surface vector [n], as shown in the following figures:

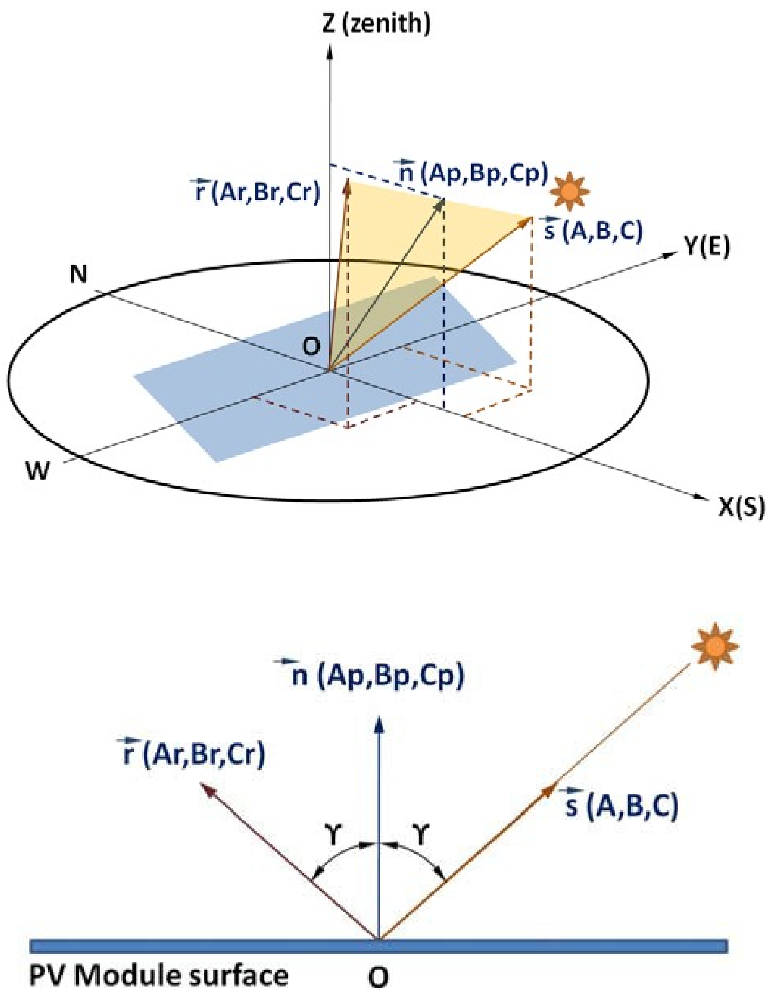


Figure 11.- Reflecting surfaces – Notation for reflected beam vector

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules' plane. The incidence angle can be calculated as per the dot product of the unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + \ C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\,\vec{n} - \vec{s}$$

with its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\,A_p - A$$
$$B_r = 2\ \cos\gamma\,B_p - B$$
$$C_r = 2\ \cos\gamma\,C_p - C$$

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position so to obtain the maximum irradiance on the modules at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates. Therefore, the vector perpendicular to the modules [n] is not constant along the day but rotating with the horizontal tracker axis. The target is to keep the incidence angle [ϒ] as close a zero to possible.

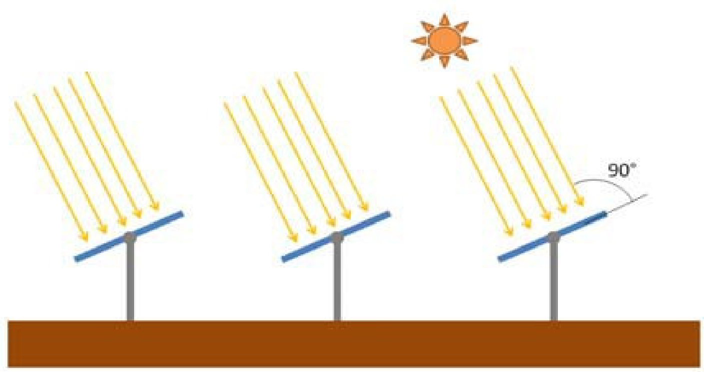


Figure 12.- Tracking angle of horizontal axis trackers

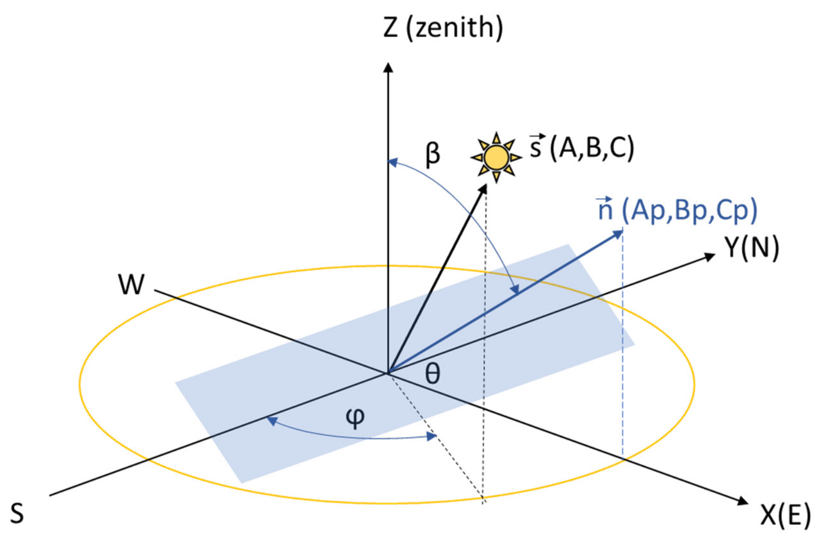


Figure 13.- Normal vector to PV modules in a horizontal axis tracker

Given the instantaneous rotation angle of the tracker (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is obtained as:

$$A_p = sin\beta$$
$$B_p = 0$$
$$C_p = cos\beta$$

The objective is to track for the minimum incidence angle (γ). This occurs if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

this can be written as

$$cos\gamma = A\ sin\beta + C\ cos\beta$$

The minimum incidence angle occurs when

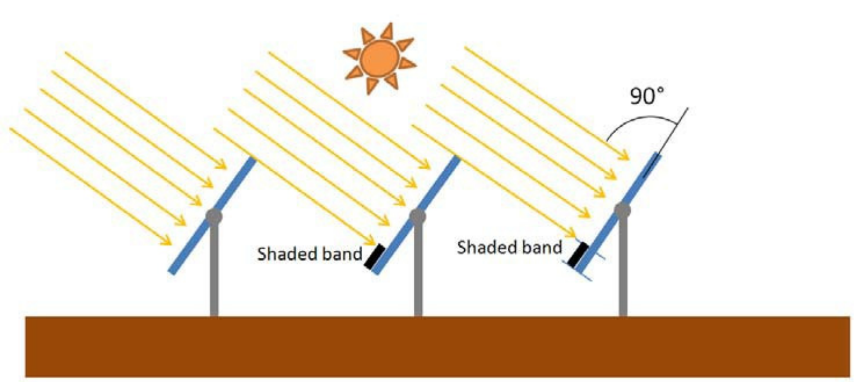
$$\frac{d(cos\gamma)}{d\beta} = A\ cos\beta - C\ sin\beta = 0$$

Which describes the rotation angle of the tracker in function of sun position (i.e., the tracking algorithm), and hence the coordinates for the vector perpendicular to the plane of the PV modules, as:

$$\tan\beta = \frac{A}{C}$$

3.3.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed (β = 90 degrees) and mutual shading between successive rows of modules would occur. To avoid this situation, the tracking control system has a *backtracking* algorithm which corrects the tracker rotation angle back so to avoid this mutual shading. When backtracking is active, the tracker will not rotate to follow the sun path anymore, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude. As a result, the module tilt at sunrise and sunset is always zero (modules in horizontal position).



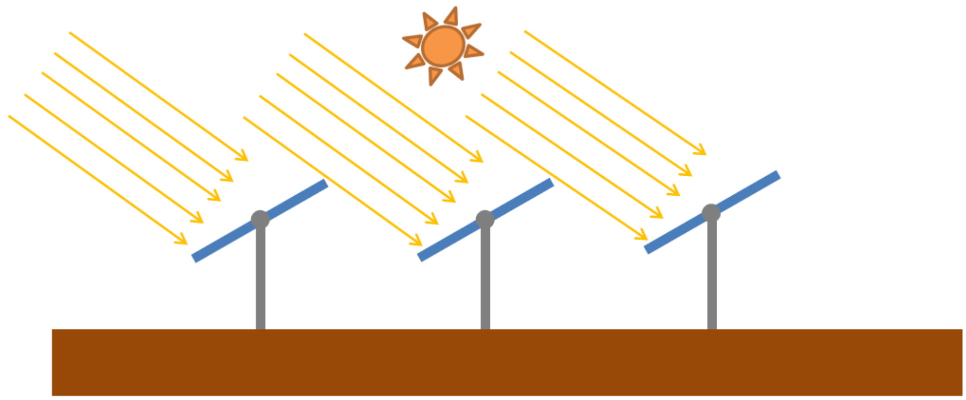


Figure 14.- Above: Mutual shading without backtracking. Below: Backtracking corrected incidence angle to avoid mutual shading

The tracker angle when the backtracking correction is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.0 ft) and [p] is the pitch between tracker rows (18.8 ft). The maximum tracker angle is limited to ±52° for mechanical and constructive reasons.

Figure 15 shows the change in tracker angle, together with sun elevation for the sample day (March, 21st).

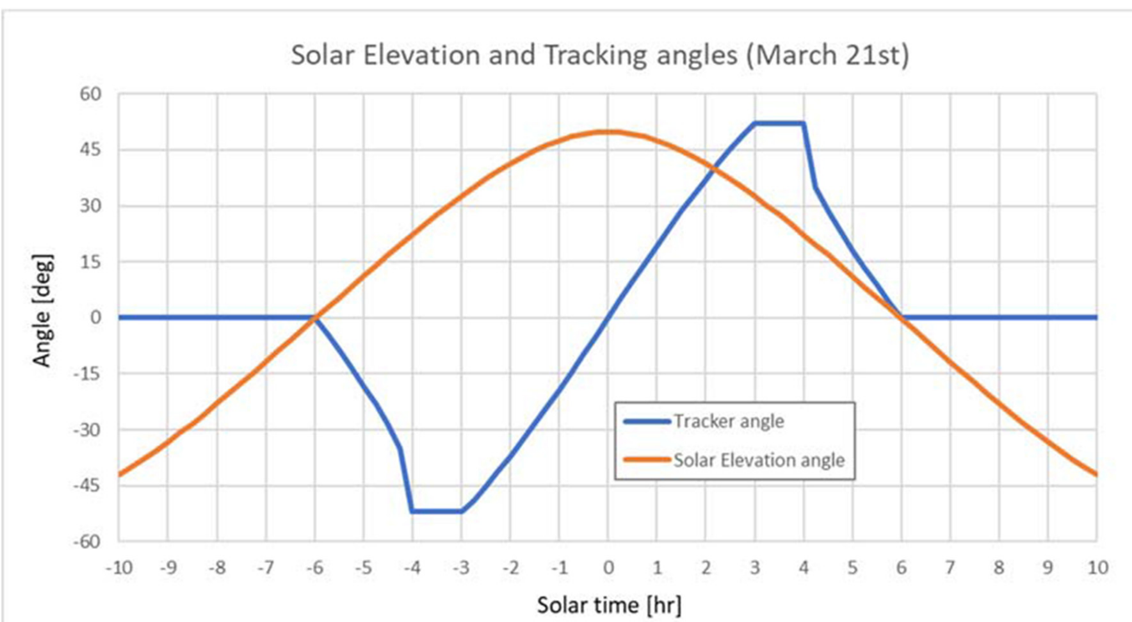


Figure 15.- Tracker angle [β] on March 21st

3.3.2 Effect of the non-planar system geometry

Because the project site orography is not planar, the solar plant design will adapt the orientation of each individual tracker row to the slope of the existing terrain underneath. In some instances, where the existing terrain slope is higher than the tracker installation slope limitations, some grading will be needed to adapt the terrain orography to these limitations. The civil design for the solar system will minimize the site grading to (i) reduce the hydrological, environmental and visual impact of the project, and (ii) optimize the construction costs, by maximizing trackers' adaptation to the existing terrain.

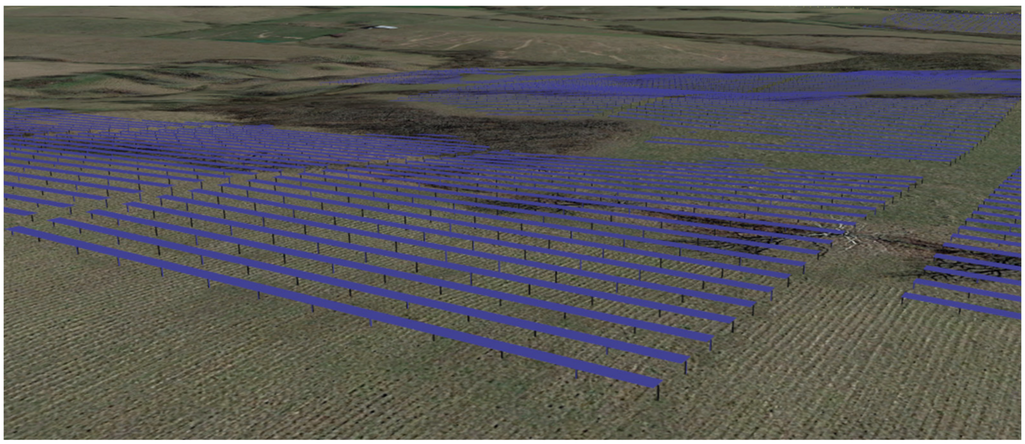
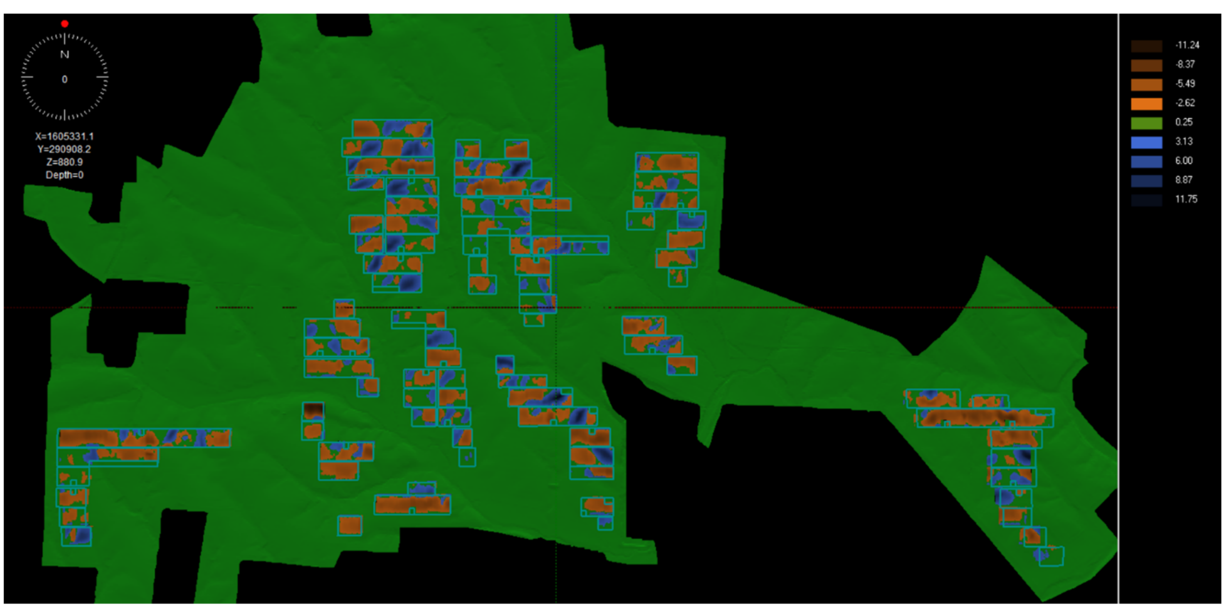


Figure 16.- 3D representation of a non-planar solar system, with trackers having different elevations and orientations in space.

A grading simulation has been completed for the project with AZTEC's proprietary simulation software (PVGRAD) so to determine the orientation for each independent tracker in the system. The grading results and tracker N-S angle distribution are shown in Figure 17.



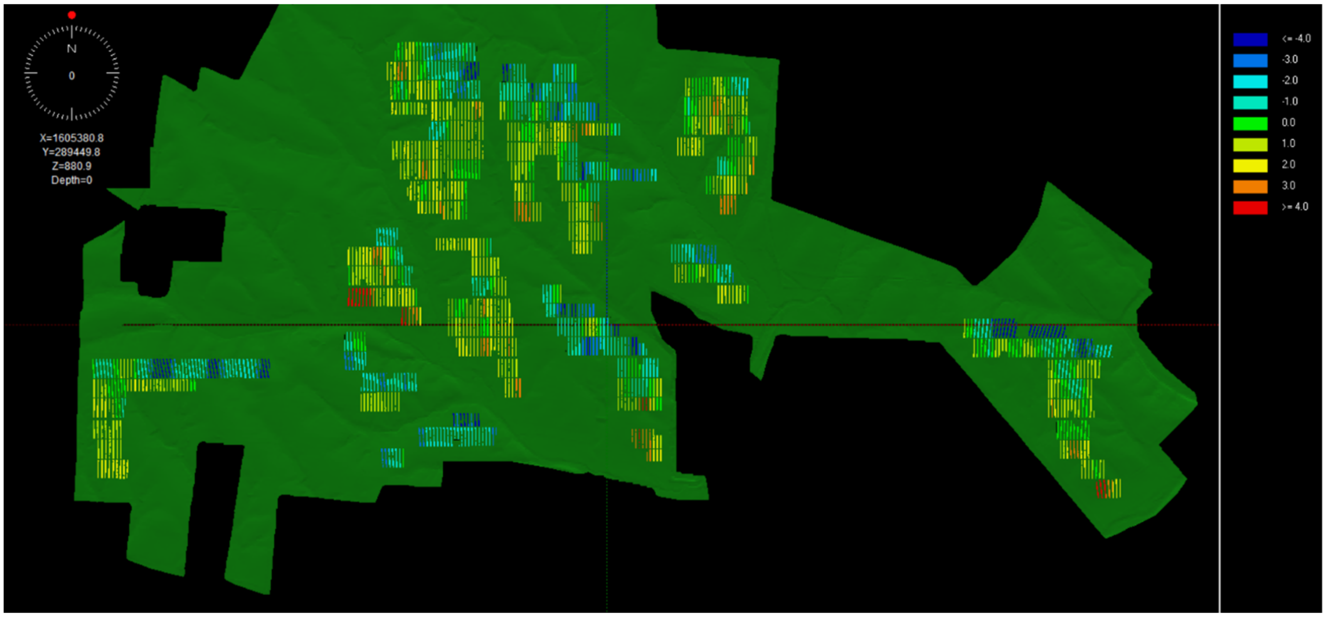
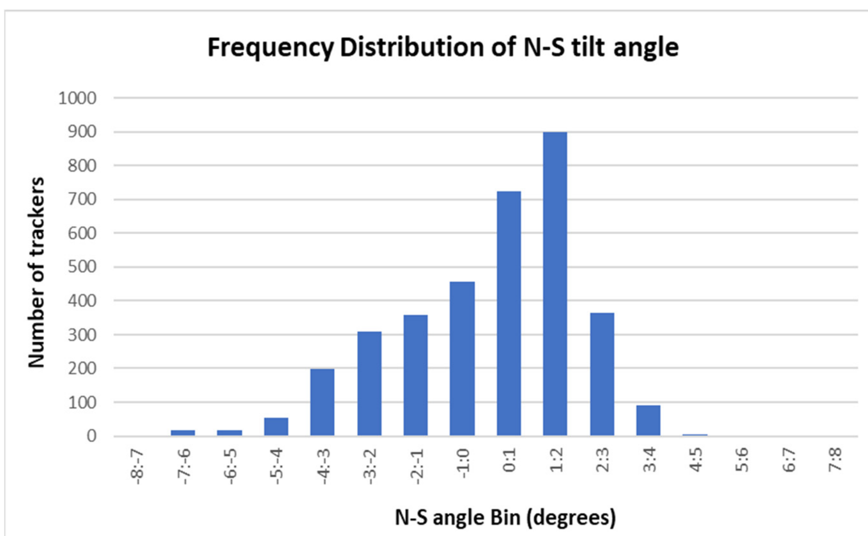


Figure 17.- Above: Grading simulations for the Bluebird Solar project (marron= cut, blue = fill).
Below: N-S tracker angle distribution after grading

The frequency distribution of trackers' N-S tilt angles for the project is shown in the table below:

Min	Max	Number of trackers
-8	-7	3
-7	-6	16
-6	-5	18
-5	-4	53
-4	-3	198
-3	-2	309
-2	-1	357
-1	0	456
0	1	724
1	2	899
2	3	365
3	4	92
4	5	6
5	6	0
6	7	0
7	8	0



When installing a tracker row on a varying slope terrain (i.e., the N-S rotation axis being a tilted line), each independent tracker row will have a different orientation in space, thus altering the moving plane equations by introducing the N-S tilt angle [α]. This N-S tilt angle correction is added in the equations for the coordinates of the perpendicular vector to the modules, which now depend on (i) the tracker aperture angle [β] and the N-S tilt angle for the rotating axis [α], and (iii) the topographical elevation of the tracker.:

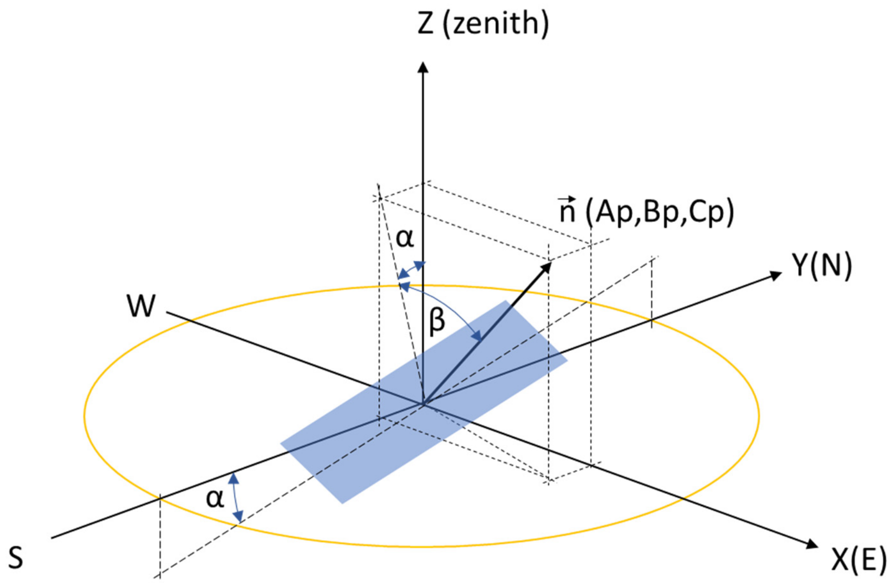


Figure 18.- Perpendicular vector to modules' plane with an arbitrary N-S tracker tilt angle.

$$A_p = sin\beta$$
$$B_p = -sin\alpha\ cos\beta$$
$$C_p = cos\alpha\ cos\beta$$

Because the N-S tilt angle [α] and topographical elevation is different for each independent tracker row, so it is the perpendicular vector of its modules' plane and the direction of the corresponding reflected beam. It is therefore necessary to evaluate the risk for each tracker row to reflect the sun beams towards the location of each KOP separately. This task is numerically intense and can only be resolved by means of computer simulations. PVGRAD has built-in all the geometric equations described above to determine the intersection events between the reflected solar beams at the specified KOP locations in space. These are evaluated in intervals of 1-minute for the full year.

4 Reflectivity Analysis

The process to numerically determine the risk for reflectivity events at the KOPs consist in deploying a virtual cylindrical surface surrounding the full solar project. This cylindrical surface acts as a 'projection screen', which intersects the reflected beams by the solar modules. The intersection events along a full year are then counted for at each point of the screen, so the glare intensity can be mapped. The daily glare intensity at any given point is defined as the total number of trackers reflecting towards that specific point in a certain minute, and then aggregating this number for all minutes of the day.

