# Shadow Flicker Impact Analysis
# for the
# Alabama Ledge Wind Farm

***Prepared for***

## Alabama Ledge Wind Farm, LLC

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## 1. Overview

A wind turbine's moving blades can cast a moving shadow on locations surrounding a wind farm. These moving shadows are called shadow flicker, and can be a nuisance to people at nearby residences or public gathering places, such as schools. The impact area depends on the time of year and day (which determines the sun's azimuth and altitude angles) and the wind turbine's physical characteristics (height, size, and orientation of the rotor blades). Shadow flicker generally occurs during low angle sunlight conditions (typical during sunrise and sunset times of the day). However, when the sun angle gets very low (less than 3 degrees), the light has to pass through more atmosphere and becomes too diffuse to form a coherent shadow. Shadow flicker will not occur when the sun is obscured by clouds/fog (or obviously, night), or when the turbine is not operating. Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensity diminishes with greater receptor-to-turbine separation distance. Shadow flicker for receptor-to-turbine distances beyond 1500 meters is very low intensity and generally considered imperceptible. Shadow flicker for receptor-to-turbine distances between 1000 and 1500 meters is also of low intensity and considered barely noticeable. At this distance shadow flicker would only be noticed under conditions that would enhance the intensity difference, such as observing from a dark room with a single window directly facing the turbine casting the shadow. At distances less than 1000 meters, shadow flicker may be more noticeable. However, since the project has a turbine siting setback requirement of 1200 feet (365.8 meters), this ensures that shadow flicker impacts are minimized, by limiting potential impact conditions to periods when long shadows are cast.

The wind turbines being considered for the Alabama Ledge Wind Farm (ALWF), and evaluated for potential shadow flicker impacts, include the following models and characteristics:

- **Gamesa G87 –** 3-Blade 87 meter diameter rotor, with a hub height of either 80 meters or 100 meters. The G87 has a nominal rotor speed of 16.7 rpm which translates to a blade pass frequency of 0.84 Hz (less than 1 alternation per second).

- **Vestas V82 –** 3-Blade 82 meter diameter rotor, with a hub height of either 80 meters or 100 meters. The V82 has a nominal rotor speed of 16.7 rpm which translates to a blade pass frequency of 0.84 Hz (less than 1 alternation per second).

- **Vestas V90 –** 3-Blade 90 meter diameter rotor, with a hub height of either 80 meters or 100 meters. The V82 has a nominal rotor speed of 16.1 rpm which translates to a blade pass frequency of 0.81 Hz (less than 1 alternation per second).

Shadow flicker frequency is related to the wind turbine's rotor blade speed and the number of blades on the rotor. From a health standpoint, such low frequencies are harmless. For comparison, strobe lights used in discotheques have frequencies which range from about 3 Hz to 10 Hz. Public concerns that flickering light from wind turbines can have negative health effects, such as triggering seizures in people with epilepsy are unfounded. According to the British Epilepsy Foundation, approximately five percent of individuals with epilepsy have sensitivity to light. Most people with photosensitive epilepsy are sensitive to flickering around 16-25Hz (Hertz or Hz = 1 flash per second), although some people may be sensitive to rates as low as 3Hz and as high as 60Hz. Since the proposed project's wind turbine blade pass frequency is approximately 0.81 to 0.84 Hz (less than 1 alternation per second), no negative health effects to individuals with photosensitive epilepsy are anticipated.

## 2. WindPro Shadow Flicker Analysis

An analysis of potential shadow flicker impacts from the project was conducted using the WindPro software package. The WindPro analysis was conducted to determine shadow flicker impacts under realistic impact conditions (actual expected shadow). This analysis calculated the total amount of time (hours and minutes per year) that shadow flicker could occur at receptors out to 1,500 meters. The realistic impact condition scenario is based on the following assumptions:

- The elevation and position geometries of the wind turbines and surrounding receptors (houses).
- The position of the sun and the incident sunlight relative to the wind turbine and receptors on a minute by minute basis over the course of a year.
- Historical sunshine hours availability (percent of total available)
- Estimated wind turbine operations and orientation (based on 2 years (2005-2006) of on-site measured wind data (wind speed / wind direction frequency distribution)).
- Receptor viewpoint (i.e. house windows) always directly facing turbine to sun line of sight ("greenhouse mode").

