

Appendix H
Triple H Wind Project Shadow Flicker Impact Analysis

Shadow Flicker Impact Analysis for the Triple H Wind Energy Project Hyde County, South Dakota

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PRESENTED TO

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
Triple H	Triple H Wind Project, LLC
Hz	Hertz
MW	megawatt
Tetra Tech	Tetra Tech, Inc.
the Project	The Triple H Wind Energy Project
UTM	Universal Transverse Mercator

1.0 OVERVIEW

Triple H Wind Project, LLC (Triple H) is proposing to construct and operate the Triple H Wind Energy Project (the Project) located in Hyde County, South Dakota. The Project is expected to have an up to nominal 250 megawatt (MW) power output capacity after constructing 92 wind turbines. Triple H has contracted Tetra Tech, Inc. (Tetra Tech) to conduct a shadow flicker impact assessment. An analysis was conducted to evaluate the expected shadow flicker impacts resulting from the Project wind turbines. The analysis evaluated 103 potential turbine locations with the Project only constructing up to 92 turbines.

2.0 PROJECT COMPONENTS

The Project will consist of up to 92 wind turbines. The turbine model selected for the Project is the General Electric GE2.72-116 and has the following specifications:

- **General Electric GE2.72-116:** Three-blade 116-meter rotor diameter, with a hub height of 90 meters and generating capacity of 2.72 MW. The GE2.72-116 has a normal high rotor speed of 15.7 rotations per minute, which translates to a blade pass frequency of 0.79 hertz (Hz; 0.79 alternations per second).

3.0 SHADOW FLICKER BACKGROUND

A wind turbine's moving blades can cast a moving shadow on locations within a certain distance of a turbine. These moving shadows are called shadow flicker and can be a temporary phenomenon experienced at nearby residences or public gathering places. The impact area depends on the time of year and day (which determine the sun's azimuth and altitude angles) and the wind turbine's physical characteristics (height, rotor diameter, blade width, and orientation of the rotor blades). Shadow flicker impact to surrounding properties generally occurs during low angle sunlight conditions, typically during sunrise and sunset times of the day. However, when the sun angle gets very low (less than three degrees), sunlight passes through more atmosphere and becomes too diffused to form a coherent shadow. Shadow flicker will not occur when the sun is obscured by clouds or fog, at night, or when the source turbine(s) are not operating. In addition, shadow flicker only occurs when at least 20 percent of the sun's disc is covered by the turbine blades.

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 intensity for receptor-to-turbine distances beyond 2,000 meters (6,562 feet) is very low and generally considered imperceptible. In general, increasing proximity to turbines may make shadow flicker more noticeable, with the largest number of shadow flicker hours, along with greatest shadow flicker intensity, occurring nearest the wind turbines.

Shadow flicker impacts are not regulated in applicable state or federal law. However, the Hyde County Zoning Ordinance Section 9-104-A-20 establishes the following requirements:

SECTION 9-104 -A-20. Flicker Analysis *A Flicker Analysis shall include the duration and location of flicker potential for all receptors and road ways within a one (1) mile radius of each turbine within a project. The applicant shall provide a site map identifying the locations of shadow flicker that may be caused by the project and the expected durations of the flicker at these locations from sun-rise to sun-set over the course of a year. The analysis shall account for topography but not for obstacles such as accessory structures and trees. Flicker at any receptor shall not exceed thirty (30) hours per year within an established dwelling and forty (40) hours per year from any occupied structure.*

4.0 WINDPRO SHADOW FLICKER ANALYSIS

An analysis of potential shadow flicker impacts from the Project was conducted using the WindPro software package. As described above, the Project will install up to 92 wind turbines. However, 103 potential turbine locations have been evaluated.

