Shadow Flicker Assessment

Foxtail Wind Energy Center
Foxtail Wind, LLC
Dickey County, North Dakota

Prepared for:

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

Foxtail Wind, a wholly owned, indirect subsidiary of NextEra Energy Resources, LLC (NEER), is submitting an Application for a Certificate of Site Compatibility (Certificate) to construct the Foxtail Wind Energy Center (Project) in Dickey County, in southeastern North Dakota. The Project will be constructed and operated by Northern States Power Company (NSP), a subsidiary of Xcel Energy (Xcel). NEER and NSP/Xcel are collaborating on development of the Project to reflect the engineering and design inputs necessary to transfer ownership of the Project to NSP/Xcel at the end of 2017 according to the executed Purchase & Sale Agreement (PSA). NSP/Xcel currently proposes to construct the Project in two phases between 2018 and 2019. Both the NEER and NSP/Xcel teams will be involved in the engineering design of the Project to be constructed, although NSP/Xcel will ultimately construct the Project.

The Project will have a nameplate capacity of approximately 150 megawatts (MW), consisting of up to 75 wind turbines using both Hybrid Vestas V-116 utility-grade wind turbines and the Vestas V-110 turbine generators, each rated at 2.0 MW. In addition to the 75 primary turbines, up to three alternative turbine locations have also been considered. The alternate turbine locations are proposed to provide siting flexibility based on on-going environmental studies and landowner preferences. Only 75 turbines will be constructed. AECOM has conducted the following shadow flicker analysis for the Project to support Foxtail Wind's application for a Certificate under the North Dakota Public Service Commission.

2.0 PROJECT COMPONENTS

The Project will consist of up to 75 wind turbines (**Figure 1**). The wind turbine technology proposed for this Project is 3-bladed, upwind, horizontal-axis wind turbines that are state of the art technology. The Hybrid Vestas V-116 utility-grade wind turbine has a nominal nameplate rating of 2.0 MW. Each turbine will have an 80-meter (262 feet) hub height and a 116-meter (381 feet) rotor diameter with a swept area of 10,568 m^2. The Vestas V-110 turbine has a nominal nameplate rating of 2.0 MW, an 80-meter hub height, and a 110-meter (361 feet) rotor diameter with a swept area of 9,503 m^2. Both turbines begin operation in wind speeds of 3.0 meters per second (m/s), or 6.7 miles per hour (mph), and are designed to operate in wind speeds of up to 20 m/s (45 mph). The coordinates for the 78 (75 proposed and 3 alternate locations) turbines are listed in **Table 1**. Seven turbines are proposed as the V-110 model and the rest of the turbines are proposed as the V-116 model.

3.0 SHADOW FLICKER BACKGROUND

Shadow flicker is a temporary condition resulting from the sun casting intermittent shadows from the rotating blades of a wind turbine onto a sensitive receptor such as a window in a building. The flicker is due to alternating light intensity between the direct beam of sunlight and the shadow from the turbine blades. For shadow flicker to occur, the following criteria must be met:

1. The sun must be shining and not obscured by any cloud cover.

2. The wind turbine blades must be between the sun and the shadow receptor. The wind turbine must be facing directly towards (or away from) the sun such that the rotational plane of the blades is perpendicular to the azimuth of incident sun rays. For this to occur, the wind direction would have to perpetually be parallel to the azimuth of the incident sun rays throughout the day.

3. The line of sight between the turbine and the shadow receptor must be clear. Light impermeable obstacles, such as trees, buildings or other structures, will prevent or reduce shadow flicker from occurring at the receptor. Terrain can also affect the exposure at a receptor.

4. The receptor has to be close enough to the turbine to be in the shadow. The shadow from a turbine extends furthest when the sun is low in the sky (sunrise and sunset) such that receptors to the east or west of a turbine will be exposed more than receptors to the north and south of a turbine.

5. The turbine is operational and not stationary due to a lack of wind or maintenance activities.

The frequency of shadow flicker is dependent on the wind turbine's rotor blade speed and the number of blades on the rotor. 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.

From a health standpoint, the low flicker frequencies associated with wind turbines, are a nuisance (Frontiers in Public Health 2014). There have been public concerns that flickering light from wind turbines can have negative health effects, such as triggering seizures in people with epilepsy, but these concerns are unfounded. The UK Epilepsy Society states that turbine blades would need to rotate at speeds greater than 3 Hertz (flashes per second) to potentially cause seizures in persons with photosensitive epilepsy (Epilepsy Society 2016); however, turbines on commercial wind farms rotate at speeds of 2 Hertz or less.

