Appendix C – Shadow Flicker Assessment

Final Report
Freeborn Wind Farm
Shadow Flicker Study
Freeborn County, MN

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Executive Summary

EAPC was hired by Merjent to provide estimates of the shadow flicker potential for a proposed wind turbine layout for the Freeborn Wind Energy project in southern Minnesota. Locations of area dwellings and a wind turbine layout were provided to EAPC by the client. A windPRO model was built combining digital elevation data with the information supplied to generate a shadow flicker model for the site. The resulting model was then used to perform shadow flicker calculations for the area. Based on the shadow flicker calculation, a site-wide realistic shadow flicker map was produced and an evaluation of the shadow flicker at all 254 area dwellings within two kilometers of any proposed turbine location was performed.

The 254 dwellings were represented in the model by omni-directional shadow receptors that simulate a 1 m x 1 m window 1 m above ground level. Reductions based on turbine operational time, turbine operational direction, and sunshine probabilities were used to calculate a realistic number of hours of shadow flicker to be expected at each shadow receptor. No obstacles were used so that shadow flicker reductions due to interference from trees and structures were not included, meaning that the "realistic" estimates are still conservative.

The number of occupied residences registering more than 30 hours per year was 7, ranging from 30 hours to 45 hours and 23 minutes.

1. INTRODUCTION

Merjent hired EAPC to conduct a shadow flicker analysis for the potential wind turbine layout located in southern Minnesota near the town of Myrtle. The layout consists of a mix of Vestas V116 2.0 and V110 2.0 turbines. The turbine model used for the study was the Vestas V116 2.0 with an 80 meter hub height for all turbine locations, which will yield a slightly more conservative result due to the smaller rotor on the V110 turbines being modeled as V116's. One array comprised of 50 wind turbines was analyzed (42 in Minnesota and 8 across the border in Iowa).

Coordinates for 254 dwellings which could potentially experience shadow flicker from the proposed wind farm were also supplied by the client.

2. BACKGROUND

Shadow flicker from wind turbines occurs when rotating wind turbine blades move between the sun and the observer. Shadow flicker is generally experienced in areas near wind turbines where the distance between the observer and wind turbine blade is short enough that sunlight has not been significantly diffused by the atmosphere. When the blades rotate, this shadow creates a pulsating effect, known as shadow flicker. If the blade's shadow is passing over the window of a building, it will have the effect of increasing and decreasing the light intensity in the room at a low frequency in the range of 0.5 to 1.2 Hz, hence the term "flicker." In this case, with a maximum rotation speed of 14.88 rpm for the V116, the frequency would be 0.75 Hz. This flickering effect can also be experienced outdoors, but the effect is typically less intense, and becomes less intense when farther from the wind turbine causing the flicker. The moving shadow of a wind turbine blade on the ground is similar to the effect one experiences when driving on a road when there are shadows cast across the road by an adjacent row of trees.

This flickering effect is most noticeable within approximately 1,000 meters of the turbine, and becomes more and more diffused as the distance increases. There are no uniform standards defining what distance from the turbine is regarded as an acceptable limit beyond which the shadow flicker is considered to be insignificant. The same applies to the number of hours of flickering that is deemed to be acceptable.

Shadow flicker is typically greatest in the winter months when the angle of the sun is lower and casts longer shadows. The effect is also more pronounced around sunrise and sunset when the sun is near the horizon and the shadows are longer. A number of factors influence the amount of shadow flicker on the shadow receptors. One consideration is the environment around the shadow receptor. Obstacles such as terrain, trees or buildings between the wind turbine and the receptor can significantly reduce or eliminate shadow flicker effects. Deciduous trees may block the shadow flickering effect to some degree, depending on the tree density, species present and time of year. Deciduous trees can lead to a reduction of shadow flicker during the summer when the trees are bearing leaves. However, during the winter months, these trees are without their leaves and their

impact on shadow flicker is not as significant. Coniferous trees tend to provide mitigation from shadow flicker year round. For this study, no credit was taken for any potential shading effects from any type of trees or other obstacles that would reduce the number of shadow flickering hours at the structures.

