Shadow Flicker Impact Analysis
for the
Brady Wind Energy Center
Stark County, North Dakota

Prepared for

Brady Wind, LLC

Prepared by

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Acronyms and Abbreviations

Brady Wind	Brady Wind, LLC
GE	General Electric
Hz	Hertz
NCDC	National Climatic Data Center
Project	Brady Wind Energy Center Project
rpm	rotations per minute
UTM	Universal Transverse Mercator

1.0 OVERVIEW

Brady Wind, LLC (Brady Wind), a wholly owned, indirect subsidiary of NextEra Energy Resources, LLC (NEER), is proposing to develop the Brady Wind Energy Center (the Project) in Stark County, North Dakota. The Project includes up to 87 wind turbines with a maximum nameplate capacity of approximately 150 megawatts. In addition to the 87 primary turbines, up to eight (8) alternate turbines locations have also been considered. Alternate locations are proposed to provide siting flexibility based on on-going environmental studies and landowner preferences. Only 87 turbines will be constructed. Tetra Tech has conducted the following shadow flicker analysis for the Project to support Brady Wind's application for a Certificate of Site Compatibility under the North Dakota Public Service Commission.

2.0 PROJECT COMPONENTS

The Project will consist of up to 87 wind turbines. Seven (7) of the turbines (numbers 48, 49, 52, 53, 54, 55, and 56) will be the GE 1.79-100 turbine model and the rest of turbines will be the General Electric (GE) 1.715-103 turbine model. The two wind turbine models being considered for the Project, and evaluated for potential shadow flicker impacts, have the following characteristics:

- **GE 1.79 100** – 3-blade 100-meter diameter rotor, with a hub height of 80 meters and generating capacity of 1.79 MW. The GE 1.79-100 has a normal high rotor speed of 17.5 rotations per minute (rpm) which translates to a blade pass frequency of 0.87 hertz (Hz) (less than 1 alternation per second). The Project plans to install up to 7 GE 1.79-100 turbines.

- **GE 1.715 103** – 3-blade 103-meter diameter rotor, with a hub height of 80 meters and generating capacity of 1.715 MW. The GE 1.715-103 has a normal high rotor speed of 17.5 rpm which translates to a blade pass frequency of 0.87 Hz (less than 1 alternation per second). The Project plans to install up to 80 GE 1.715-100 turbines.

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 3 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 is only an issue 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 2,500 meters (8,202 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 standpoint, 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 (working name for the British Epilepsy Foundation) states that there is no evidence that wind turbines can cause seizures (Epilepsy Action 2008). However, they recommend that wind turbine flicker frequency be limited to 3 Hz. (For comparison, strobe lights used in discotheques have frequencies which range from about 3 Hz to 10 Hz (1 Hz = 1 flash per second). Since the proposed Project's wind turbine blade pass frequency is approximately 0.87 Hz (less than 1 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, and there is no permitting threshold with regard to hours per year of anticipated impacts to a receptor from a wind energy project. However, a widely used industry standard of 30 hours per year, has been used for this shadow flicker impact analysis.

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 87 wind turbines (7 GE 1.79-100 and the rest GE 1.715-103 model turbines). While only 87 turbines will be constructed, 95 turbines have been evaluated with WindPro so that the analysis includes assessment of up to eight (8) alternative turbine locations (layout dated November 6, 2015). The analysis evaluated the following two turbine layout scenarios:

- Scenario A – 87 wind turbines (primary turbines only)
- Scenario B – 95 wind turbines (primary plus alternate 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. The realistic impact condition scenario is based on the following assumptions:

- 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 13 (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 2012] for nearby Bismarck, North Dakota) used in this analysis are as follows:

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
53%	53%	58%	58%	61%	64%	73%	72%	65%	58%	43%	47%

- Estimated wind turbine operations and orientation (based on approximately 5 years of wind data (6/15/2006–10/19/2011), including wind speed/wind direction frequency distribution, measured at a meteorological tower located approximately 50 miles northeast of the Project).

- Receptor viewpoints (i.e., house windows) are assumed to always be directly facing turbine to sun line of sight (“greenhouse mode”), which is a conservative assumption.