Figure 19 shows the projection screen for the project as a color heat map for reflected beam intersections (red for high number of events, blue for low number of events):

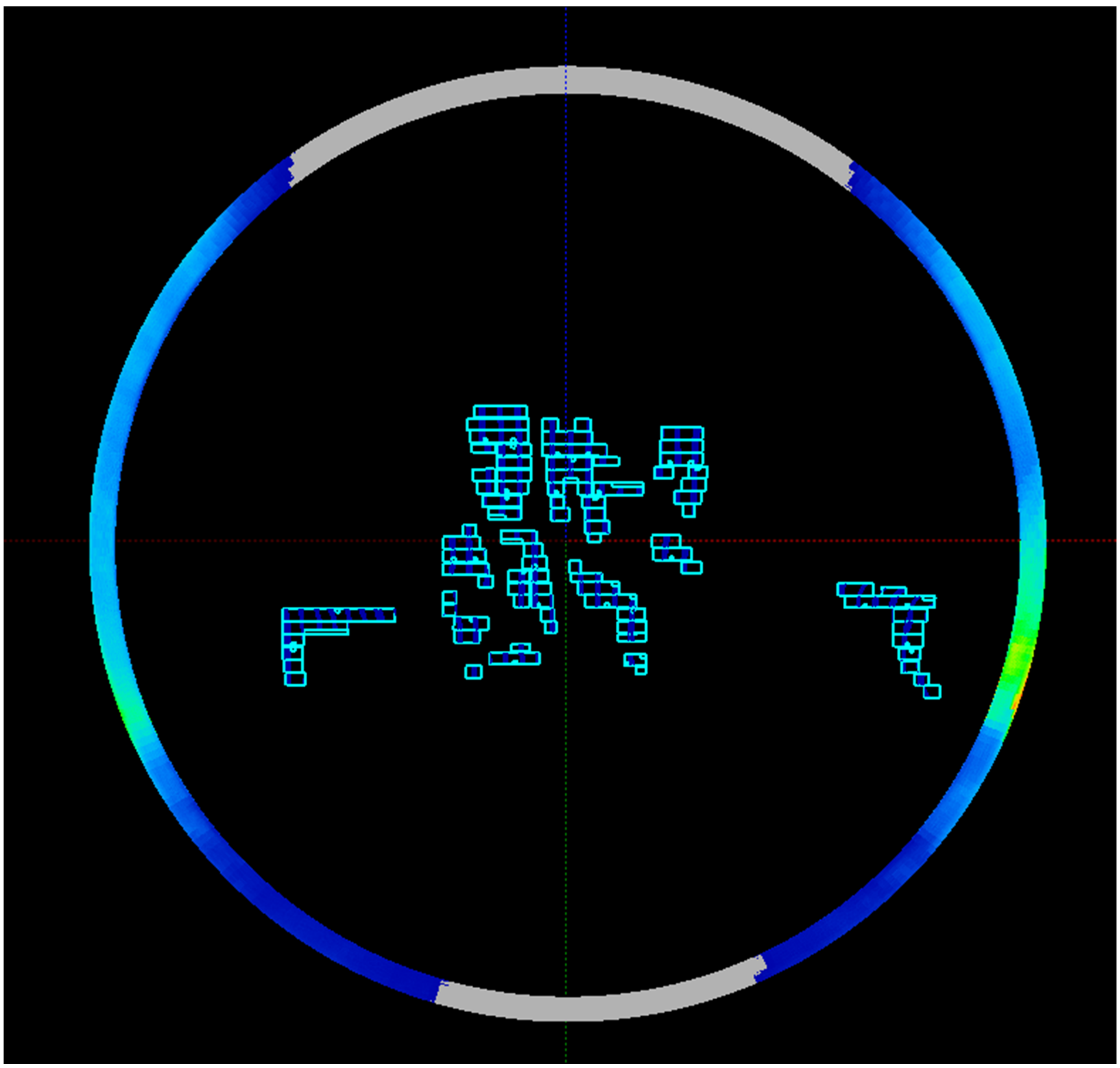


Figure 19A.- Cylindrical projection screen for the project (Top view).

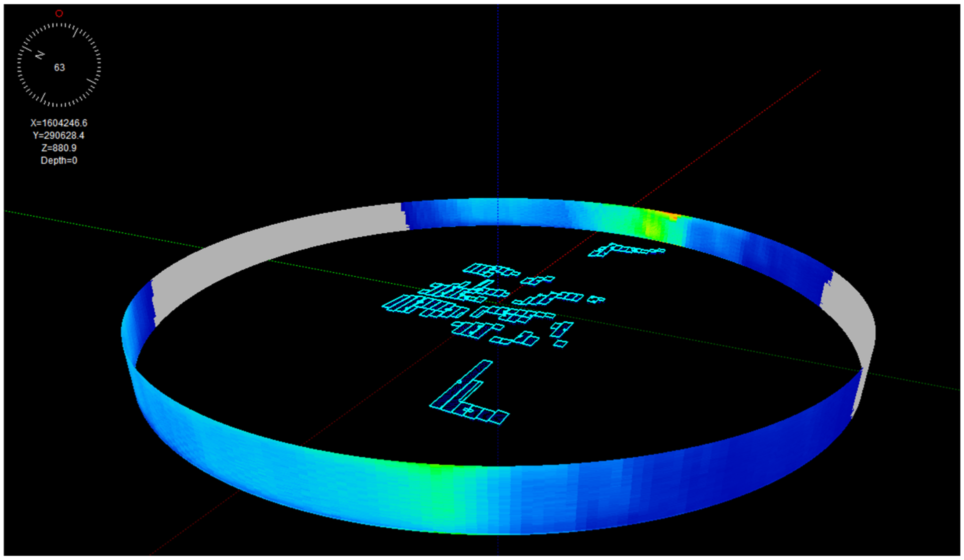


Figure 19B.- Cylindrical reflectivity projection screen for the project (view from West).

The cylindrical projection screen is developed in a flat diagram as shown in Figure 20:

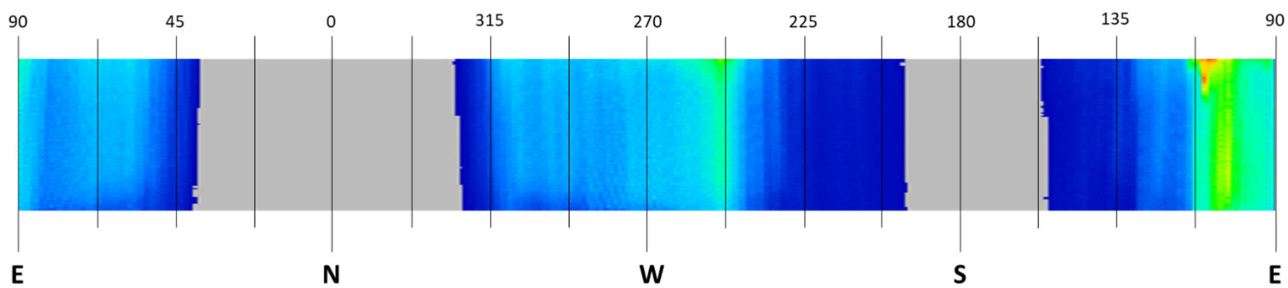


Figure 20.- Cylindrical reflectivity projection screen for the project. Developed surface (view from outside).

4.1 Analysis of Static Key Observation Points (KOPs)

Each Key Observation Point (KOP) is identified in a projection screen to obtain the specific days and minutes of the day the reflectivity events occur. Because this is a purely geometric analysis, no external visual barriers blocking the potential for glare (as vegetation or specific terrain topography in between trackers and KOPs) are accounted for in the results. These will be included later in the study process. The results below for reflectivity events at individual KOPs are therefore a worst-case scenario with no visual barriers considered. Most of the calculated glare events are screened by the existing vegetation, added native vegetation (landscaping mitigation) and topography (plant visibility), as evaluated in Section 5 of this document. Also, the specific trackers in the plant layout causing reflectivity events at KOPs are recorded.

The location of the static KOPs is shown in Figure 21A:

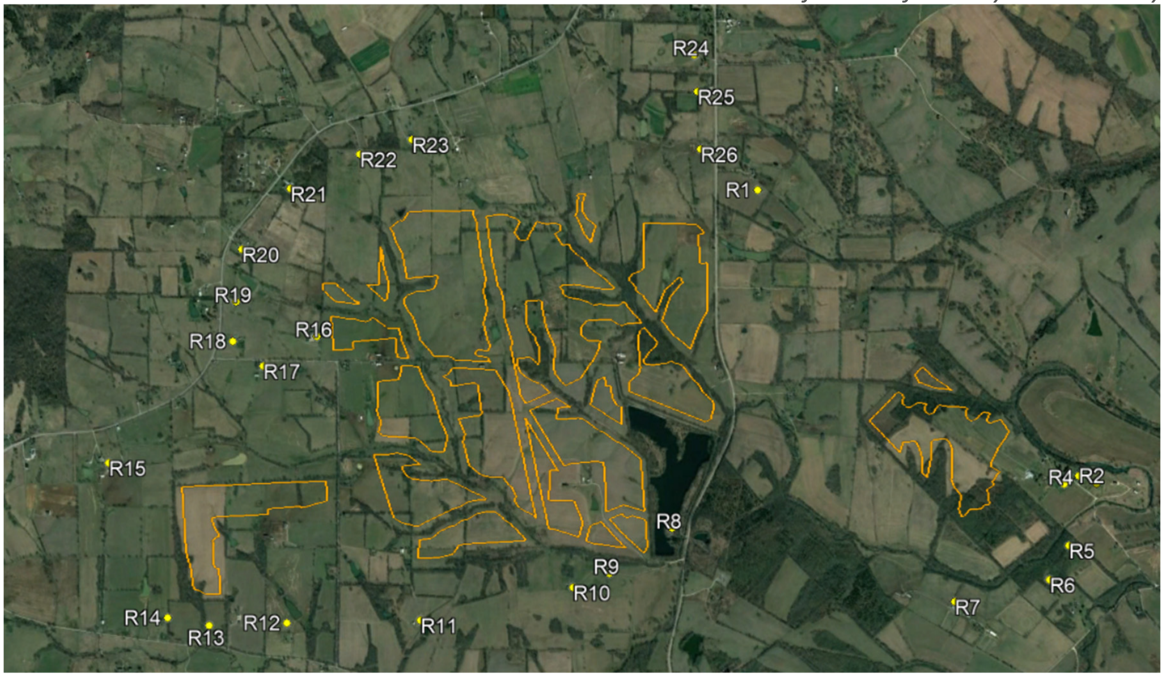
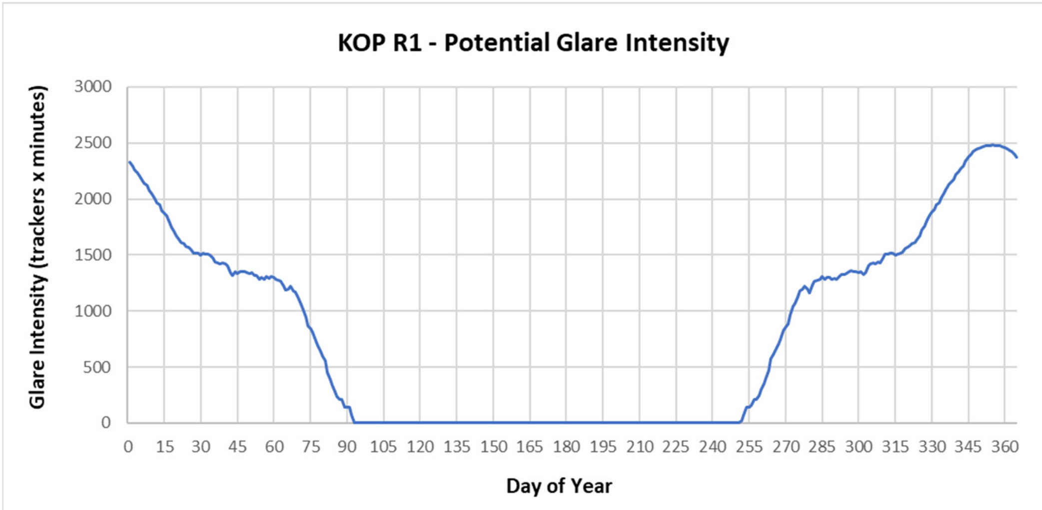
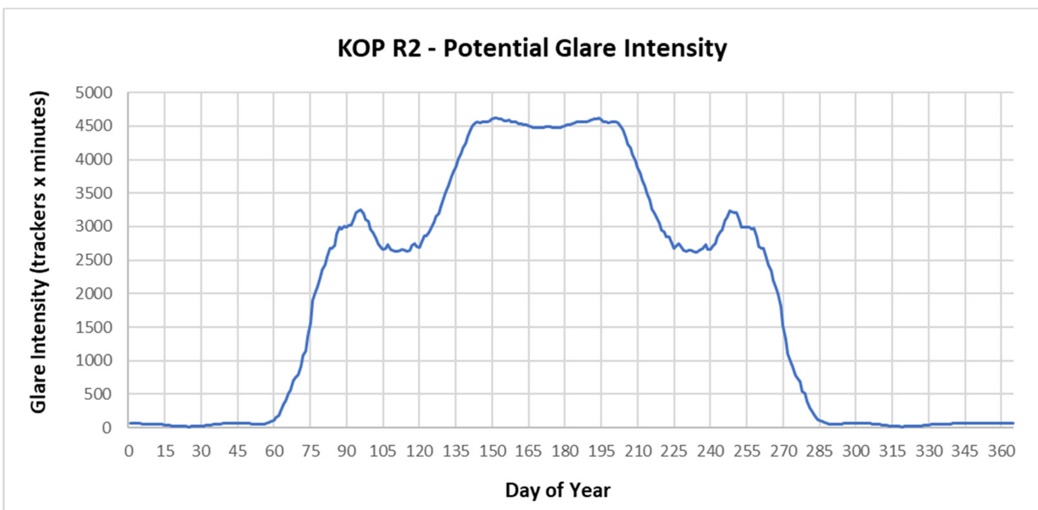


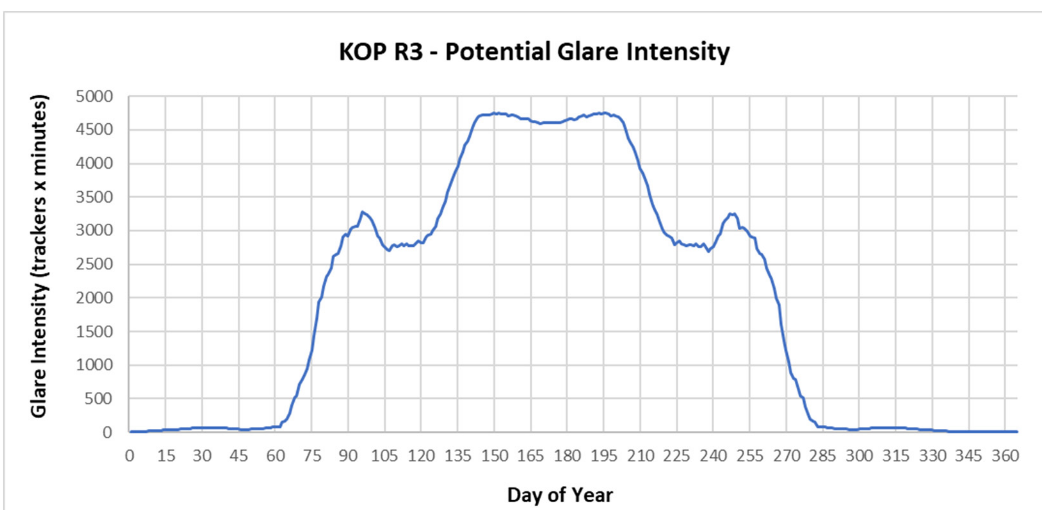
Figure 21A – Location for KOPs (Sensitive Receptors)

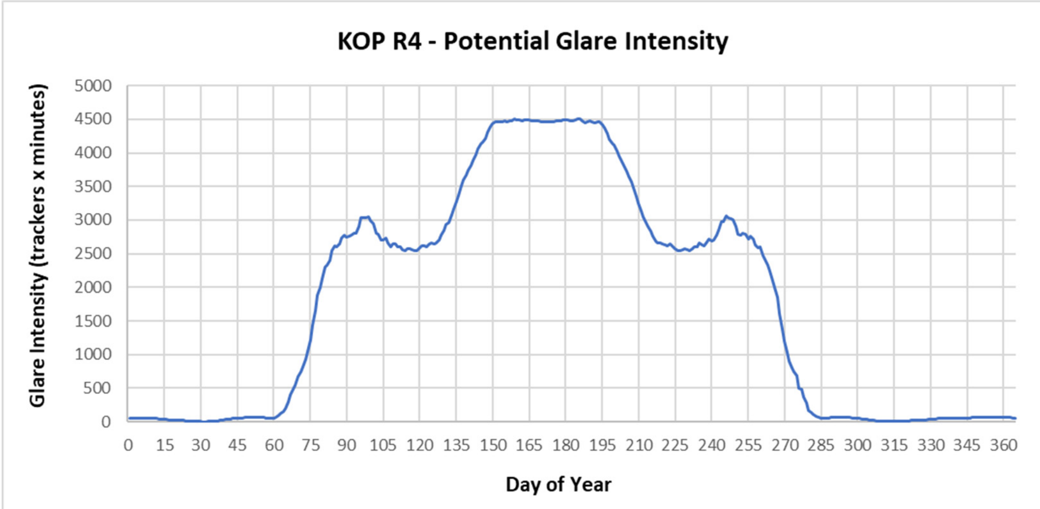
The relative location of the KOPs with respect to the origin of the reference coordinate system is given in the table below. The reflectivity results for each KOP is depicted as glare intensity numerical curves for each day of the year.

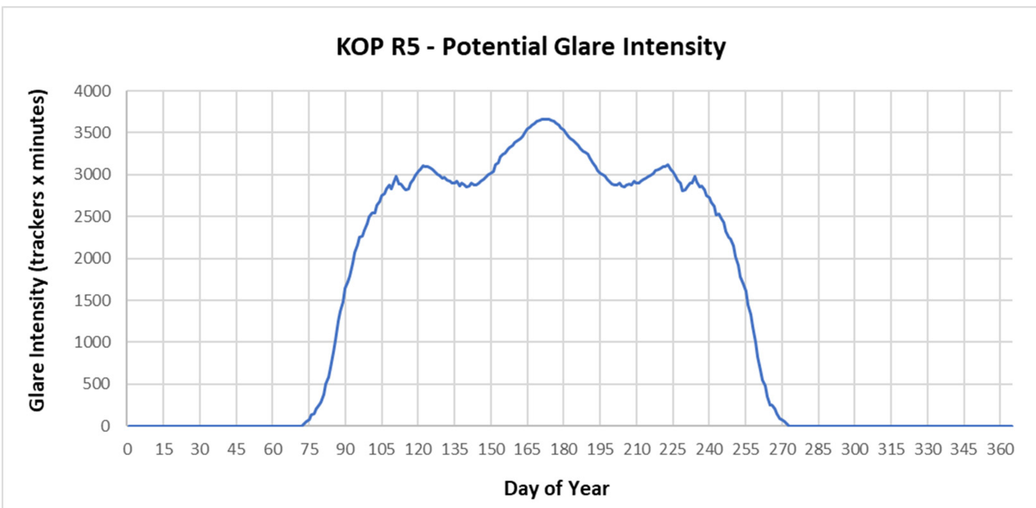
KOP	X	Y	Z
R1	4569	3364	3
R2	10654	-2724	-36
R3	11014	-2894	-48
R4	10337	-2873	-41
R5	10359	-4079	-27
R6	9930	-4732	-37
R7	7999	-5073	-22
R8	2425	-3238	-44
R9	1137	-4026	-8
R10	385	-4214	13
R11	-2701	-4677	12
R12	-5415	-4609	9
R13	-6936	-4555	-2
R14	-8572	-4777	9
R15	-8751	-1165	58
R16	-4423	1084	52
R17	-5485	610	49
R18	-6063	1143	46
R19	-5940	1924	54
R20	-5753	2959	54
R21	-4708	4102	31
R22	-3269	4691	45
R23	-2205	4908	50
R24	3562	6213	17
R25	3572	5473	49
R26	3556	4325	37

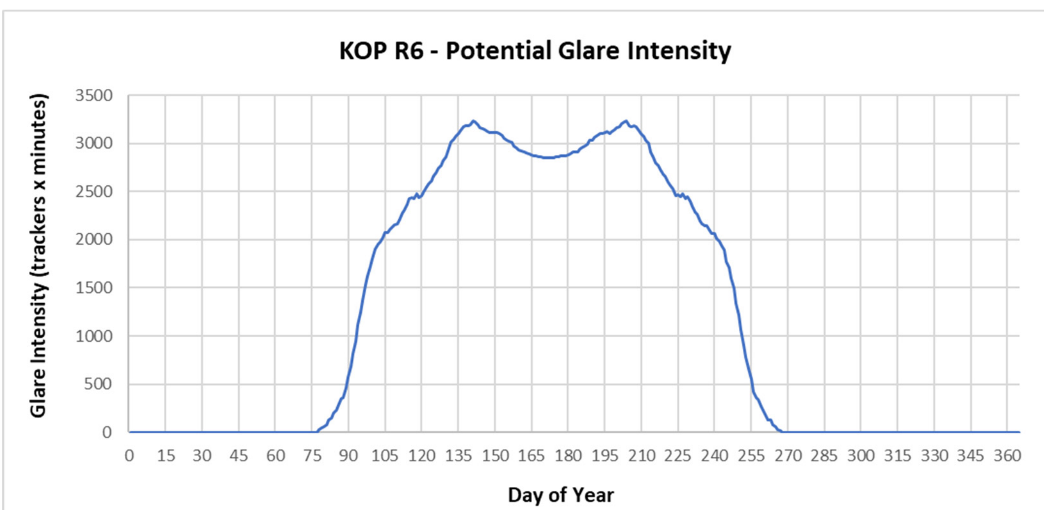

KOP R1 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

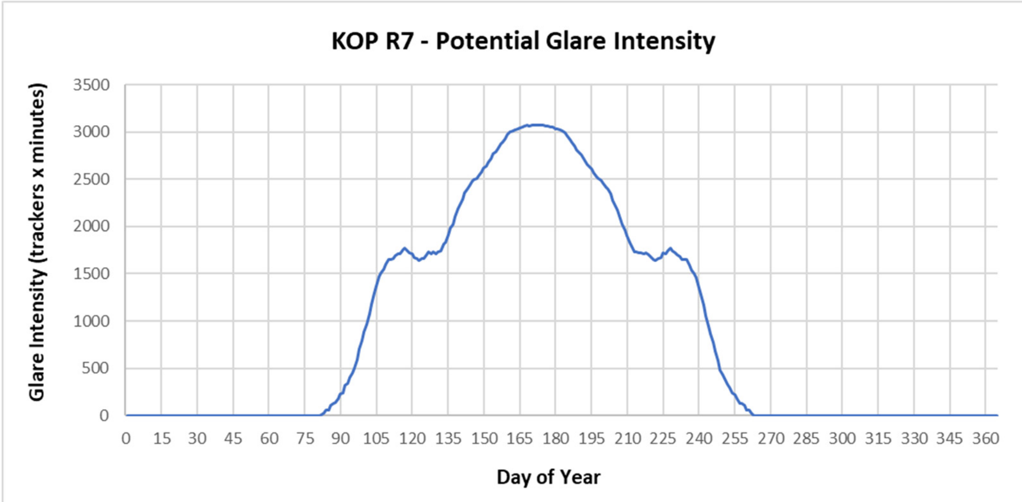

KOP R2 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

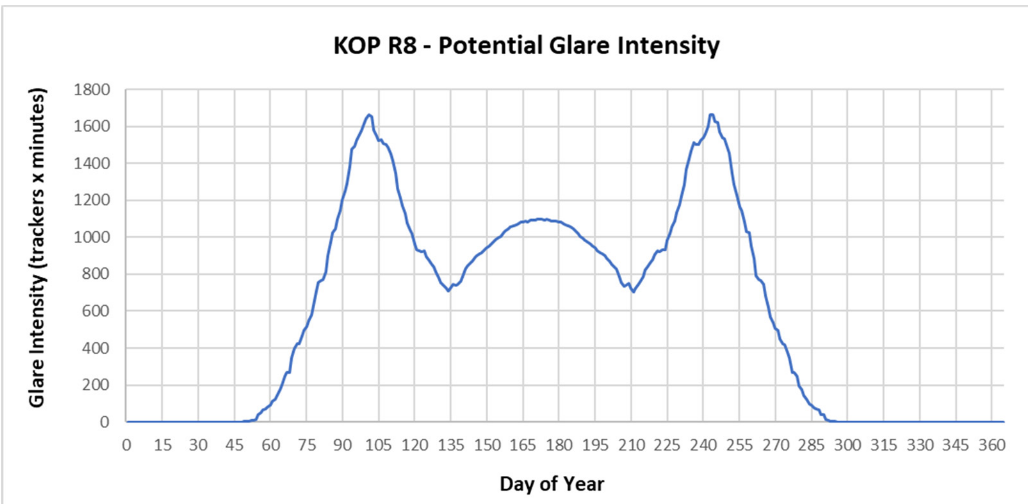

KOP R3 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

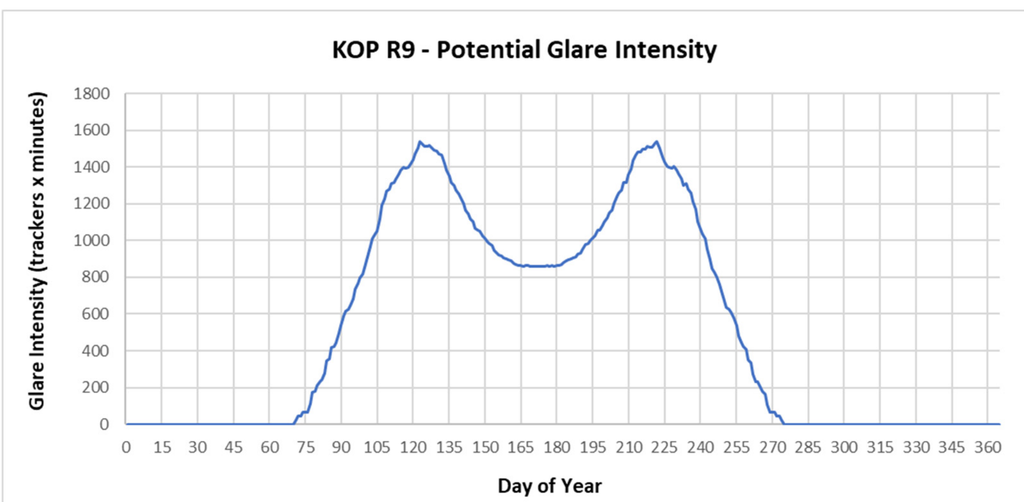

KOP R4 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360

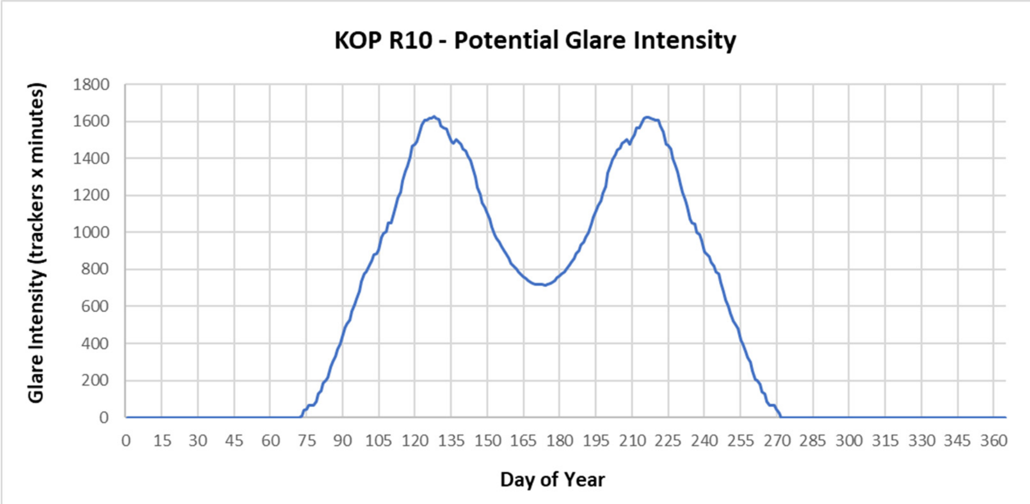

KOP R5 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year
0 500 1000 1500 2000 2500 3000 3500 4000
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360