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 surrounding the Project turbines. The realistic impact condition scenario is based on the following:

- The elevation and position geometries of the wind turbines and surrounding receptors (potentially occupied residences). Elevations were determined using U.S. Geological Survey digital elevation model data. Positions geometries were determined using geographic information system and referenced to Universal Transverse Mercator (UTM) Zone 14 (NAD83).
- 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 availability (percent of total hours available). Historical sunshine rates for the area (as summarized by the National Climatic Data Center [NOAA 2016] for nearby Huron, South Dakota) used in this analysis are provided in Table 1.
- Estimated wind turbine operations and orientation based on wind data (wind speed and direction) measured at meteorological towers located on the Project site.
- Receptor viewpoints (i.e., house windows) are assumed to always be directly facing turbine to sun line of sight (“greenhouse mode”).

Table 1. Historical Sunshine Availability

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
62%	62%	62%	59%	66%	69%	76%	74%	69%	59%	51%	51%

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 the horizon were excluded for the reasons identified earlier in Section 3. Since shadow flicker is only an issue when at least 20 percent of the sun disc is covered by the blades, WindPro uses blade dimension data to calculate the maximum distance from the turbine where shadow flicker must be calculated. Beyond this distance, the turbine will not contribute to the shadow flicker impact. It should be noted however, that WindPro provides a conservative estimate of shadow flicker as obstacles such as trees, haze, and visual obstructions (window facing, coverings) are not accounted for despite the likelihood of their reducing or eliminating shadow flicker impacts to receptors.

A total of 117 residential structures were identified within and near the Project Area as occupied or potentially occupied residences and are considered potential shadow-flicker receptors for the purpose of this analysis and are shown on Figures 1 and 2. A receptor in the model is defined as a one meter squared area (approximate size of a typical window), 1 meter (3.28 feet) above ground level. Approximate eye level is set at 1.5 meters (4.94 feet). Figure 1 shows the locations of all 117 identified residential structures, along with the 103 potential turbine locations considered.

5.0 SHADOW FLICKER ANALYSIS RESULTS

As expected, WindPro predicts that shadow flicker impacts will be greatest at locations closer to the wind turbines. Figure 2 illustrates the WindPro predicted shadow flicker impact areas for each of the turbine model scenarios.

Table 2 presents the WindPro predicted shadow flicker impacts for the top ten worst case impact receptors. Table 3 summarizes the shadow flicker impact prediction statistics. The predicted shadow flicker impact for all 117 receptors is presented in Appendix A. The maximum predicted shadow flicker impact at any occupied residence receptor is 24 hours and 57 minutes per year (Receptor 81). This is approximately 0.56 percent of the potential available daylight hours. All of the receptor locations had modeled shadow flicker impacts below the ordinance threshold of 30 hours per year.

Table 2. WindPro Top Ten Expected Shadow Flicker Impacts

Receptor ID	Receptor Type	Receptor Project Participation Status	Expected Shadow Flicker Hours per Year (Hours/Year)
81	Residential	Participant	24:57
11	Residential	Participant	22:24
7	Residential	Participant	21:22
19	Residential	Participant	18:24
5	Residential	Participant	11:58
6	Residential	Participant	10:20
3	Residential	Participant	9:34
78	Residential	Participant	8:57
79	Residential	Participant	8:27
76	Residential	Non-Participant	7:39

Table 3. Statistical Summary of WindPro Expected Shadow Flicker Impacts – Number of Modeled Receptors

Cumulative Shadow Flicker Time (Expected)	Number of Modeled Receptors
Total	117
= 0 Hours	104
> 0 Hours < 10 Hours	7
≥ 10 Hours < 20 Hours	3
≥ 20 Hours < 30 Hours	3
≥ 30 Hours	0

