# Solar Glare Assessment

## South Ripley Solar Project

Town of Ripley, Chautauqua County, New York

**Matter No. 21-00750**

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# 1.0 INTRODUCTION

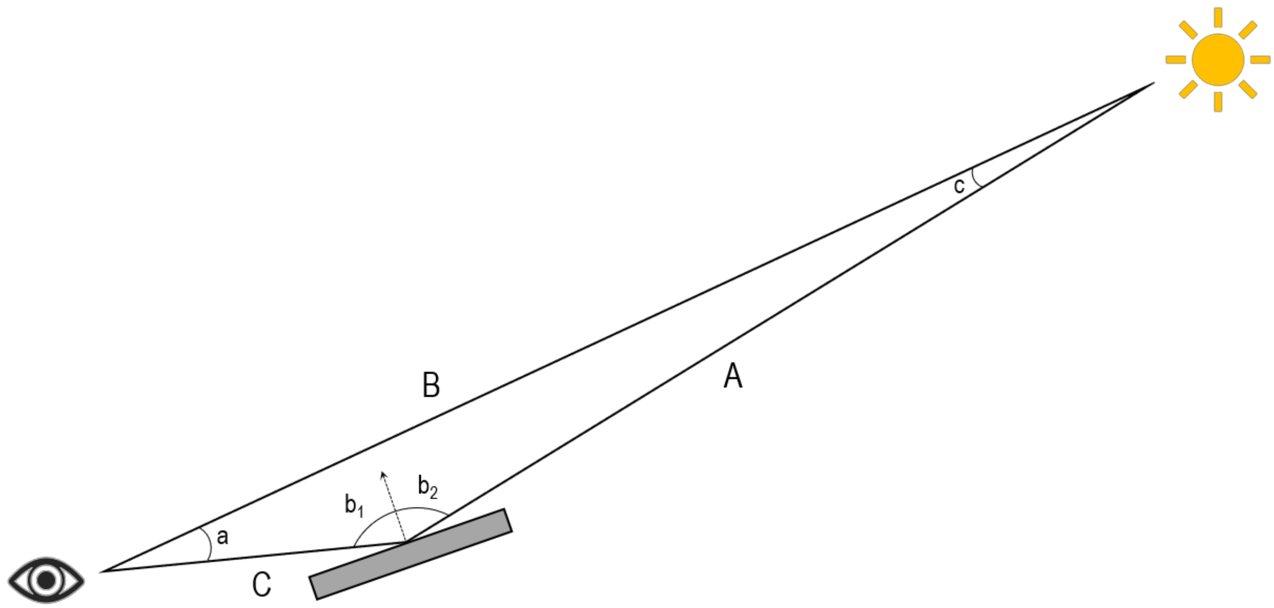
On behalf of ConnectGen Chautauqua County, LLC (the Applicant), Environmental Design & Research, Landscape Architecture, Engineering, & Environmental Services, D.P.C. (EDR) prepared this Solar Glare Assessment for the proposed South Ripley Solar Project (the Facility). The Facility is a proposed solar energy generating installation located in the Town of Ripley, Chautauqua County, New York. In accordance with Section 900-2.9(d) of the regulations established in Section 94-c of the New York State Executive Law, this Solar Glare Assessment provides an assessment of potential glare impacts resultant from the operation of the Facility.

## 1.1 *Definitions*

The following terms are used throughout this assessment.

| | |
|---|---|
| Direct Normal Irradiance (DNI) | The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. |
| Diffuse Solar Radiation: | Solar radiation scattered by molecules and particles in the atmosphere. |
| Direct Solar Radiation: | Solar radiation that has travelled from the sun to the earth's surface in a straight line without scattering. Direct radiation is the component of solar radiation that causes visible glare from flat-plate photovoltaic systems. |
| Facility: | Facility refers to all components of the proposed project, including PV panels and support structures, inverters, transformers, access roads, collection lines, a collection substation, a POI switchyard, and laydown areas. |
| Facility Site: | The parcels of land proposed to host the Facility components, totaling 3,381 acres. |
| Glare: | A continuous source of bright light. |
| Glint: | A momentary flash of bright light. |
| Incidence Angle: | The angle between the direct component of insolation (i.e., the sun) and a ray perpendicular to the PV panel (angle $b_2$ in Inset Figure 1 below). The Incidence Angle is equal to the Reflectance Angle. |
| Potentially Sensitive Receptors: | Non-participating residences and public roadways within 1,500 feet of the Facility Site with the potential to receive glare from the Facility's PV arrays. |
| PV Panels: | Refers to the photovoltaic panels that are fixed to a ground mounted racking system. On this Facility, a fixed-tilt racking system is proposed. |
| PV Array: | Refers to a contiguous group of PV panels which collectively will be enclosed by security fencing and landscape screening plantings, where applicable. |

| | |
|---|---|
| Reflectance Angle: | The angle between the reflected component of insolation and a ray perpendicular to the PV panel (angle $b_1$ in Inset Figure 1 below). The Reflectance Angle is equal to the Incidence angle. |
| Retinal Irradiance | The flux of radiant energy per unit area impacting the retina. |
| Specular Reflection: | The mirror-like reflection of waves, such as light, from a surface. |




**Inset Figure 1.** Trigonometric depiction of a receptor, a PV panel, and the sun. Reflectance Angle = $b_1$; Incidence Angle = $b_2$. The distance between the sun and the earth (sides A and B; approximately 91 million miles) is great enough, relative to side C (less than 1,500 feet or 0.28 miles), that angle c is effectively 0°.

## 1.2 *Facility Description*

The proposed Facility is a utility-scale photovoltaic (PV) solar project located in the Town of Ripley, Chautauqua County, New York. The proposed Facility will have a generating capacity of up to 270 megawatts (MW). The proposed solar arrays are primarily located on flat agricultural, post-agricultural, and forested lands. The surrounding landscape consists of a mosaic habitat types that is dominated by forested woodlots and open fields.

The Facility will include approximately PV solar panels grouped into distinct groups of PV solar panels (i.e., solar arrays). Each solar array will be surrounded by security fencing and landscape screening plantings, where applicable, and will consist of PV panels mounted on racking arranged in parallel rows (linear arrangements). In total, the solar arrays will occupy approximately 833 acres within the 3,381-acre Facility Site.

PV panels will be mounted on a fixed-tilt racking system. Fixed-tilt racking designs usually consist of a steel frame that creates a "table" on which the individual PV modules are mounted. The tables are fastened together to create a continuous row. The rows of PV panels will generally follow the existing topography of the Facility Site. Rows will be aligned east to west, with the PV panels tilted to the south at an angle of 30 degrees from horizontal. The PV panels will have a typical maximum height of 12 feet above the ground at their highest point.

## 1.3 *Photovoltaic Systems and Solar Glare*

Glare is defined as a continuous source of bright light and differs from glint in its temporal duration. Where glint is a momentary flash of bright light, the effects of glare are generally only realized after 0.15 seconds or more of exposure (Ho et al., 2011; Zehndorfer Engineering, 2019). Both glint and glare are common in the existing environment. The sun and artificial light sources can cause glare or glint either directly (such as from a sunset when driving westbound) or indirectly (such as from the sun's reflection off of a lake or glass window). The potential effects of glare include annoyance impacts, such as distraction, after-image in the viewer's vision, or temporary avoidance of a view due to the presence of reflected light (Dwyer, 2017; Slana, 2018); safety impacts, such as the potential to disorient road users or pilots (Auffray et al., 2007; Ho et al., 2011; Riley and Olson, 2011); and human health impacts, such as permanent retinal damage (Ho et al., 2009). It is important to note here that human health impacts are typically only associated with concentrating solar power plants or other convex reflective surfaces (e.g., convex curtain wall buildings) that concentrate the incoming solar radiation. Flat-plate photovoltaic systems, such as the proposed Facility, are incapable of producing the retinal irradiance levels necessary to result in permanent retinal damage.

Although photovoltaic systems are designed to absorb as much of the solar spectrum as possible, PV panels can reflect a significant proportion of the incoming solar radiation at high incidence angles (Parretta et al., 1999). As a result, under clear sky conditions, fixed-tilt photovoltaic systems, such as the proposed Facility, may produce glare in the early morning and evening when the sun is low on the horizon and there are no obstructions (e.g., topography, vegetation, structures, etc.) limiting the production and receipt of glare.

### 1.3.1 Modeling Glare

To develop a general estimate of the occurrence, duration, and intensity of glare produced by a PV system and received at a given observation point, the following information is needed:

(1) Location, size, height, spacing, orientation, and reflectance of the PV panels;
(2) Location and height of the observation point;
(3) Position of the sun;

(4) Direct Normal Irradiance (DNI);[1] and

(5) Geospatial characteristics of any topography, vegetation, buildings, or other potential obstructions between the observation point and the PV panels producing glare and between the PV panels and the sun.

ForgeSolar is the only company the Applicant is aware of that provides software that allows a user to model glare using the Solar Glare Hazard Analysis Tool (SGHAT). This software, "GlareGauge," is entirely based on the SGHAT model,[2] a conceptual model that was initially developed for use by the Federal Aviation Administration (FAA) in evaluating safety impacts to pilots while landing aircraft (Ho et al., 2015). This tool has since expanded and can be used to identify the potential for a photovoltaic system to produce glare receivable by ground-based receptors (Forge Solar, 2021). However, the application of this tool is limited, as described in Section 1.3.2. as this software is based on a clear sky and bare earth model that assumes each PV array is a uniform surface. As discussed further below, this model does not consider atmospheric conditions that scatter incoming solar radiation, terrestrial obstructions that block PV panels from receiving direct radiation and/or block an observer from receiving glare, other intense sources of radiation that might mask the effect of glare (i.e., the sun), and other variables that would affect the production and receipt of glare from potentially sensitive receptors. In addition, the model does not allow a user to provide site-specific information on the spacing, size, or characteristics of the PV panels that make up an array.

### 1.3.2 SGHAT Model Limitations

#### *1.3.2.1 Atmospheric Obstructions*

Direct solar radiation is the component of solar radiation that causes visible glare from flat-plate PV systems (Riley and Olson 2011). Direct radiation is radiation that has travelled from the sun to the earth's surface in a straight line without scattering. In order for PV panels to produce glare, direct solar radiation must strike PV panels at a high incidence angle.[3] Clouds, humidity, and other atmospheric elements scatter and absorb a certain percentage of solar radiation as it travels through the earth's atmosphere, reducing the amount of sunlight that reaches the earth's surface as direct radiation. Under some conditions (e.g., overcast skies), little to no solar radiation reaches the earth's surface without scattering.

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[1] As DNI varies with both the sun position and changing atmospheric conditions, site-specific data with high temporal resolution is needed to accurately estimate glare.

[2] For the purposes of this assessment, the terms "GlareGauge software" and "SGHAT model" are used interchangeably.

[3] Specular reflectance is limited at low incidence angles (Parretta et al., 1999).

The SGHAT model assumes a clear sky with limited radiative scattering. Direct normal irradiance (DNI) values built into the model represent the maximum values possible for the site, considering the latitude and position of the sun. In the desert southwest, where most of the studies that support the SHGAT model were conducted (e.g., Ho et al., 2011 and Ho, 2013), this assumption is not likely to be problematic. However, in the northeastern United States, where high humidity levels and cloudy or overcast conditions are common, this assumption contributes to an overestimation of glare occurrence, duration, and intensity, as DNI has a direct relationship with glare intensity (Ho et al., 2011).

As an example, the models presented by Ho et al. (2011) were validated at the National Solar Thermal Test Facility located just outside of Albuquerque, NM. The annual percent average of possible sunshine in Albuquerque, NM is 76%, one of the highest values in the nation (NOAA, 2020). In comparison, the annual average percent of possible sunshine in Buffalo, NY (located approximately 60 miles northeast of the Facility) is 47% (NOAA, 2020). Sites such as the Facility that have a high occurrence of cloudy or overcast conditions are expected to have lower glare occurrence, duration, and intensity in the real world as compared to the SGHAT model outputs.