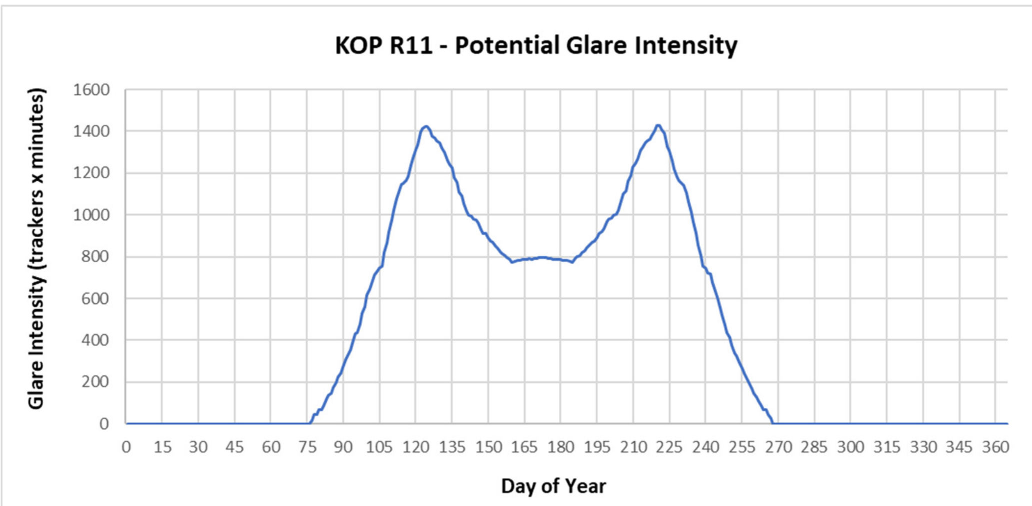

KOP R6 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year
0 500 1000 1500 2000 2500 3000 3500
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360

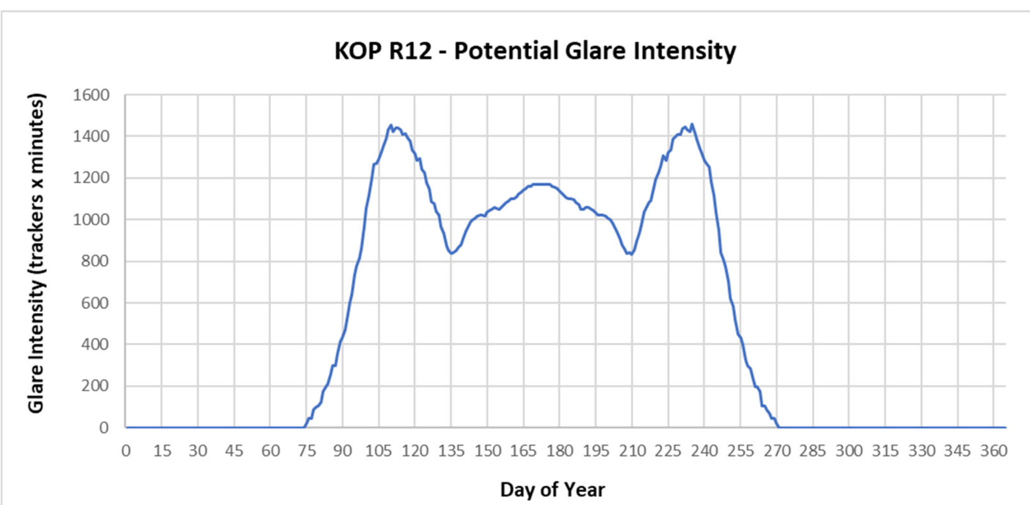

KOP R7 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

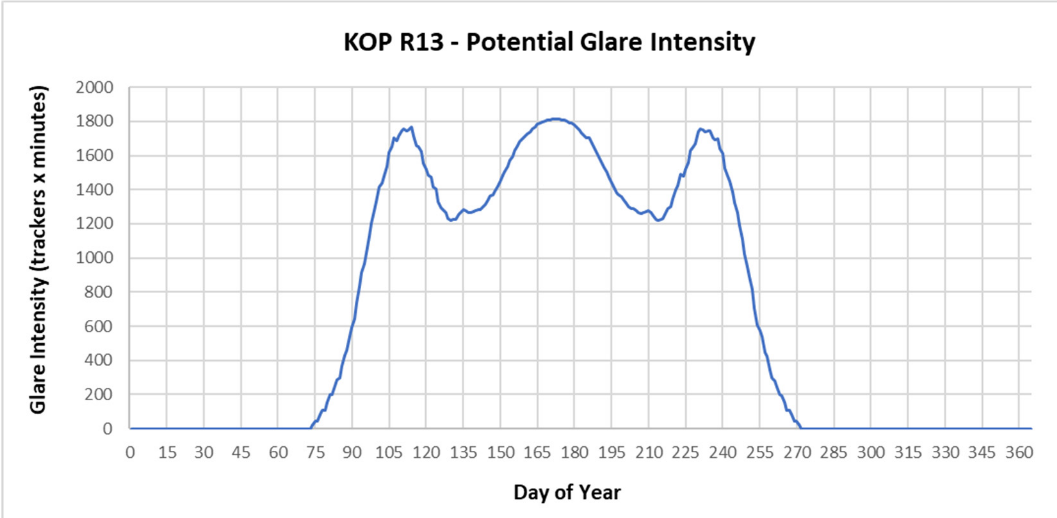

KOP R8 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
1800
1600
1400
1200
1000
800
600
400
200
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

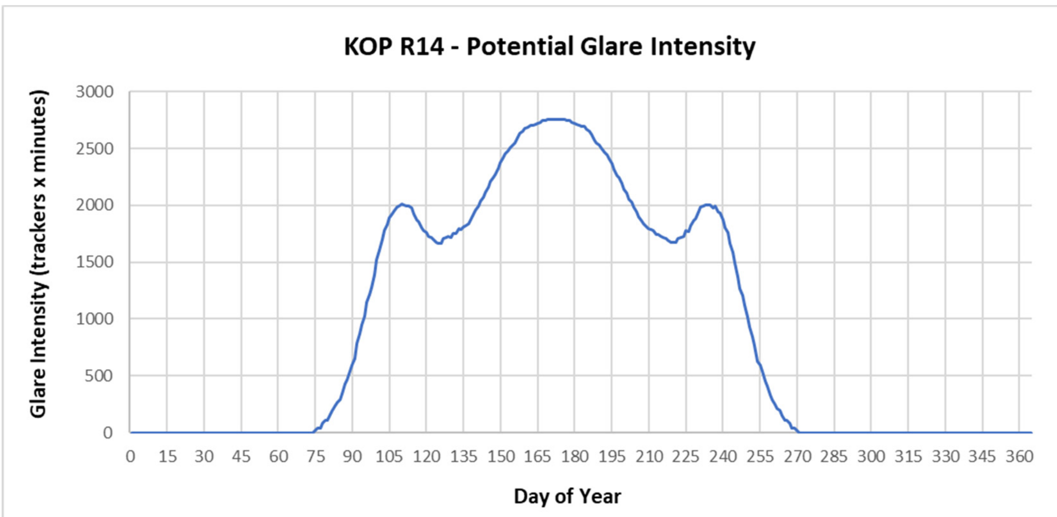

KOP R9 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
1800
1600
1400
1200
1000
800
600
400
200
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

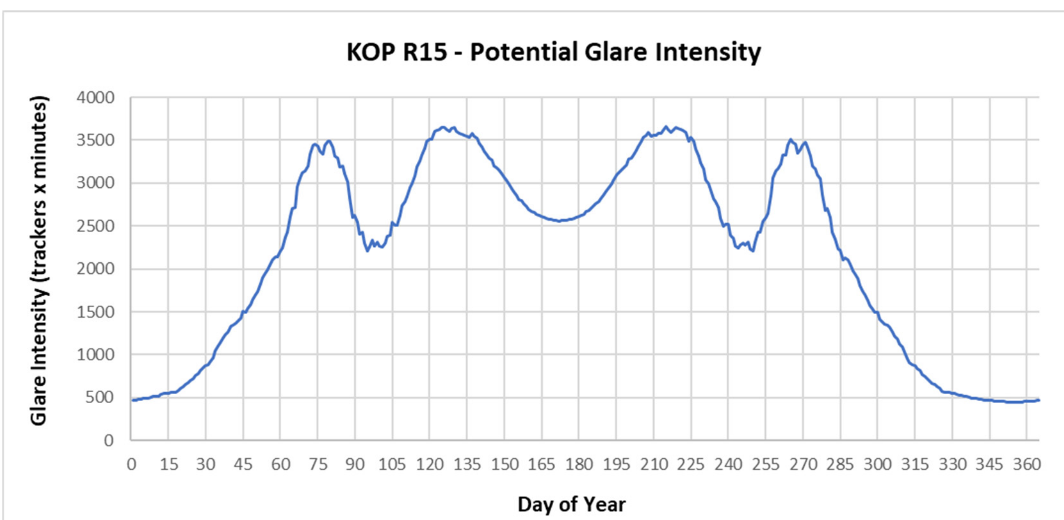

KOP R10 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year

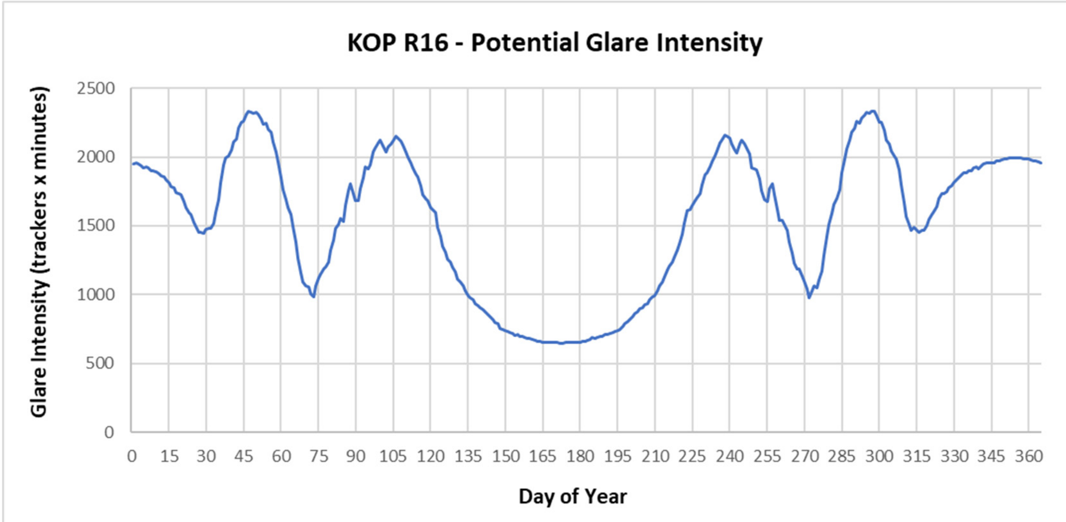

KOP R11 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year

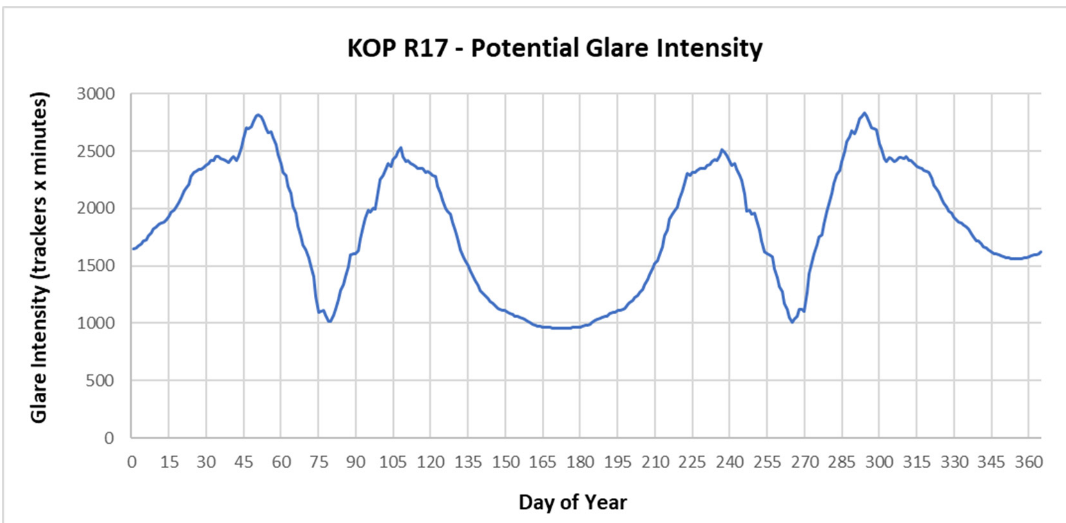

KOP R12 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
Day of Year

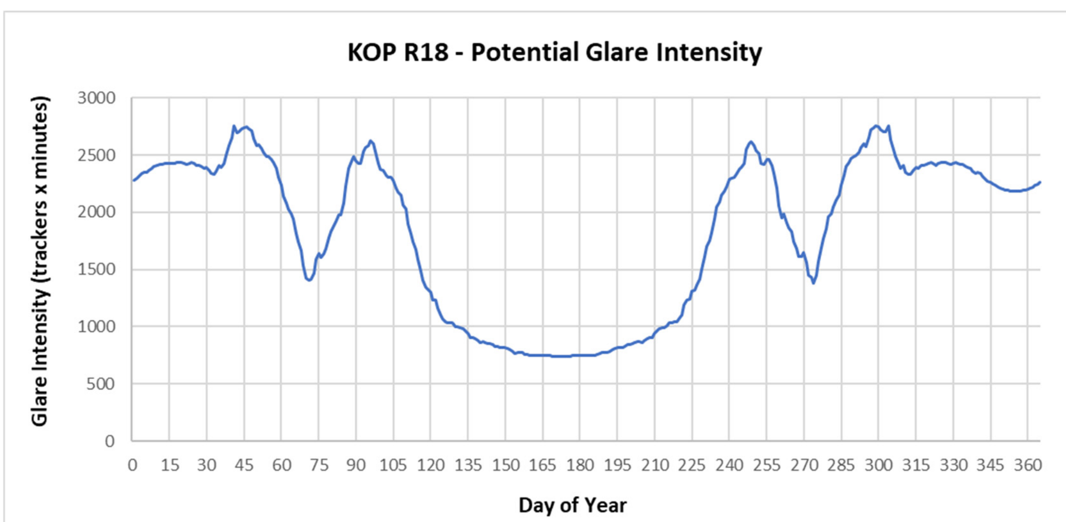

KOP R13 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

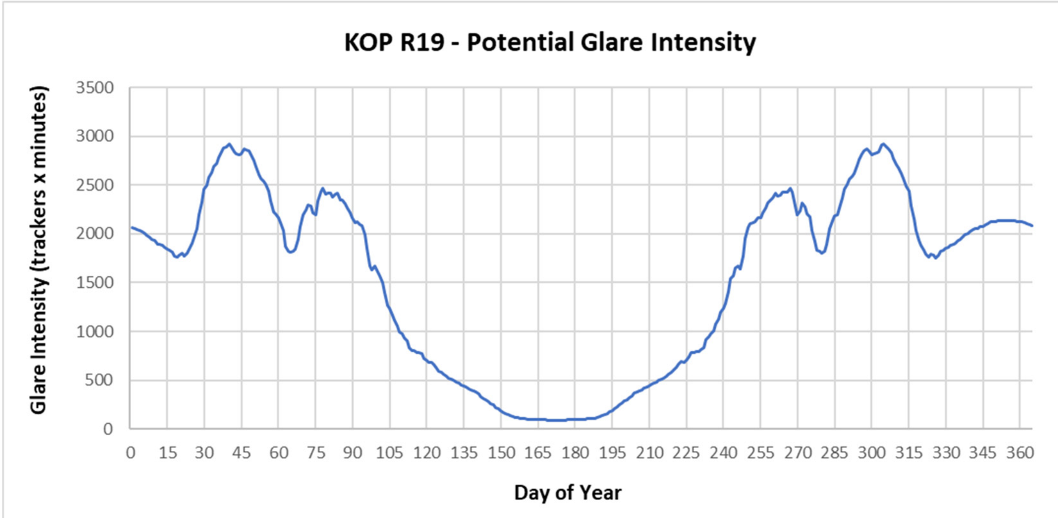

KOP R14 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

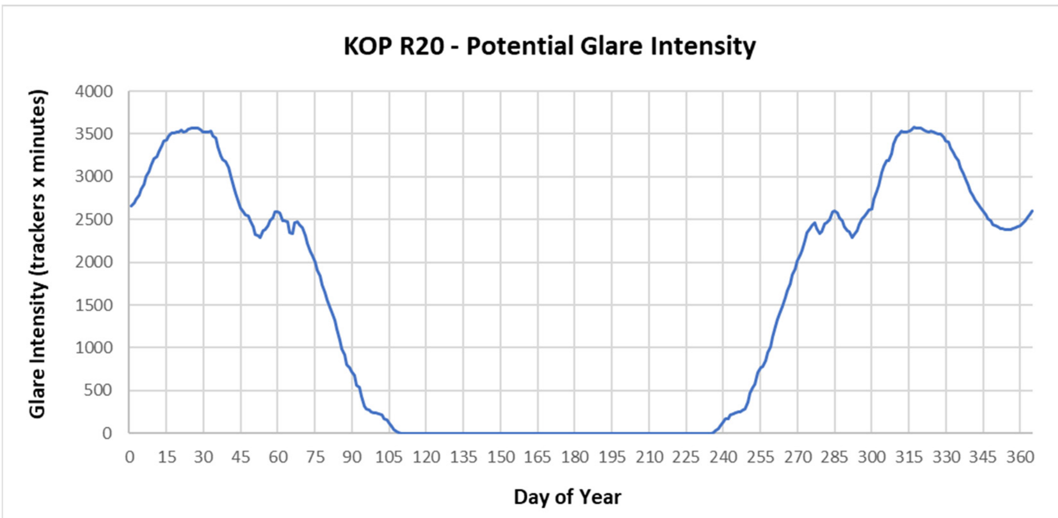

KOP R15 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
4000
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

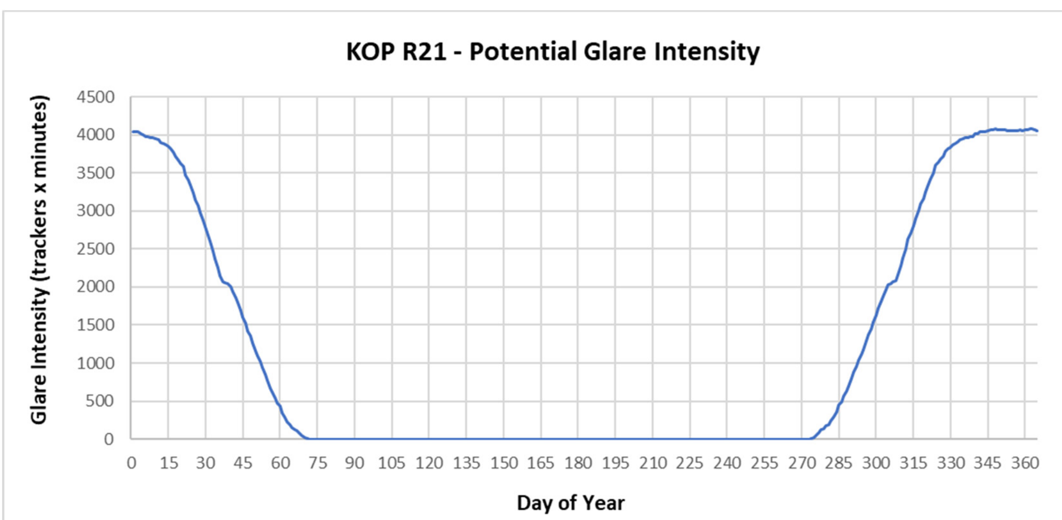

KOP R16 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

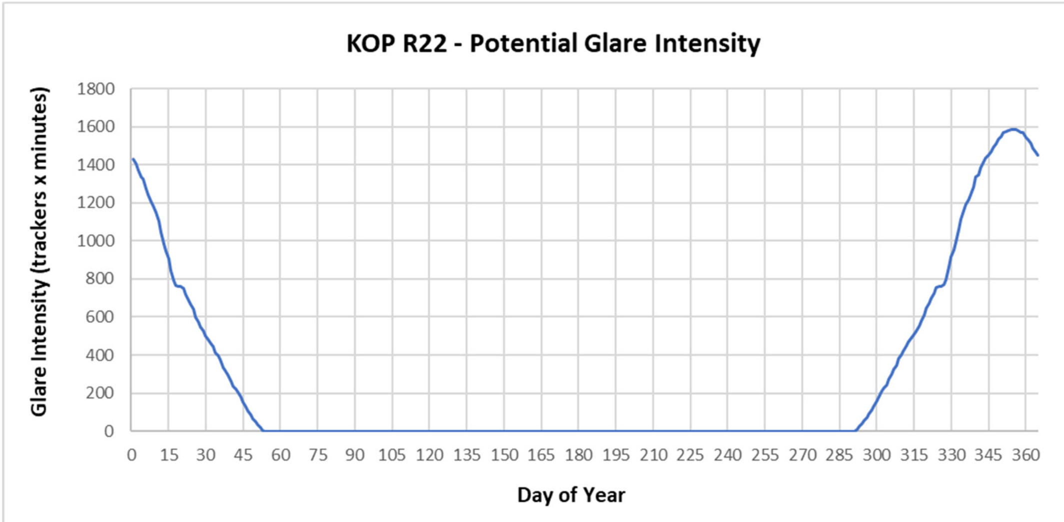

KOP R17 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

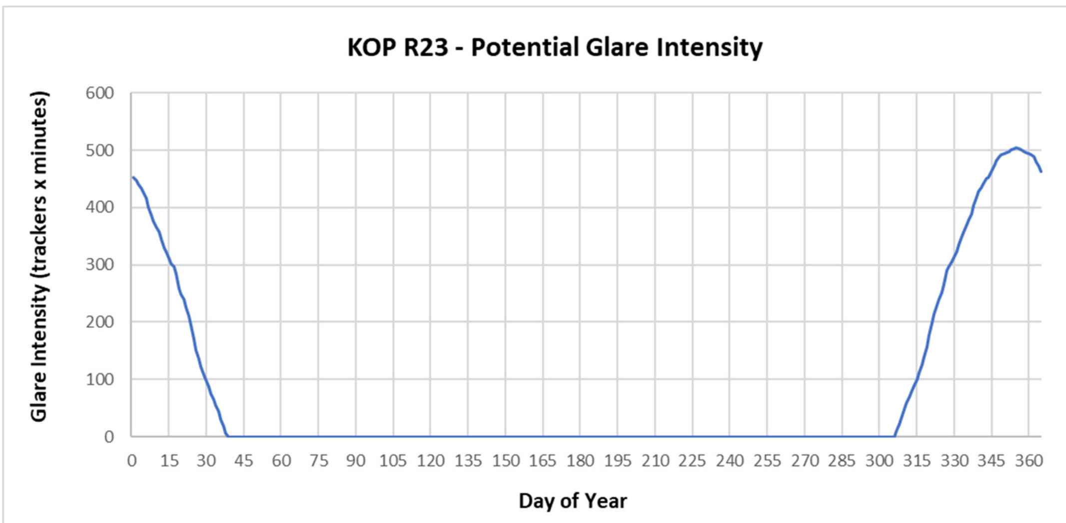

KOP R18 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

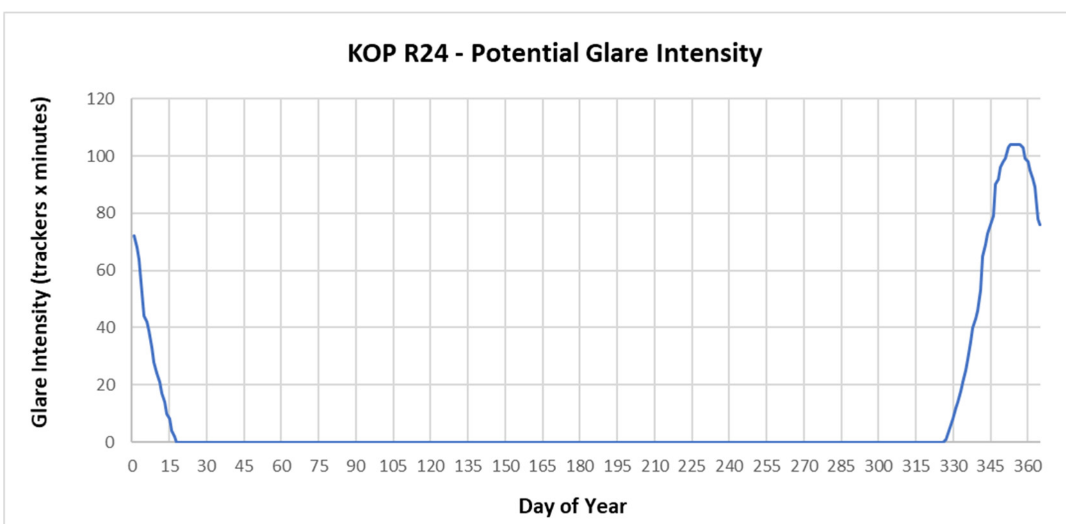

KOP R19 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

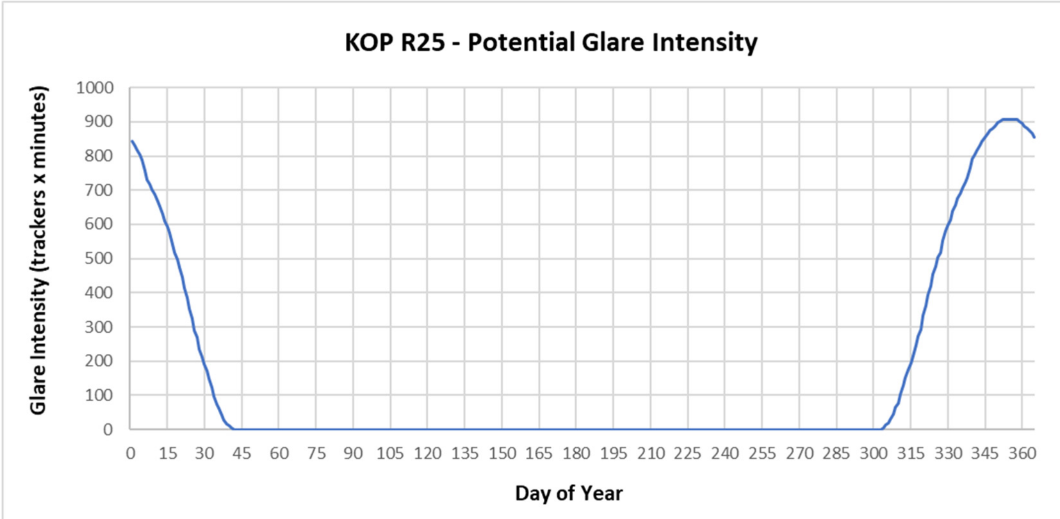

KOP R20 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
4000
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year

