Appendix E
Shadow Flicker Impact Analysis for the Meridian Wind Project

Shadow Flicker Impact Analysis for the Meridian Wind Project
Hyde County, South Dakota

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PRESENTED TO

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TABLE OF CONTENTS

LIST OF TABLES

ATTACHMENTS

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
GE	General Electric
Hz	Hertz
Meridian	Meridian Wind Project, LLC
MW	megawatt
Project area	the encompassing 15,043-acre area where the Project is located
Tetra Tech	Tetra Tech, Inc.
the Project	The Meridian Wind Project
UTM	Universal Transverse Mercator

1.0 OVERVIEW

Meridian Wind Project, LLC (Meridian) is proposing to construct and operate the Meridian Wind Project (the Project) located in Hyde County, South Dakota. The Project will be located on privately held land within an area that encompasses approximately 15,043 acres (Project area). The Project is expected to have an up to nominal 174 megawatt (MW) power output capacity after constructing up to 64 wind turbines. Meridian has contracted Tetra Tech, Inc. (Tetra Tech) to conduct a shadow flicker impact assessment to evaluate the expected shadow flicker impacts resulting from the Project wind turbines.

2.0 PROJECT COMPONENTS

The Project is considering a layout consisting of 64 General Electric (GE) wind turbines. The turbine layout being considered for the Project has the following specifications:

- **64 GE 2.72-116 wind turbines:** Three-blade 116-meter rotor diameter, with a hub height of 90 meters and generating capacity of 2.72 MW. The GE 2.72-116 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). While only 64 GE wind turbines would be constructed, 74 potential wind turbine locations were evaluated.

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. However, when the sun angle is very low (less than three degrees), sunlight passes through more atmosphere and becomes too diffused to form a coherent shadow. Shadow flicker does 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 occurs only 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 frequency is related to the wind turbine's rotor blade speed and the number of blades on the rotor. From a health perspective, the low flicker frequencies associated with wind turbines are harmless, and public concerns that flickering light from wind turbines can have negative health effects, such as triggering seizures in people with epilepsy, are unfounded. Epilepsy Action (the working name for the British Epilepsy Foundation) states that there is no evidence that wind turbines can cause seizures (Epilepsy Action 2018). However, they recommend that wind turbine flicker frequency be limited to 3 Hz. For comparison, strobe lights used in discos have frequencies that range from about 3 Hz to 10 Hz (1 Hz = one flash per second). Since the proposed Project's wind turbine blade pass frequency is approximately 0.79 Hz (less than one alternation per second), no negative health effects to individuals with photosensitive epilepsy are anticipated.

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, 74 wind turbine locations were evaluated though the Project would only install up to 64 wind turbines.

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 wind 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 2019] 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 area.
- Receptor viewpoints (i.e., house windows) were assumed to be directly facing the 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’s 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 would not contribute to the shadow flicker impact. It should be noted however, that WindPro provides a conservative estimate of shadow flicker since 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 34 residential structures were identified within and near the Project area as occupied or potentially occupied residences. These residences are considered potential shadow-flicker receptors for the purpose of this analysis and are shown on Figure 1 (Attachment A). A receptor in the model is defined as a 1-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). In addition to the identified residential structures, Figure 1 shows the potential turbine locations considered.

5.0 SHADOW FLICKER ANALYSIS RESULTS

As expected, WindPro predicts that shadow flicker impacts would be greatest at locations closer to the wind turbines. Figure 1 (Attachment A) illustrates the WindPro-predicted shadow flicker impact areas.

Table 2 presents the WindPro-predicted shadow flicker impacts for the top 10 worst-case impact receptors. Table 4 summarizes the shadow flicker impact prediction statistics. The predicted shadow flicker impact for all 34 receptors is presented in Attachment B. The maximum predicted shadow flicker impact at any occupied residence receptor is 25 hours and 17 minutes per year (Receptor 28). This is approximately 0.6 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 10 Expected Shadow Flicker Impacts

Receptor ID	Receptor Type	Receptor Project Participation Status	Expected Shadow Flicker Hours per Year (Hours/Year)
28	Residential	Participant	25:17
34	Residential	Participant	25:02
19	Residential	Participant	22:34
3	Residential	Participant	21:24
32	Residential	Non-Participant	17:26
2	Residential	Participant	15:34
18	Residential	Participant	12:17
24	Residential	Participant	9:54
31	Residential	Participant	9:13
33	Residential	Participant	8:18

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

Cumulative Shadow Flicker Time (Expected)	Number of Modeled Receptors
Total	34
= 0 Hours	16
> 0 Hours ≤ 10 Hours	11
> 10 Hours ≤ 20 Hours	3
> 20 Hours ≤ 30 Hours	4
> 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 and/or health hazards. 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 that may block sunlight. 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 in this conservative analysis, and shadow flicker is not expected to be a significant environmental impact.

7.0 REFERENCES

Epilepsy Action. 2018. Information Web Page on Photosensitive Epilepsy. British Epilepsy Association. http://www.epilepsy.org.uk/info/photo_other.html. Accessed July 2018.

NOAA (National Oceanic and Atmospheric Administration). 2019. Comparative Climatic Data for the United States Through 2018.