#### *1.3.2.2 Terrestrial Obstructions*

Another primary limitation of the SGHAT model is its assumption of a bare earth condition. To produce glare at a given observation point, there must be a clear line-of-sight between the sun and the PV panels, and between the PV panels producing glare and the observer. In the area within and adjacent to the Facility, topography, vegetation, buildings, and other obstructions significantly limit the visibility of the Facility's solar arrays. Where these terrestrial obstructions do not completely block a receptor's view of the PV arrays, they often disrupt that view, breaking it into smaller, less contiguous sections. The SGHAT model does not consider these obstructions that currently exist in the landscape.

As noted above, the SGHAT model was designed to meet the FAA's glare analysis requirements (78 FR 63276[4]). In assessing potential glare for pilots and airports, the relevant sensitive receptors (e.g., aircraft and air traffic control towers) are well above the ground surface and terrestrial obstructions are typically limited.[5] In contrast, the proposed Facility is comprised of multiple PV arrays spread out across miles of variable terrain that includes a patchwork of existing vegetative communities (e.g., forests and farmland).

No commercial or municipal airports or air traffic control towers are found within two miles of the Facility Site. Potentially sensitive receptors are limited to residents and road users, which are located near the ground surface and, in many cases, are lower in elevation than the PV panels. Many areas within the Facility Site are densely forested; the forests

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[4] Available at: https://www.govinfo.gov/content/pkg/FR-2013-10-23/pdf/2013-24729.pdf
[5] Airports are typically sited in locations with limited topographic relief. In addition, the height of adjacent vegetation is controlled.

and hedgerows located adjacent to the PV panels substantially reduce the visibility of the Facility from adjacent observation points and shade the panels from direct radiation in the early morning and late evening. In heavily forested areas, such as the Facility Site, tall trees located adjacent to the PV arrays can significantly affect experienced sunrise and sunset times.

Considering that glare is almost exclusively produced in the morning and the evening—the times of day when the incidence angle between the sun and the PV panel (angle $b_2$ in Inset Figure 1) is highest—this is a potentially significant model limitation. As an example, 40-foot trees located 120 feet west of a PV panel would delay sunset by roughly an hour and a half in mid-summer. Any glare predicted by the SGHAT model under these conditions would not be produced by the PV panel as direct radiation would be lacking.

As a final point, most PV panels have a maximum height of 8-14 feet. At these heights, the panels themselves can act as form of visual screening, preventing a receptor from viewing more than edges of a PV array, particularly for receptor's located at an elevation equal to or less than that of the PV array or in cases with a PV array is located on a slope that grades away from a receptor.[6] This is problematic because, as described above, the SGHAT model assumes that a receptor has full visibility of the PV array. However, in many cases, inter-array panel screening may block most, or all of the glare potentially received by an adjacent residence or roadway. Considering the maximum height of most PV panels and the heights of most ground-based receptors (residences and road users), it is likely that the SGHAT frequently overestimates glare in failing to account for inter-array panel screening.

All of this being said, the SGHAT model is a tool, and in fact may be the only commercially available tool, to assess worst-case predictions of glare from the Facility Site and identify locations where the potential incidence of glare may be highest. The number of "hours" of glare output by the model can be used to characterize the potential impact and identify the potential need for minimization and mitigation.

#### *1.3.2.3 Sun-masking Angle*

A variable that is not accounted for in the SGHAT model, but which is important in determining the effect glare may have on a receptor, is the sun-masking angle concept. When the sun is low on the horizon, the sun and PV panels producing glare can be viewed simultaneously by a potential receptor. As the intensity of retinal irradiance produced by the sun is several orders of magnitude greater than what is capable of being produced by flat plate (i.e., non-

[6] In some cases, depending on the topographic and trigonometric relationship between a receptor and the PV array, a receptor located nearly due east or due west of an array may have visibility of one full row of the PV array. However, in the northern hemisphere, such views are unlikely to produce glare with a sun masking angle of more than 10 degrees.

concentrating) PV panels (Ho et al., 2011), the sun's intensity can partially or wholly overshadow the glare produced by the PV panels, depending on the angle between the sun and the PV panels, as perceived from the receptor (i.e., angle a in Inset Figure 1). Although there is some ambiguity regarding the angle at which the sun fully masks glare produced by PV panels (Zehndorfer Engineering, 2019), Germany and Austria have established a conservative sun-masking angle standard: glare received by PV panels can be discounted when the sun-masking angle is less than 10° (LAI, 2012; Zehndorfer Engineering, 2019).

#### *1.3.2.4 Additional Considerations*

In addition to the limitations described above, the SGHAT model offers no opportunities for a user to modify the characteristics of a PV array to reflect site-specific details regarding the panel dimensions, the spacing between rows of PV panels, or component variation within a PV array (e.g., access road placement). All PV arrays are treated equally as a unified reflective surface; PV arrays with 40 feet of spacing between panels to allow continuing agricultural equipment access are treated the same as tightly packed arrays with less than half the spacing between panels.

All conceptual models are limited in their ability to represent or anticipate real world phenomena and require correction and validation in order to output accurate data. What is unusual about the SGHAT model, as applied to flat-plate PV systems and ground-based receptors, is the scope of the corrections needed to accurately assess glare receivable by ground-based receptors and—perhaps most importantly—the lack of model validation for this specific application. Ho et al. (2011) validated the accuracy of the model in the desert southwest in predicting the timing and duration of glare produced by concentrating solar energy facilities, and the model was applied and further validated in other locations in the United States, including the northeast (Ho et al., 2013), but none of these studies assessed the accuracy of the SGHAT model in predicting the occurrence, duration, and intensity of glare received by ground-based receptors, such as year-round residences. Neither the SGHAT Technical Reference Manual (Ho et al., 2015) or the studies cited on ForgeSolar's website provide any further information indicating that the GlareGauge software has been validated for this specific application.

The SGHAT model used by ForgeSolar appears to be the only software tool available to conduct a solar glare assessment. However, for flat-plate photovoltaic systems sited in areas with atmospheric and terrestrial conditions that are not favorable to the production or receipt of glare, the raw outputs of the SGHAT model may not be representative of potential on-site conditions.

# 2.0 METHODS

As discussed above, the SGHAT model outputs represent a worst-case scenario that is unlikely to be realized for the majority of ground-based receptors, particularly in locations such as the Facility Site where atmospheric and terrestrial obstructions are prevalent. That being said, some of the limitations of the SGHAT model can be partially or wholly corrected through pre- and post-processing.

With the advent of publicly available lidar-derived high-resolution digital elevation model (DEM) data, terrestrial obstructions can be modeled at landscape scales. To correct the SGHAT model's bare earth assumption for residences, lidar-derived DEM data can be used in concert with field-based surveys to understand visibility an observation point might have of the PV panels producing glare, and to determine when panels would be shaded by adjacent vegetation and topography. These data could then be used to eliminate receptors lacking visibility of the PV arrays and modify the user-defined SGHAT model inputs for receptors with only partial visibility.

To account for the SGHAT model's clear sky assumption, publicly available monthly percent average of possible sunshine values can be incorporated into the SGHAT model outputs for residences[7] through post-processing to reflect overcast and cloudy conditions where glare occurrence is limited.

With respect to the sun-masking angle, conservative standards established by other governing bodies could be applied correctly account for this condition for residences.[8] Considering the distance between the sun and the earth[9] and the fact that the incidence angle and the reflectance angle (angles $b_2$ and $b_1$ in Inset Figure 1, respectively) are equivalent, the angle between the sun and the PV panels, as perceived from the receptor (angle a in Inset Figure 1), can be calculated as: 180 – (2 x Incidence Angle). Under the standard established by Germany and Austria, any glare received by a receptor where the incidence angle is over 85° would be determined to have a sun masking angle less than 10°, and therefore that glare could be discounted.[10] As the SGHAT model provides incidence angle information for every minute of modeled glare, model outputs could be post-processed to account for any sun-masking angle standard determined to be relevant by a municipality or developer.

Although some of the limitations of the SGHAT model can be corrected through applying the methods outlined above, several of the model limitations discussed in Section 1.3.2 are more difficult to remedy. As an example, although it is

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[7] Road users travel on a three-dimensional surface at varying velocities. The SGHAT model outputs for these users are not organized in a manner that would allow this post-processing.
[8] The model outputs for road routes are not organized in a manner that would allow this post-processing.
[9] The earth is approximately 91 million miles from the sun during the perihelion.
[10] 180 – (2 x 85°) = 10°

possible to account for obstructions between a residence or road user and the portions of a PV array causing glare, it is much more difficult to account for terrestrial obstructions between the sun and the PV array that limit the production of glare. Sunrise and sunset times change daily and the effect of terrestrial obstructions on the production of glare will be different for each individual PV panel within an array based on the trigonometric relationship between a PV panel and the specific characteristics of the obstructions blocking the receipt of direct solar radiation. Although lidar data could be used to derive a better understanding of the effective sunrise and sunset time in a specific location, this information would have to be built into the SGHAT model algorithm for each individual PV panel. The SGHAT model does not have this capacity.

The methods applied by the Applicant, as outlined in the sections below, are intended to correct some of the limitations of the SGHAT model, where possible. However, even where corrections could be applied, not all model limitations were able to be accounted for. Accordingly, the intent of methods outlined below is to support an overall qualitative assessment of the Facility's glare impacts.

## 2.1 *Residences*

### 2.1.1 Pre-processing

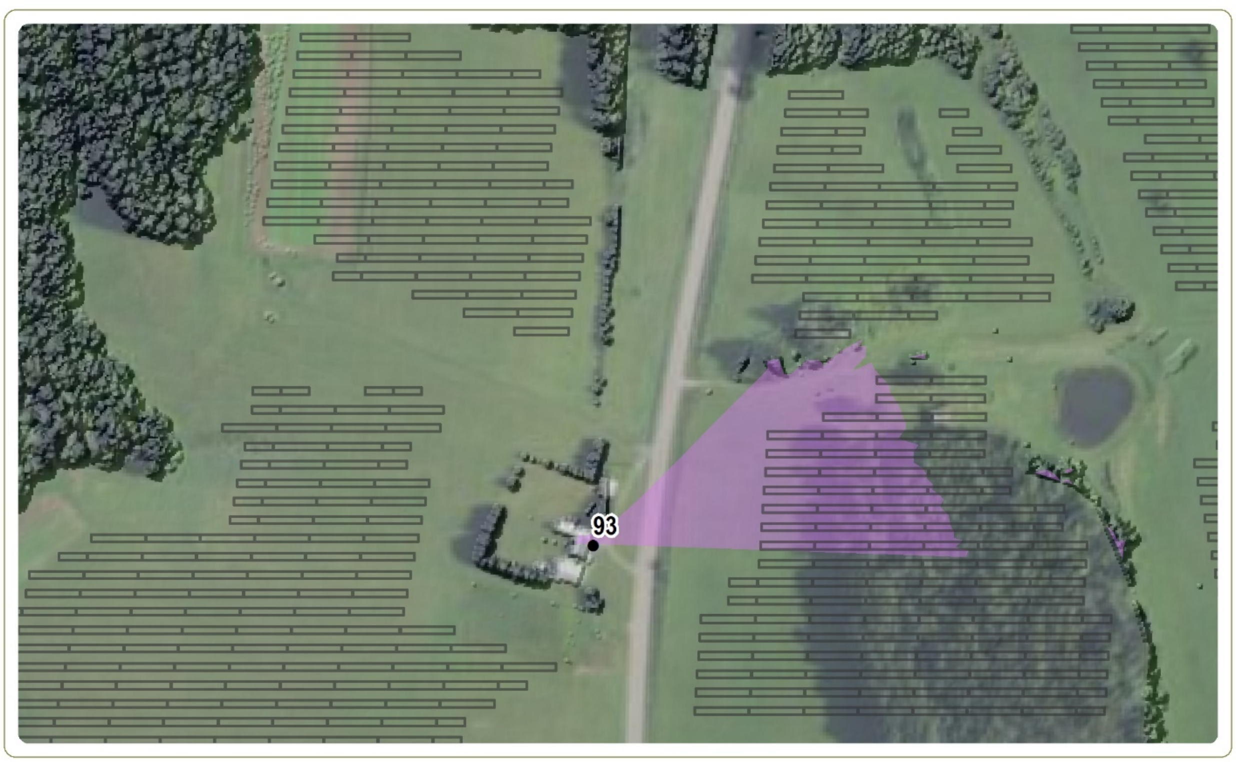
A total of 72 permanent non-participating residences are located within 1,500 feet of the Facility. In addition, there are a number of public roads running through the Facility. No commercial or municipal airports or heliports are located within 2 miles of the Facility. As intervening vegetation and topography (i.e., visual obstructions) are ubiquitous across the Facility Site, an initial desktop screening process was conducted using general viewshed modeling, aerial imagery, and the trigonometric relationships between receptors and the PV arrays to identify receptors with the potential to receive solar glare from the Facility.