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 this section. Since shadow flicker is only an issue when at least 20 percent of the sun disc is covered by the blades, WindPro uses blade width 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 160 structures were identified within and near the Project Area; of these, 108 were determined to be occupied or potentially occupied residences and are considered potential shadow-flicker receptors for the purpose of this analysis. A receptor in the model is defined as a 1 meter squared area (approximate size of a typical window), 3.28 feet (1 meter) above ground level. Approximate eye level is set at 4.94 feet (1.5 meters). Figure 1 shows the locations of all identified structures and the 89 shadow flicker receptors (occupied residences), along with the 94 potential turbine locations considered.

5.0 SHADOW FLICKER ANALYSIS RESULTS

As expected, WindPro predicts that shadow flicker impacts will be greatest at locations nearer to the wind turbines. Figures 2 illustrates the WindPro predicted shadow flicker impact areas. A detailed WindPro shadow flicker analysis summary, for each of the modeled receptor location, is provided in Attachment A.

Tables 1 and 2 present the WindPro predicted shadow flicker impacts for the ten highest impacts for the 160 identified receptors, for the turbine scenarios A and B, respectively. The predicted shadow flicker for all 160 receptors is presented in Appendix A. Because the Project is using a minimum turbine siting setback requirement of 2,000 feet (609.6 meters) to occupied residences as required by the Stark County Zoning Ordinance, the most sensitive receptors are generally not located in the high potential shadow flicker impact zones. The maximum predicted shadow flicker impact at any occupied residence receptor is 44 hours and 55 minutes per year (Receptor 880001) if only the 87 planned turbines are constructed, and 52 hours 56 minutes per year (Receptor 610121), if the alternate turbines are also included in the analysis. The highest predicted shadow flicker impacts, 52 hours and 56 minutes, is approximately 1.2 percent of the potential available daylight hours. There are only two occupied receptors with shadow flicker impacts greater than 30 hours per year. Both of these residences are owned by landowners that are participating in the Project and have granted an easement for shadow flicker effects on the property.

Table 1. WindPro Predicted Shadow Flicker Impacts for Receptors – Scenario A (Primary Turbines Only)			
Receptor ID	**Shadow Hours per Year (expected) [hh:mm / year]**	**Receptor Type**	**Assumed Receptor Occupation Status**
610063	65:02	barn	Unoccupied
811236	56:48	barn	Unoccupied
880001	44:55	new house	Occupied
811228	35:16	abandoned house	Unoccupied
610121	35:08	house	Occupied
811231	31:10	abandoned house	Unoccupied
610053	27:40	house	Occupied
610197	26:05	outbuildings	Unoccupied
811069	25:24	abandoned house	Unoccupied
610181	23:23	house	Occupied

Table 2. WindPro Predicted Shadow Flicker Impacts for Receptors – Scenario B (Primary Plus Alternate Turbines)			
Receptor ID	**Shadow Hours per Year (expected) [hh:mm / year]**	**Receptor Type**	**Assumed Receptor Occupation Status**
610063	65:02	barn	Unoccupied
811236	57:42	barn	Unoccupied
610121	52:56	house	Occupied
880001	44:55	new house	Occupied
811228	37:17	abandoned house	Unoccupied
610197	37:00	due south outbuildings	Unoccupied
811231	32:50	abandoned house	Unoccupied
610053	27:40	house	Occupied
610049	26:52	house	Occupied
811069	25:24	abandoned house	Unoccupied

The shadow flicker impact prediction statistics are summarized in Tables 3 and 4 below.

Table 3. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Scenario A (Primary Turbines Only)

Cumulative Shadow Flicker Time (expected)	Number of Receptors
Total	160
= 0 Hours	114
> 0 Hours < 10 Hours	21
≥ 10 Hours < 20 Hours	13
≥ 20 Hours < 30 Hours	6
≥ 30 Hours	6

Table 4. Statistical Summary of WindPro Predicted Shadow Flicker Impacts at Modeled Receptor Locations – Scenario B (Primary Plus Alternate Turbines)

Cumulative Shadow Flicker Time (expected)	Number of Receptors
Total	160
= 0 Hours	114
> 0 Hours < 10 Hours	20
≥ 10 Hours < 20 Hours	10
≥ 20 Hours < 30 Hours	9
≥ 30 Hours	7

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 conditions. Shadow flicker is not expected to be a significant environmental impact.

The analysis was deliberately conservative and actual shadow flicker is expected to occur for less than the modeled durations. 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. Adding to the analysis' conservatism, both the primary and alternate turbines were modeled cumulatively. Brady will only construct up to 87 turbines, which is fewer wind turbines than were included in the Scenario B modeled results.