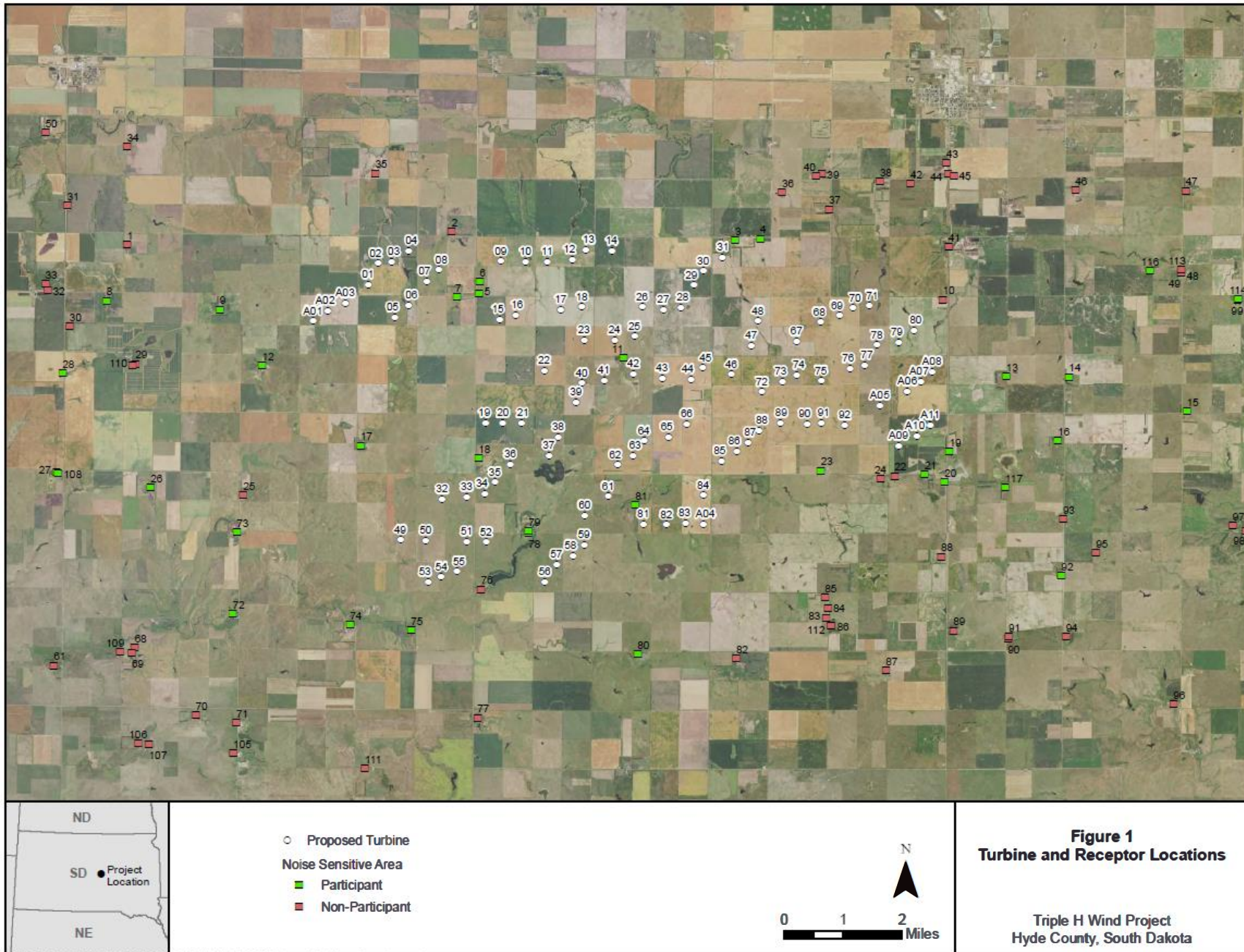
6.0 CONCLUSION

The analysis of potential shadow flicker impacts from the Project on nearby receptors shows that shadow flicker impacts within the area of study are expected to be minor and well within acceptable ranges for avoiding nuisance. All of the receptor locations had modeled shadow flicker impacts below the ordinance threshold of 30 hours per year. The analysis assumes that the receptors all have a direct in-line view of the incoming shadow flicker sunlight and does not account for trees or other obstructions which may block sunlight. In reality, the windows of many houses will not face the sun directly for the key shadow flicker impact times.