Using USDA lidar data for Chautauqua County, a 2-meter resolution digital surface model (DSM) was created, which included the elevations of buildings, trees, and other objects large enough to be resolved by lidar technology. As part of the development of the DSM, woodlots and hedgerows that may potentially be cleared during construction of the Facility were removed from the resulting DSM to reflect the bare-earth elevation in these locations. The modified DSM was then used as a base layer for a general viewshed model of the Facility. In this viewshed analysis, the height of sensitive receptors was set to 5.4 feet, and the height of the proposed PV arrays was set to 12 feet.

At the Facility's latitude (42.2° N), and considering the proposed PV panel orientation (180 degrees, i.e., east-west) and tilt (30 degrees south), a receptor must be located generally due east, due west, east southeast, or west southwest of adjacent visible PV arrays in order to receive glare produced by that array. Receptors located north of adjacent PV arrays would not receive glare as fixed tilt PV arrays that have a 180-degree orientation and a southern tilt are not capable of producing glare that can be received by terrestrial receptors located north of their east-west axis; the view of any receptor located north of this axis will be limited to the back or the side of the PV panels. Receptors located due south, southeast, or southwest of adjacent PV arrays would not receive glare as none of the solar position and receptor location combinations possible at this site would result in incoming solar radiation striking the panels at high incidence angles in a manner that could be received by such receptors. The potential for non-participating receptors to receive glare was analyzed further using the methods outlined in Sections 2.1.2, 2.1.3, 2.1.4, and 2.1.5 below.

### 2.1.2 Observation Point Viewshed Analysis

An observation point viewshed analysis was completed for each of the receptors. This analysis utilized the DSM and model inputs identified above to identify the visibility each of the receptors are anticipated to have of the PV arrays. Inset Figure 2 provides a representative example of the observation point viewshed analysis results for Receptor 93. Figure 1 provides the results of all observation viewsheds that were completed. As a result of this process and considering PV panel orientation, 48 of the non-participating receptors were identified as not having visibility of the panels and an additional 13 receptors did not have panel visibility within a portion of panels that have the correct position to cause glare receivable at that receptor.



**Inset Figure 2. Observation viewpoint analysis results for Receptor 93. The proposed photovoltaic (PV) panels are shown outlined in dark gray and the results of the viewshed analysis are shown in purple.**

### 2.1.3 Field Verification

To verify the results of the observation point viewshed analysis, a field survey of receptor visibility was conducted in June 2021 by EDR staff with experience in conducting visual impact assessments. All sensitive receptors identified in the observation point viewshed analysis as having visibility of the PV panels with the potential to cause glare were visited and the existing viewshed of these receptors was assessed.[11] This field survey accounted for site-specific characteristics that could not be derived from the DSM, such as the composition and shape of intervening vegetation, specific characteristics of the receptor, unaccounted for changes in the vegetation or landscape (e.g., new buildings or removed trees), and other elements affecting the visibility of the PV arrays. The results of this field survey were documented in the field; geotagged photographs were taken from multiple angles at each assessment location. Inset Figure 3 shows the photograph taken from the proposed PV array looking toward Receptor 93.

**Inset Figure 3.** Photograph taken during field verification of the observation point viewshed analysis results for Receptor 93. This photograph was taken from proposed PV array toward Receptor 93. As shown in this photograph, a hedgerow of evergreen trees blocks potential views to the west, whereas no obstructions exist between the receptor and the proposed PV array to the east.

[11] Where the Applicant lacked access to specific receptors not participating in this project, the field survey was conducted from public rights-of-way (ROW).

### 2.1.4 SGHAT Modeling

The results of the observation point viewshed analysis and the results of the field verification were used to develop a final geospatial dataset identifying the specific PV panel areas likely to produce glare that can be received by the potentially affected receptors. This dataset accounted for all terrestrial obstructions known at the time of the field survey that could affect the receipt of glare.[12] Figure 2 shows the final geospatial data for all receptors included in the final modeling. Inset Figure 4 provides an example of the final geospatial data for Receptor 93 specifically.


**Inset Figure 4.** Final model input data for Receptor 93 (shown in orange). These model input data were developed based on the results of the observation point viewshed analysis (shown in purple, for reference), the results of the field verification, and the results of the Preliminary Glare Analysis. Proposed photovoltaic (PV) panels are outlined in dark gray.

This final geospatial dataset was then input into the ForgeSolar modeling software, along with the core assumptions outlined in Table 1 to produce the SGHAT model outputs.

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[12] It is important to note that in interpreting the results of a typical viewshed analysis where vegetation is incorporated in the DSM, some consideration needs to be made for leaf-off conditions. Lidar-derived viewshed data, i.e., the data utilized in this analysis, has the potential to underestimate visibility in the dormant season where the lack of deciduous foliage can improve visibility. In this case, leaf-off conditions are largely irrelevant. As indicated in the results of this assessment (see Appendix A), the Facility's potential to produce glare is almost exclusively limited to the late spring, summer, and early fall.

**Table 1. SGHAT Model Inputs.**

| Parameter | Input |
|---|---|
| Panel Height | 12 feet[1] |
| Receptor Height | 5.4 feet[2] |
| Axis Tracking | Fixed |
| Orientation | 180° |
| Tilt | 30° (facing south) |
| Panel Material | Glass with an anti-reflective coating |
| Slope Error | 6.55 mrad |

[1]The maximum height of the PV panels.
[2] Average eye height for males in the United States.

### 2.1.5 Post-processing

Percent of possible sunshine is a measurement of the total time that sunshine reaches the earth, expressed as the percent of the possible maximum amount of sunshine, under clear sky conditions, from sunrise to sunset. As discussed in Section 1.4, this variable can be used to correct the clear sky assumption of the SGHAT model and account for climatic conditions that reduce the occurrence, duration, and intensity of glare (e.g., overcast skies, cloud cover, etc.).

The National Weather Service (NWS) typically measures percent of possible sunshine using Marvin sunshine recorders, devices that are sensitive to direct radiation, but which also measure diffuse radiation to some extent (American Meteorological Society, 2020). Direct radiation is the component of solar radiation that causes visible glare from flat-plate photovoltaic systems; diffuse radiation is radiation that has been scattered by molecules in the atmosphere, this type of radiation does not play a central role in producing glare (Riley and Olson, 2011). As Marvin sunshine recorders measure both direct and diffuse radiation, the percent possible sunshine values recorded by the NWS represent a conservative estimation of the climatic conditions under which glare may be produced.

Monthly average percent possible sunshine records for Buffalo, NY were acquired from the National Oceanic and Atmospheric Administration (NOAA; NOAA, 2021) (see Table 2).

**Table 2. Monthly Percent of Possible Sunshine Values for Buffalo, New York**

| Month | Percent of Possible Sunshine |
|---|---|
| January | 31 |
| February | 36 |
| March | 45 |
| April | 54 |
| May | 59 |
| June | 62 |
| July | 66 |
| August | 63 |
| September | 45 |
| October | 44 |
| November | 29 |
| December | 23 |

*NOAA, 2021*

These data were incorporated into the raw SGHAT model outputs directly. For each minute where the SGHAT model predicted glare would be received at a given receptor, a corrective factor was applied specific to the timing of the produced glare. For example, if the raw SGHAT model output data predicted that 12 minutes of glare would be received on July 15, this value would be corrected to an average value of 8 minutes to account for the fact that on average, direct incoming solar radiation reaches the earth's surface only 66% of the time in the month of July in the Buffalo area.

As discussed in Section 1.4, when a receptor views glare from PV panels and glare from the sun in the same general line-of-sight, the sun's significantly greater intensity overshadows (i.e., "masks") the glare produced by the PV panels. To address the masking effect of the sun, a 10-degree sun-masking angle threshold was set[13] and a logical equation was applied to the raw SGHAT model outputs to discount glare received at a sun-masking angle of less than 10 degrees (i.e., an incidence angle greater than 85 degrees).

## 2.2 *Public Roadways*

The limitations of the SGHAT model are even more difficult to address for road users traveling through the Facility Site. In modeling the potential for glare to be received at a residence, the receptor can be assumed to be a relatively static point with known attributes. Road users travel in multiple directions on a three-dimensional surface at differing velocities. Although it would be possible to provide a general correction for climatic variables that affect the production of glare (as described in Section 2.1.5), all other model limitations would be difficult or impossible to address as each point along a travel route would

[13] Germany and Austria have established a similar threshold (LAI, 2012; Zehndorfer Engineering, 2019). See Section 1.4 for a further discussion.

have unique conditions (e.g., visibility, effective sunrise/sunset, inter-array PV panel screening, sun-masking angle, etc.). Although the SGHAT model provides the option to model glare along roadways, considering the limitations discussed in this assessment, the results are not anticipated to be representative of on-site conditions. Accordingly, a qualitative assessment of potential glare impacts was completed for public roadways within and adjacent to the Facility Site.

As an initial step, the viewshed modeling described in Section 2.1.1 was applied to determine which roadways in the vicinity of the Facility Site have some visibility of the PV panels. Portions of the following public roads were identified as having will have visibility of the Facility's PV arrays: NE Sherman Road/County Touring Route 6, Miller Road/County Touring Route 3, Sinden Road, Sulfur Springs Road/Post Road, Rater Road, Klondyke Road, Mina Road/County Touring Route 13, and Sherman Road.

Although portions of these roads may have visibility of the Facility PV arrays, an additional consideration that is relevant for roadways is whether glare has the potential to be received within a road user's inner field of view. Pilots and road users have to deal with visual distractions, including glare, on a daily basis. This is typically not an issue unless such distractions are located within the operator's inner field of view, generally +/- 25 degrees for pilots and +/- 15 degrees for road users (Rogers et al., 2015; Zehndorfer et al., 2019). Glare received within a road user's inner field of view is less easily ignored and can more directly affect an operator. The likelihood that glare produced by the Facility's PV arrays would be received within a road user's inner field of view was analyzed qualitatively.

# 3.0 RESULTS AND DISCUSSION

## 3.1 *Residences*

In completing the methods outlined in Section 2.1.1, 2.1.2, and 2.1.3, it was determined that only 10 of the 72 non-participating receptors located within 1,500 feet of the Facility Site had the potential to receive glare produced by the Facility. For the receptors where glare impacts are not anticipated, vegetation, existing structures (e.g., barns and outbuildings), and topography were found to be the most important terrestrial factors in limiting the potential receipt of glare. In most cases, intervening vegetation was found to completely eliminate a receptor's visibility of potential glare-producing PV panels when that receptor was located more than 300 feet from the nearest PV arrays. Even where receptors were found within 300 feet of adjacent PV arrays, intervening vegetation was often found to obscure or disrupt a receptor's view of potential glare-producing PV panels, as illustrated in Inset Figures 3 and 4.