7.0 REFERENCES

Epilepsy Action. 2008. Information Web Page on Photosensitive Epilepsy. British Epilepsy Association. http://www.epilepsy.org.uk/info/photo_other.html. Accessed November 2015.

National Oceanic and Atmospheric Administration (NOAA). 2012. Comparative Climatic Data for the United States Through 2012.

Figures

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FIGURE 1

TURBINE AND RECEPTOR LOCATIONS

JANUARY 2016

Proposed Turbine Array (11/6/2015)

- GE Xle 1.715-103 Turbine
- GE Xle 1.715-103 Turbine (Alt)
- GE Xle 1.79-100 Turbine

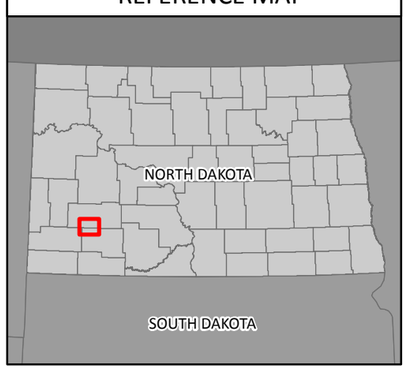
Receptors

- Occupied
- Unoccupied

N

0 0.5 1 1.5 2 MILES

REFERENCE MAP



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STARK COUNTY

NORTH DAKOTA

FIGURE 2

EXPECTED SHADOW FLICKER IMPACT AREAS (SCENARIO A – PRIMARY TURBINES ONLY)

JANUARY 2016

Proposed Turbine Array (11/6/2015)

- GE Xle 1.715-103 Turbine
- GE Xle 1.79-100 Turbine

Shadow Flicker (hours per year)

- 0 - 15
- >15 - 30
- >30 - 50
- >50 - 100
- >100 - 200
- >200
- 30 hours per year limit

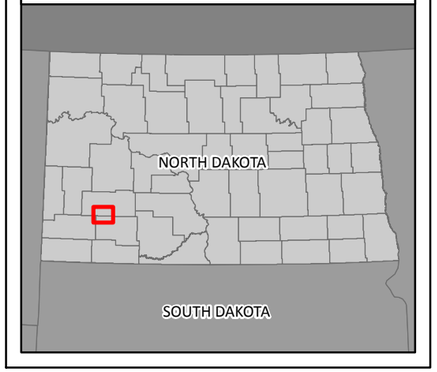
Receptors

- Occupied
- Unoccupied

N

0 0.5 1 1.5 2 MILES

REFERENCE MAP



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STARK COUNTY
NORTH DAKOTA

FIGURE 3
EXPECTED SHADOW FLICKER IMPACT AREAS (SCENARIO B – PRIMARY PLUS ALTERNATE TURBINES)

JANUARY 2016

Proposed Turbine Array (11/6/2015)

- GE Xle 1.715-103 Turbine
- GE Xle 1.715-103 Turbine (Alt)
- GE Xle 1.79-100 Turbine

Shadow Flicker (hours per year)

- 0 - 15
- >15 - 30
- >30 - 50
- >50 - 100
- >100 - 200
- >200
- 30 hours per year limit

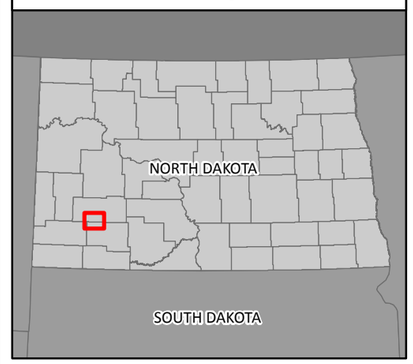
Receptors

- Occupied
- Unoccupied

N

0 0.5 1 1.5 2 MILES

REFERENCE MAP



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Attachment A:
Detailed Summary of WindPro Shadow Flicker Analysis Results