WindPro incorporates terrain elevation contour information and the analysis accounts for terrain elevation differences. The sun's path with respect to each turbine location is calculated by the software to determine the cast shadow paths every minute over a full year. Sun angles less than 3 degrees above horizon were excluded.

A total of 365 sensitive receptor locations were considered. These locations correspond to structures (primarily houses) in the project site area. A receptor in the model is defined as a 1 $m^2$ area (approximate size of a typical window), 1.5 meters above ground level (approximate eye level). Figure 1 shows the sensitive receptor locations considered.

## 3. WindPro Shadow Flicker Analysis Results

WindPro predicts that shadow flicker impacts will primarily occur near to the wind turbines. Figure 2 describes the WindPRo predicted expected shadow flicker impact areas. A detailed WindPro shadow flicker analysis results summary, for each of the receptor locations, and each of the turbine option scenarios, is provided in Attachment A. Table 1 presents the WindPro predicted shadow flicker impacts for the worst case wind turbine option scenario (V90, 100 m hub). Predicted shadow flicker impacts are presented for the worst receptors, where WindPro predicted greater than 30 hours per year of expected shadow flicker impact. Under the worst cast wind turbine scenario, only 21 of the 365 receptors modeled had shadow flicker impact predicted more than 30 hours per year

The maximum predicted shadow flicker impact at any receptor, for the range of potential wind turbine options, is 49 hours, 24 minutes per year, which is only approximately 1.1 % of the potential available daylight hours. Figure 3 shows a portion of the study area around the receptor (receptor CX) where the maximum shadow flicker impacts (in hours per year) were predicted to occur. The figure shows the annual shadow flicker isolines (lines of constant impact value) near the worst case receptor along with the surrounding turbines. The figure shows that the predicted shadow flicker impacts are primarily caused by wind turbine number 35. However, wind turbines number 40, and 34 also contribute shadow flicker that receptor.

The majority of the receptor locations evaluated have less than 30 hours per year of predicted shadow flicker impact. The shadow flicker impact prediction statistics are as summarized in Table 2.

## 4. Conclusion

The analysis of potential shadow flicker impacts from the proposed wind farm turbines on nearby houses (receptors) shows that shadow flicker impacts are expected to be minor. The analysis conducted is conservative and actual shadow flicker impacts are likely to be less than those presented here. The analysis assumes that the houses all have a direct in line view of the incoming shadow flicker sunlight and does not account for trees or other obstructions. In reality, the windows of many houses will not face the sun directly for the key shadow flicker impact times. For these reasons, shadow flicker impacts are expected to be less than estimated with the conservative analysis, and shadow flicker is not expected to be a significant environmental impact.