The post-processed SGHAT model results, which account for terrestrial obstructions between the receptors and the potential glare-producing PV panels, average atmospheric conditions, and the masking effect of the sun, indicate that eight of the 72 non-participating residences within 1,500 feet of the Facility (11%) may receive some amount of glare over the course of the year: receptors 8, 23, 47, 79, 93, 94, 95, and 100. The average annual duration of glare at residences anticipated to receive glare, is estimated at 27 hours (for additional details see Appendices A and B). Timing and duration of glare at individual residences vary depending on the position and proximity of the receptor relative to the potential glare-producing PV panels. In general, glare is anticipated primarily during the summer months and would not be received after 7 AM or before 5 PM. Typically, residences with higher modeled glare levels receive glare somewhat evenly throughout the spring and summer months, whereas residences with lower modeled glare levels receive glare generally around either the summer equinox or closer to the vernal and autumnal equinoxes (see Appendix B for further details regarding the raw SGHAT model outputs).

As discussed previously, these estimates represent a worst-case scenario of average conditions. These estimates do not account for terrestrial obstructions between the sun and the PV panels that would prevent the production of glare (i.e., the effects of PV panel shading in the morning and evening) or other model limitations that would further reduce the production and receipt of glare in the real world (e.g., panels in the viewing foreground blocking a receptors view of glare being produced by panels deeper in the array). In effect, these results assume that (1) each of the eight receptors has full visibility of the PV array causing glare, (2) no trees or other terrestrial obstructions exist adjacent to the PV arrays that would shade the panels in the morning and evening, and (3) the PV arrays are uniform surfaces.

As one or more of these assumptions are incorrect for each of the six receptors, the glare received by residences adjacent to the Facility Site is anticipated to be substantially less than raw SGHAT model output data or the post-processed data. Table 3 provides a qualitative summary of anticipated glare impacts at each of the residences identified above.

**Table 3. Anticipated Glare Impacts**

| Receptor ID | Potential Glare Impacts | Analytical Basis |
|---|---|---|
| 8 | Minimal | A small fraction of the PV array is producing glare receivable at this location; glare estimated in SGHAT model is very minimal. Inter-array panel screening and existing vegetative screening in this location limit the receipt of glare by this receptor. Proposed visual mitigation plantings are anticipated to be effective in mitigating all potential glare impacts. |
| 23 | Minimal | Small fraction of PV array producing glare; glare estimated in SGHAT model is minimal. Inter-array panel screening and existing vegetative screening in this location limit the receipt of glare by this receptor. Proposed visual mitigation plantings are anticipated to be effective in mitigating all potential glare impacts. |
| 47 | Minimal | Inter-array panel screening and shading of the panels in the evening by adjacent vegetation will minimize glare received in this location. Field verification indicates receptors position relative to the PV panels producing glare will increase the effectiveness of the proposed vegetative screening. |
| 79 | Minimal–Moderate | Inter-array panel screening and shading of the panels in the evening by the hill located west of this receptor may reduce the potential for glare to be received in this location. The proposed visual screening and any other mitigation measures determined to be necessary are anticipated to be sufficient to mitigate glare impacts. |
| 93 | Minimal – Moderate | Inter-array panel screening and shading of the panels in the morning by adjacent topography may minimize glare received in this location. The proposed visual screening and any other mitigation measures determined to be necessary are anticipated to be sufficient to mitigate glare impacts. |
| 94 | Minimal–Moderate | Inter-array panel screening and shading of the panels in the morning and evening by adjacent vegetation and topography may minimize glare received in this location. The proposed visual screening and any other mitigation measures determined to be necessary are anticipated to be sufficient to mitigate glare impacts. |
| 95 | Minimal | Inter-array panel screening and existing vegetative screening will minimize glare received at this location. Field verification indicates the receptor's position relative to the PV panels producing glare will increase the effectiveness of the proposed vegetative screening. |
| 100 | Minimal | Inter-array panel screening will minimize glare received at this location. Field verification indicates the receptor's position relative to the PV panels producing glare will increase the effectiveness of the proposed vegetative screening. |

As discussed in Table 3, the comprehensive vegetative screening proposed throughout the Facility is anticipated to meaningfully contribute to the mitigation of glare impacts. Considering that (1) glare at this site is predicted to occur primarily in the summer, during the leaf-on period and (2) the majority of receptors have a narrow window of visibility of the panels predicted to produce glare (see Appendix A), for most receptors, vegetative screening plantings—once established—are likely to be an effective remedy in further mitigating the potential effects of glare. In addition, in the final design of the Facility, the Applicant will retain existing on-site vegetation wherever feasible, particularly along roadways and property lines to retain the screening benefits of existing vegetation.

During operations, the Applicant will implement a complaint resolution plan that will require the Applicant to work proactively with residents and stakeholders in the community in responding to concerns with glare, if they should occur. If complaints arise that cannot be resolved, the Applicant will propose additional measures to mitigate potential glare impacts, which may include installing additional vegetative screening plantings, fencing, or other forms of visual screening or potentially securing good neighbor agreements (GNAs) with impacted landowners.

## 3.2 *Public Roadways*

In locations where the Facility's PV arrays are visible, Miller Road/County Touring Route 3, Sinden Road, Rater Road, Mina Road/County Touring Route 13, and Sherman Road are all oriented North/South. Glare received by road users traveling along these roads will only be viewable from +/- 60-90 degrees, well outside a road user's inner field of view. For this reason, glare received along these roadways will not be considered further in this analysis. Existing visual screening will largely block views of those portions of the PV arrays located north of Sulfur Springs Road/Post Road and Klondyke Road that could produce glare receivable within a road user's inner field of view. There are only two short segments along these roads where glare could be received within a road user's inner field of view. However, any perceivable glare at these locations is not anticipated to impede traffic movements or create safety hazards.

The majority of the Facility's PV arrays are located along NE Sherman Road/County Touring Route 6. However, with a few of exceptions, most of the panels sited along this road have been set back far enough from the edge of the road that glare produced by the panels will be screened by existing vegetation or will be received outside a road user's inner field of view. The primary location along this road—and, more generally, within the Facility—where glare could be received within a road user's inner field of view is found just west of where NE Sherman Road merges with Sherman Road. In this location, road users travelling eastward in the morning and, to a lesser extent, traveling westward in the evening may receive some glare from the PV array located north of NE Sherman Road and west of Sherman Road.

Although the majority of glare produced by the Facility will be received outside a road user's inner field of view (i.e., +/- 15 degrees), glare is anticipated to be received within a road user's inner field of view under some conditions at the locations outlined above. In these locations, glare will be received in the morning and the evening, at times of the day when road users are accustomed to coping with glare from the sun and glare produced by other specular bodies (e.g., water bodies, curtain wall buildings, large windows, etc.). For all road users, glare is a common and well-studied phenomena (e.g., Auffray et al., 2008; Redweik, 2019). As evidence of this, all vehicles sold in the United States come standard with features intended to help a road user cope with glare received from the sun or other sources (sun visors and shade bands).

Furthermore, considering the timing of the glare anticipated and the east-west orientation of the roads where glare could occur, glare within a road user's inner field of view will be produced under conditions where a road user is already actively mitigating glare impacts from the sun in the evening and morning. In consideration of these factors and the Applicant's planned mitigation strategy (see Section 3.1.2), road users travelling through the Facility Site will generally not be exposed to glare in a manner that would impede traffic movements or create safety hazards.

# 4.0 CONCLUSIONS

Fixed-tilt photovoltaic systems, such as the proposed Facility, can produce glare in the morning and evening when the sun is low on the horizon. The receipt of this glare by potentially sensitive receptors (e.g., residences and public road users) can be modeled using ForgeSolar's GlareGauge tool, a commercial software program that is based on the Solar Glare Hazard Analysis Tool (SGHAT) developed by Sandia National Laboratories. However, this tool is a conceptual model with limited accuracy in quantifying potential glare impacts for ground-based receptors in locations such as the Facility where terrestrial and atmospheric obstructions limit the production of glare are common.

In considering the effects of cloud cover, the sun masking angle, and terrestrial obstruction preventing the receipt of glare at non-participating residences, this Solar Glare Assessment addresses some of the primary limitations of the SGHAT model. However, significant unresolved model shortcomings limit the accuracy of the quantitative aspects of the SGHAT model outputs. To account for this, a qualitative analysis of glare impact was completed for residences that have the potential to be impacted by glare. This assessment incorporated the post-processed results of the SGHAT model, where applicable, and found that glare has the potential to be received at eight non-participating residences and portions of three public roadways located adjacent to the Facility Site.

The potential glare impacts to these residences are anticipated to be generally minimal or minimal to moderate, and will be limited in duration and intensity, when compared to the raw or post-processed SGHAT results. Potential glare impacts to roadways will occur around sunrise and sunset, times of the day that road users are accustomed to dealing with glare impacts from the sun. To mitigate potential glare impacts, the Applicant is proposing a comprehensive vegetation screening program, is considering other mitigation options, and is committed to working with members of the community to proactively resolve concerns. These measures will be sufficient to ensure solar glare exposure is avoided or minimized, and will not result in complaints, impede traffic movements, or create safety hazards.

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# Figures


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Figure 1. Receptor Viewsheds

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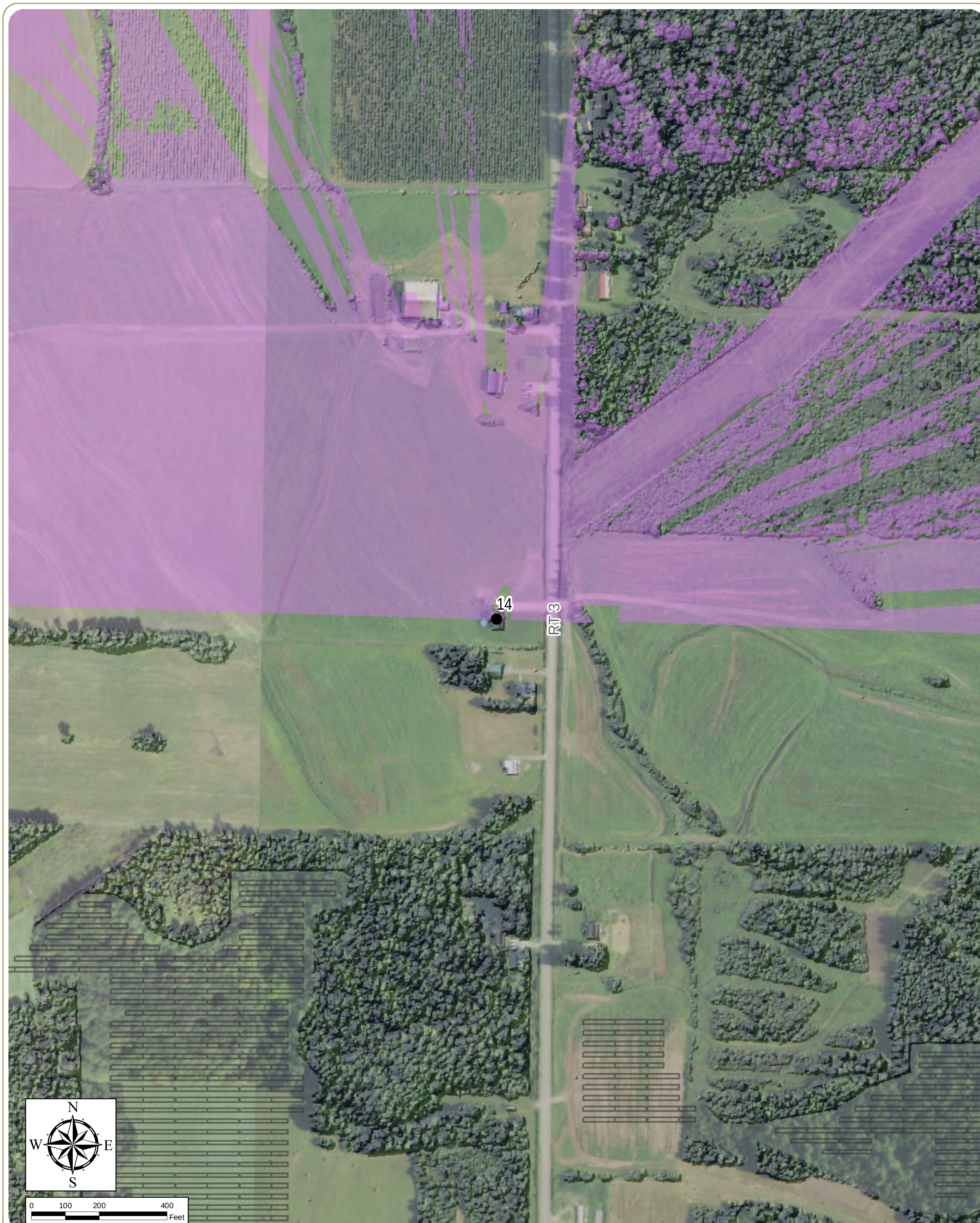