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 WINDFARM SHADOW FLICKER ANALYSIS

The shadow flicker analysis for the Project was completed using the WindFarm modelling software. As discussed above, the Project will install up to 75 wind turbines. The 75 proposed locations as well as three alternate locations have been assessed in two scenarios:

- Scenario A: 75 wind turbines (proposed locations only)
- Scenario B: 78 wind turbines (proposed and alternate locations)

WindFarm considers the terrain features determined by U.S. Geological Survey (USGS) Digital Elevation Model (DEM) data, receptor, and turbine locations in the modelling analysis. It is generally accepted that shadow flicker from wind turbines does not occur beyond a certain distance from a wind turbine (Department of Energy and Climate Change 2011). The *Update of UK Shadow Flicker Evidence Base* by Parsons Brinckerhoff, on behalf of the Department of Energy and Climate Change, this distance is equivalent to 10 rotor diameters. AECOM conservatively calculated a maximum distance of 1,380 meters (80 meter hub height plus 58 meter blade times 10). WindFarm also assumes the sun is shining during all daytime hours and that the turbines are always operating. This method produces a theoretical worst case astronomical prediction at each receptor. Hourly meteorological data from the nearby Oakes, North Dakota agricultural weather network station shows that the wind blows predominantly from the northwest or south and that receptors to the east or west of a turbine are less likely to experience shadow flicker (NDAWN 2017).

The orientation of windows at each receptor location will determine what rooms at each receptor would be exposed to shadow flicker. AECOM did not catalogue the number or orientation of windows at each receptor; instead each receptor is assumed to have eight windows (one every 45 degrees) to capture all angles for exposure. The amount of bright sunshine can also affect the frequency and duration of exposure to shadow flicker. **Table 2** summarizes the percentage of bright sunshine (classified as zero or few clouds) at Jamestown Airport, North Dakota, and Aberdeen, South Dakota based on 30-year climatological data (1983 – 2012) from the National Climatic Data Center (NCDC 2017). The average between the two airports during daytime hours is 44.3% bright sunshine. This factor was used to adjust the number of hours when shadow flicker occurs on an annual basis.

The analysis is inherently conservative by assuming 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. Adding to the analysis' conservatism, both the primary and alternate turbines are modeled cumulatively for Scenario B, as Foxtail Wind will only construct up to 75 turbines.

The receptors in this analysis have been classified into two different categories. A total of 50 structures were identified within and near the Project area, 26 of which are considered unlikely to be or unequivocally unoccupied, with the remaining 24 structures considered either inhabited or capable of habitation. Determination of habitation for existing structures was limited to public knowledge and roadside surveys in order to reduce disturbances to non-participating land owners. For purposes of conservatism in this analysis, all structures located on non-participating land that were identified as capable of habitation were considered active residential structures. Receptors that were identified as participating in the Project are associated with the wind farm development via a legal agreement with the owner of the subject property.

5.0 SHADOW FLICKER ANALYSIS RESULTS

The shadow flicker analysis accounts for the placement of turbines, receptors, and sun angle such that the time when the turbine is in between the sun and the receptor is included in the total hours per year that shadow flicker could occur. However, this is a conservative analysis that does not account for maintenance time, wind speeds less than 3 m/s when the turbines will not operate, light permeable obstacles such as trees and other structures, or that the turbine will rarely be directly facing the sun, which will shorten the shadow from the turbine blades. The house number in the study files correspond to the Receptor ID and it was assumed that there are eight windows (located at 0, 45, 90, 135, 180, 225, 270, and 315 degrees from north) at each house located 2 meters high off the ground.

5.1 Scenario A Results

The results of the Scenario A analysis are summarized in **Table 3** and **Table 4** and shown on **Figure 2**. The worst case maximum shadow flicker per year at an occupied receptor is 98.0 hours per year based on annual percentage of sunshine in **Table 2**. The maximum hours of shadow flicker cannot be corrected as there could be 100% sunshine for an entire day.

5.2 Scenario B Results

The results of the Scenario B analysis are summarized in **Table 5** and **Table 6** and shown on **Figure 3**. The worst case maximum shadow flicker per year at an occupied receptor is 98.0 hours per year based on annual percentage of sunshine in **Table 2**. The maximum hours of shadow flicker cannot be corrected as there could be 100% sunshine for an entire day.