Detailed Summary of WindPro Shadow Flicker Analysis Results Scenario A

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
880001	680,270	5,173,773	44:55	new house
610121	672,258	5,168,851	35:08	house
610053	660,882	5,167,398	27:40	house
610181	670,466	5,167,264	23:23	house
610057	660,875	5,167,437	22:24	future trailer home
501068	677,851	5,169,797	21:59	house
610049	662,204	5,167,996	19:59	house
610185	670,516	5,167,245	19:02	house
501053	678,555	5,173,259	17:57	foundation
610045	662,204	5,167,951	16:20	travel trailer
610042	662,190	5,167,946	16:07	trailer home
900070	679,567	5,171,280	13:21	house
501012	681,646	5,173,097	13:07	house
501040	678,406	5,173,332	12:00	house
610098	664,446	5,167,109	10:38	house
501037	679,718	5,171,197	9:59	house
610009	657,243	5,168,249	9:50	house
610031	660,171	5,167,459	9:06	house
501050	678,419	5,173,433	7:50	house
501030	679,723	5,174,632	5:19	house
610111	670,742	5,169,632	4:13	house
610014	657,329	5,168,365	3:56	porch
610021	658,588	5,168,791	3:54	house
610139	675,979	5,170,362	3:35	house
610094	663,473	5,168,761	3:27	no access/approx.
610025	659,083	5,169,071	1:20	house
501065	678,822	5,170,399	0:59	old house
500002	680,617	5,158,589	0:00	house
500006	679,633	5,157,936	0:00	house
500012	679,628	5,157,991	0:00	trailer
500018	679,256	5,165,366	0:00	house
500022	677,510	5,165,047	0:00	house
500028	677,401	5,165,136	0:00	house
500035	673,147	5,158,516	0:00	house
500039	671,766	5,158,494	0:00	house
500053	672,221	5,159,146	0:00	house
500059	669,892	5,159,454	0:00	house

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
500064	669,899	5,159,550	0:00	house
501000	684,105	5,172,245	0:00	trailer house
501019	680,468	5,175,745	0:00	house
501022	680,563	5,175,382	0:00	house
501073	681,345	5,169,634	0:00	house
501081	681,279	5,169,706	0:00	house
501082	675,324	5,171,958	0:00	house
501085	672,965	5,164,410	0:00	trailer house
501096	672,947	5,164,396	0:00	old house
501099	675,017	5,163,411	0:00	house
501104	675,027	5,163,439	0:00	garage
501108	670,613	5,160,034	0:00	house
501118	659,777	5,163,091	0:00	house
501122	661,117	5,163,653	0:00	house
501126	663,477	5,163,902	0:00	house
501131	664,747	5,163,175	0:00	house
501138	664,349	5,164,755	0:00	house
501141	665,127	5,163,747	0:00	house
501147	665,442	5,161,863	0:00	house
501156	674,657	5,162,748	0:00	house
610001	657,943	5,169,457	0:00	house
610084	666,867	5,164,930	0:00	trailer home
610089	668,413	5,169,125	0:00	house
610102	669,505	5,169,577	0:00	house
610108	669,518	5,169,514	0:00	house
610149	674,773	5,165,354	0:00	house
610170	667,574	5,164,565	0:00	house
811201	680,019	5,177,169	0:00	house
811205	679,691	5,178,020	0:00	house
811210	680,887	5,178,421	0:00	garage
900002	661,988	5,161,930	0:00	house
900007	662,323	5,161,469	0:00	house
900011	662,065	5,161,089	0:00	house
900015	658,130	5,161,120	0:00	house & garage
900019	658,166	5,161,105	0:00	house
900027	664,500	5,161,670	0:00	house
900031	665,522	5,158,935	0:00	house
900035	665,494	5,159,171	0:00	house
900039	665,496	5,159,110	0:00	house

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
900047	663,971	5,160,025	0:00	house
900053	664,011	5,160,036	0:00	house
900059	665,090	5,160,153	0:00	house
210001	654,902	5,169,176	0:00	house
210002	662,957	5,171,200	0:00	house
210003	664,035	5,171,226	0:00	house
210004	663,967	5,171,255	0:00	house
210005	663,054	5,171,188	0:00	house
210006	667,898	5,171,588	0:00	house
210007	668,756	5,170,679	0:00	house
210008	668,421	5,170,744	0:00	house
210009	666,568	5,170,295	0:00	house
210018	664,088	5,171,362	0:00	house