ATTACHMENT A. FIGURES

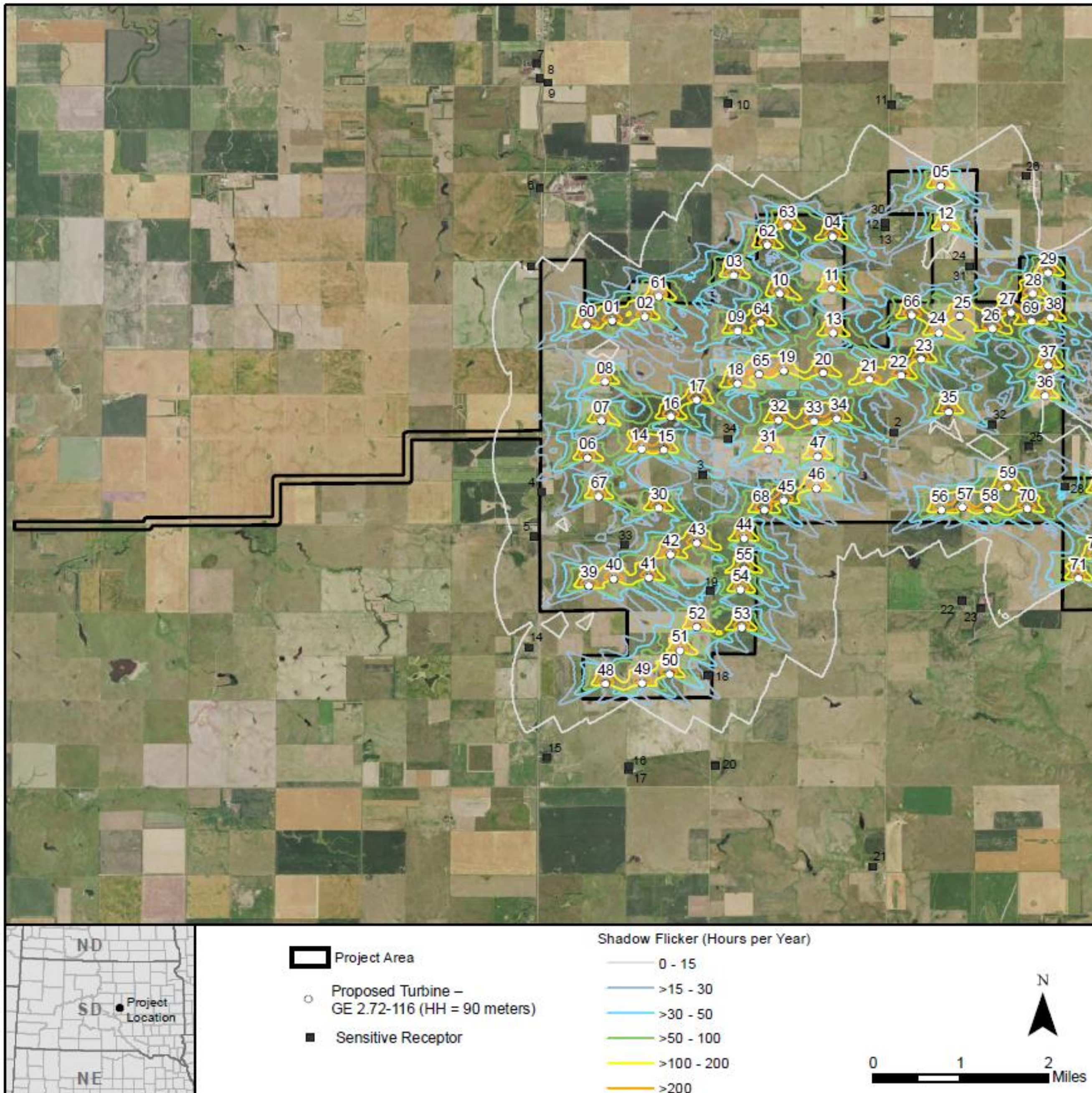

Figure 1
Expected Shadow Flicker Impact Area - GE Layout

Meridian Wind Project, LLC
Hyde County, South Dakota

ATTACHMENT B. 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	464695.63	4924004.78	0:00	Non-Participant
2	471361.71	4920960.07	15:34	Participant
3	467845.14	4920174.53	21:24	Participant
4	464883.58	4919863.43	3:51	Non-Participant
5	464747.60	4919035.33	4:54	Non-Participant
6	464857.46	4925440.86	0:00	Non-Participant
7	464803.36	4927721.85	0:00	Non-Participant
8	464850.69	4927458.91	0:00	Non-Participant
9	465001.71	4927395.95	0:00	Non-Participant
10	468316.29	4927007.42	0:00	Non-Participant
11	471331.92	4926983.25	0:00	Non-Participant
12	471208.74	4924768.18	7:19	Non-Participant
13	471205.75	4924735.42	7:25	Non-Participant
14	464660.35	4916996.77	1:41	Non-Participant
15	464995.85	4914978.64	0:00	Non-Participant
16	466480.42	4914752.27	0:00	Non-Participant
17	466494.97	4914818.80	0:00	Non-Participant
18	467930.84	4916490.19	12:17	Participant
19	467980.00	4918030.73	22:34	Participant
20	468070.11	4914825.66	0:00	Non-Participant
21	470985.18	4912972.17	0:00	Non-Participant
22	472613.19	4917854.38	0:00	Non-Participant
23	472968.70	4917714.26	0:00	Non-Participant
24	472739.00	4924005.57	9:54	Participant
25	473852.01	4920692.17	5:56	Participant
26	473794.68	4925677.69	0:53	Non-Participant
27	475241.24	4920717.37	0:00	Non-Participant
28	474503.82	4919959.59	25:17	Participant
29	477592.41	4926816.55	0:00	Non-Participant
30	471200.86	4924811.19	7:10	Non-Participant
31	472754.86	4924015.59	9:13	Participant
32	473176.93	4921096.41	17:26	Non-Participant
33	466406.70	4918894.22	8:18	Participant
34	468325.59	4920833.97	25:02	Participant