The results for occupied and unoccupied receptors for both scenarios are shown in **Appendix A**.

6.0 CONCLUSIONS

As expected, the analysis predicts that shadow flicker impacts will be greatest at locations nearer to the wind turbines. Foxtail Wind has used a minimum setback of three times the turbine height per North Dakota Administrative Code (NDAC) Section 69-06-08-01(2). 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. Predicted shadow flicker impacts are less than the industry standard of 30 hours per year for all occupied residential receptors except one participating landowner (Receptor R07).

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. Foxtail Wind will only construct up to 75 turbines, which is fewer wind turbines than were included in the Scenario B modeled results.

7.0 LITERATURE CITED

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Tables

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Table 1. Wind Turbine Locations

Turbine ID	UTM Coordinates X	UTM Coordinates Y	Turbine ID	UTM Coordinates X	UTM Coordinates Y	Turbine ID	UTM Coordinates X	UTM Coordinates Y
1	505566	5107633	27	507904	5106935	53	510631	5104679
2	505471	5108089	28	508097	5107284	54	511154	5104660
3	505400	5108739	29	508231	5107608	55	511765	5104727
4	505496	5109154	30	508667	5107633	56	512130	5104709
5	505777	5109393	31	509026	5107742	57	512985	5104622
6	506244	5109666	32	509532	5107725	58	509402	5101208
7	506187	5108574	33	510131	5107757	59	509523	5101580
8	506505	5108893	34	510587	5107811	60	510214	5101260
9	507083	5109002	35(1)	511026	5107764	61	510559	5101511
10	507050	5109504	36(1)	511524	5107614	62	510993	5101507
11	507386	5109609	37(1)	512009	5107658	63	511778	5101532
12	507792	5109663	38(1)	512161	5107996	64	509933	5100693
13	508264	5109629	39	508852	5107116	65	510610	5100623
14	508078	5108437	40	509702	5106442	66	511123	5100387
15	508538	5108459	41	510185	5106416	67	511467	5100510
16	509022	5108877	42	510650	5107031	68	509376	5099965
17(1)	509890	5108719	43	511148	5106813	69	509512	5099546
18(1)	510364	5108429	44	511892	5107083	70	510139	5099532
19(1)	511406	5108616	45	509494	5105466	71	510346	5099837
20	505711	5106924	46	509932	5105968	72	509869	5098846
21	506182	5107145	47	510416	5105327	73	510403	5098918
22	506570	5107274	48	511394	5105944	74	509432	5098311
23	506552	5107707	49	509620	5103645	75	509842	5098376
24	506995	5106832	50	509400	5104120	Alt2	511130	5105511
25	507346	5107360	51	509576	5104425	Alt3	510607	5105669
26	507388	5107821	52	510305	5104556	Alt4	510255	5106810

(1) V-110 Turbines. All other turbines are V-116.

Table 2. Percent of Bright Sunshine at Nearby Airports

Hour	% Bright Sunshine (Jamestown, ND)	% Bright Sunshine (Aberdeen, SD)	% Bright Sunshine (Average)
0	0.0	0.0	0.0
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	0.0	0.0	0.0
6	49.6	55.2	52.4
7	49.2	49.1	49.2
8	49.1	47.5	48.3
9	48.0	46.9	47.5
10	46.6	46.5	46.6
11	44.9	44.1	44.5
12	43.4	47.3	45.4
13	41.7	41.2	41.5
14	40.1	40.4	40.3
15	39.7	39.6	39.7
16	40.2	40.1	40.2
17	40.4	40.7	40.6
18	40.6	47.5	44.1
19	39.7	40.7	40.2
20	0.0	0.0	0.0
21	0.0	0.0	0.0
22	0.0	0.0	0.0
23	0.0	0.0	0.0
Daytime Hours (0600-1900)	**43.8**	**44.8**	**44.3**

Table 3. Scenario A Statistical Summary of Predicted Shadow Flicker at Occupied/Possibly Occupied Receptors

Total Shadow Flicker Time (expected)	Number of Receptors
Total	24
= 0 Hours	19
> 0 Hours < 10 Hours	2
> 10 Hours < 20 Hours	2
> 20 Hours < 30 Hours	0
> 30 Hours	1 (Receptor R07)