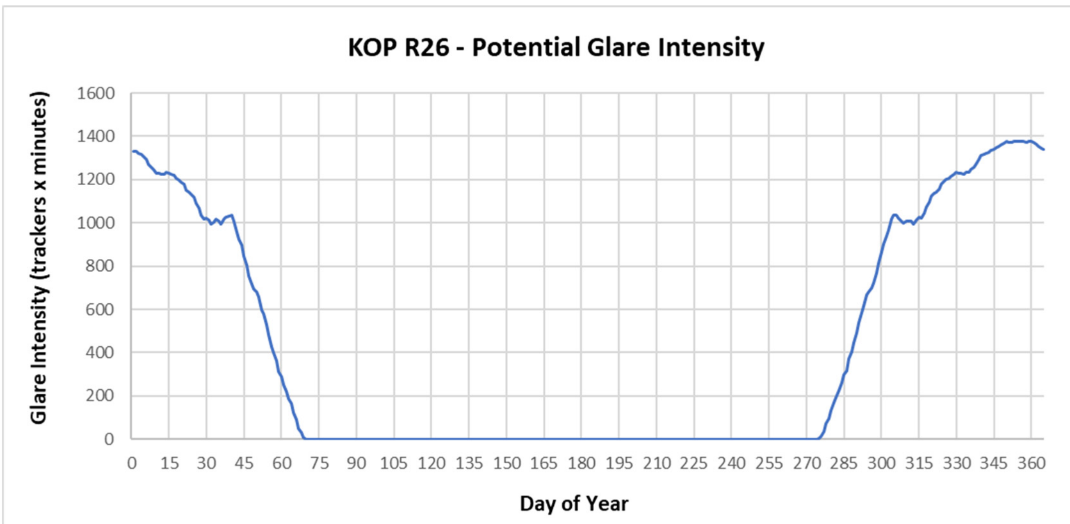

KOP R21 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year


KOP R22 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
1800
1600
1400
1200
1000
800
600
400
200
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year


KOP R23 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
600
500
400
300
200
100
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year


KOP R24 - Potential Glare Intensity
Glare Intensity (trackers x minutes)
120
100
80
60
40
20
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year





4.2 Analysis of Moving Key Observation Points (Land Traffic)

Land traffic in roads adjacent to the project site may also be subjected to reflectivity events. The process to evaluate the potential for glare events on traffic is the same as for static KOPs. A number of reference static KOPs are distributed along the Russell Cave Road, also known as KY 353 and Leesburg Pike, also known as KY 62.

The location of these reference KOPs is shown in Figure 21B:

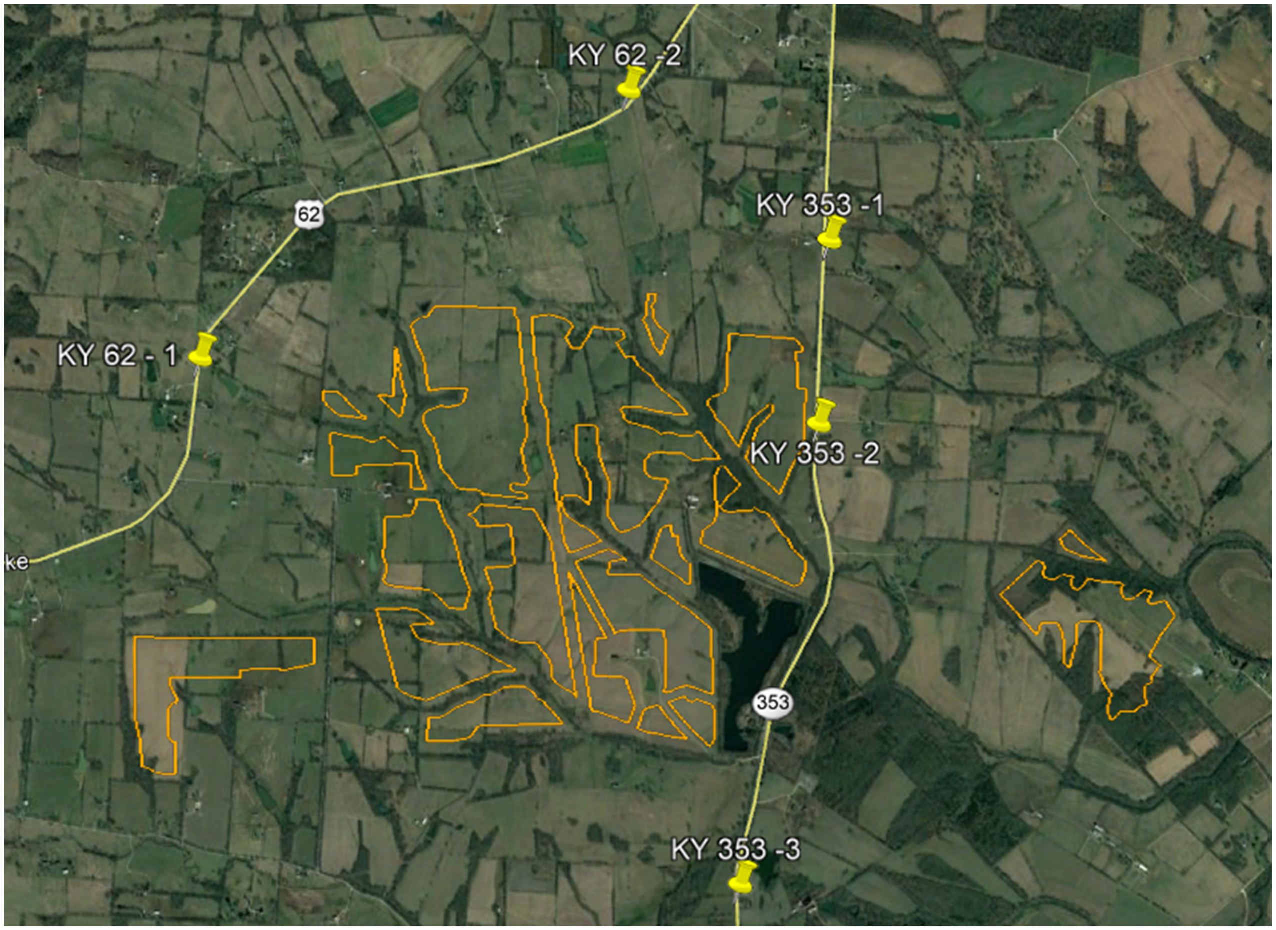
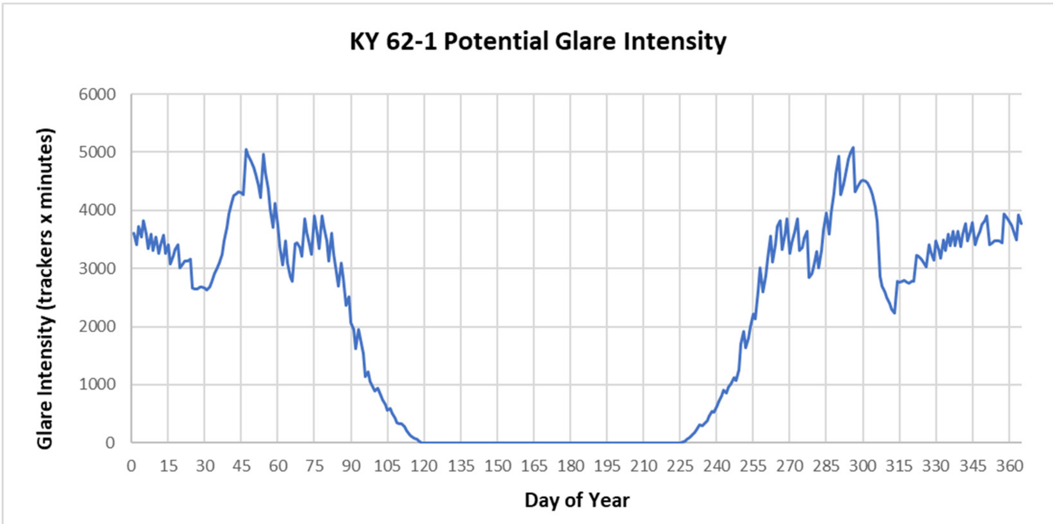


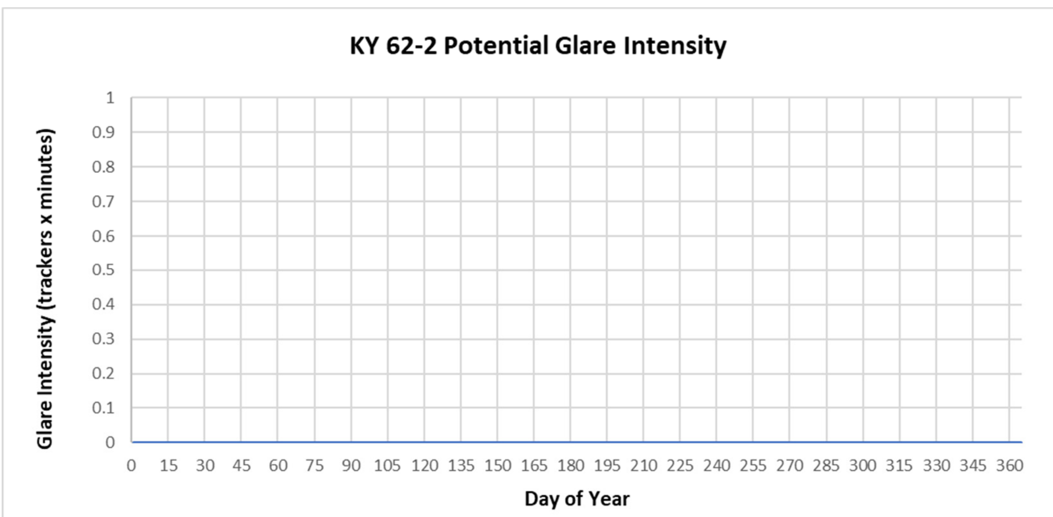
Figure 21B – Location of reference KOPs at KY 62 and KY 353.

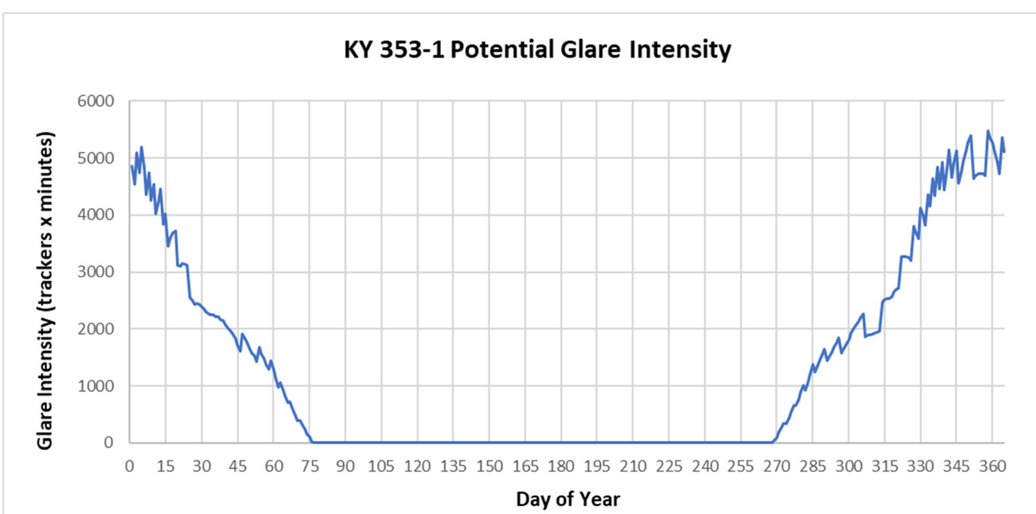
The relative location of the KOPs with respect to the origin of the reference coordinate system is given in the table below (distances in ft). The reflectivity results for each reference KOP is depicted as glare intensity numerical curves for each day of the year.

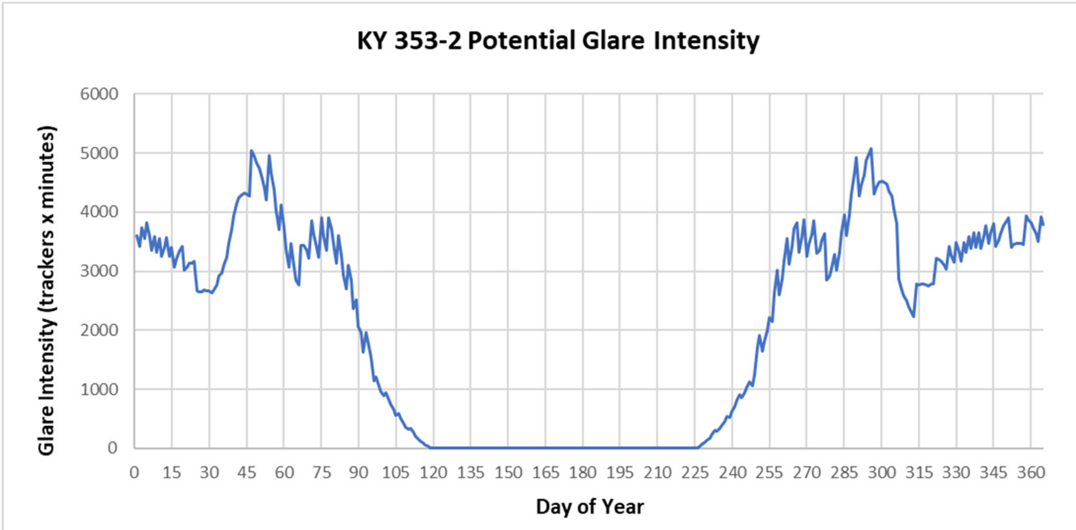
Reference KOP	X	Y	Z
KY 62 -1	-6033	2458	55
KY 62 -2	851	6543	48
KY 353 -1	3954	4116	27
KY 353 -2	3698	1117	-17
KY 353 -3	2348	-6055	-2

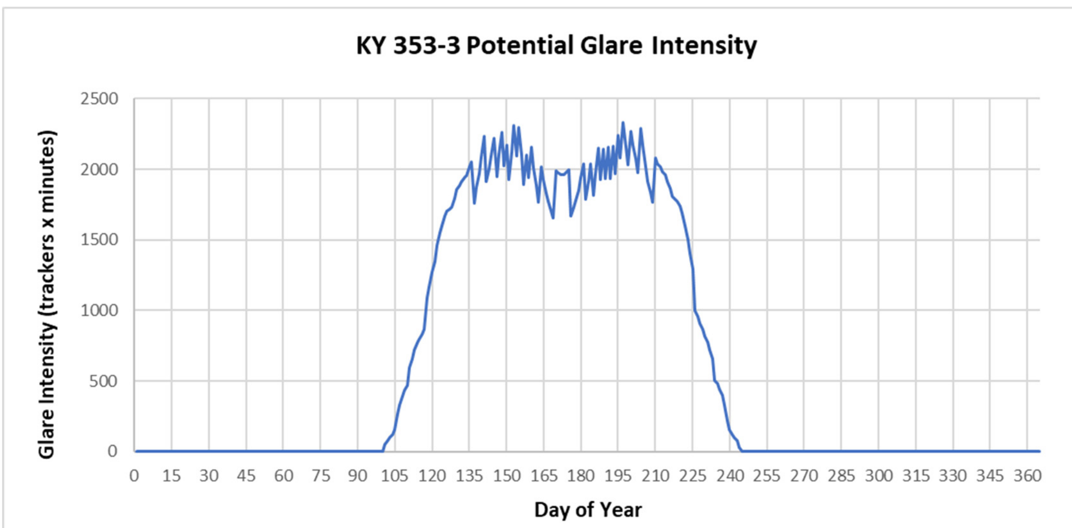
Intermediate points in between the selected ones along KY 62 and KY 353 can also be analyzed independently. It will be shown later in this reports that the selected KOPs are the points from where the solar plant is more likely to be visible.


KY 62-1 Potential Glare Intensity
Glare Intensity (trackers x minutes)
6000
5000
4000
3000
2000
1000
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year


KY 62-2 Potential Glare Intensity
Glare Intensity (trackers x minutes)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year


KY 353-1 Potential Glare Intensity
Glare Intensity (trackers x minutes)
6000
5000
4000
3000
2000
1000
0
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360
Day of Year





5 Visibility Analysis

The reflectivity events depicted above for all KOPs assume that no vegetation nor topographic visual screens exist to block the reflected beams. Most of the KOPs are protected against reflectivity events because of existing dense vegetation. In addition, a landscaping plan has been designed to complement these natural barriers with added vegetation. A full *Visibility Map* of the project (viewshed simulation) is included in Attachment A. This map represents the areas around the project from where the solar arrays are visible, with darker colors representing larger fractions of the total project area being visible from the observation point in question.

The existing vegetation and proposed additional landscaping are depicted in Figure 22, where it can be seen that all KOPs have at least one layer of visual barriers to mitigate potential glare events. However, because of the topographical elevation differences between the KOPs and certain areas of the solar plant, the KOPs may be exposed to glare events even with developed vegetal cover. The site topography is depicted in Figure 23, where it can be seen that KOPs located Northwest of the project site have the higher elevations, thus are more exposed -especially if visual barriers are not close to them.

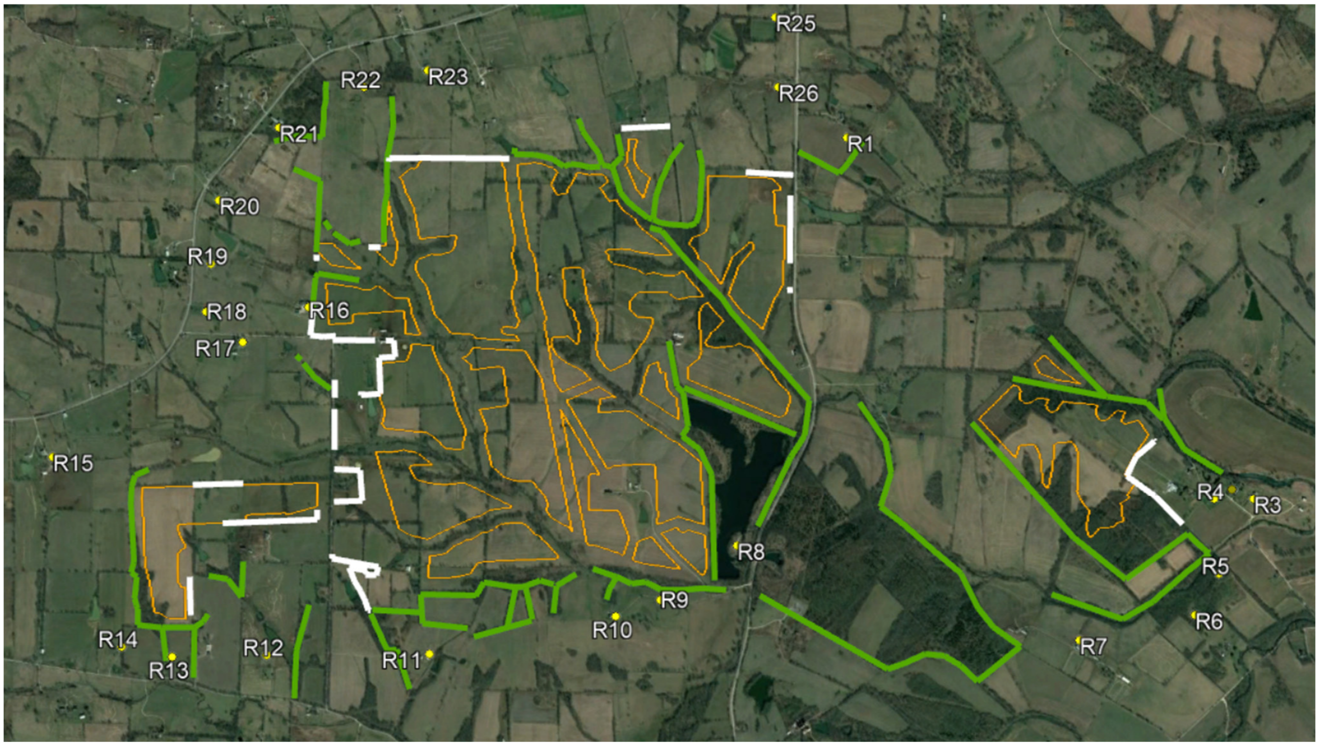


Figure 22 – Existing vegetation masses (green) and Proposed additional landscaping visual barriers (white).

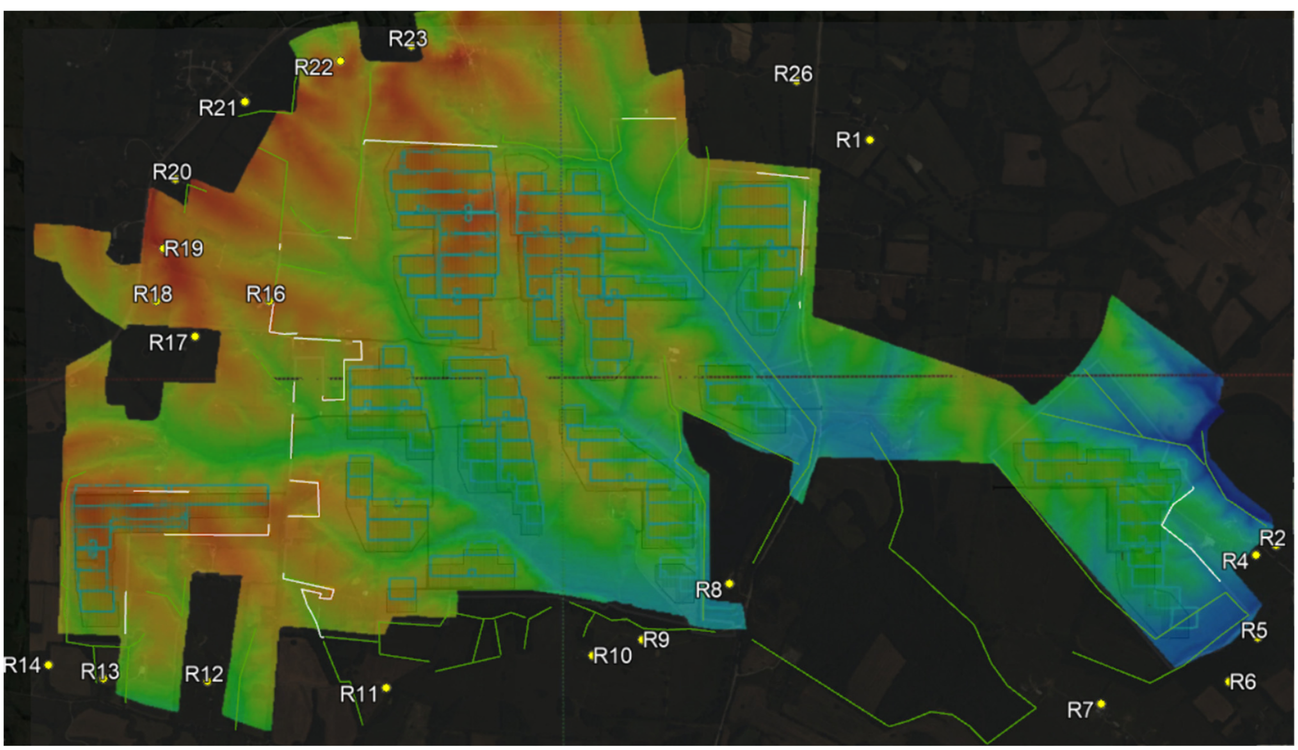


Figure 23 – Site topographical elevations (red = higher, blue = lower).