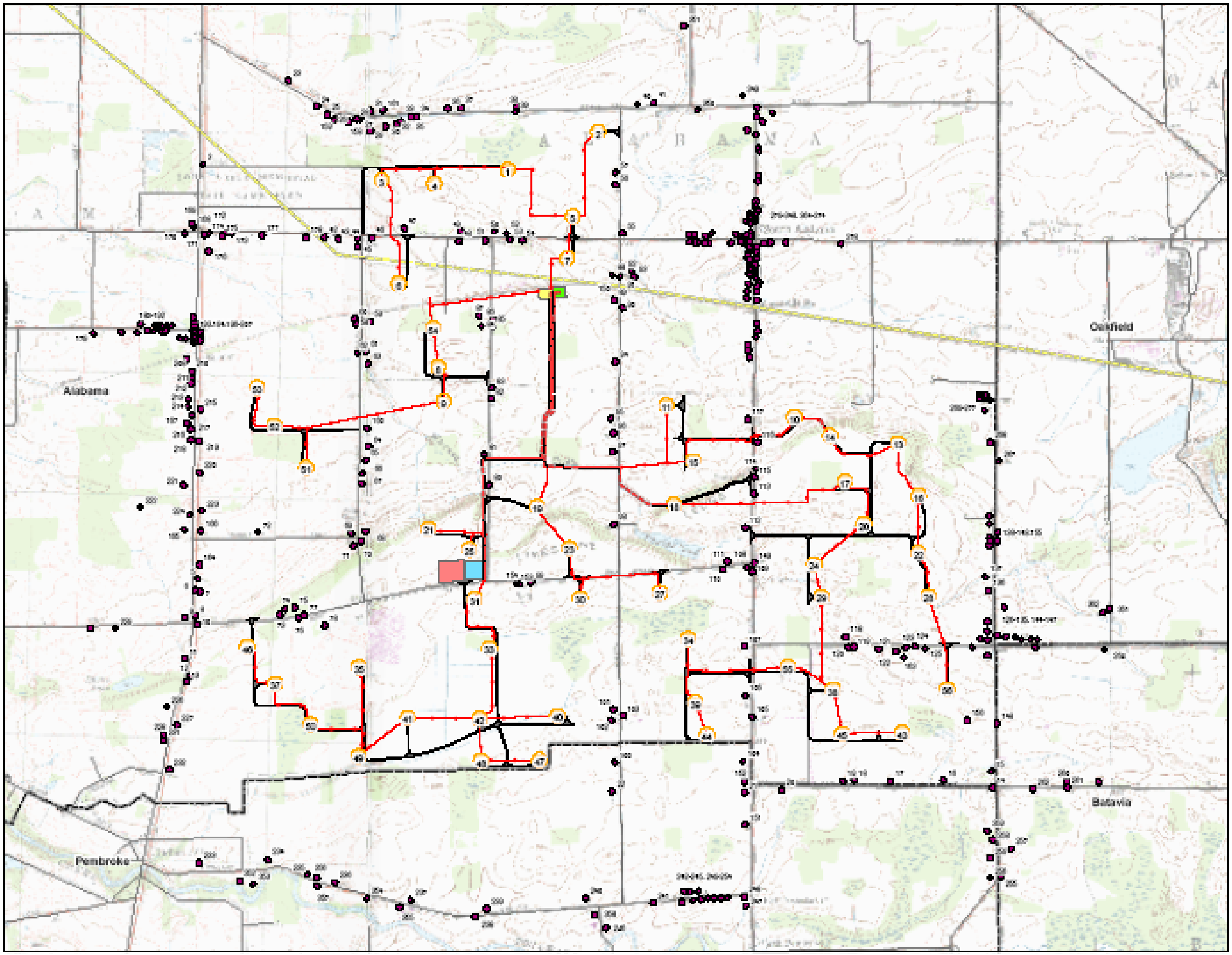


**Figure 1: Map Describing Sensitive Receptors (Houses) Modeled with WindPro to Predict Potential**

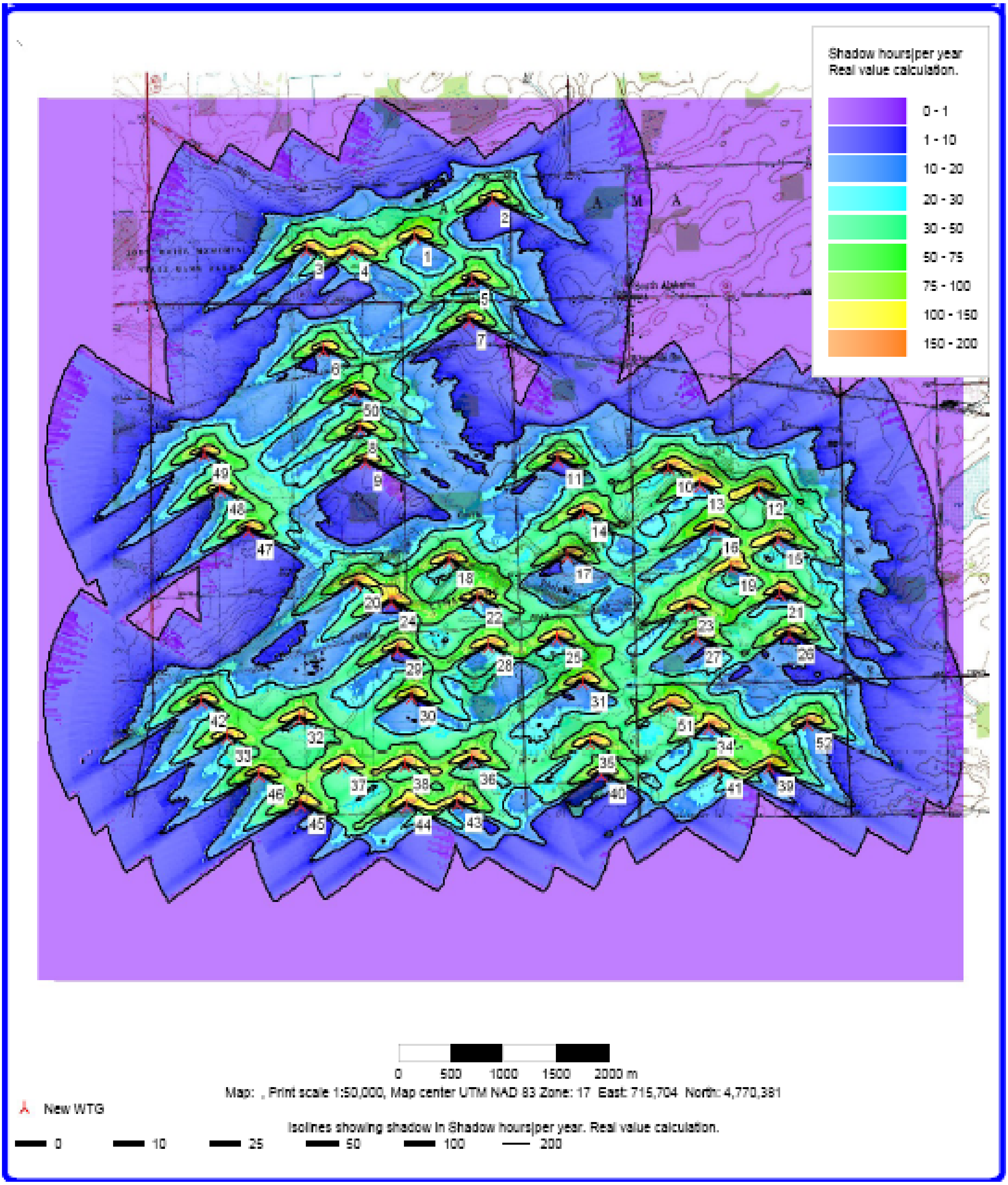


**Figure 2: WindPro Predicted Potential Shadow Flicker Impact Areas Map for the Alabama Ledge Wind Farm Project**

**Note: Figure presents WindPro predicted shadow flicker impacts for the worst case wind turbine option scenario (V90, 100 m hub)**