Table 4. Scenario A Results by Modeled Receptor

WindFarm ID	Receptor ID	Receptor Status: Occupation Status	Receptor Status: Receptor Located on Participating Land?	Nearest Turbine ID	Distance to Nearest Turbine (m)	Modeled Receptor Coordinates (UTM Zone 14, NAD 83): Easting (m)	Modeled Receptor Coordinates (UTM Zone 14, NAD 83): Northing (m)	Adjusted Total Hours of Shadow Flicker per Year
H4	R04	Occupied	No	4	1,198	504718	5110064	9.0
H5	R05	Occupied	No	4	2,353	503234	5109794	0.0
H6	R07	Occupied	Yes	10	415	506666	5109352	98.0
H8	R09	Occupied	No	20	1,140	506262	5105925	0.0
H13	R14	Occupied	No	38	2,142	513814	5109359	0.0
H15	R16	Occupied	No	59	2,832	506811	5102390	0.0
H17	R18	Occupied	No	68	2,059	507343	5100283	0.0
H19	R20	Occupied	No	69	1,051	508485	5099326	7.3
H20	R21	Occupied	No	74	2,328	507782	5096671	0.0
H21	R22	Occupied	Yes	75	1,925	511104	5096921	0.0
H24	R25	Occupied	No	67	1,812	513250	5100181	0.0
H25	R26	Occupied	No	63	785	512553	5101399	10.8
H27	R28	Occupied	No	63	2,252	513886	5102327	0.0
H31	R32	Occupied	Yes	51	413	509571	5104838	19.5
H33	R34	Occupied	No	38	3,651	514856	5110461	0.0
H37	R39	Occupied	No	6	1,137	506421	5110789	0.0
H42	R45	Occupied	No	38	3,318	515481	5108010	0.0
H44	R47	Occupied	No	63	3,185	514720	5100308	0.0
H45	R48	Occupied	No	73	3,106	512740	5096871	0.0
H47	R50	Occupied	No	20	3,294	505944	5103638	0.0
H48	R51	Occupied	No	3	2,174	503289	5108224	0.0
H50	R53	Occupied	No	68	1,906	507481	5100152	0.0
H22	R23	Possibly Occupied	No	73	2,231	512329	5097789	0.0
H28	R29	Possibly Occupied	Yes	57	1,373	513647	5103418	0.0

Table 5. Scenario B Results by Modeled Receptor

WindFarm ID	Receptor ID	Receptor Status		Nearest Turbine ID	Distance to Nearest Turbine (m)	Modeled Receptor Coordinates (UTM Zone 14, NAD 83)		Adjusted Total Hours of Shadow Flicker per Year
		Occupation Status	Receptor Located on Participating Land?			Easting (m)	Northing (m)	
H4	R04	Occupied	No	4	1,198	504718	5110064	9.0
H5	R05	Occupied	No	4	2,353	503234	5109794	0.0
H6	R07	Occupied	Yes	10	415	506666	5109352	98.0
H8	R09	Occupied	No	20	1,140	506262	5105925	0.0
H13	R14	Occupied	No	38	2,142	513814	5109359	0.0
H15	R16	Occupied	No	59	2,832	506811	5102390	0.0
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H21	R22	Occupied	No	75	1,925	511104	5096921	0.0
H24	R25	Occupied	No	67	1,812	513250	5100181	0.0
H25	R26	Occupied	No	63	785	512553	5101399	10.8
H27	R28	Occupied	No	63	2,252	513886	5102327	0.0
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H33	R34	Occupied	No	38	3,651	514856	5110461	0.0
H37	R39	Occupied	No	6	1,137	506421	5110789	0.0
H42	R45	Occupied	No	38	3,318	515481	5108010	0.0
H44	R47	Occupied	No	63	3,185	514720	5100308	0.0
H45	R48	Occupied	No	73	3,106	512740	5096871	0.0
H47	R50	Occupied	No	20	3,294	505944	5103638	0.0
H48	R51	Occupied	No	3	2,174	503289	5108224	0.0
H50	R53	Occupied	No	68	1,906	507481	5100152	0.0
H22	R23	Possibly Occupied	No	73	2,231	512329	5097789	0.0
H28	R29	Possibly Occupied	Yes	57	1,373	513647	5103418	0.0

Table 6. Scenario B Statistical Summary of Predicted Shadow Flicker at Occupied/Possibly Occupied Receptors