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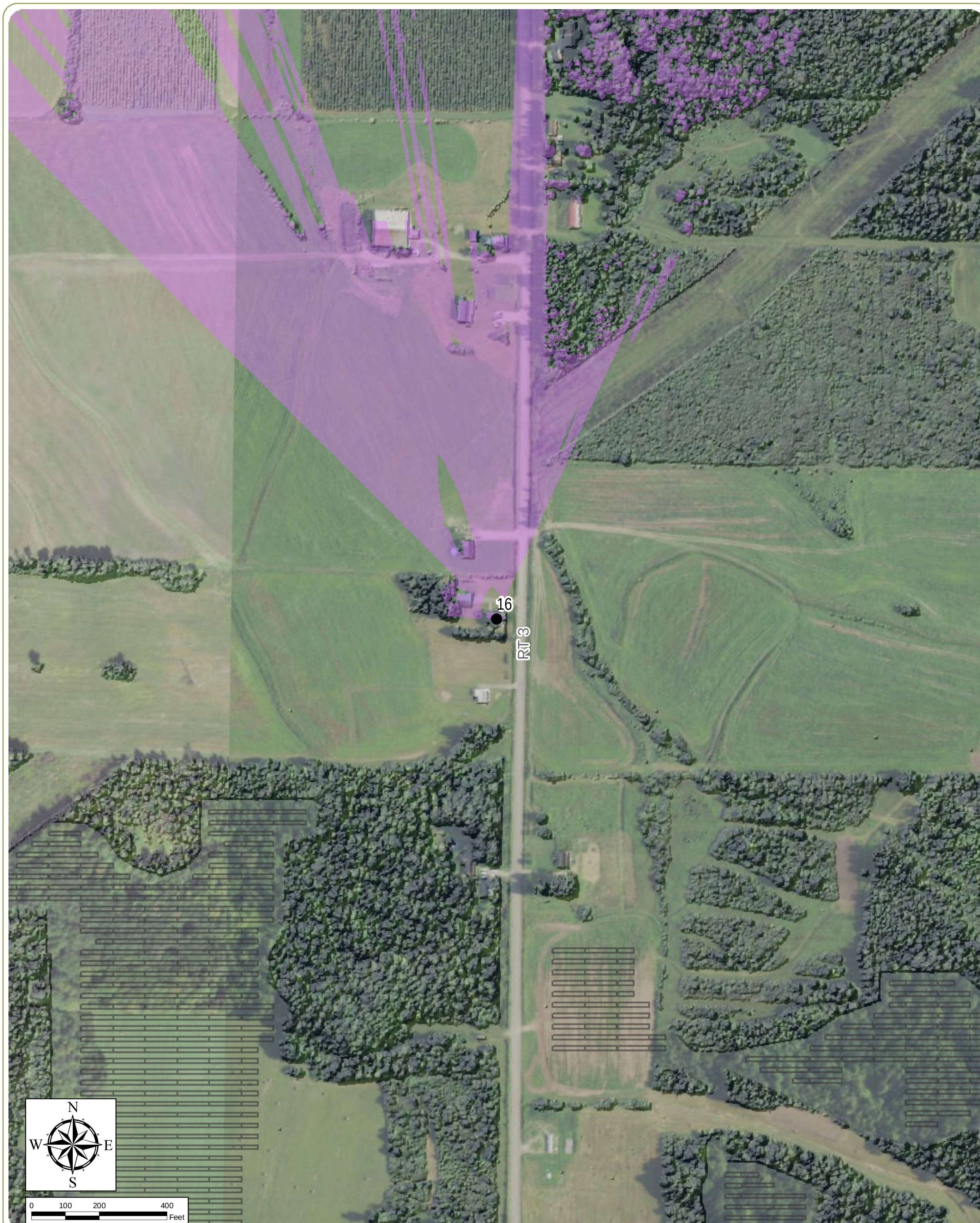


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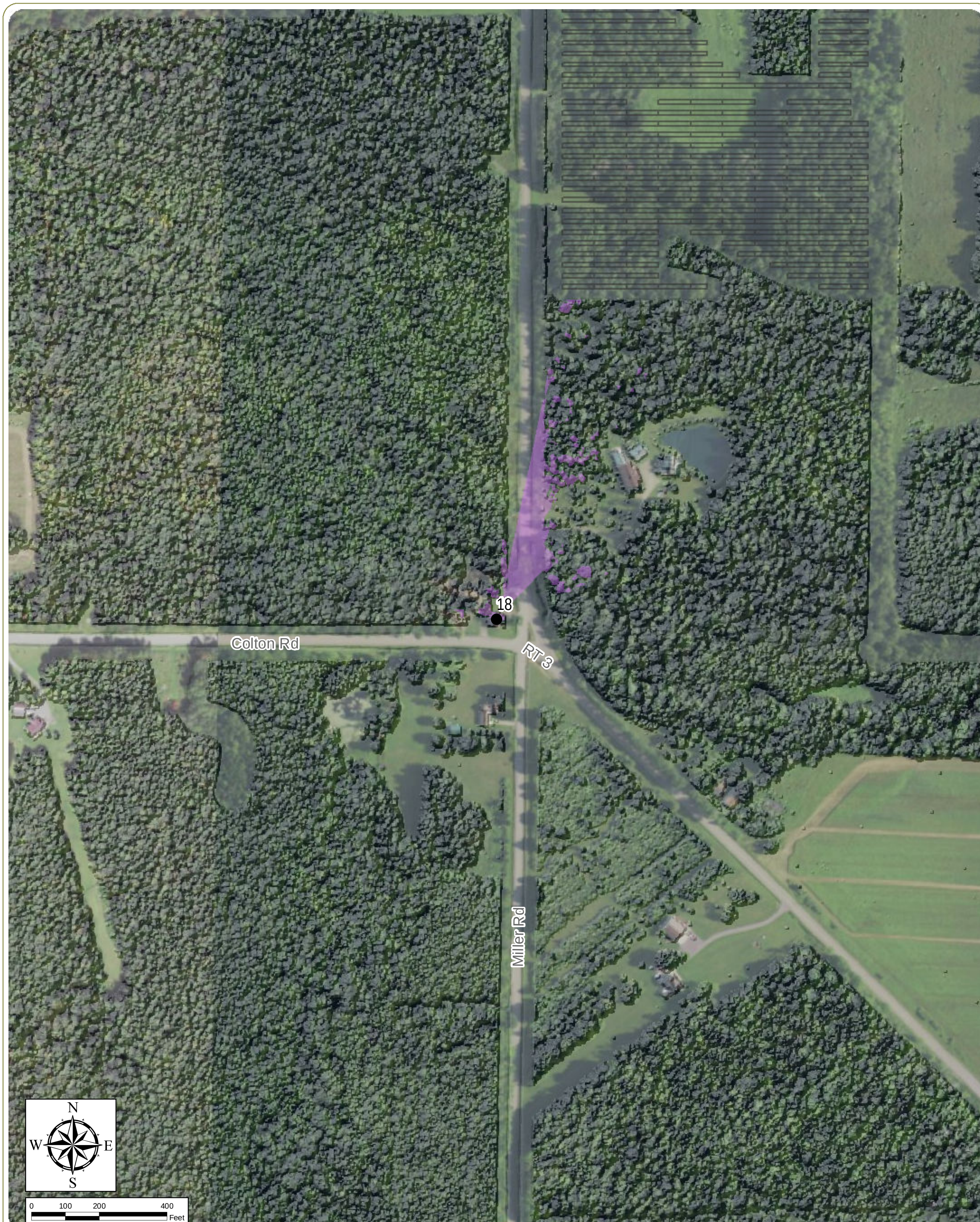


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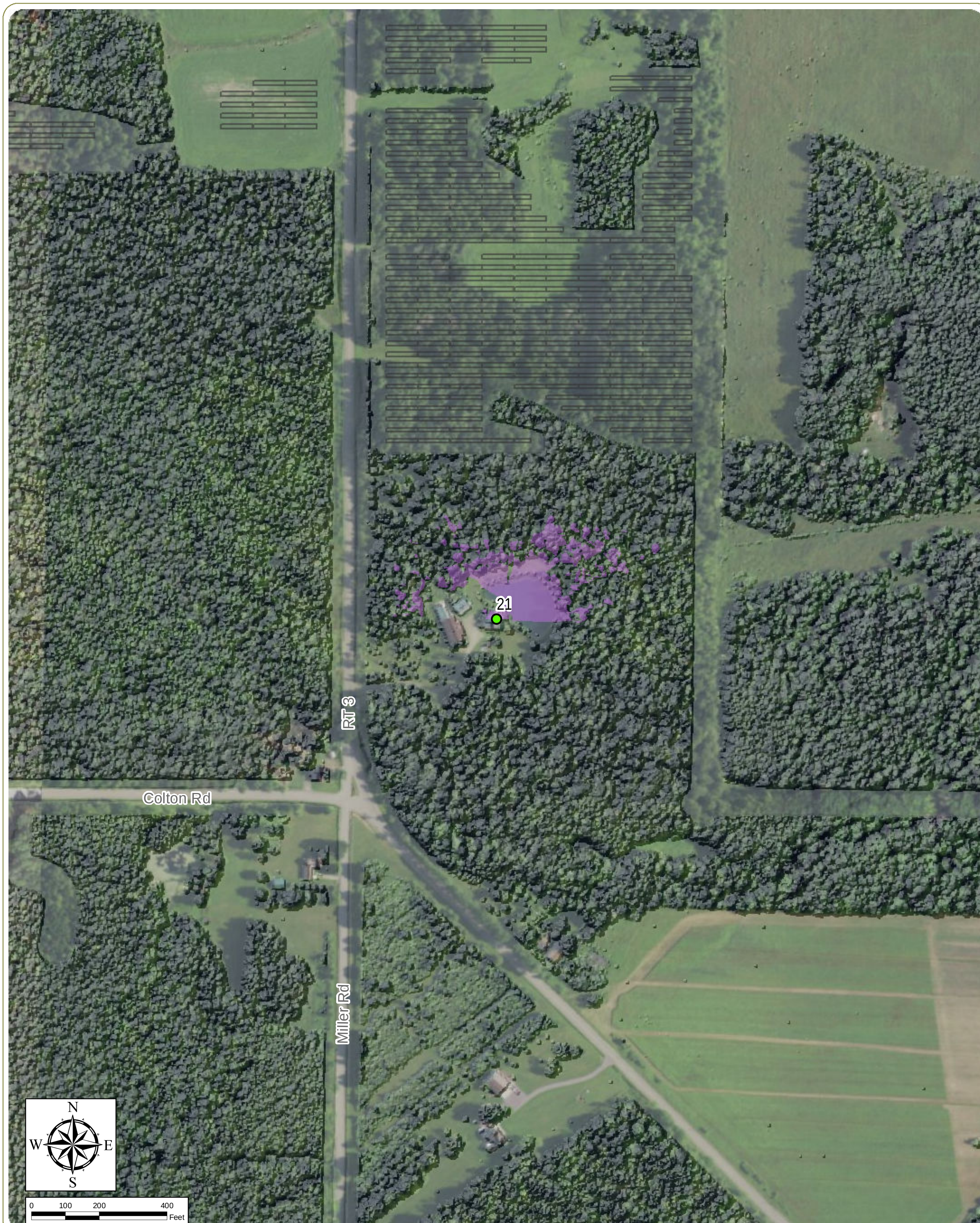