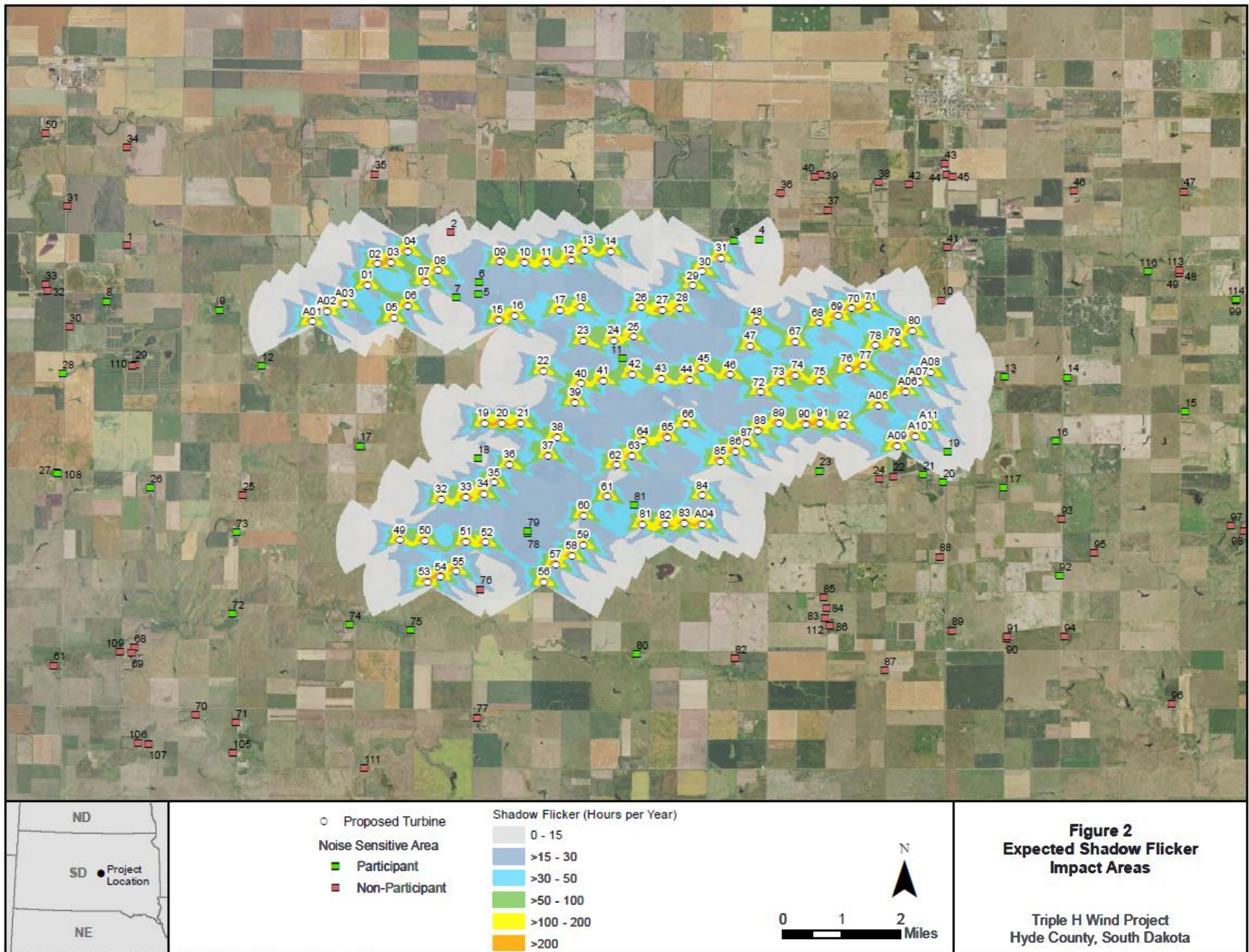
7.0 REFERENCES

National Oceanic and Atmospheric Administration (NOAA). 2016. Comparative Climatic Data for the United States Through 2015.