Total Shadow Flicker Time (expected)	Number of Receptors
Total	24
= 0 Hours	19
> 0 Hours < 10 Hours	2
> 10 Hours < 20 Hours	2
> 20 Hours < 30 Hours	0
> 30 Hours	1 (Receptor R07)

Figures

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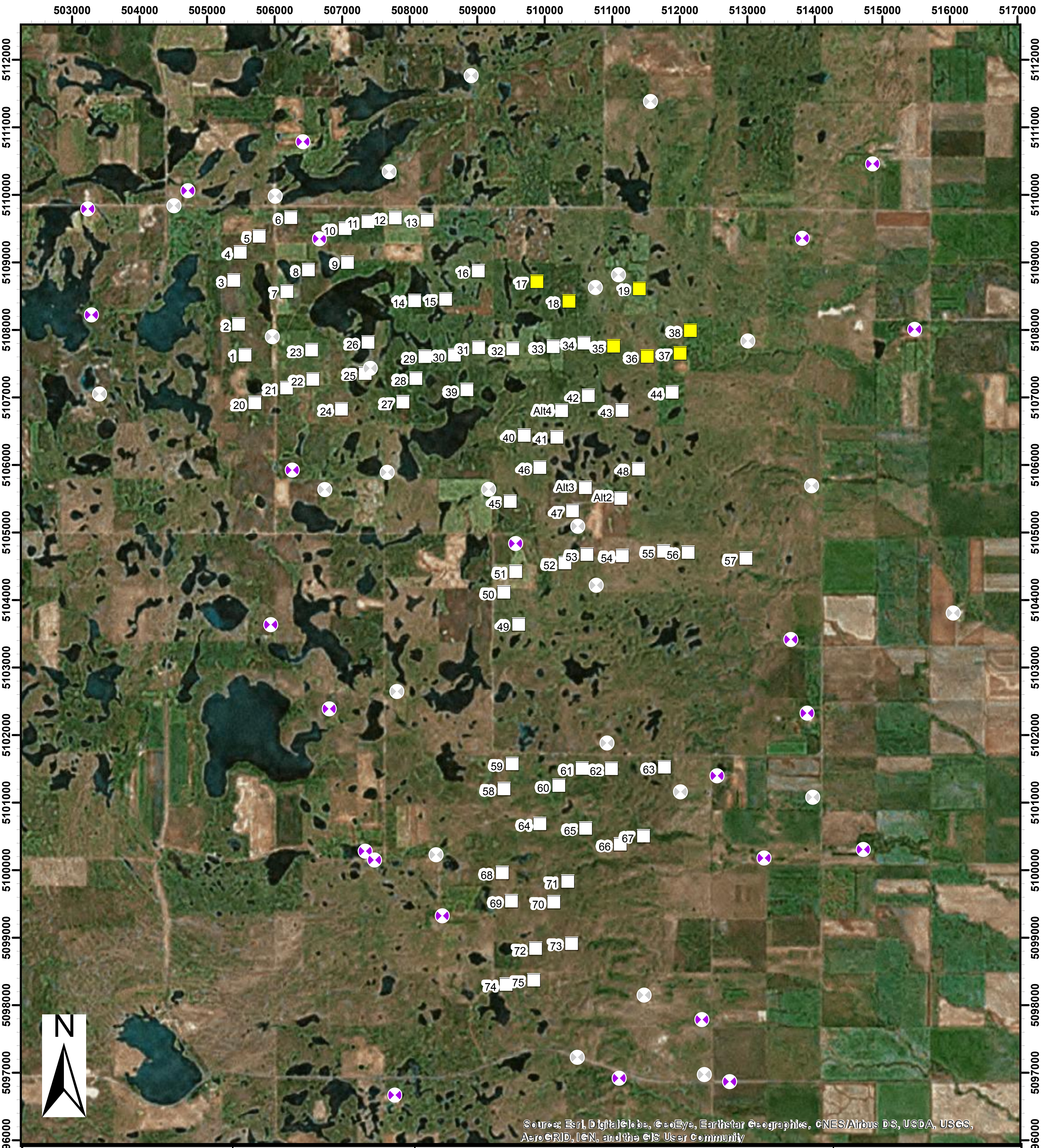

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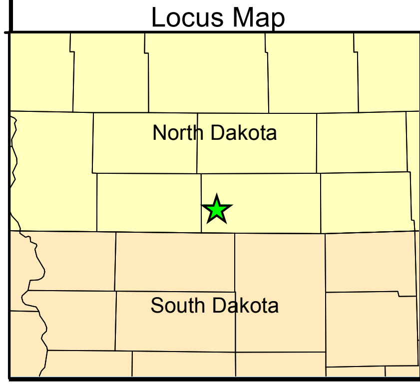