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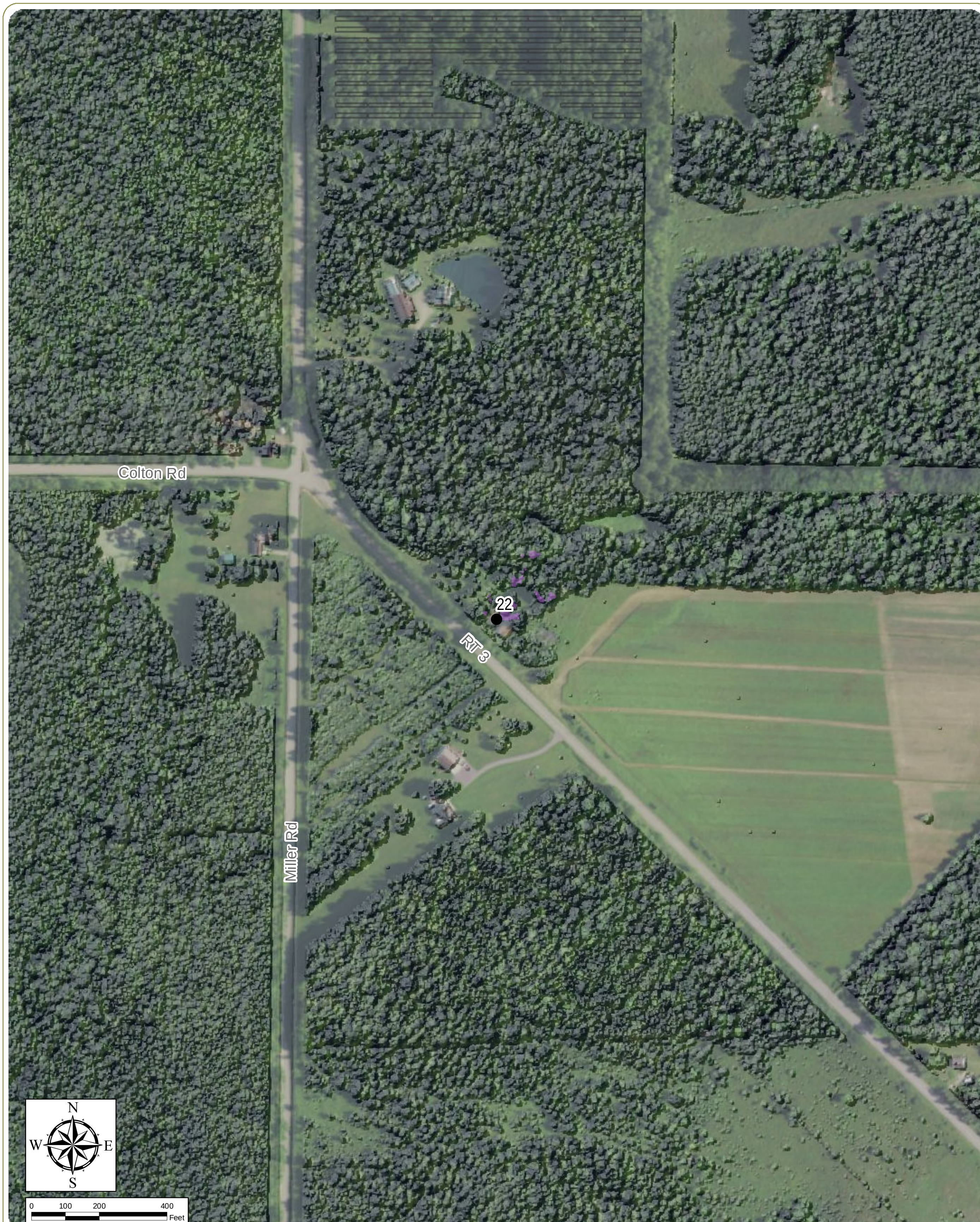


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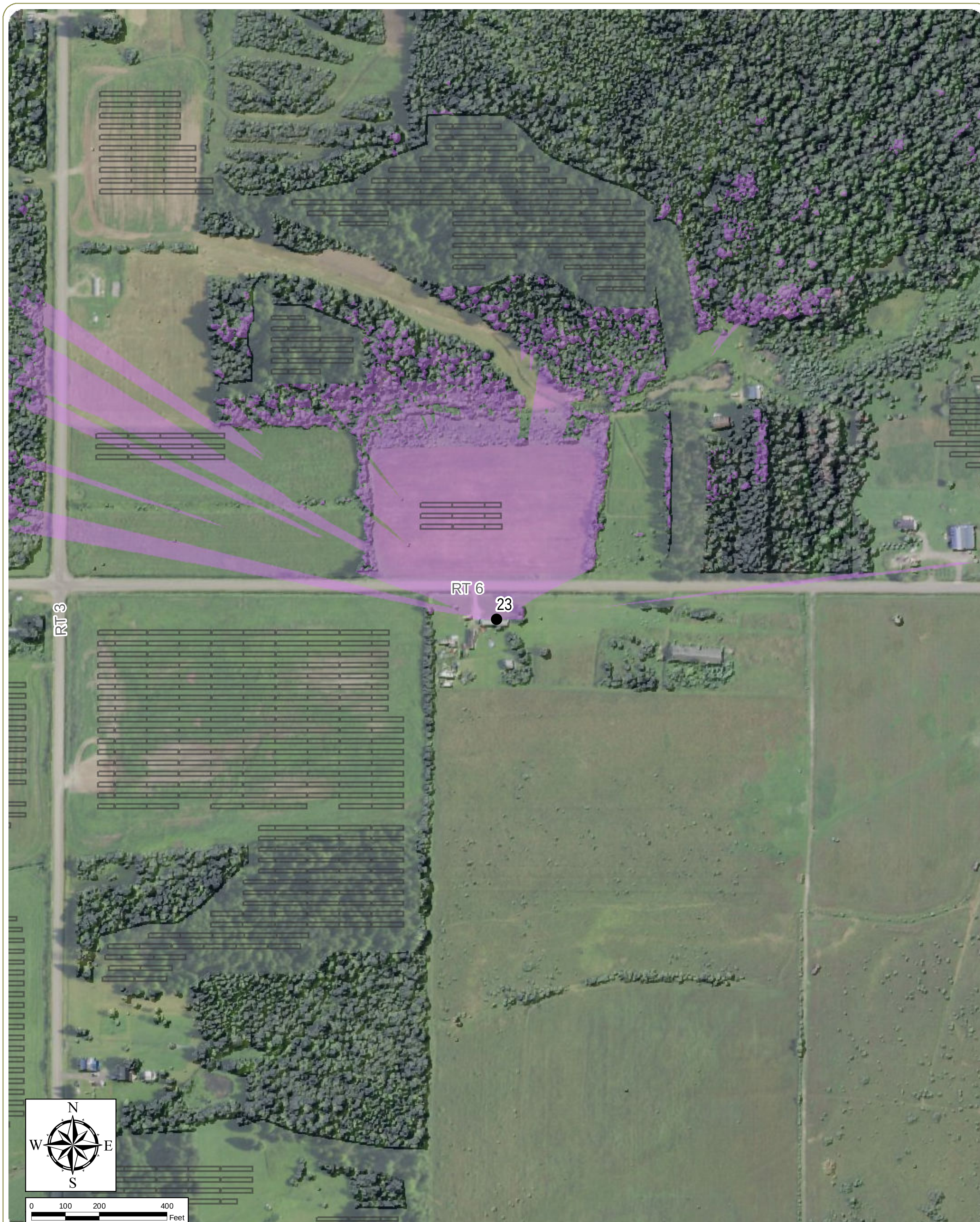


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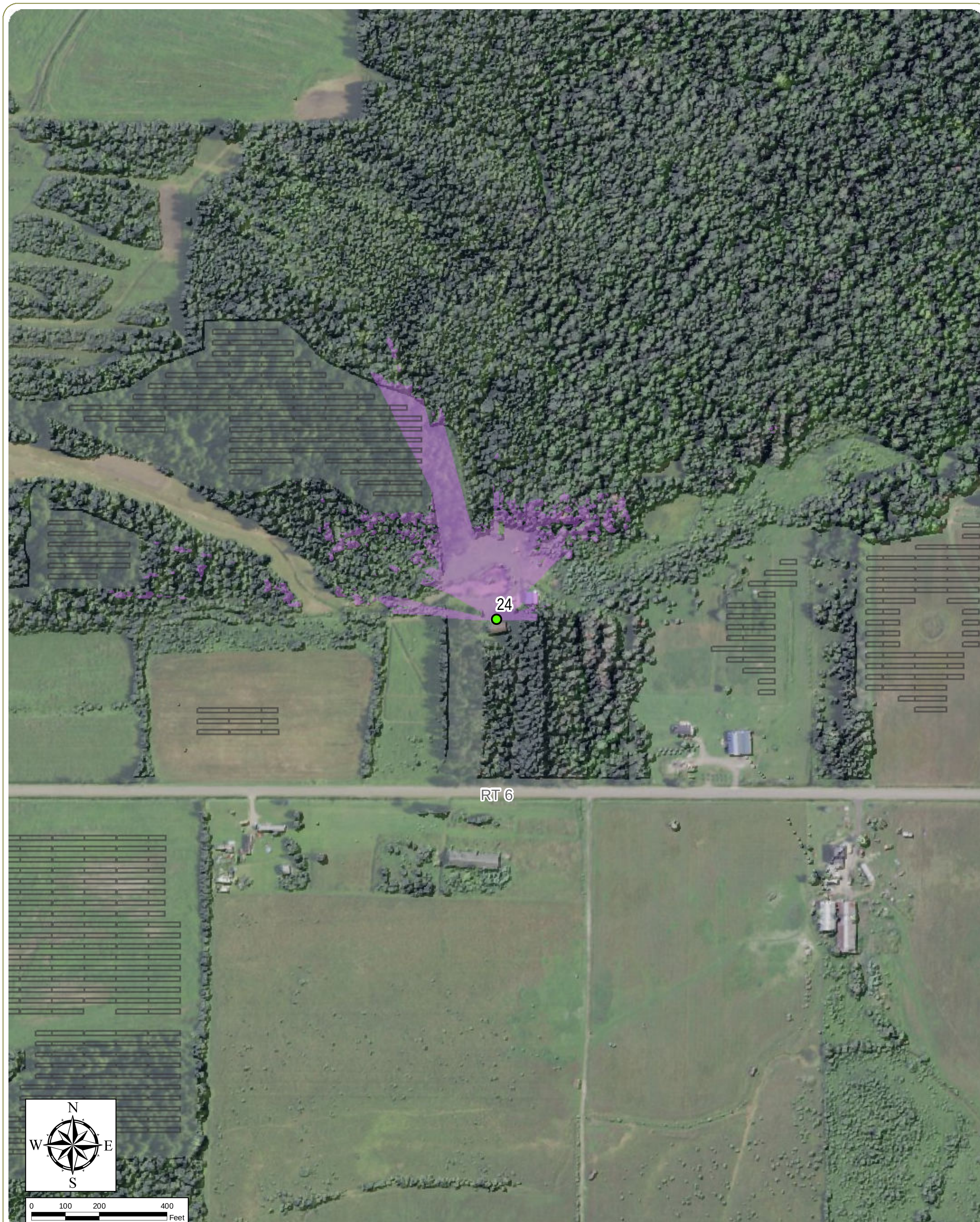