To evaluate if the existing and proposed tree barriers are sufficient to visually isolate the solar plant from observers at KOPs, these have been depicted in a Google Earth 3D model as 20ft tall visual walls. The site plan is overlapped to the site terrain, so to identify the location of the solar arrays. A general view of the 3D scene is rendered in Figure 24:

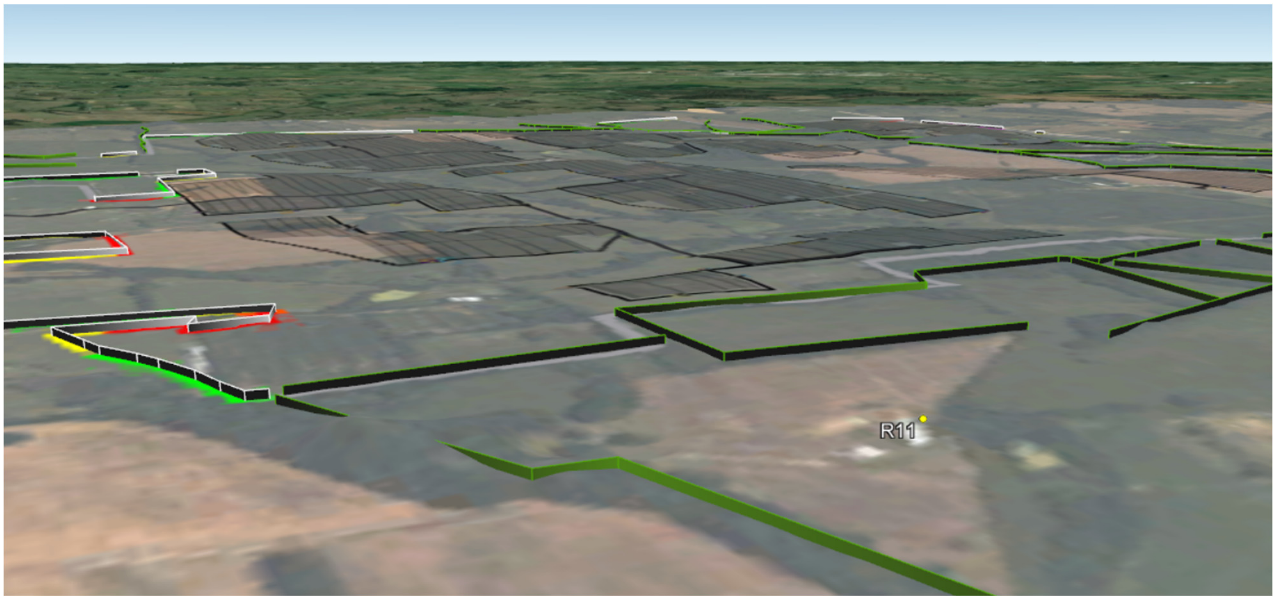
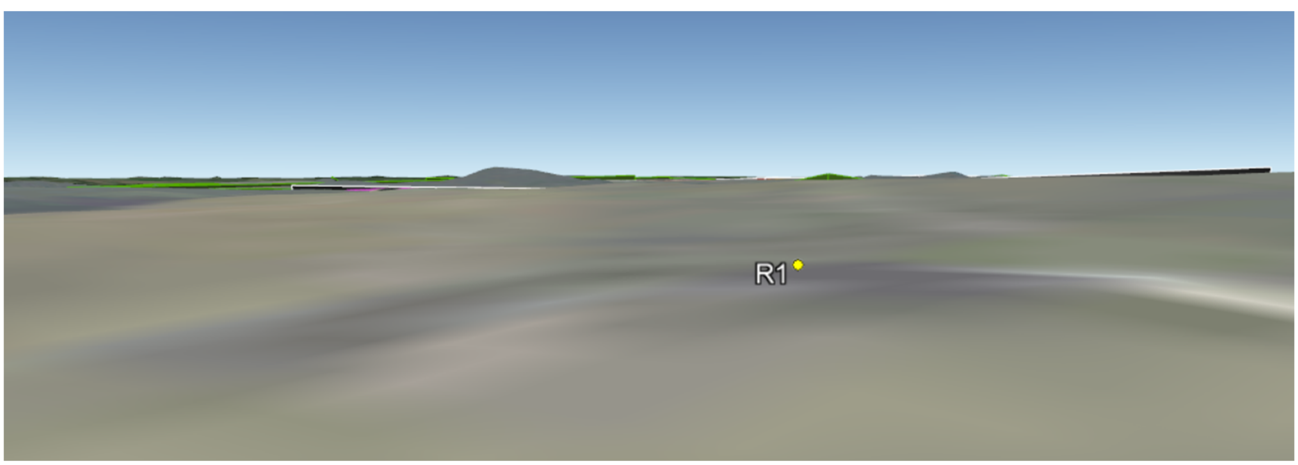
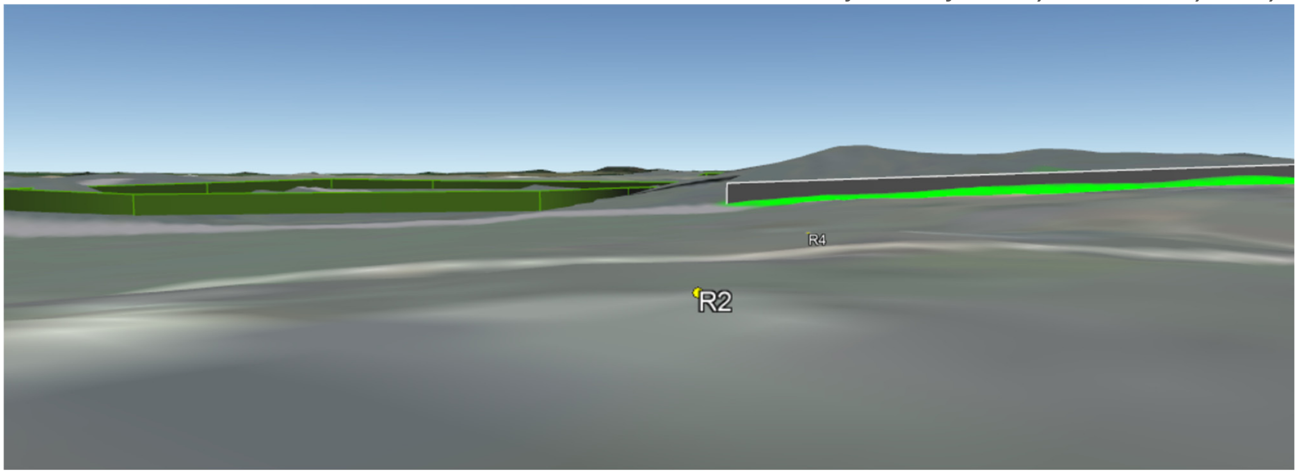


Figure 24 – Google Earth 3D model of the relevant visual barriers, KOPs and solar arrays' locations.

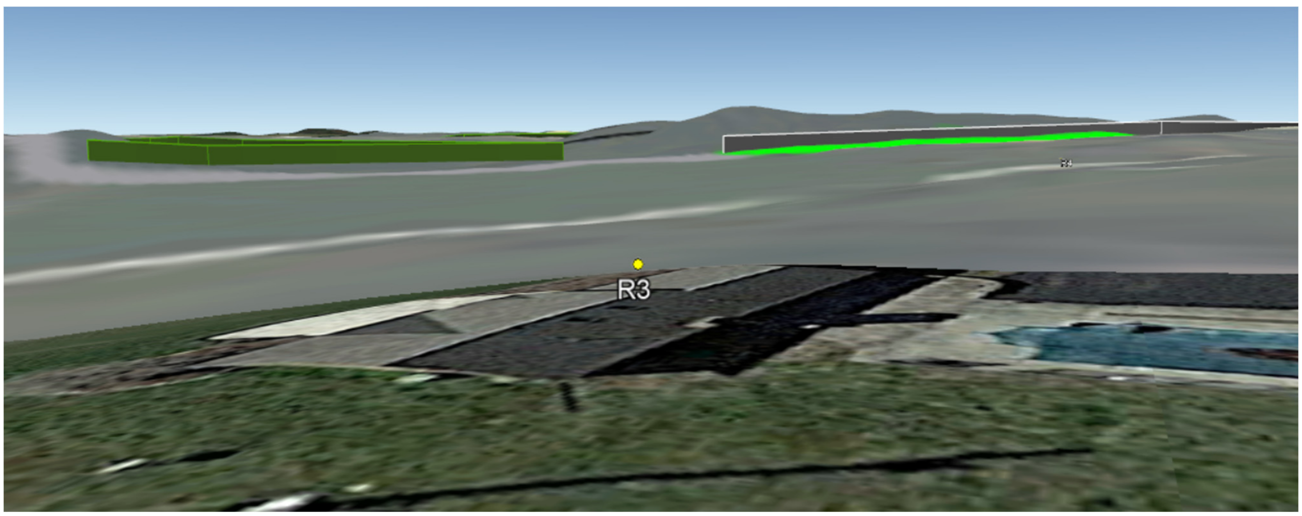
With this model, a series of images are captured at each KOP to determine if the solar arrays are visible. The camera is located at approximately 18 ft height (corresponding to an observer located at the 2-story level of a dwelling unit).



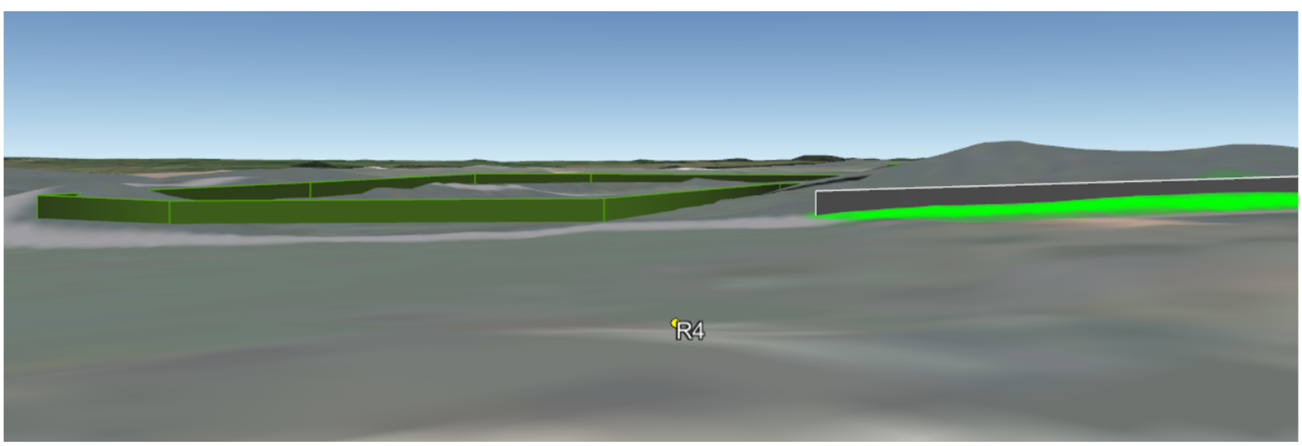
KOP R1 – No visibility



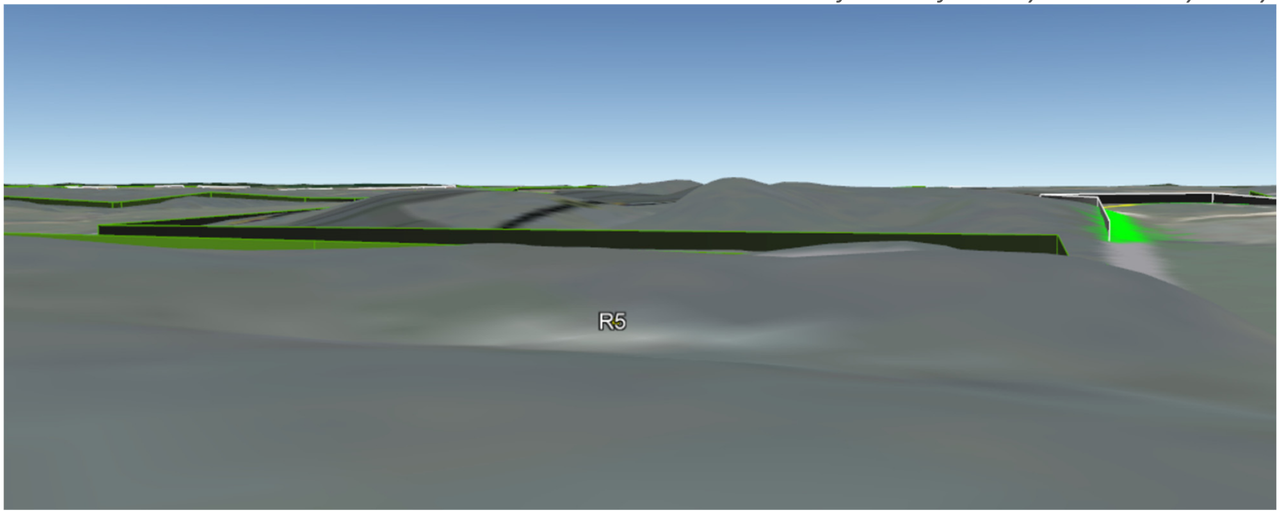
KOP R2 – No visibility



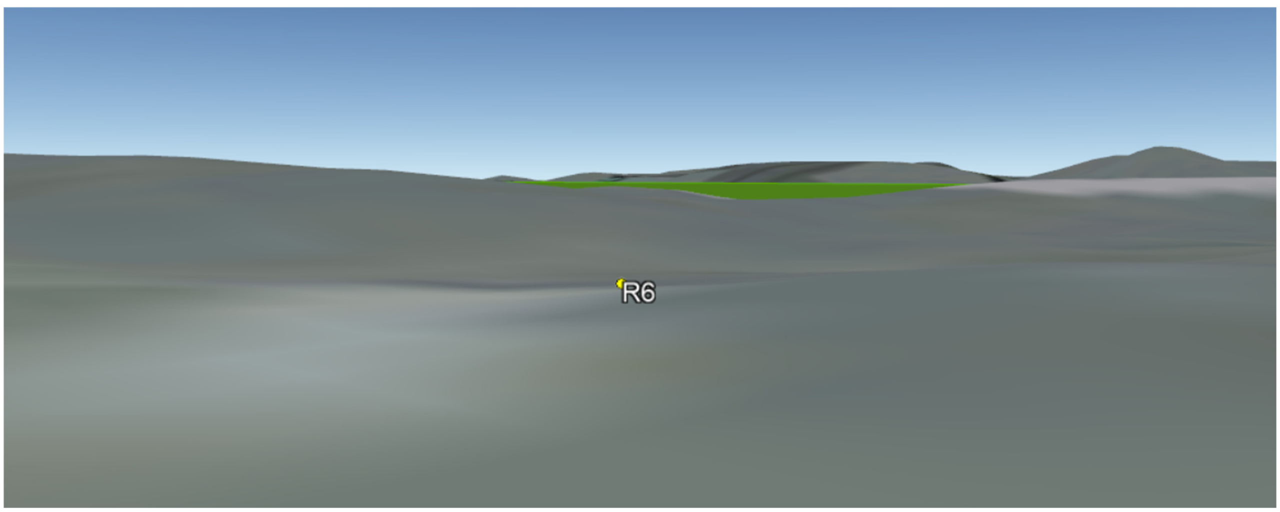
KOP R3 – No visibility



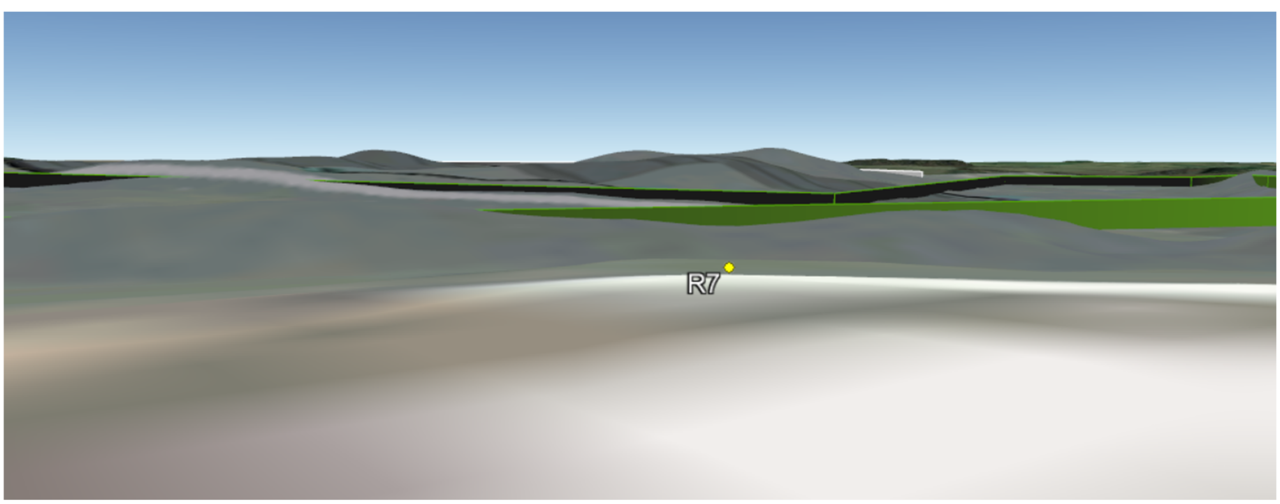
KOP R4 – No visibility



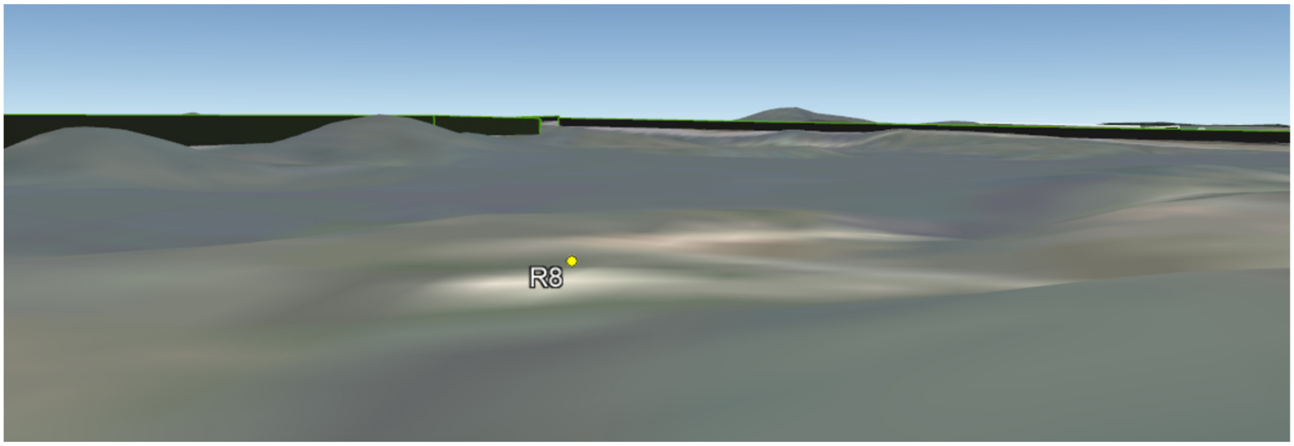
KOP R5 – No visibility



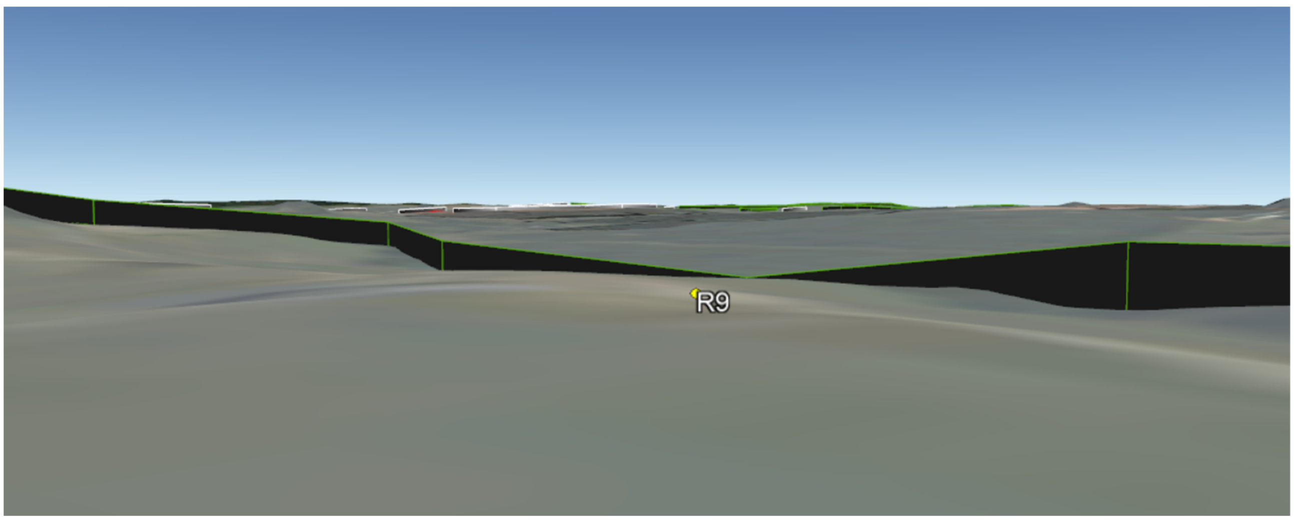
KOP R6 – No visibility



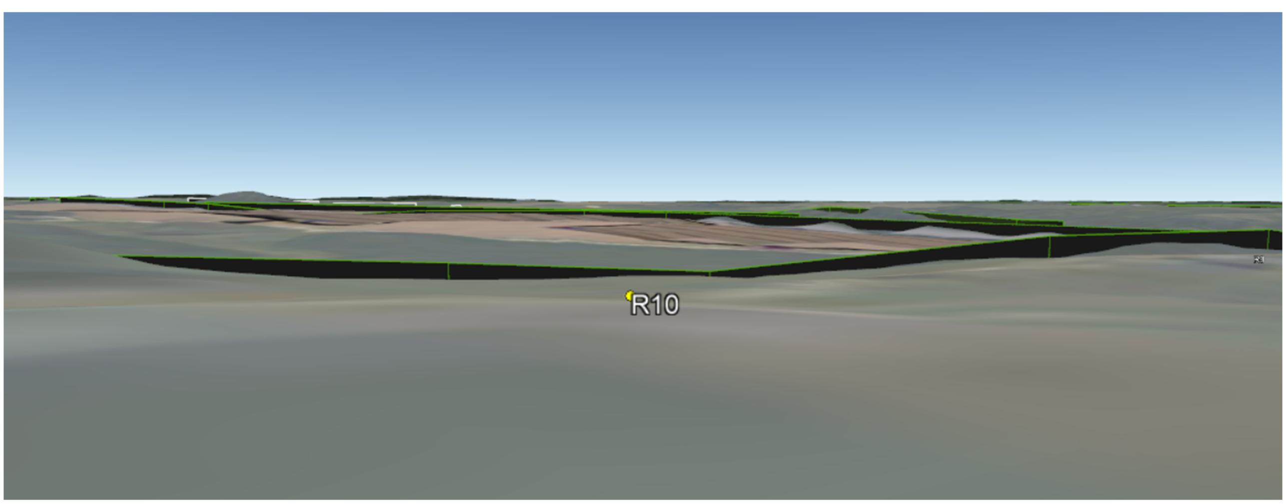
KOP R7 – No visibility



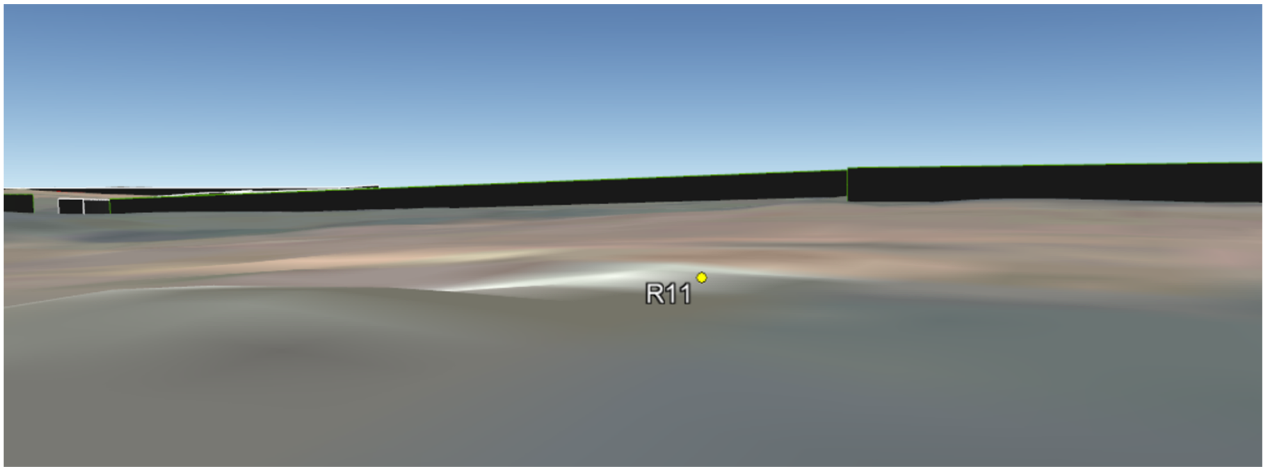
KOP R8 – No visibility



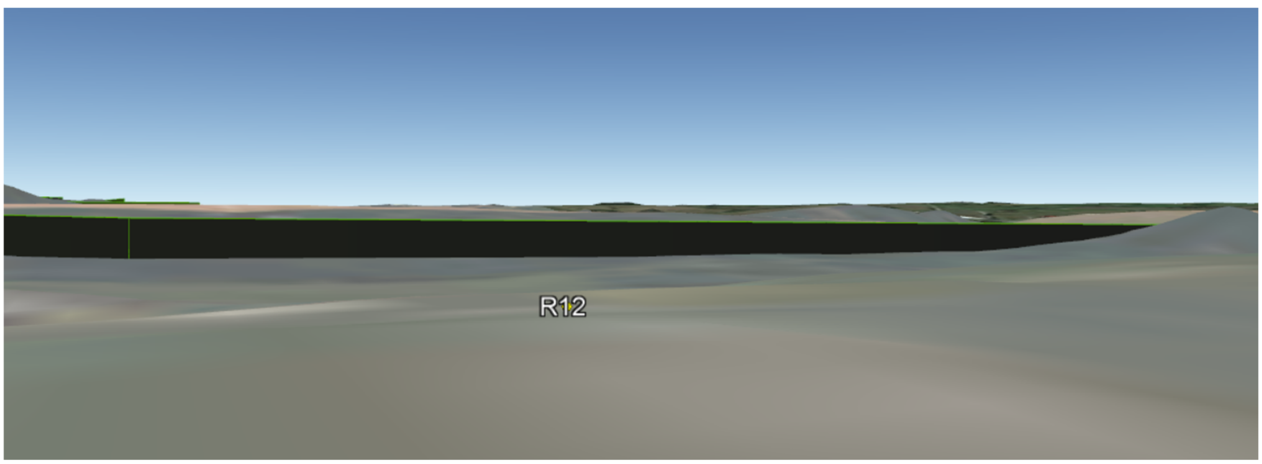
KOP R9 – Solar arrays visible looking East