Legend
- Turbine (V-116)
- Turbine (V-110)
- Occupied/Possibly Occupied Receptor
- Unoccupied Receptor

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Foxtail Wind Energy Center
Figure 1
Wind Turbine and Receptor Locations

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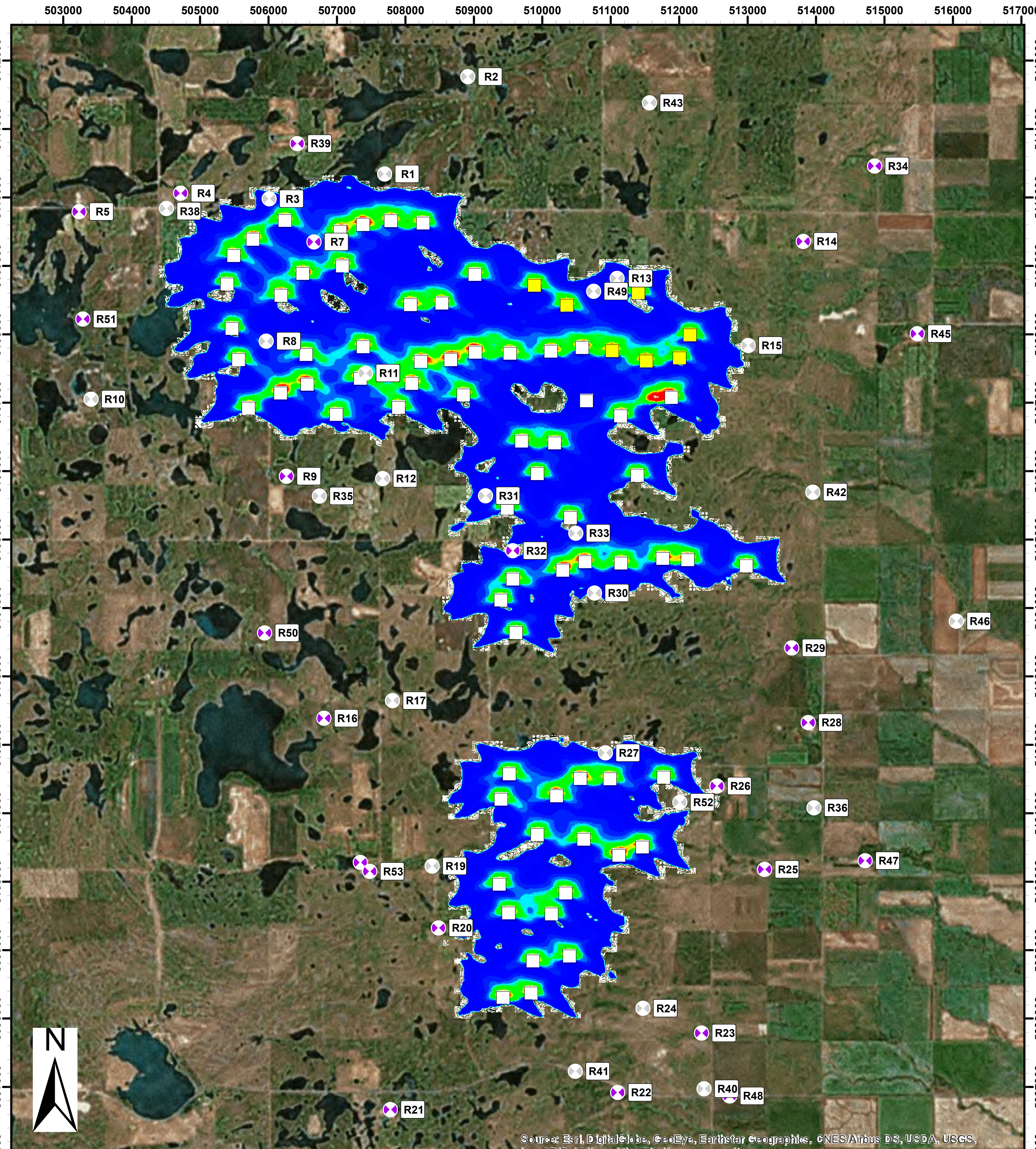
Scale 0 1 2 4 6 8 Kilometers