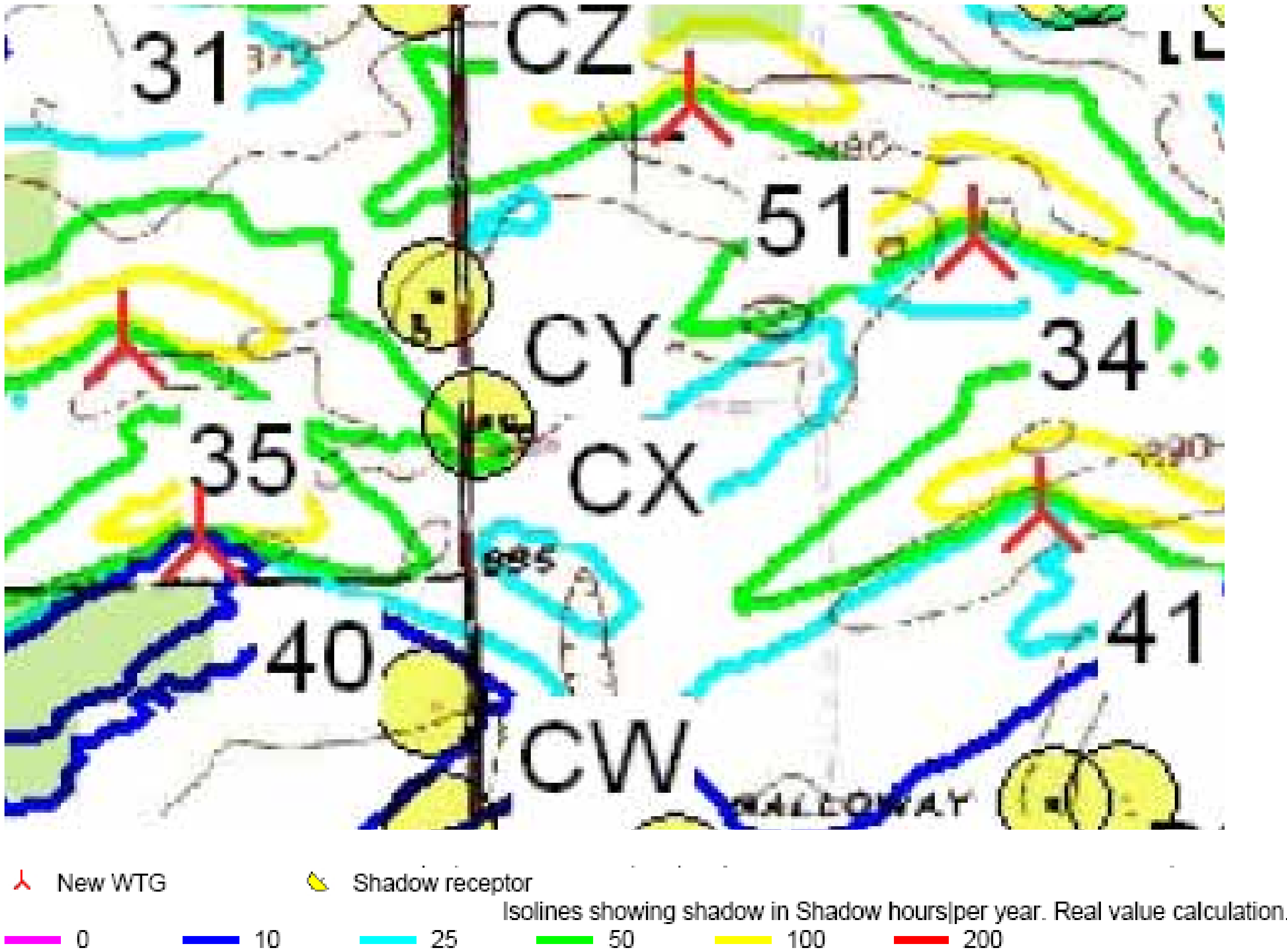


**Figure 3: Graphical Description of WindPro Predicted Shadow Flicker Impact Isolines Surrounding Maximum Impact Receptor (in Shadow Hours per Year)**

**Note: Figure presents WindPro predicted shadow flicker impacts for the worst case wind turbine option scenario (V90, 100 m hub)**

**Table 1: WindPro Predicted Shadow Flicker Impacts for Receptors with Maximum Impacts**

| Receptor (WindPro ID) | Shadow Hours per Year (expected) [hh:mm / year] |
|---|---|
| CX | 49:24 |
| CQ | 46:06 |
| DE | 44:43 |
| DJ | 41:14 |
| DI | 37:04 |
| AX | 35:58 |
| DG | 35:51 |
| CY | 35:45 |
| CC | 34:39 |
| BF | 34:18 |
| CT | 33:57 |
| DB | 33:36 |
| CV | 33:21 |
| AZ | 33:02 |
| CU | 32:25 |
| ED | 31:49 |
| CR | 31:46 |
| EZ | 31:30 |
| CZ | 31:10 |
| CB | 30:52 |
| CF | 30:45 |

**Note: Table presents WindPro predicted shadow flicker impacts for the worst case wind turbine option scenario (V90, 100 m hub)**

**Table 2: Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Sensitive Receptor Locations**

| | Number of Receptors | | | | | |
|---|---|---|---|---|---|---|
| **Cumulative Shadow Flicker Time (Expected)** | **G87 (80 m Hub)** | **G87 (100 m Hub)** | **V82 (80 m Hub)** | **V82 (100 m Hub)** | **V90 (80 m Hub)** | **V90 (100 m Hub)** |
| Total | 365 | 365 | 365 | 365 | 365 | 365 |
| = 0 Hours | 78 | 78 | 78 | 78 | 78 | 78 |
| > 0 Hours | 177 | 168 | 185 | 181 | 172 | 165 |
| > 10 Hours | 65 | 72 | 69 | 69 | 67 | 71 |
| > 20 Hours | 32 | 30 | 27 | 29 | 30 | 29 |
| > 30 Hours | 11 | 14 | 6 | 7 | 15 | 17 |
| > 40 Hours | 2 | 3 | 0 | 1 | 3 | 4 |

## ATTACHMENT A

## Detailed Summary of WindPro Shadow Flicker Analysis Results