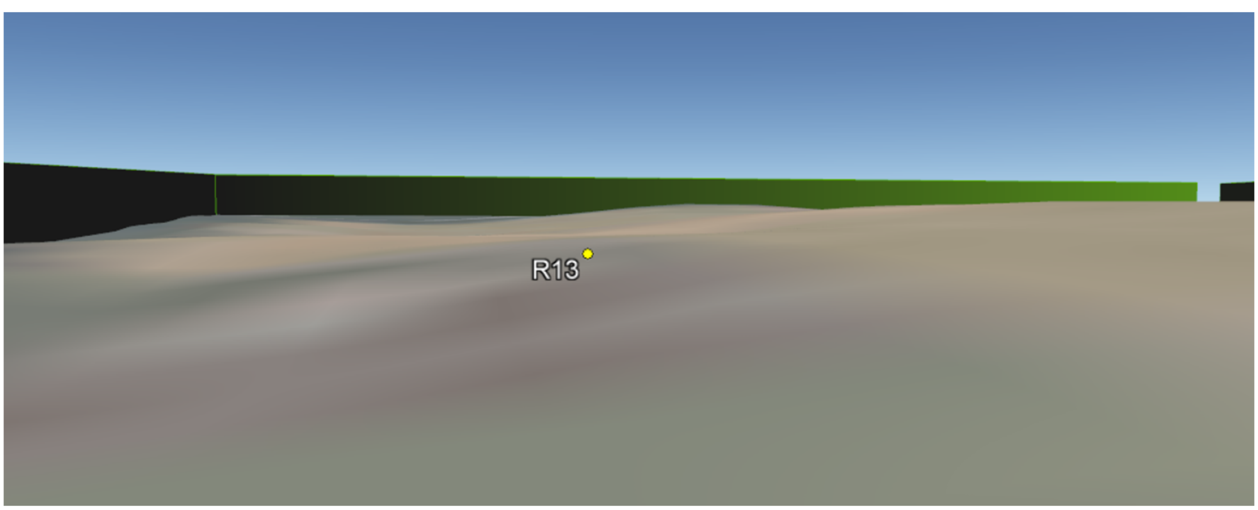
KOP R10 – Solar arrays visible looking East and West



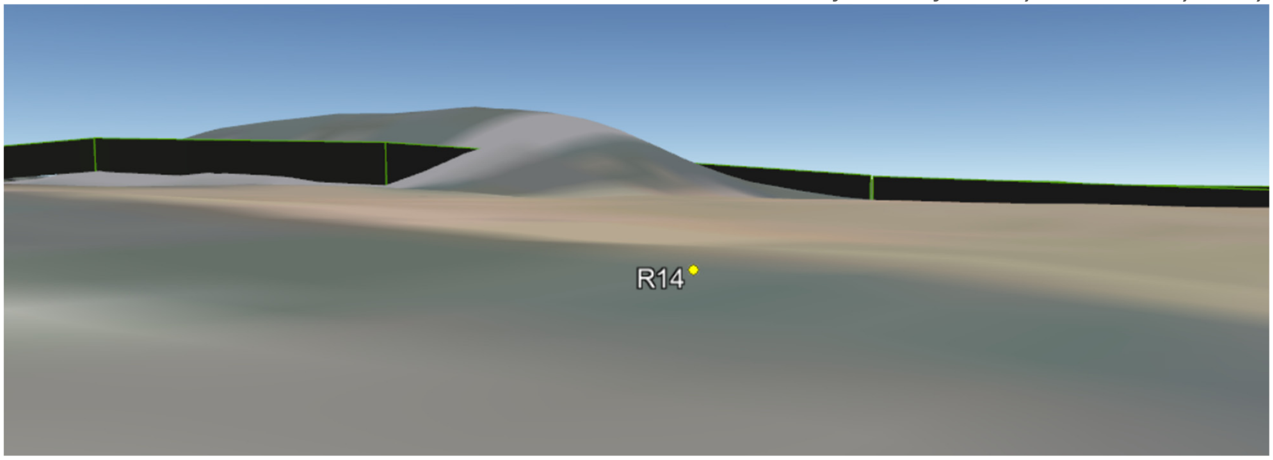
KOP R11 – No visibility



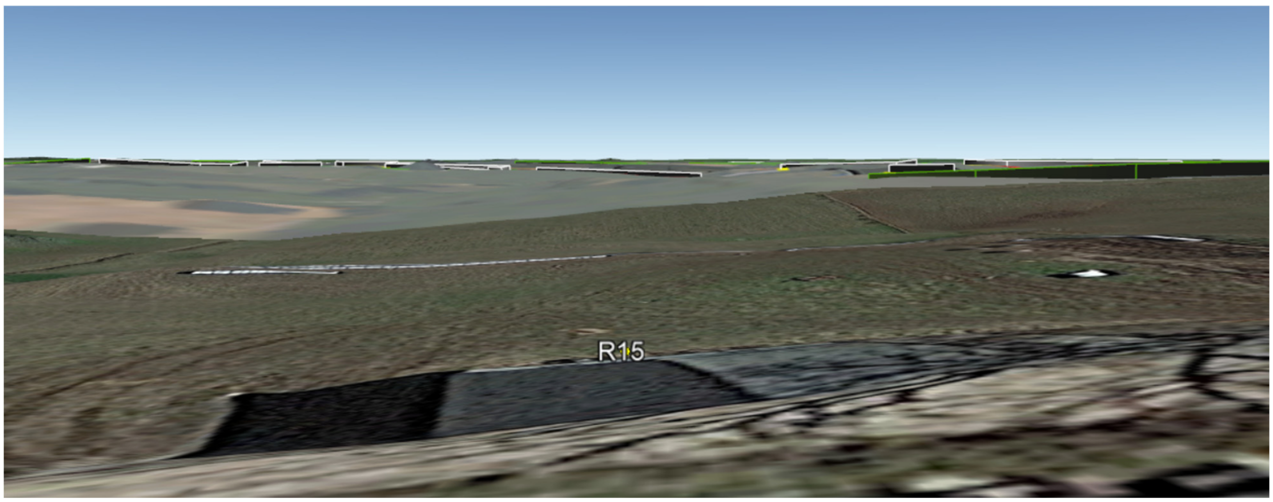
KOP R12 – No visibility



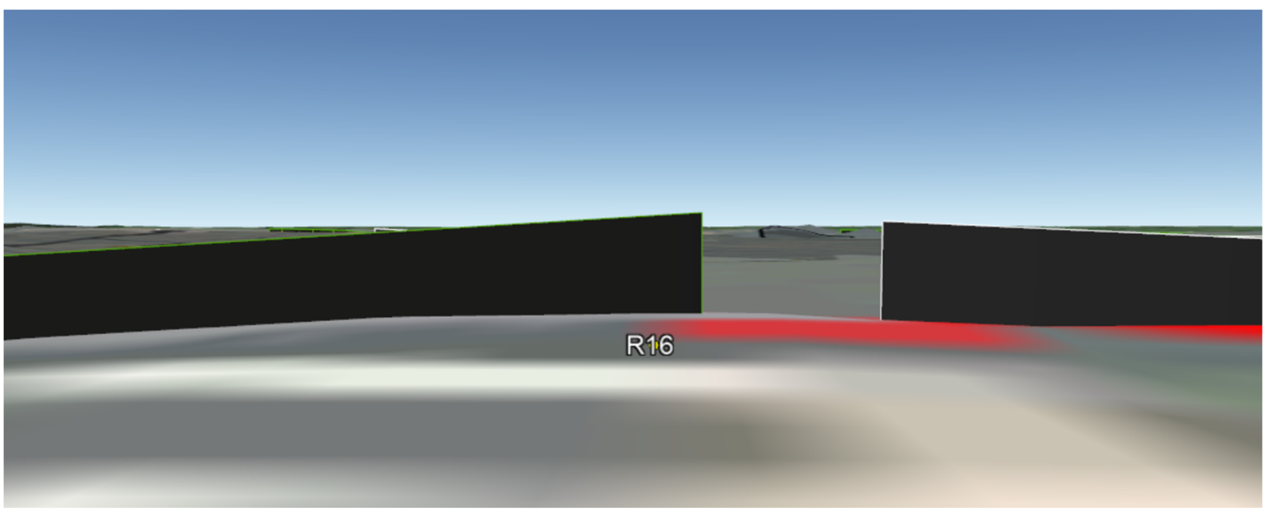
KOP R13 – No visibility



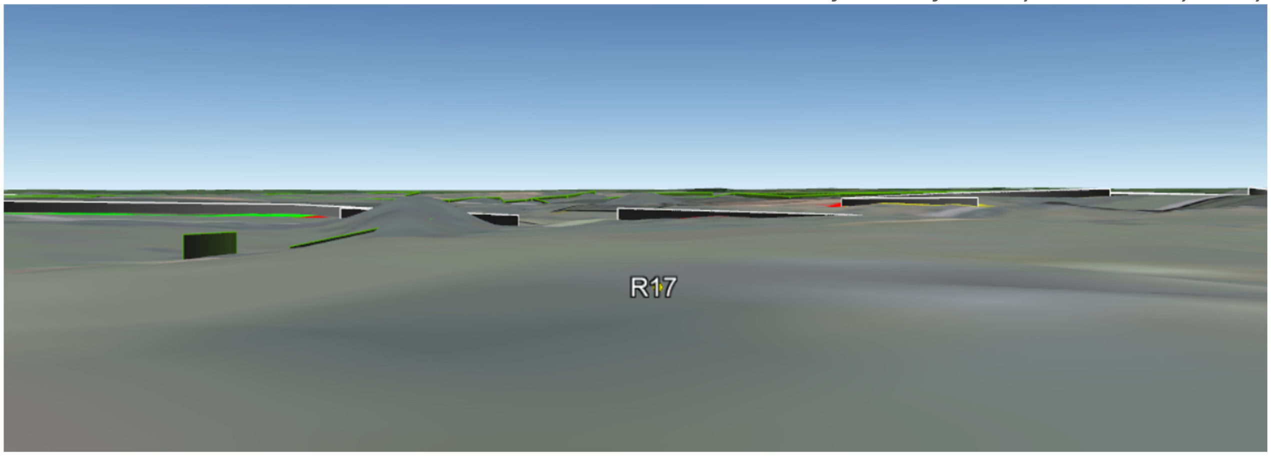
KOP R14 – No visibility



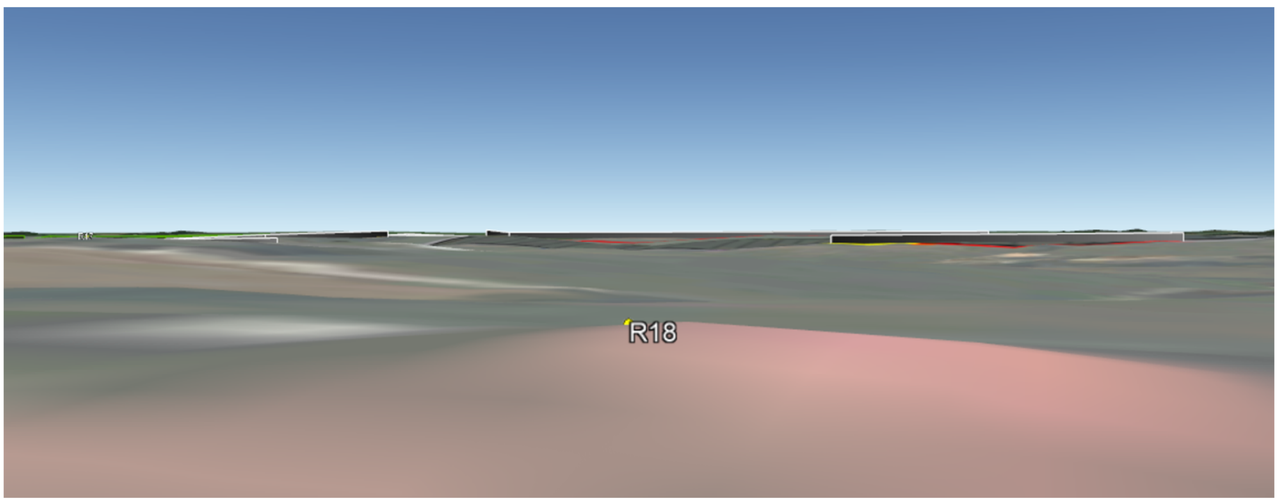
KOP R15 – Solar arrays visible looking East



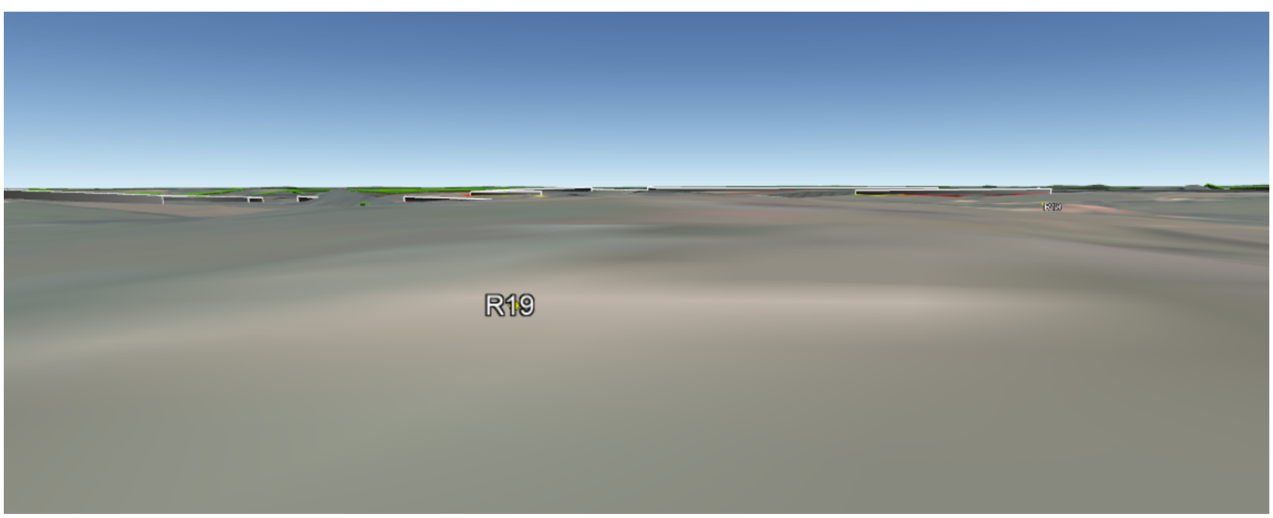
KOP R16 – No visibility



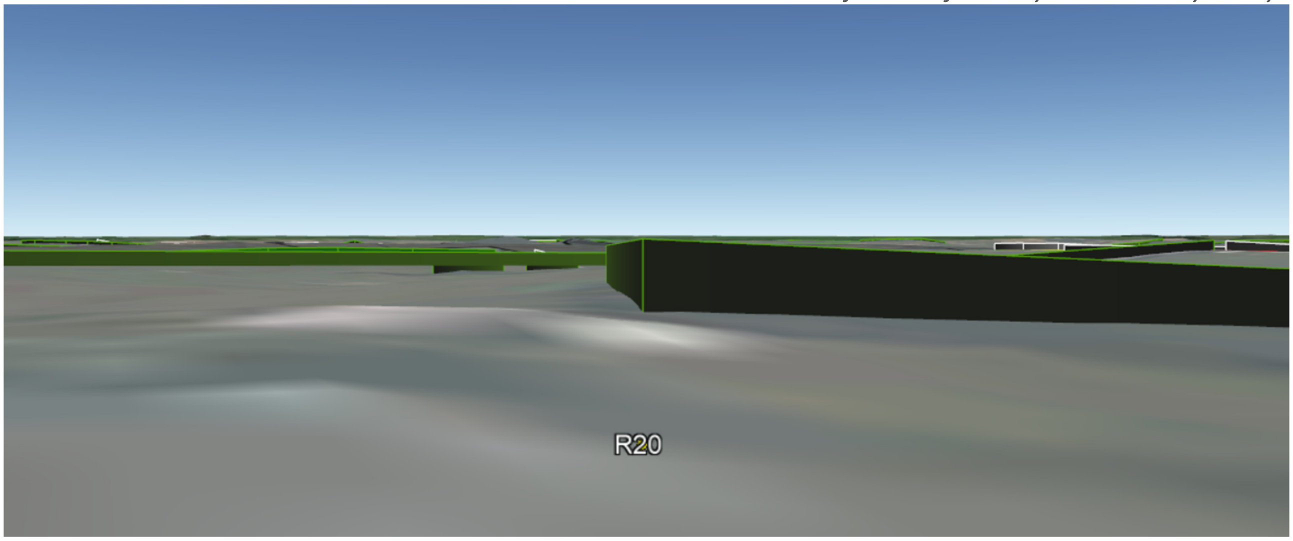
KOP R17 – Solar arrays visible looking East



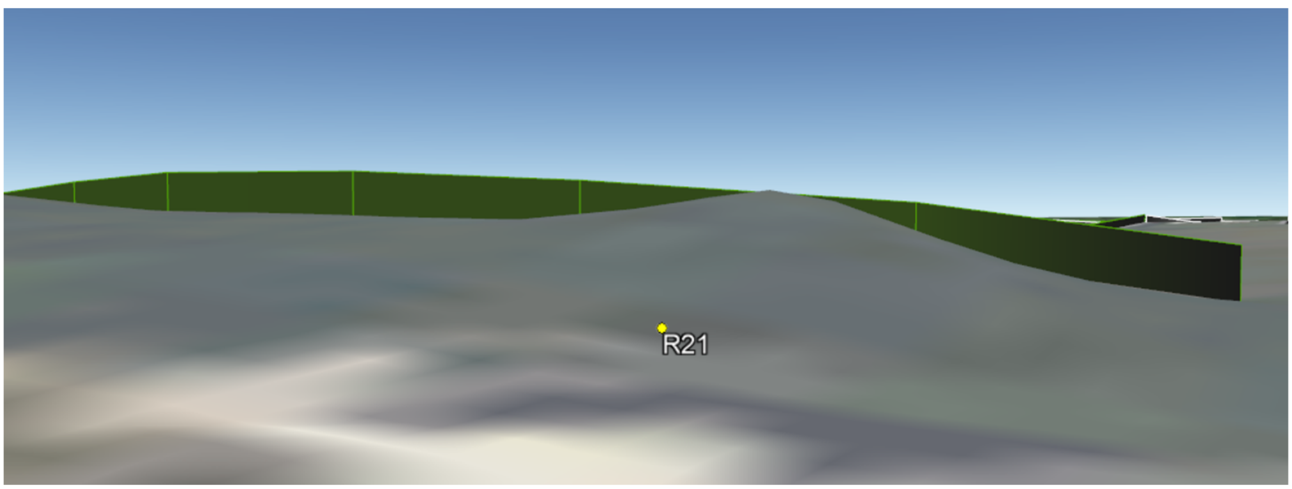
KOP R18 – Solar arrays visible looking East



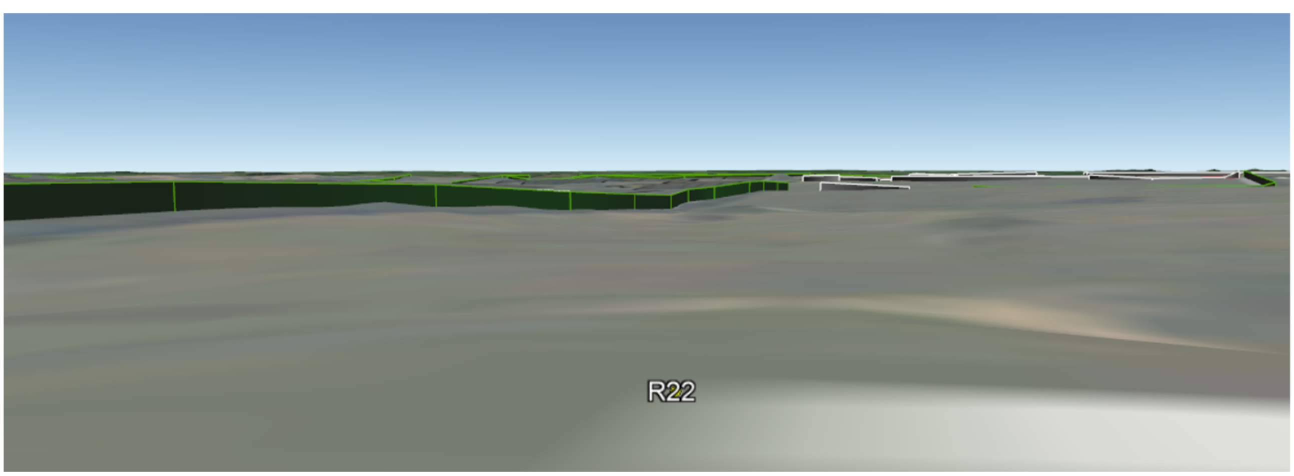
KOP R19 – Solar arrays visible looking East



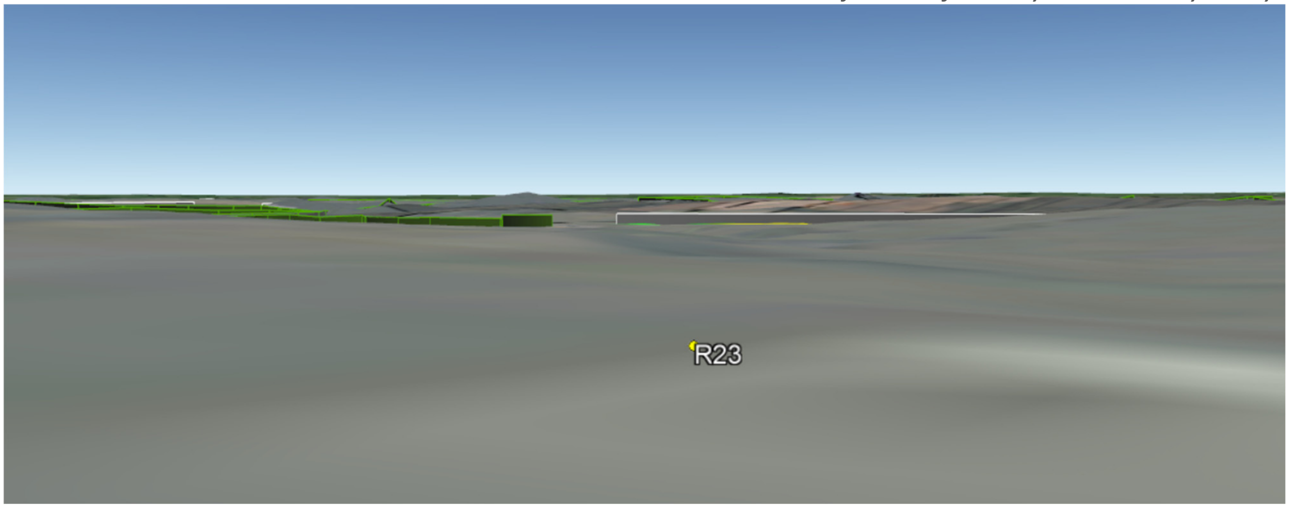
KOP R20 – Solar arrays visible looking East