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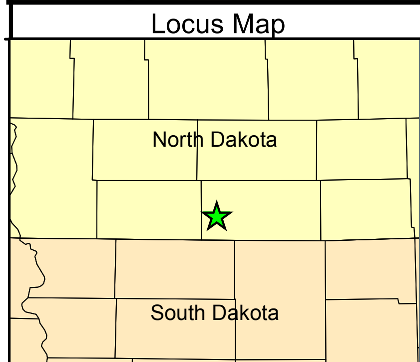

Legend
- Turbine (V-116)
- Turbine (V-110)
- Occupied/Possibly Occupied Receptor
- Unoccupied Receptor

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Foxtail Wind Energy Center
Figure 2
Predicted Shadow Flicker for Scenario A

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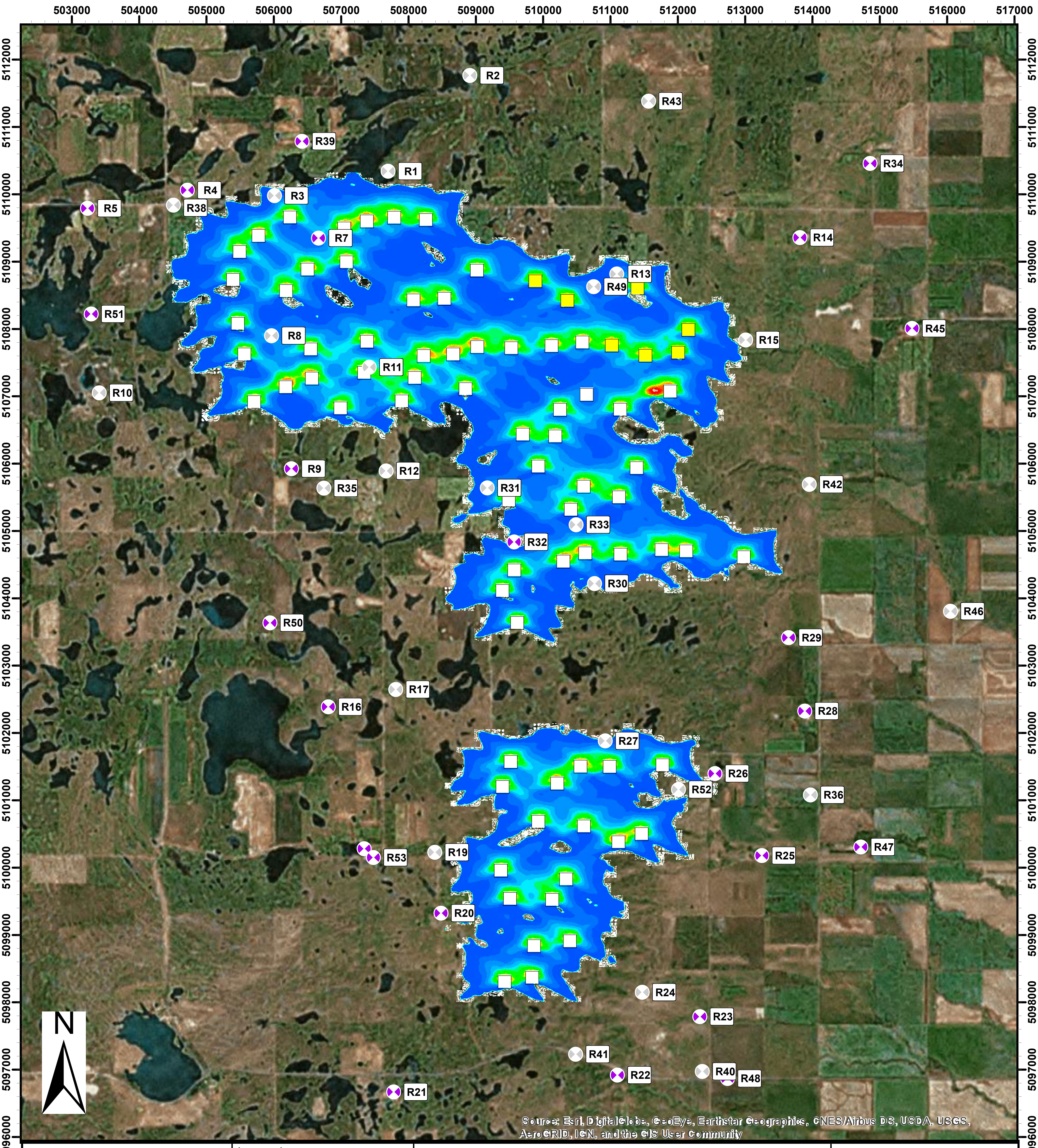
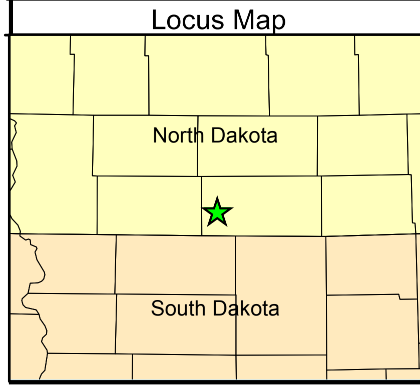
AECOM