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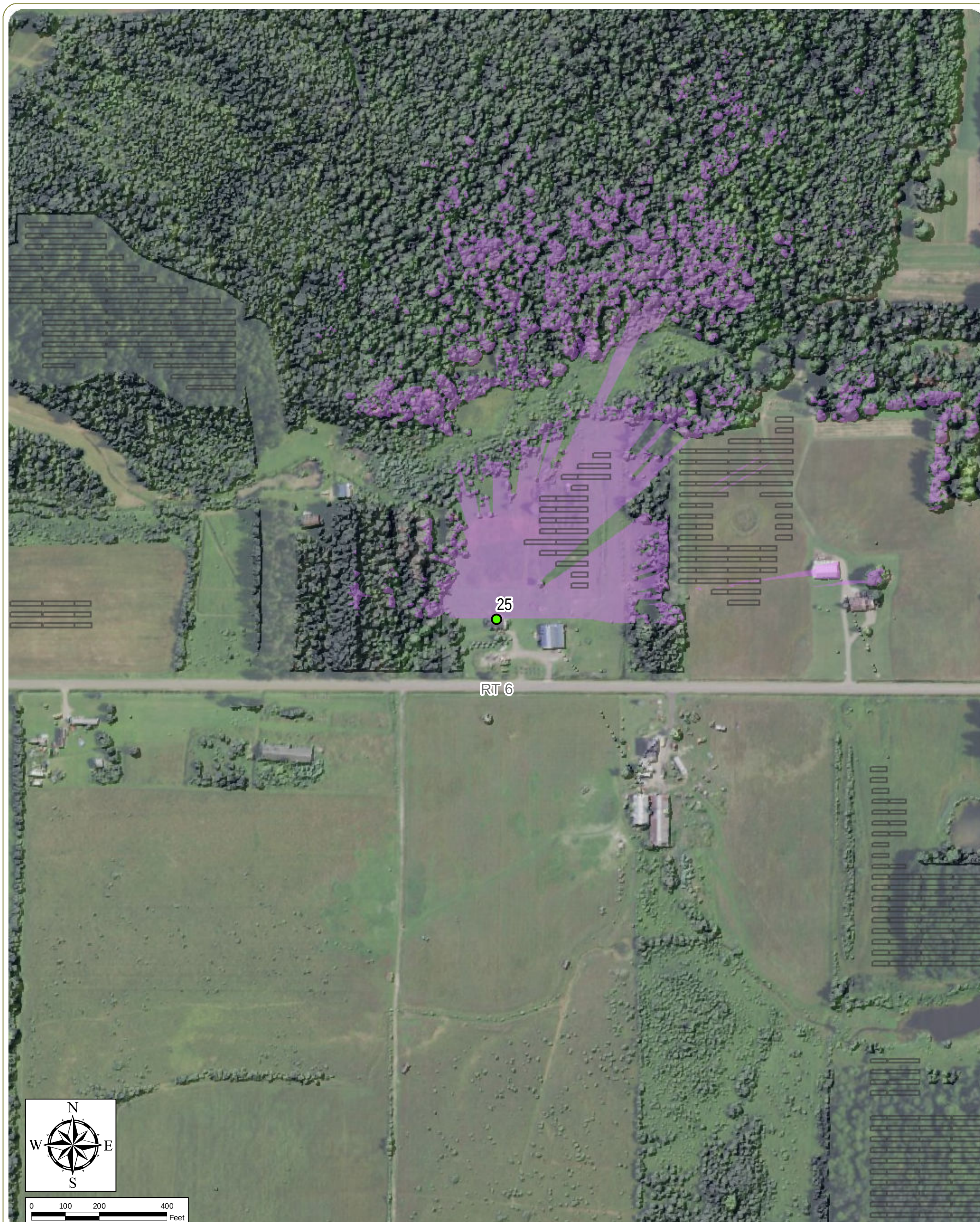


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Notes: 1. Basemap:USDA NAIP "2019 New York 60cm" orthoimagery map service. 2. This map was generated in ArcMap on July 27, 2021. 3. This is a color graphic. Reproduction in grayscale may misrepresent the data.

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South Ripley Solar Project
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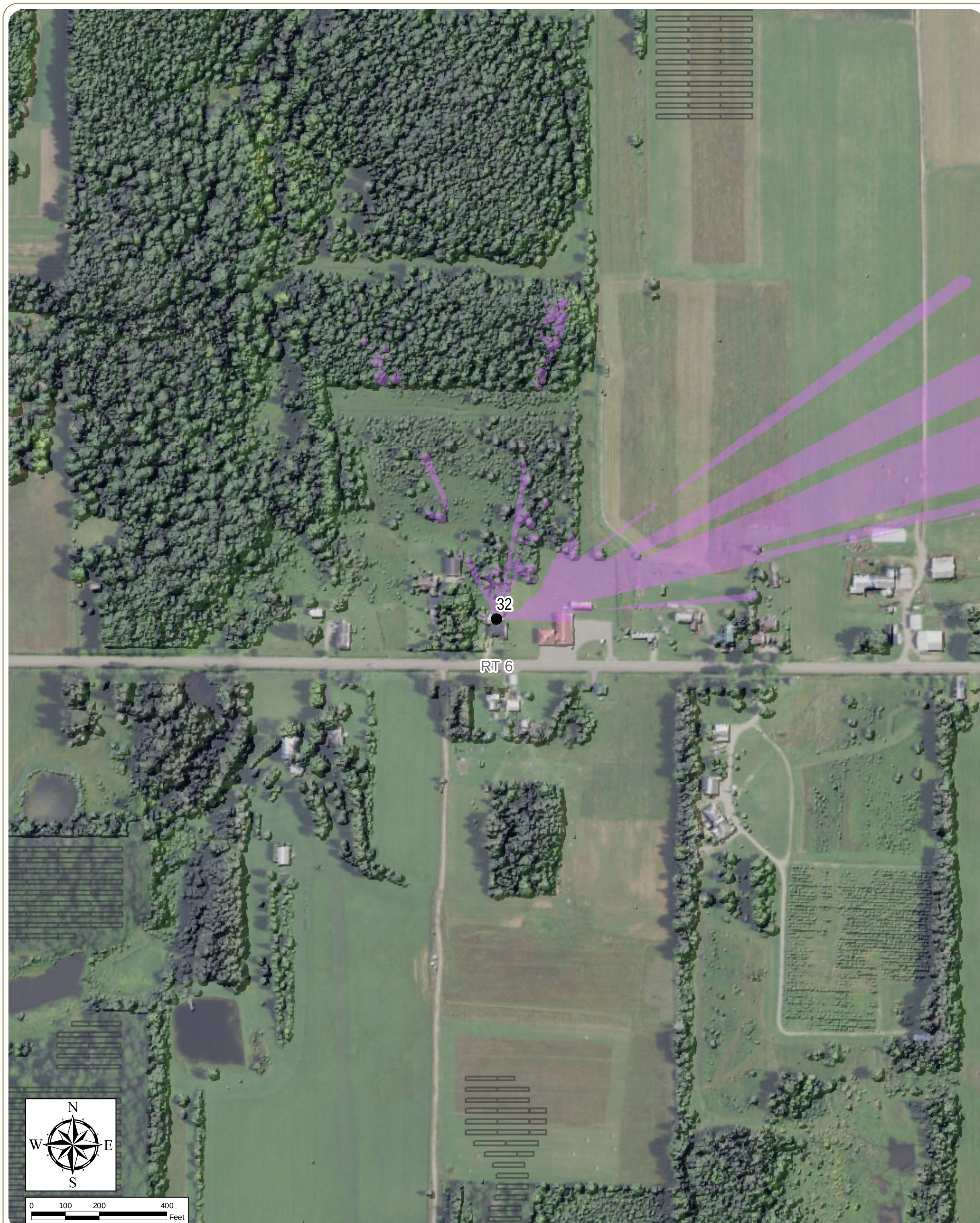


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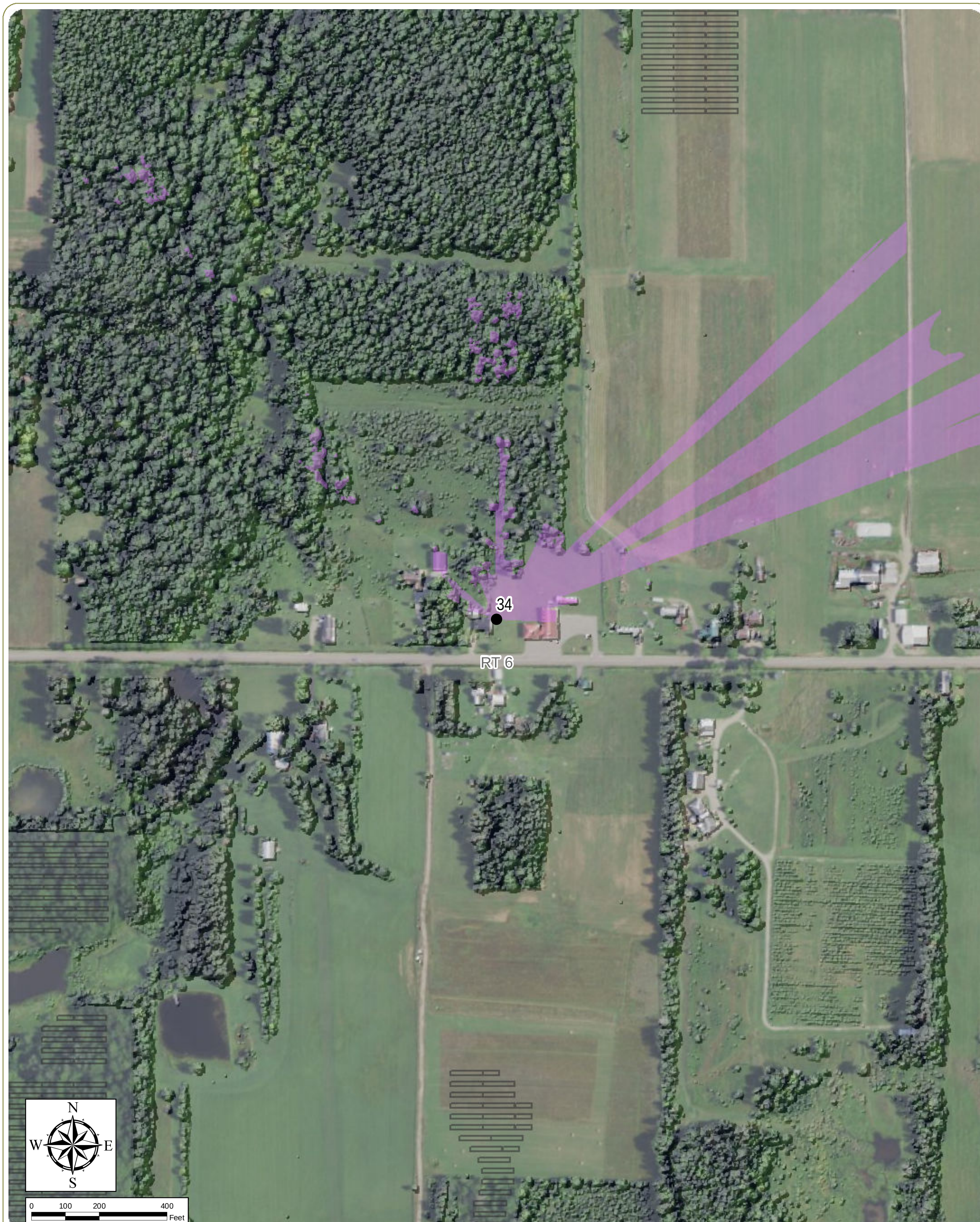