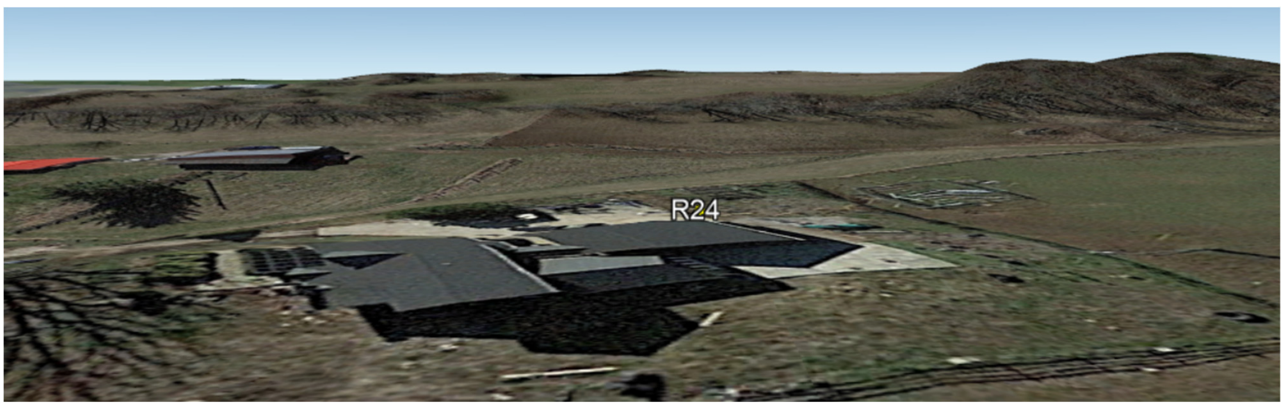
KOP R21 – No visibility



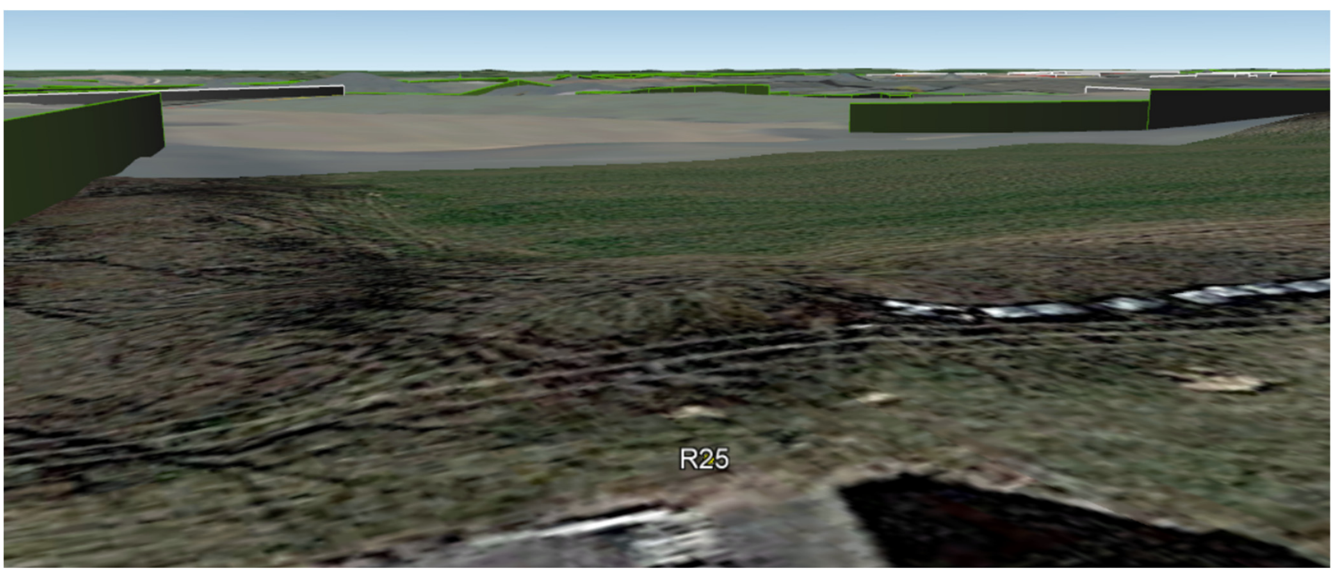
KOP R22 – Solar arrays visible looking Southeast



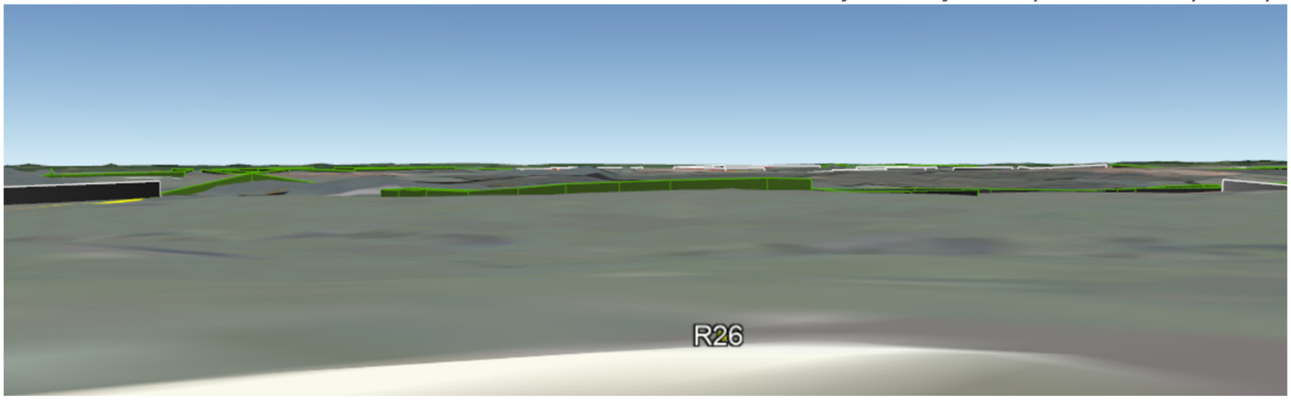
KOP R23 – Solar arrays visible looking Southeast



KOP R24 – No visibility

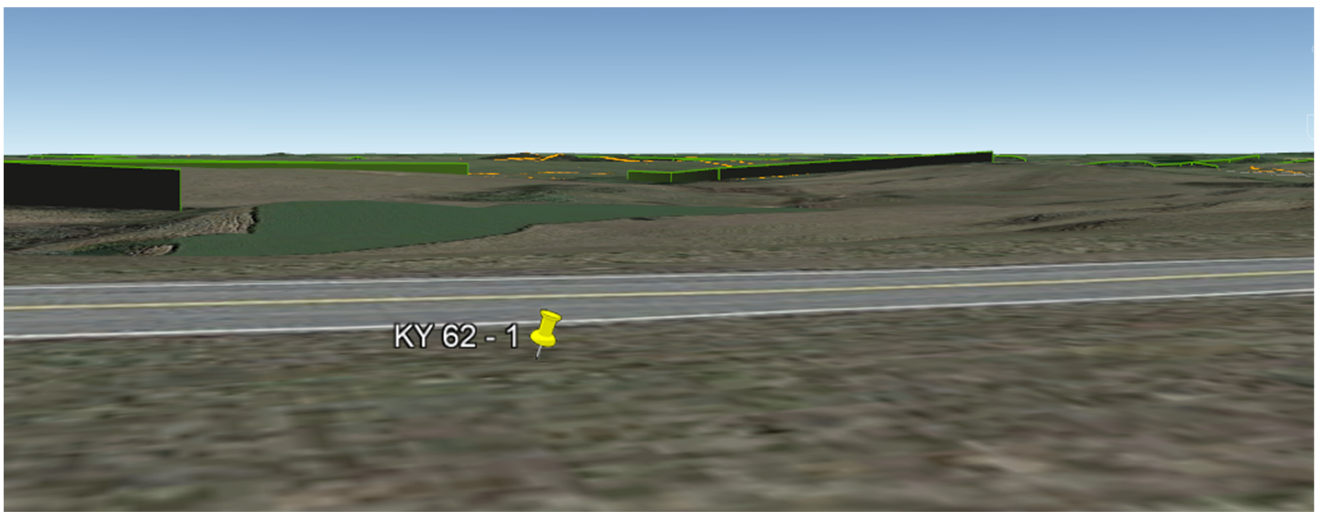


KOP R25 – Solar arrays visible looking Southwest

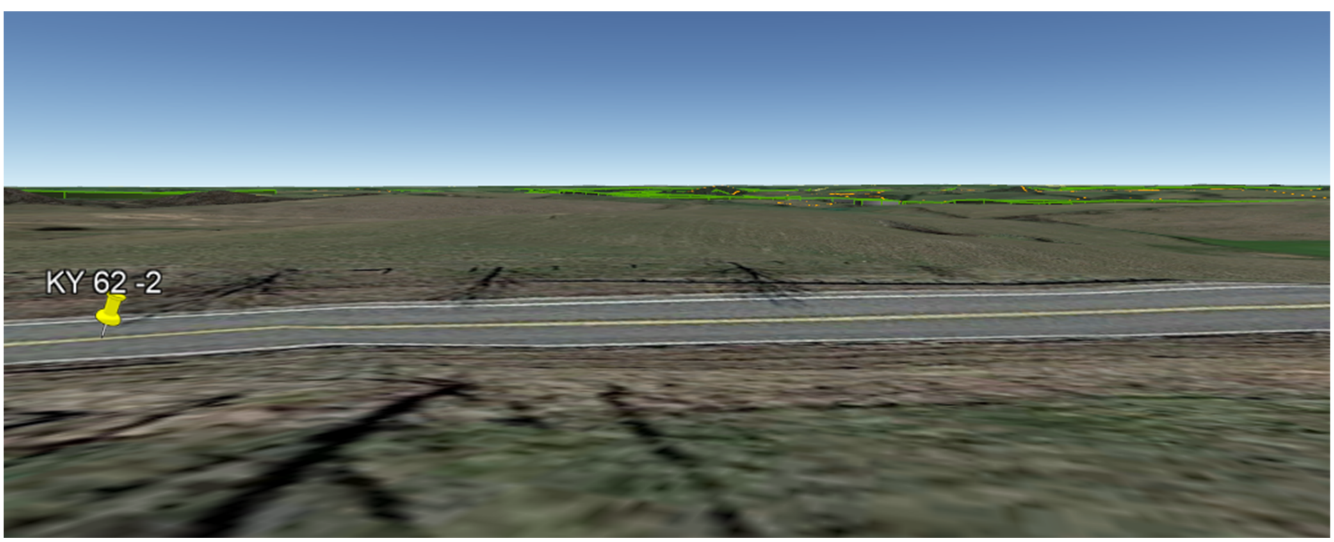


KOP R26 – Solar arrays visible looking Southwest

As for land traffic in KY 62 and KY 353, the visibility images are shown below. In these cases, the 'Street View' capability in Google Earth provides a picture of the visual.

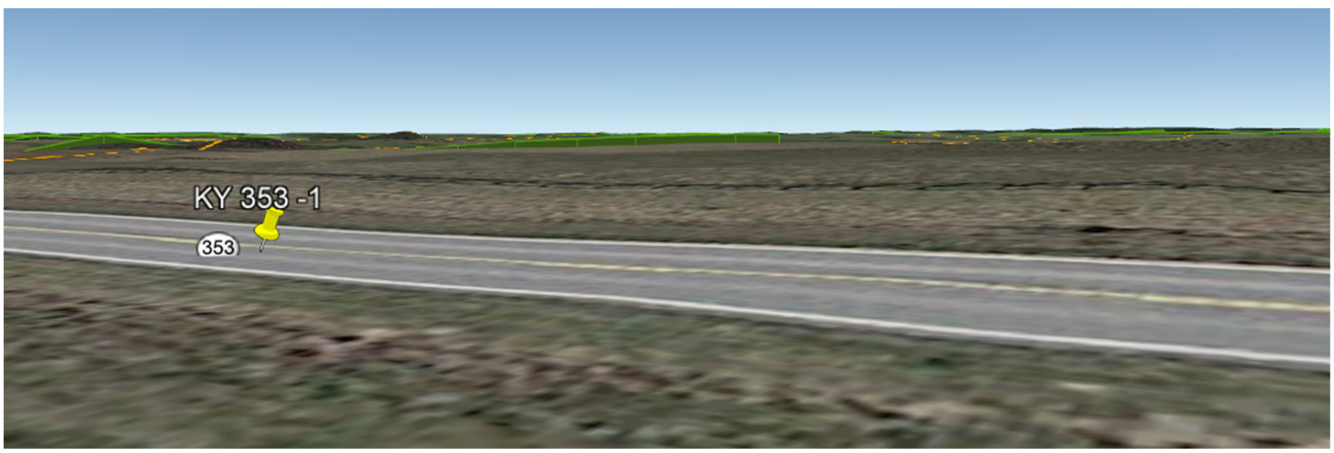


KOP KY 62-1 – Solar arrays visible looking Southeast



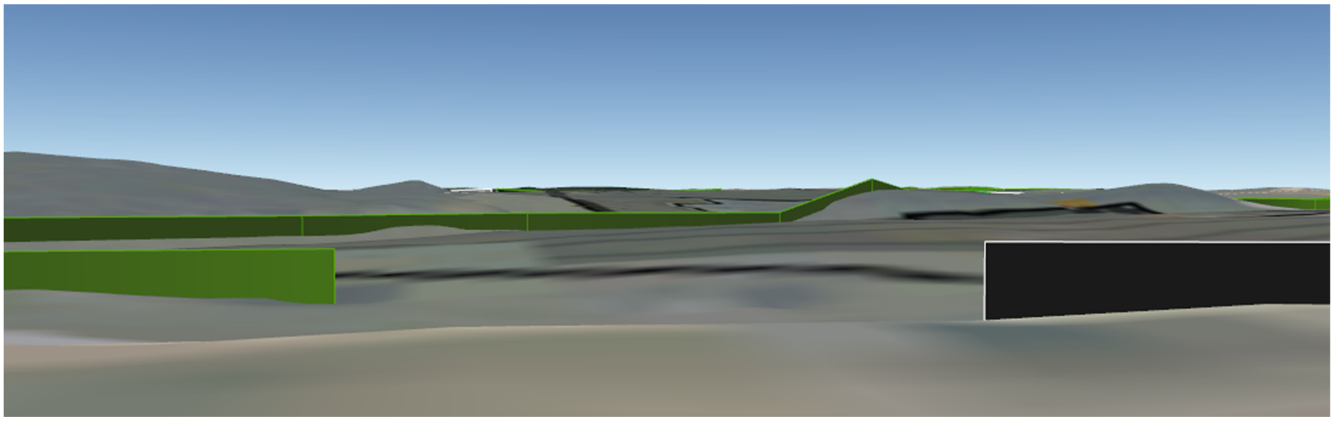
KOP KY 62-2 – Solar arrays visible looking South, however no reflectivity events occur at this point.

KOP KY 62-1 – Street View picture of existing condition - looking Southeast. No visibility.



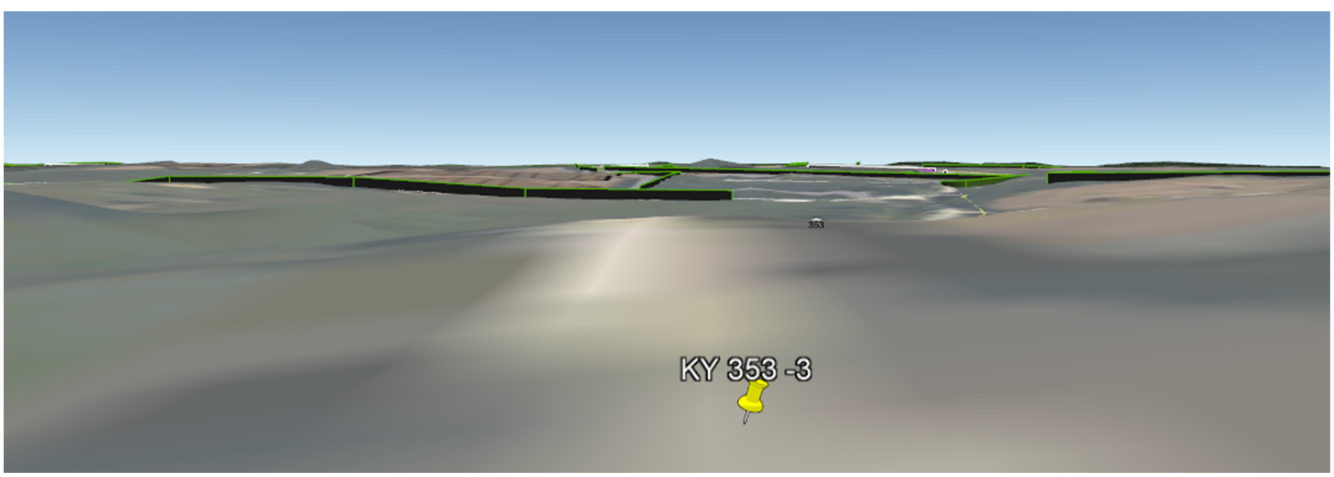
KOP KY 353-1 – Solar arrays visible looking Southwest

KOP KY 353-1 – Street View picture of existing condition - looking Southwest



KOP KY 353-2 – Solar arrays visible looking West

KOP KY 353-2 – Street View picture of existing condition - looking West



KOP KY 353-3 – Solar arrays visible looking North

KOP KY 353-3 – Street View picture of existing condition - looking North. Note winter vegetation provides sufficient visual barrier: Denser summer vegetation will block view in months with potential glare events.

6 Summary of results

KOP	Reflectivity Events	Visibility
R1	Aug to Mar	N
R2	Feb to Sep	N
R3	Feb to Sep	N
R4	Feb to Sep	N
R5	Mar to Jul	N
R6	Mar to Jul	N
R7	Mar to Jul	N
R8	Feb to Sep	N
R9	Mar to Jul	Y
R10	Mar to Jul	Y
R11	Mar to Jul	N
R12	Mar to Jul	N
R13	Mar to Jul	N
R14	Mar to Jul	N
R15	All year	Y
R16	All year	N
R17	All year	Y
R18	All year	Y
R19	All year	Y
R20	Aug to Mar	Y
R21	Sep to Feb	N
R22	Oct to Feb	Y
R23	Nov to Jan	Y
R24	Nov to Jan	N
R25	Nov to Jan	Y
R26	Oct to Feb	Y

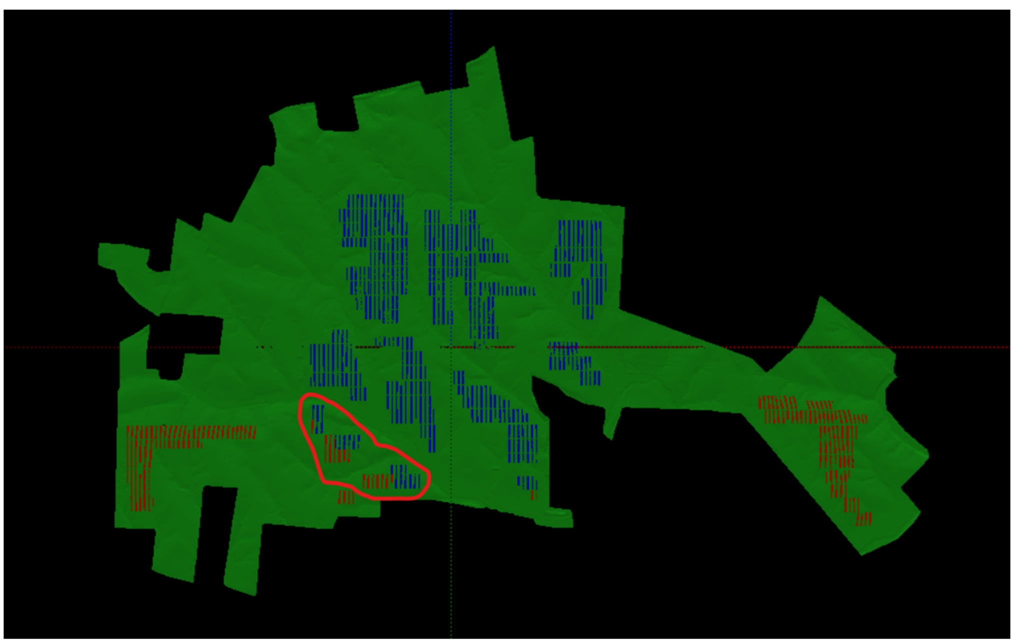
KOP	Reflectivity Events	Visibility
KY 62-1	Aug to Apr	N
KY 62-2	None	-
KY 353-1	Sep to Feb	Y
KY 353-2	Aug to Apr	Y
KY 353-3	Mar to Aug	N

7 Proposed mitigation

7.1 Visual Barriers

To define the proposed mitigation for reflectivity events at the selected KOPs it is convenient to determine which areas (trackers) of the solar plant are causing the events calculated in Section 4.1. The following images show the maps of the trackers affecting each KOP per this geometric analysis, therefore indicating where to increase the visual barriers for mitigation.

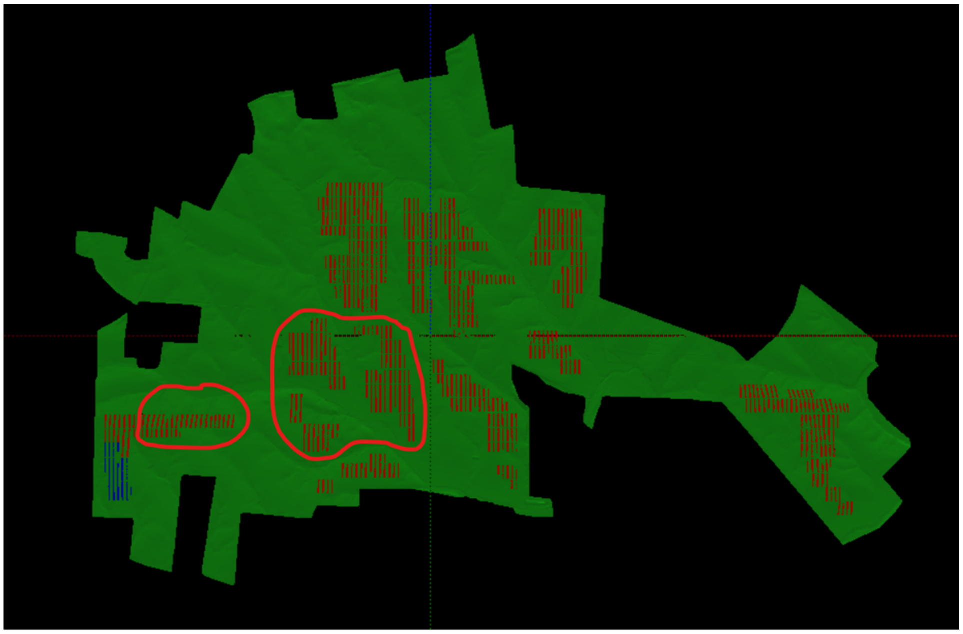
KOPs R9 & R10



Trackers causing potential reflectivity events at KOPs R9 and R10 (depicted in red). Visible trackers enclosed in red shape.

Because R9 and R10 are located at high topographical elevation with respect to the trackers causing the reflectivity events, it is advisable to increase the tree barrier closer to the KOPs rather than at the project boundary. Both KOPs should be visually isolated at its Northwest side with trees aligned between the KOPs and the source trackers.

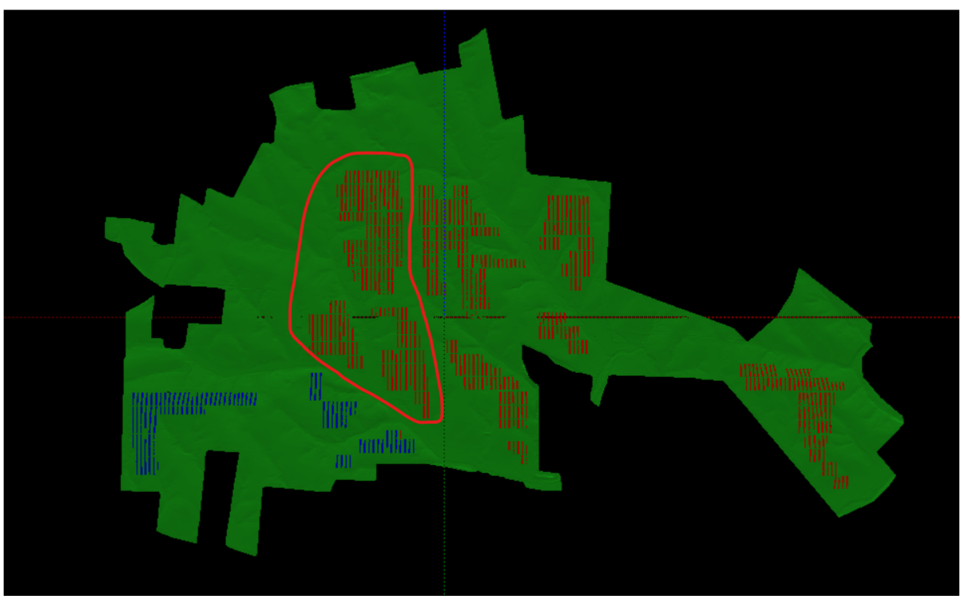
KOP R15



Trackers causing potential reflectivity events at KOP R15. Visible trackers enclosed in red shape.

Because R15 is located at high topographical elevation with respect to the trackers causing the reflectivity events, it is advisable to increase the tree barrier closer to the KOPs rather than at the project boundary. KOP R15 should be visually isolated at its North and Northwest side with trees aligned between the KOPs and the source trackers.

KOPs R17, R18 & R19



Trackers causing potential reflectivity events at KOPs R17, R18 & R19. Visible trackers enclosed in red shape.