FIGURES



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R:\PROJECTS\TRIPLE_H_8695\SHADOW_FLICKER\MAPS\Figure_2_Shadow_Flicker.mxd

**ATTACHMENT A. DETAILED SUMMARY OF WINDPRO SHADOW
FLICKER ANALYSIS RESULTS**

Table A-1. Detailed Summary of WindPro Shadow Flicker Analysis Results

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
1	442,456.26	4,925,508.32	0:00	Non-Participant
2	451,309.23	4,925,851.08	4:12	Non-Participant
3	459,033.36	4,925,620.41	9:34	Participant
4	459,719.35	4,925,668.16	2:53	Participant
5	452,061.95	4,924,181.53	11:58	Participant
6	452,074.51	4,924,501.35	10:20	Participant
7	451,447.06	4,924,096.78	21:22	Participant
8	441,895.48	4,923,972.76	0:00	Participant
9	444,984.14	4,923,740.84	0:00	Participant
10	464,695.63	4,924,004.78	0:00	Non-Participant
11	455,989.55	4,922,425.59	22:24	Participant
12	446,141.03	4,922,203.18	0:00	Participant
13	466,431.22	4,921,922.58	0:00	Participant
14	468,148.14	4,921,890.92	0:00	Participant
15	471,361.71	4,920,960.07	0:00	Participant
16	467,845.14	4,920,174.53	0:00	Participant
17	448,828.25	4,920,034.25	0:00	Participant
18	452,047.91	4,919,693.57	6:00	Participant
19	464,883.58	4,919,863.43	18:24	Participant
20	464,747.60	4,919,035.33	0:00	Participant
21	464,202.94	4,919,233.79	0:00	Participant
22	463,390.83	4,919,194.43	0:00	Non-Participant
23	461,381.17	4,919,346.80	0:00	Participant
24	463,004.21	4,919,118.23	0:00	Non-Participant
25	445,619.14	4,918,666.11	0:00	Non-Participant
26	443,100.43	4,918,874.19	0:00	Participant
27	440,534.20	4,919,289.67	0:00	Participant
28	440,696.36	4,922,013.54	0:00	Participant
29	442,687.25	4,922,261.08	0:00	Non-Participant
30	440,889.23	4,923,288.60	0:00	Non-Participant
31	440,819.14	4,926,573.61	0:00	Non-Participant
32	440,289.74	4,924,270.91	0:00	Non-Participant
33	440,236.76	4,924,430.42	0:00	Non-Participant

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
34	442,458.37	4,928,172.22	0:00	Non-Participant
35	449,221.49	4,927,448.03	0:00	Non-Participant
36	460,325.43	4,926,928.71	0:00	Non-Participant
37	461,602.59	4,926,471.63	0:00	Non-Participant
38	462,994.07	4,927,231.05	0:00	Non-Participant
39	461,400.16	4,927,436.64	0:00	Non-Participant
40	461,242.30	4,927,391.26	0:00	Non-Participant
41	464,857.46	4,925,440.86	0:00	Non-Participant
42	463,829.03	4,927,184.39	0:00	Non-Participant
43	464,803.36	4,927,721.85	0:00	Non-Participant
44	464,850.69	4,927,458.91	0:00	Non-Participant
45	465,001.71	4,927,395.95	0:00	Non-Participant
46	468,316.29	4,927,007.42	0:00	Non-Participant
47	471,331.92	4,926,983.25	0:00	Non-Participant
48	471,208.74	4,924,768.18	0:00	Non-Participant
49	471,205.75	4,924,735.42	0:00	Non-Participant
50	440,237.77	4,928,577.23	0:00	Non-Participant
51	438,694.28	4,928,202.00	0:00	Non-Participant
52	435,698.03	4,928,234.26	0:00	Non-Participant
53	438,709.80	4,926,367.01	0:00	Non-Participant
54	437,502.98	4,925,640.23	0:00	Non-Participant
55	438,592.37	4,919,466.53	0:00	Non-Participant
56	437,526.11	4,918,519.03	0:00	Participant
57	437,553.68	4,918,480.44	0:00	Participant
58	435,778.81	4,916,792.12	0:00	Non-Participant
59	436,640.15	4,914,868.00	0:00	Non-Participant
60	435,784.29	4,915,279.60	0:00	Non-Participant
61	440,462.08	4,914,035.21	0:00	Non-Participant
62	435,967.05	4,912,462.21	0:00	Non-Participant
63	435,918.99	4,912,202.98	0:00	Non-Participant
64	435,242.00	4,912,249.71	0:00	Non-Participant
65	435,422.53	4,912,000.64	0:00	Non-Participant
66	435,330.77	4,912,501.13	0:00	Non-Participant
67	434,868.17	4,912,262.28	0:00	Non-Participant