Detailed Summary of WindPro Shadow Flicker Analysis Results- Scenario B

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
610121	672,258	5,168,851	52:56	house
880001	680,270	5,173,773	44:55	new house
610053	660,882	5,167,398	27:40	house
610049	662,204	5,167,996	26:52	house
610042	662,190	5,167,946	24:17	trailer home
610045	662,204	5,167,951	24:00	travel trailer
610181	670,466	5,167,264	23:23	house
610057	660,875	5,167,437	22:24	future trailer home
501068	677,851	5,169,797	21:59	house
610185	670,516	5,167,245	19:02	house
501053	678,555	5,173,259	17:57	foundation
900070	679,567	5,171,280	13:21	house
501012	681,646	5,173,097	13:07	house
610031	660,171	5,167,459	12:16	house
501040	678,406	5,173,332	12:00	house
610098	664,446	5,167,109	10:38	house
501037	679,718	5,171,197	9:59	house
610009	657,243	5,168,249	9:50	house
501050	678,419	5,173,433	7:50	house
501030	679,723	5,174,632	6:58	house
610094	663,473	5,168,761	5:09	no access/approx.
610111	670,742	5,169,632	4:13	house
610014	657,329	5,168,365	3:56	porch
610021	658,588	5,168,791	3:54	house
610139	675,979	5,170,362	3:35	house
610025	659,083	5,169,071	1:20	house
501065	678,822	5,170,399	0:59	old house
500002	680,617	5,158,589	0:00	house
500006	679,633	5,157,936	0:00	house
500012	679,628	5,157,991	0:00	trailer
500018	679,256	5,165,366	0:00	house
500022	677,510	5,165,047	0:00	house
500028	677,401	5,165,136	0:00	house
500035	673,147	5,158,516	0:00	house
500039	671,766	5,158,494	0:00	house
500053	672,221	5,159,146	0:00	house
500059	669,892	5,159,454	0:00	house
500064	669,899	5,159,550	0:00	house
501000	684,105	5,172,245	0:00	trailer house

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
501019	680,468	5,175,745	0:00	house
501022	680,563	5,175,382	0:00	house
501073	681,345	5,169,634	0:00	house
501081	681,279	5,169,706	0:00	house
501082	675,324	5,171,958	0:00	house
501085	672,965	5,164,410	0:00	trailer house
501096	672,947	5,164,396	0:00	old house
501099	675,017	5,163,411	0:00	house
501104	675,027	5,163,439	0:00	garage
501108	670,613	5,160,034	0:00	house
501118	659,777	5,163,091	0:00	house
501122	661,117	5,163,653	0:00	house
501126	663,477	5,163,902	0:00	house
501131	664,747	5,163,175	0:00	house
501138	664,349	5,164,755	0:00	house
501141	665,127	5,163,747	0:00	house
501147	665,442	5,161,863	0:00	house
501156	674,657	5,162,748	0:00	house
610001	657,943	5,169,457	0:00	house
610084	666,867	5,164,930	0:00	trailer home
610089	668,413	5,169,125	0:00	house
610102	669,505	5,169,577	0:00	house
610108	669,518	5,169,514	0:00	house
610149	674,773	5,165,354	0:00	house
610170	667,574	5,164,565	0:00	house
811201	680,019	5,177,169	0:00	house
811205	679,691	5,178,020	0:00	house
811210	680,887	5,178,421	0:00	garage
900002	661,988	5,161,930	0:00	house
900007	662,323	5,161,469	0:00	house
900011	662,065	5,161,089	0:00	house
900015	658,130	5,161,120	0:00	house & garage
900019	658,166	5,161,105	0:00	house
900027	664,500	5,161,670	0:00	house
900031	665,522	5,158,935	0:00	house
900035	665,494	5,159,171	0:00	house
900039	665,496	5,159,110	0:00	house
900047	663,971	5,160,025	0:00	house
900053	664,011	5,160,036	0:00	house

Brady Wind Receptor ID	UTM-E (m)	UTM-N (m)	WindPro Predicted Expected Shadow Flicker (Hours per Year)	Type
900059	665,090	5,160,153	0:00	house
210001	654,902	5,169,176	0:00	house
210002	662,957	5,171,200	0:00	house
210003	664,035	5,171,226	0:00	house
210004	663,967	5,171,255	0:00	house
210005	663,054	5,171,188	0:00	house
210006	667,898	5,171,588	0:00	house
210007	668,756	5,170,679	0:00	house
210008	668,421	5,170,744	0:00	house
210009	666,568	5,170,295	0:00	house
210018	664,088	5,171,362	0:00	house