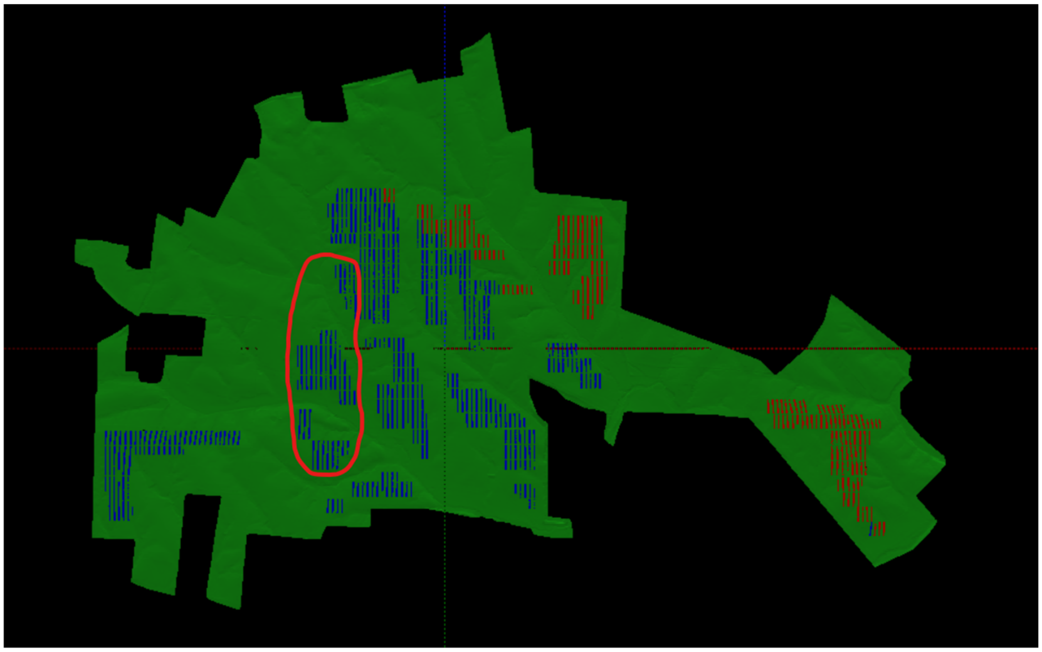
Because R17, R18 & R19 are located at high topographical elevation with respect to the trackers causing the reflectivity events, it is advisable to increase the tree barrier closer to the KOPs rather than at the project boundary. KOPs should be visually isolated at its East side with trees aligned between the KOPs and the source trackers.

KOP R20

Trackers causing potential reflectivity events at KOP R20. Visible trackers enclosed in red shape.

Because R20 is located at high topographical elevation with respect to the trackers causing the reflectivity events, it is advisable to increase the tree barrier closer to the KOPs rather than at the project boundary. KOP R20 should be visually isolated at its East side with trees aligned between the KOPs and the source trackers. It should be noted that this KOP already has some vegetation density close to the dwelling unit. This additional mitigation could be avoided if the currently existing vegetation provides sufficient screening.

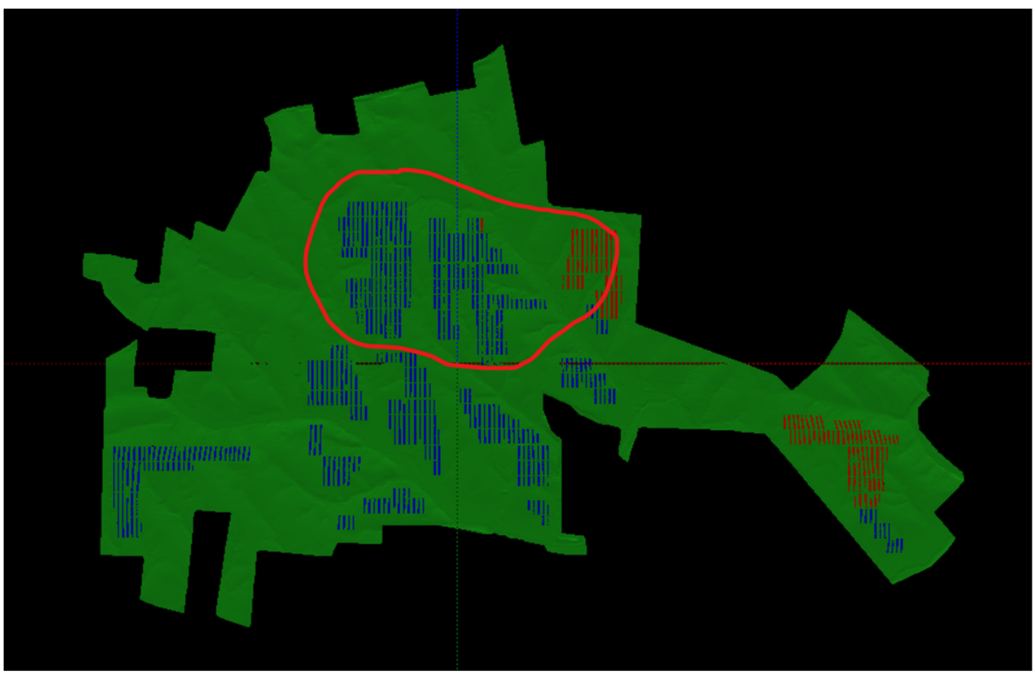
KOP R22



Trackers causing potential reflectivity events at KOP R20. Visible trackers enclosed in red shape.

The trackers causing potential glare events at R22 are not visible from this KOP. No mitigation needed.

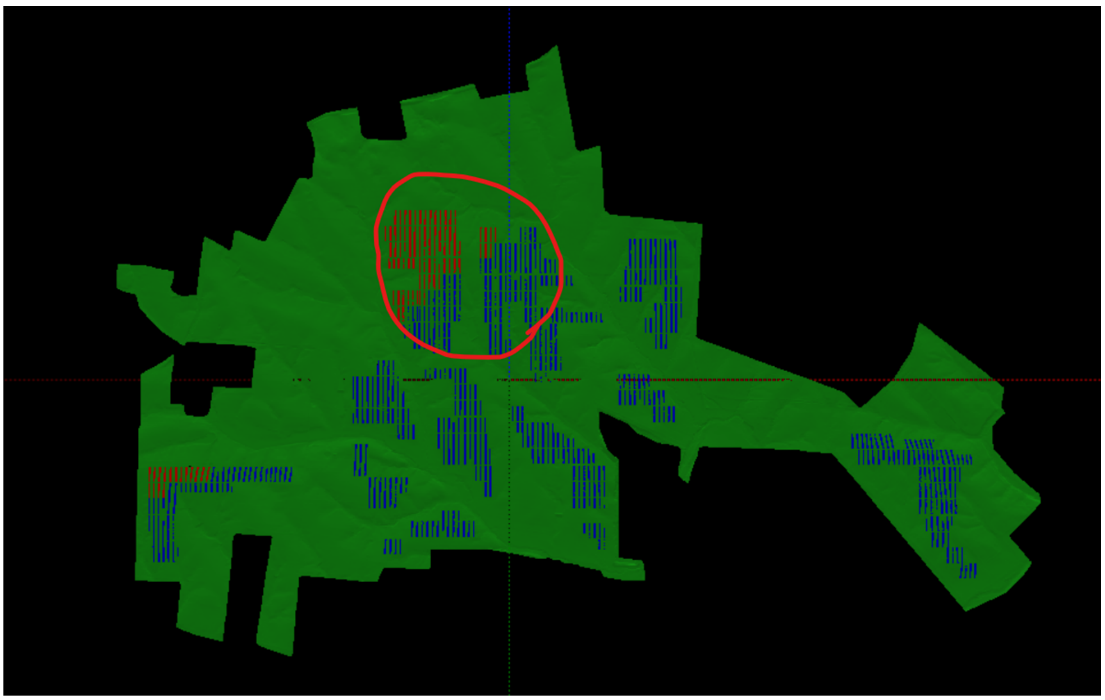
KOP R23



Trackers causing potential reflectivity events at KOP R20. Visible trackers enclosed in red shape.

Because R23 is located at high topographical elevation with respect to the trackers causing the reflectivity events, it is advisable to increase the tree barrier closer to the KOPs rather than at the project boundary. KOP R23 should be visually isolated at its East side with trees aligned between the KOPs and the source trackers. It should be noted that this KOP already has some vegetation density close to the dwelling unit. This additional mitigation could be avoided if the currently existing vegetation provides sufficient screening.

KOP R25 and R26

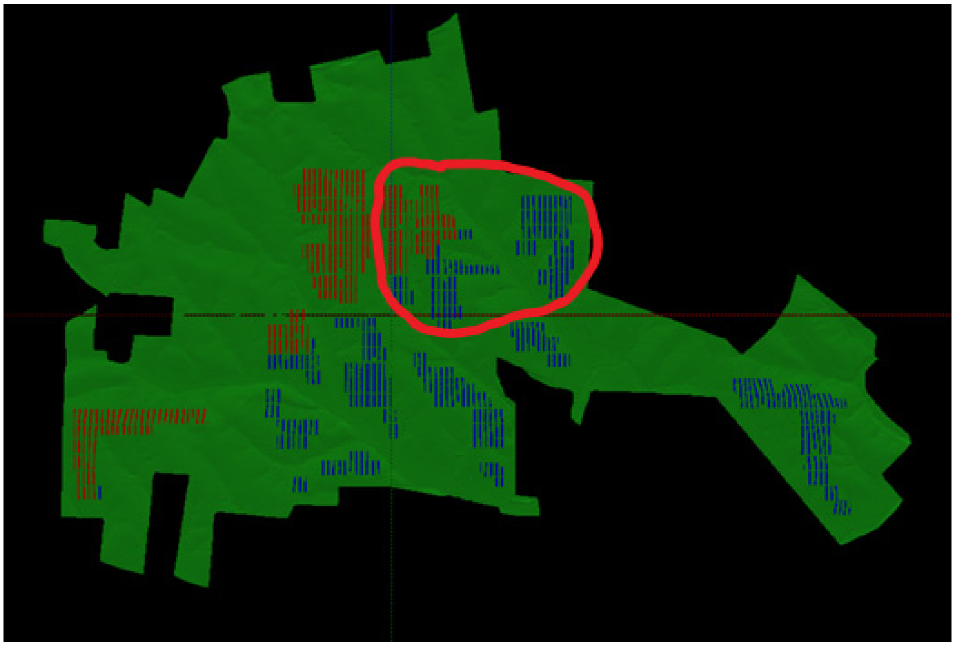


Trackers causing potential reflectivity events at KOPs R25 & R26. Visible trackers enclosed in red shape.

It should be noted that KOP R25 already has some vegetation density close to it. It is advisable to verify if the currently existing vegetation provides sufficient screening.

The results for the selected KOPs located at KY 62 and KY 353 are as follows:

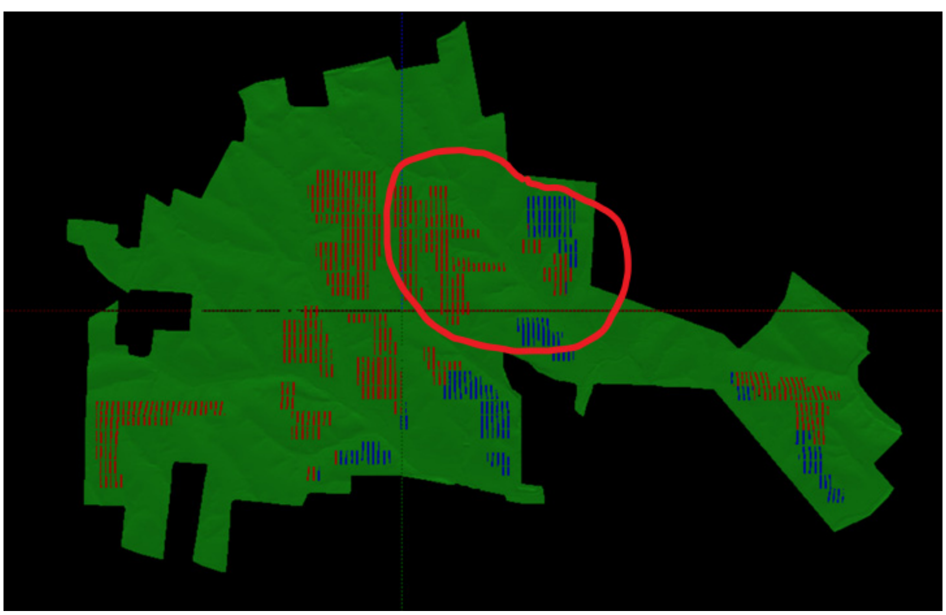
KOP KY 353-1



Trackers causing potential reflectivity events at Ky 353-1. Visible trackers enclosed in red shape.

Additional vegetation needed close to West curve of the road in the open field area.

KOP KY 353-2



Trackers causing potential reflectivity events at Ky 353-2. Visible trackers enclosed in red shape.

Additional vegetation needed close to West curve of the road in the open field area.

The above analysis is based on 3D imagery and assumptions regarding existing vegetation density, average tree heigh and available topographic data. It is recommended to confirm visibility from KOPs through physical inspection to validate these assumptions and visual simulation results.

7.2 Modified Backtracking Algorithm

An alternative means to cancel reflectivity events at KOPs consist in altering the backtracking algorithm for the trackers (see Section 3.3.1).

Reflectivity events at ground level with single axis trackers occur only at very low sun elevation angles (sunrise and sunset). In these occasions, the solar modules are in horizontal position because the backtracking algorithm operates to avoid mutual shading between tracker rows. An observer aligned with the solar plant and the sun's disk would see the reflection of the sun in the surface of the solar plant. All potential reflectivity events found in this report are of this nature.

By altering the backtracking algorithm, it is possible to re-orient the modules towards the sun position so that the reflected beams will be directed upwards. If the tracker angle [β] is sufficient (cut-off angle), the reflected beams will overpass the KOPs thus avoiding glare events. The trade-off of this strategy is mutual shading between modules, therefore reducing the energy yield of the solar plant. It has been determined that the minimum cut-off angle for the backtracking algorithm for this project to avoid reflectivity events at all KOPs is 8 degrees. The cylindrical projection screen for this cut-off angle is shown in Figure 25, where the reflected beams are not reaching the ground level in any case.

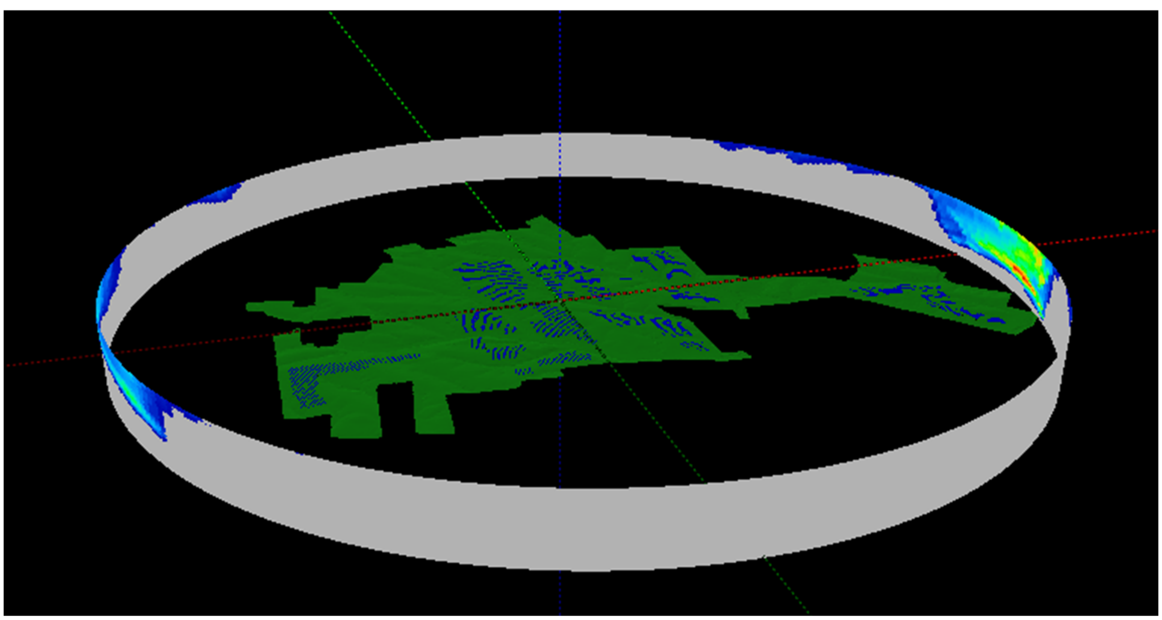


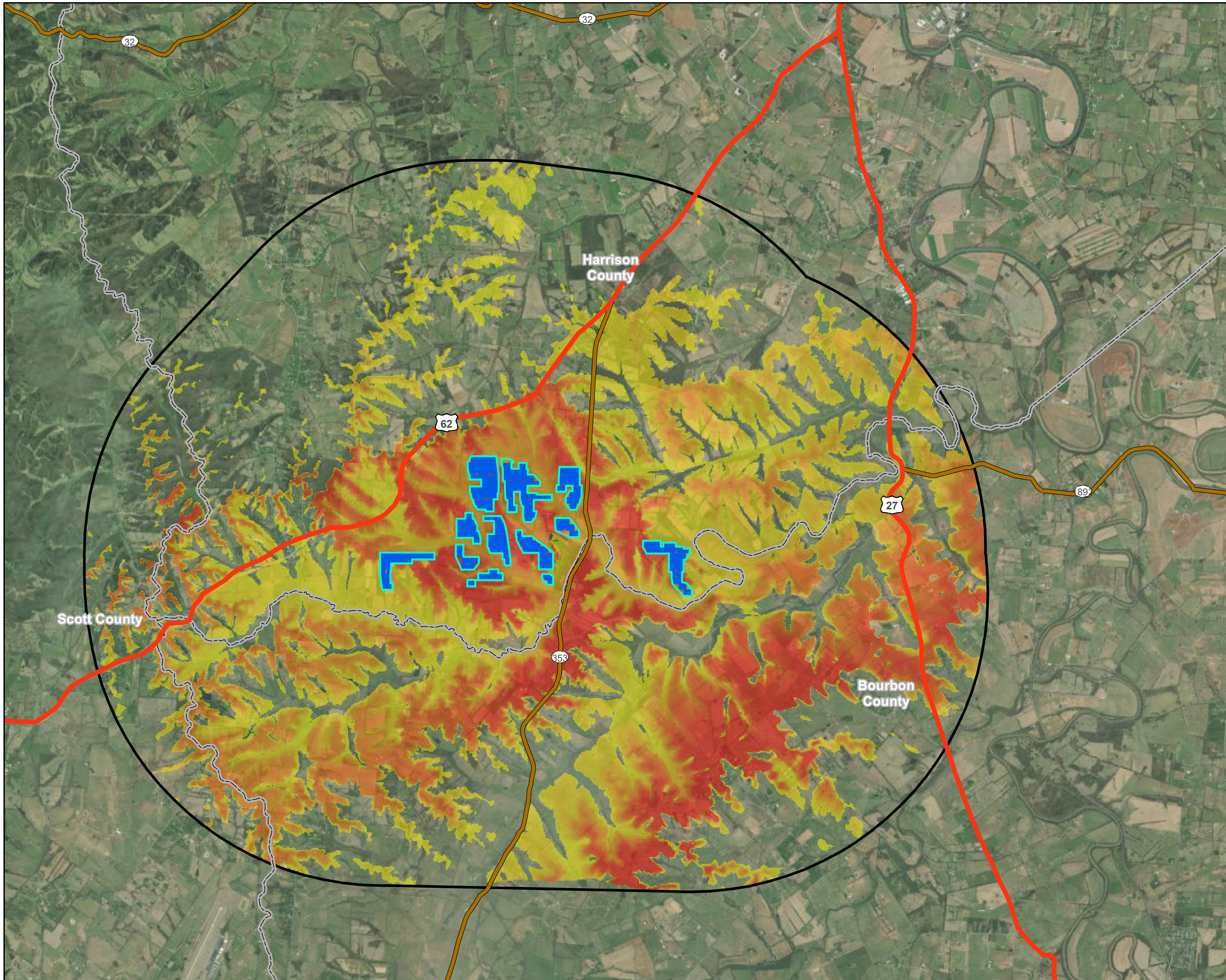
Figure 25.- Cylindrical reflectivity projection screen for the project (view from South). Compares to Figure 19B.

The cut-off angle strategy is advised if the existing vegetation proves to be an insufficient visual barrier for glare events at the selected KOPs. These can only be fully determined through observations during the first 12 months of plant operation. In this period, and as soon as an event would be detected, it would be mitigated with adequate adjustments to the control system of the plant. After these first 12 months of operation, no future reflectivity events would ever occur.

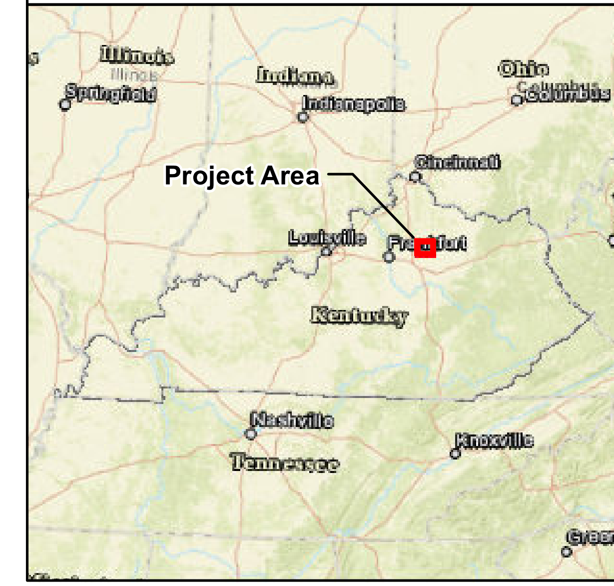
Because the source of the reflectivity events for each independent KOP is a limited set of trackers (see solar plant images in Section 7) the cut-off angle strategy can be implemented just for those trackers causing the events, and not necessarily the full system. Because the reflectivity events are inherently dependent on the time of the year, the cut-off angle strategy can also be activated and de-activated as needed. This is especially convenient if the reflectivity events occur because of the seasonal variability of the screening capability of deciduous trees.

ATTACHMENT A

Viewshed Simulations



OVERVIEW MAP



Legend

- Solar Fields
- Solar Fields Perimeter Fence
- 3-Mile Radius Buffer of Solar Fields

Visibility

- More Visible
- Less Visible

N

Miles

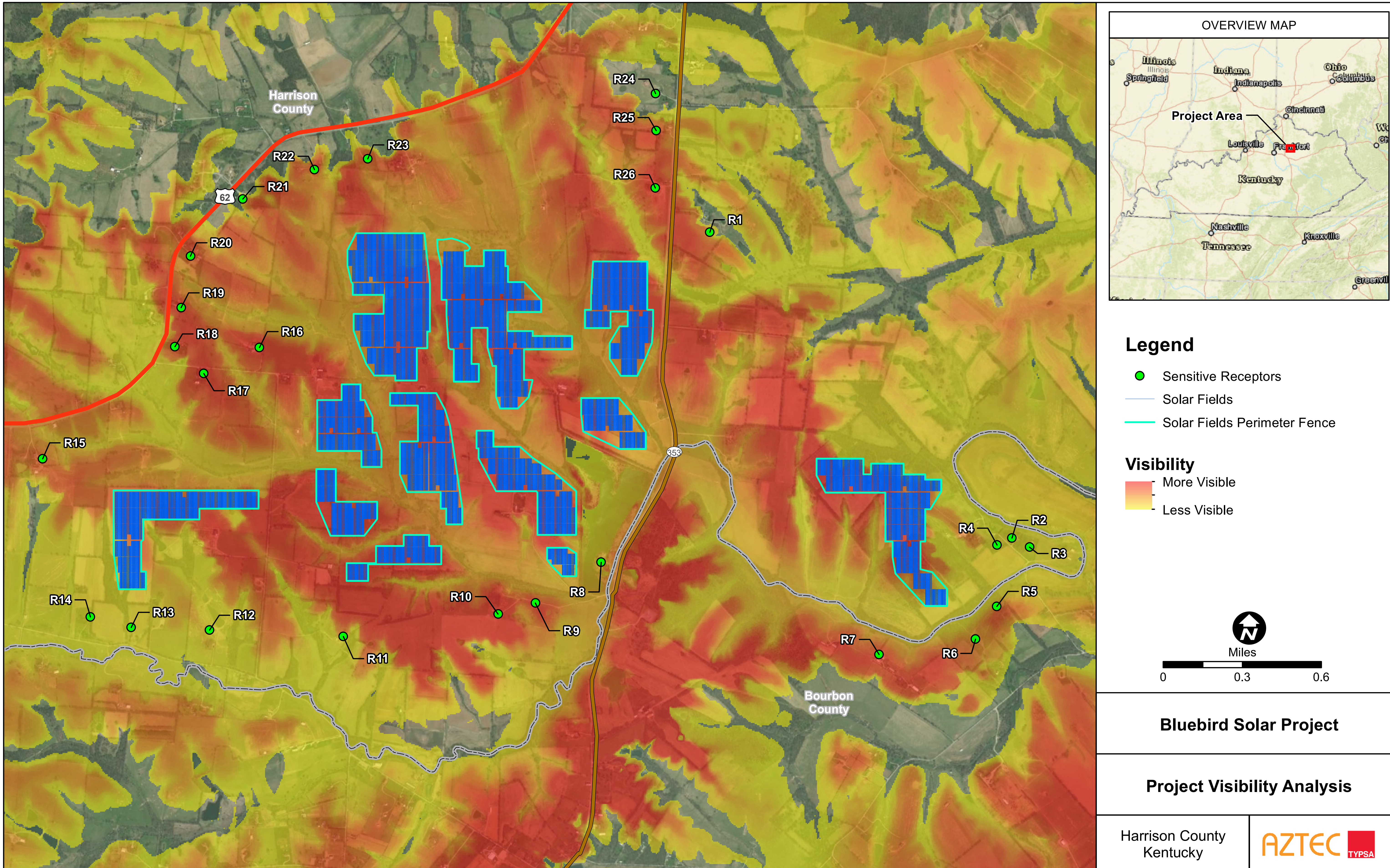
0 1 2

Bluebird Solar Project

Project Visibility Analysis

Harrison County
Kentucky

5/4/2021 @ Time: 9:17:31 PM



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