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
68	442,662.10	4,914,507.36	0:00	Non-Participant
69	442,582.39	4,914,366.92	0:00	Non-Participant
70	444,336.96	4,912,679.47	0:00	Non-Participant
71	445,434.86	4,912,474.49	0:00	Non-Participant
72	445,330.11	4,915,442.75	0:00	Participant
73	445,448.01	4,917,655.08	0:00	Participant
74	448,546.35	4,915,131.53	0:00	Participant
75	450,195.89	4,915,007.85	0:00	Participant
76	452,105.81	4,916,109.70	7:39	Non-Participant
77	452,006.07	4,912,596.78	0:00	Non-Participant
78	453,409.61	4,917,626.01	8:57	Participant
79	453,396.76	4,917,705.12	8:27	Participant
80	456,381.21	4,914,352.43	0:00	Participant
81	456,314.79	4,918,412.11	24:57	Participant
82	459,067.69	4,914,217.47	0:00	Non-Participant
83	461,525.95	4,915,309.40	0:00	Non-Participant
84	461,566.53	4,915,598.31	0:00	Non-Participant
85	461,490.02	4,915,879.59	0:00	Non-Participant
86	461,668.15	4,915,110.25	0:00	Non-Participant
87	463,152.50	4,913,889.19	0:00	Non-Participant
88	464,660.35	4,916,996.77	0:00	Non-Participant
89	464,995.85	4,914,978.64	0:00	Non-Participant
90	466,480.42	4,914,752.27	0:00	Non-Participant
91	466,494.97	4,914,818.80	0:00	Non-Participant
92	467,930.84	4,916,490.19	0:00	Participant
93	467,980.00	4,918,030.73	0:00	Non-Participant
94	468,070.11	4,914,825.66	0:00	Non-Participant
95	468,885.51	4,917,101.29	0:00	Non-Participant
96	470,985.18	4,912,972.17	0:00	Non-Participant
97	472,613.19	4,917,854.38	0:00	Non-Participant
98	472,968.70	4,917,714.26	0:00	Non-Participant
99	472,739.00	4,924,005.57	0:00	Participant
100	473,852.01	4,920,692.17	0:00	Participant
101	473,794.68	4,925,677.69	0:00	Non-Participant

Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Participation Status
102	475,241.24	4,920,717.37	0:00	Non-Participant
103	474,503.82	4,919,959.59	0:00	Non-Participant
104	477,592.41	4,926,816.55	0:00	Non-Participant
105	445,355.63	4,911,623.53	0:00	Non-Participant
106	442,768.85	4,911,898.41	0:00	Non-Participant
107	443,050.22	4,911,872.87	0:00	Non-Participant
108	440,574.43	4,919,272.51	0:00	Participant
109	442,257.40	4,914,401.38	0:00	Non-Participant
110	442,602.42	4,922,218.87	0:00	Non-Participant
111	448,944.33	4,911,211.73	0:00	Non-Participant
112	461,641.60	4,915,097.18	0:00	Non-Participant
113	471,200.86	4,924,811.19	0:00	Non-Participant
114	472,754.86	4,924,015.59	0:00	Participant
115	473,176.93	4,921,096.41	0:00	Non-Participant
116	470,357.76	4,924,798.28	0:00	Participant
117	466,406.70	4,918,894.22	0:00	Participant