Scale 0 1 2 4 6 8 Kilometers



Locus Map



Legend

- Turbine (V-116)
- Turbine (V-110)
- Occupied/Possibly Occupied Receptor
- Unoccupied Receptor

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Foxtail Wind Energy Center
Figure 3
Predicted Shadow Flicker
for Scenario B

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Scale 0 1 2 4 6 8 Kilometers

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Appendix A

Detailed Shadow Flicker Results

Scenario A and B Shadow Flicker Results

WindFarm ID	Receptor ID	Receptor Status: Occupation Status	Receptor Status: Receptor Located on Participating Land?	Nearest Turbine ID	Distance to Nearest Turbine (m)	Modeled Receiver Coordinates (UTM Zone 14, NAD 83): Easting (m)	Modeled Receiver Coordinates (UTM Zone 14, NAD 83): Northing (m)	Total Adjusted Hours per Year
H4	R04	Occupied	No	4	1,198	504718	5110064	9.0
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H28	R29	Possibly Occupied	Yes	57	1,373	513647	5103418	0.0

Scenario A and B Shadow Flicker Results

WindFarm ID	Receptor ID	Receptor Status: Occupation Status	Receptor Status: Receptor Located on Participating Land?	Nearest Turbine ID	Distance to Nearest Turbine (m)	Modeled Receiver Coordinates (UTM Zone 14, NAD 83): Easting (m)	Modeled Receiver Coordinates (UTM Zone 14, NAD 83): Northing (m)	Total Adjusted Hours per Year
H1	R01	Not occupied	No	12	688	507698	5110344	5.7
H2	R02	Not occupied	No	13	2,234	508912	5111767	0.0
H3	R03	Not occupied	No	6	394	506010	5109982	57.5
H7	R08	Not occupied	No	1	482	505968	5107901	108.5
H9	R10	Not occupied	No	1	2,236	503409	5107053	0.0
H10	R11	Not occupied	Yes	25	102	507419	5107433	430.0
H11	R12	Not occupied	Yes	27	1,067	507669	5105894	0.0
H12	R13	Not occupied	Yes	19	373	511095	5108819	61.7
H14	R15	Not occupied	No	38	863	513011	5107838	23.7
H16	R17	Not occupied	Yes	59	2,018	507813	5102648	0.0
H18	R19	Not occupied	No	68	1,020	508393	5100230	11.1
H23	R24	Not occupied	No	73	1,315	511472	5098151	0.0
H26	R27	Not occupied	No	62	384	510924	5101885	43.5
H29	R30	Not occupied	Yes	53	477	510765	5104221	37.0
H30	R31	Not occupied	No	45	368	509172	5105641	66.1
H32	R33	Not occupied	Yes	47	243	510491	5105095	41.7
H34	R35	Not occupied	No	24	1,121	506744	5105637	0.0
H35	R36	Not occupied	No	63	2,238	513971	5101082	0.0
H36	R38	Not occupied	No	4	1,202	504511	5109841	10.3
H38	R40	Not occupied	No	73	2,760	512365	5096976	0.0
H39	R41	Not occupied	Yes	75	1,313	510484	5097231	0.0
H40	R42	Not occupied	Yes	57	1,444	513954	5105695	0.0
H41	R43	Not occupied	Yes	19	2,773	511567	5111384	0.0
H43	R46	Not occupied	No	57	3,171	516052	5103810	0.0
H46	R49	Not occupied	Yes	18	436	510752	5108630	52.1
H49	R52	Not occupied	Yes	63	437	512011	5101162	7.8