Another consideration is the time of day when shadow flicker occurs. For example, it may be more acceptable for private homes to experience the shadow flickering during daytime hours when family members may be at work or school. Likewise, a commercial property would not be significantly affected if all the shadow flicker impact occurred before or after business hours.

The climate also needs be considered when assessing shadow flicker. In areas with a significant amount of overcast weather, there would be less shadow flicker, as there are no shadows if the sun is blocked by clouds. Also, if the wind is not blowing, the turbines would not be operational and therefore not creating shadow flickering.

3. STUDY METHODOLOGY

This shadow flicker analysis was performed utilizing windPRO[1], a sophisticated wind modeling software program. windPRO has the ability to calculate detailed shadow flicker maps across an entire area of interest or at site-specific locations using shadow receptors.

Shadow maps which indicate where the shadows will be cast and for how long, are generated using windPRO, calculating the shadow flicker in varying user-defined resolutions. Standard resolution was used for this study and represents shadow flicker being calculated every three minutes of every day over the period of an entire year over a grid with a 20 m by 20 m resolution.

In addition to generating a shadow flicker map, the amount of shadow flicker that may occur at a specific point can be calculated more precisely by placing a shadow receptor at the location of interest and essentially "recording" the shadow flicker that occurs as the relative sunrise to sunset motion of the sun is simulated throughout an entire year.

The point-specific shadow flicker calculation is run at a higher resolution as compared to the shadow flicker map calculation to include the highest precision possible within windPRO. Shadow flicker at each shadow receptor location is calculated every minute of every day for an entire year. Shadow receptors can be configured to represent an omni-directional window of a specific size at a specific point (greenhouse mode) or a window facing a single direction of a specific size at a specific point (single direction mode). The shadow receptors used in this analysis were configured as greenhouse-mode receptors

[1] windPRO is the world's leading software tool for wind farm design including shadow flicker analysis.

representing a 1 m x 1 m window located 1 m above ground level. This represents more of a "worst-case" scenario and thus will produce more conservative results.

As a part of the calculation method, windPRO must determine whether or not a turbine will be visible at the receptor locations and not blocked by local topography or obstacles. It does this by performing a preliminary Zones of Visual Influence (ZVI) calculation, utilizing 10 m grid spacing. If a particular turbine is not visible within the 10 m x 10 m area that the shadow receptor is contained within, then that turbine is not included in the shadow flicker calculation for that receptor.

The maximum distance limit for which shadow flicker should be counted was set to 2,000 meters. Any shadow flicker contributions from turbines within this distance limit are added to the total for each receptor.

The inputs for the windPRO shadow flicker calculation include the following:

- Turbine Coordinates
- Turbine Specifications
- Shadow Receptor Coordinates
- Monthly Sunshine Probabilities
- Joint Wind Speed and Direction Frequency Distribution
- USGS Digital Elevation Model (DEM) (height contour data)
- Existing Turbines

A description of each input variable and how they affect the shadow flicker calculation are included below.

Turbine Coordinates: The location of a wind turbine in relation to a shadow receptor is one of the most important factors in determining shadow flicker impacts. A line-of-site is required for shadow flicker to occur. The intensity of the shadow flicker is dependent upon the distance from the wind turbine and weather conditions.

Turbine Specifications: A wind turbine's total height and rotor diameter will be included in the windPRO shadow flicker model. The taller the wind turbine, the more likely shadow flicker could have an impact on local shadow receptors as the ability to clear obstacles (such as hills or trees) is greater, although in this analysis, no credit is taken for any such blockage from trees. The larger the rotor diameter is, the wider the area where shadows will be cast. Also included with the turbine specifications are the cut-in and cut-out wind speeds within which the wind turbine is operational. If the wind speed is below the cut-in threshold or above the cut-out threshold, the turbine rotor will not be spinning and thus shadow flicker will not occur. The specifications for the Vestas V116 2.0 wind turbine model used in this study are included in Table 1 below. While the project will also utilize some V110 turbines, this analysis assumes all turbines are V116's, making it a more

conservative estimate of shadow flicker. Due to the smaller rotor diameter, the V110s shadow flicker effects will be less than the V116.

Table 1: Freeborn Wind Turbine Specifications.