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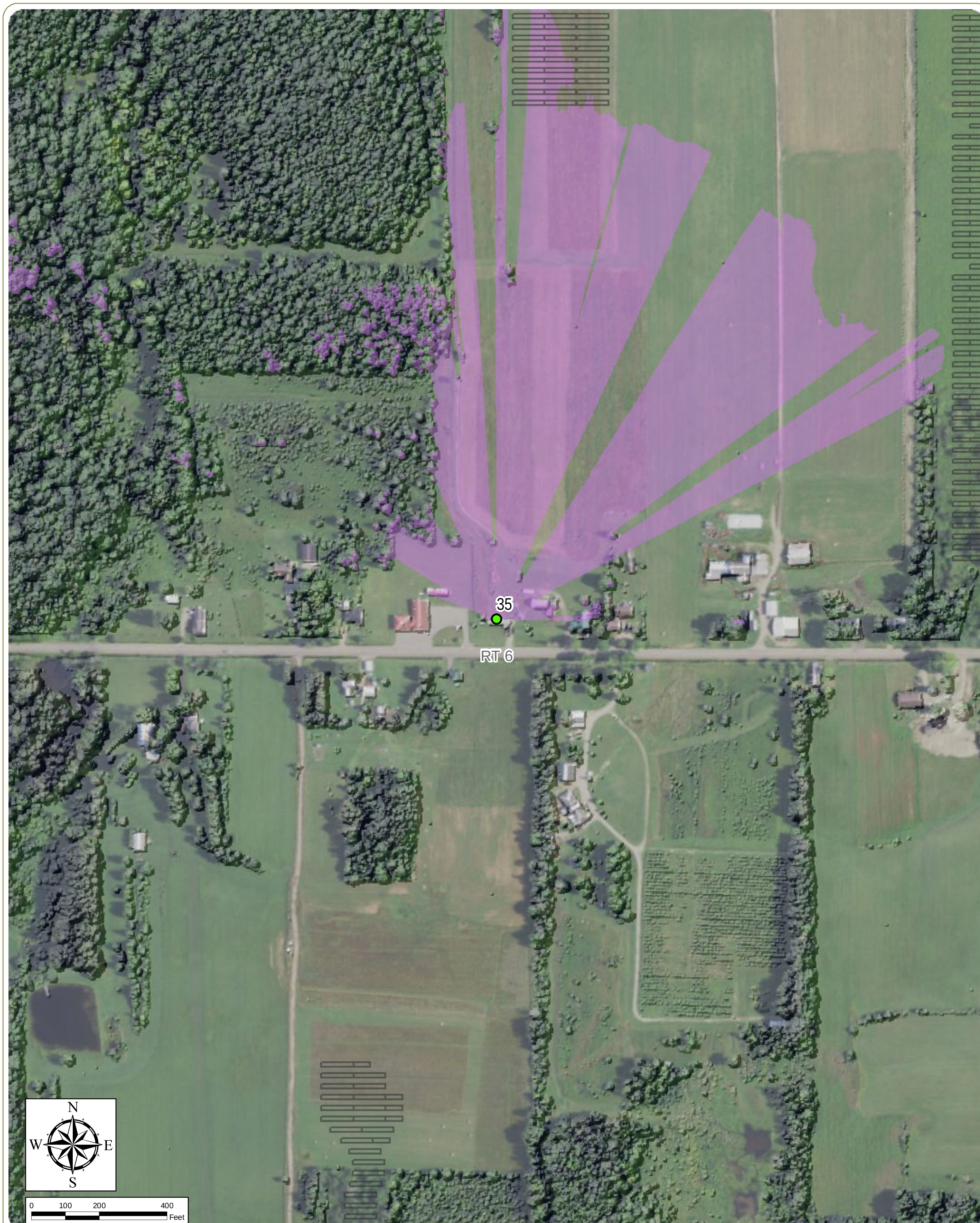


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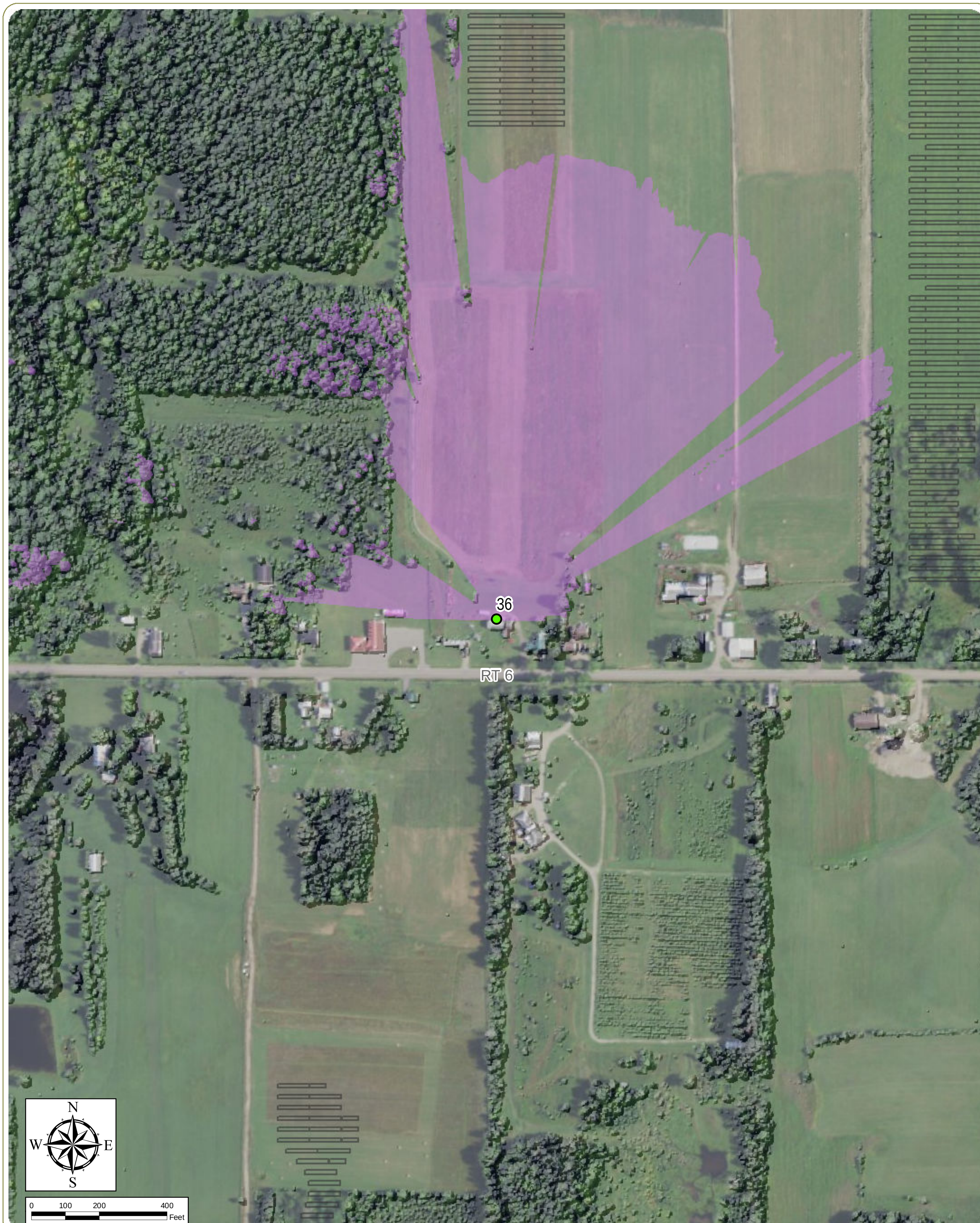


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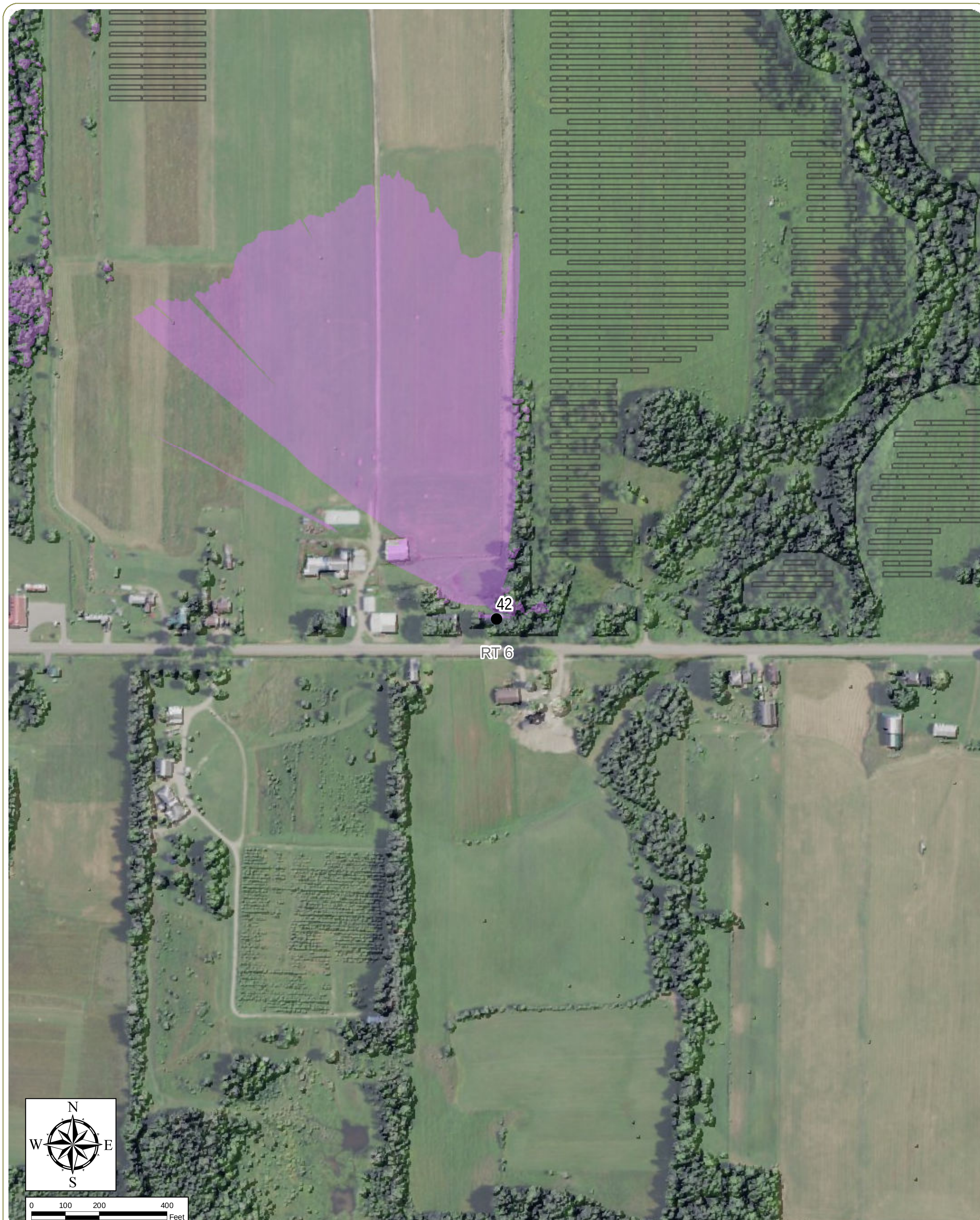


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