Freeborn Wind - Shadow Modeled Turbine Specifications					
Manufacturer	**Model**	**Hub Height (m)**	**Rotor Diameter (m)**	**Cut-In Wind Speed (m/s)**	**Cut-Out Wind Speed (m/s)**
Vestas	V116	80	116	3	20

Shadow Receptor Coordinates: As with the wind turbine coordinates, the elevation, distance and orientation of a shadow receptor in relation to the wind turbines and the sun are the main factors in determining the impact of shadow flicker. EAPC was provided with coordinates for 254 structures found to be located within two kilometers of the 42 proposed wind turbine locations.

Monthly Sunshine Probabilities: windPRO calculates sunrise and sunset times to determine the total annual hours of daylight for the modeled area. To further refine the shadow flicker calculations, the monthly probability of sunshine is included to account for cloud cover. The greater the probability of cloud cover, the less of an impact from shadow flicker. The monthly sunshine probabilities for many of the larger cities across the United States are available from the National Climatic Data Center (NCDC). For this study, 18 years' worth of monthly sunshine probability data were retrieved for Minneapolis, MN, which was the closest, most representative station, to create the long-term representative monthly sunshine probabilities. The long-term representative monthly average sunshine probabilities are presented in Table 2.

Table 2: Minneapolis, MN monthly sunshine probabilities.

Minneapolis, MN Monthly Sunshine Probabilities (1965-1983)												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunshine %	53%	59%	57%	56%	62%	67%	74%	69%	62%	51%	37%	38%
retrieved from: http:// http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos15.dat												

Joint Wind Speed and Direction Frequency Distribution: A set of long-term corrected wind distributions generated from an on-site meteorological mast was provided by the client to represent the annual wind speed and direction distribution for the project site. This data was used to estimate the probable number of operational hours for the wind turbines from each of the 12 wind direction sectors. During operation, the wind turbine rotors will always be assumed to face into the wind and automatically orient themselves as the wind direction changes. Shadow flicker can only occur when the blades are turning and the wind turbine rotor is between the sun and the receptor. Shadow flicker is most significant when the rotor is facing the sun.

USGS Digital Elevation Model (DEM) (height contour data): For this study, 10 m USGS National Elevation Database (NED) DEM's were used to construct 10-foot interval height

contour lines for the windPRO shadow flicker model. The height contour information is important to the shadow flicker calculation since it allows the model to place the wind turbines and the shadow receptors at the correct elevations. The height contour lines also allow the model to include the topography of the site when calculating the zones of visual influence surrounding the wind turbine and shadow receptor locations.

The actual calculation of potential shadow flicker at a given shadow receptor is carried out by simulating the environment near the wind turbines and the shadow receptors. The position of the sun relative to the turbine rotor disk and the resulting shadow is calculated in time steps of one minute throughout an entire year. If the shadow of the rotor disk (which in the calculation is assumed solid) at any time casts a shadow on a receptor window, then this step will be registered as one minute of shadow flicker. The calculation also requires that the sun must be at least 3.0° above the horizon in order to register shadow flicker. When the sun angle is less than 3.0°, the shadow quickly becomes too diffuse to be distinguished as the amount of atmosphere that the light must pass through is 15 times greater than when the sun is directly overhead.

The sun's path with respect to each wind turbine location is calculated by the software to determine the paths of cast shadows for every minute of every day over a full year. The turbine runtime and direction are calculated from the site's long-term wind speed and direction distribution. Finally, the effects of cloud cover are calculated using long-term reference data (monthly sunshine probability) to arrive at the projected annual flicker time at each receptor.

4. *SITE OVERVIEW*

The area of interest is located in Freeborn County near the town of Myrtle in southern Minnesota. The surrounding terrain has a change in elevation across the project site ranging from 369 meters to 393 meters (1,210 feet to 1,290 feet). The regions vegetation is comprised primarily of agricultural land. The area also has a number of existing wind energy projects currently in operation.

5. *RESULTS OF ANALYSIS*

The term "realistic" as used in this report means that turbine operational hours and direction as well as local sunshine probabilities have been factored in, but no blocking or shading effects due to trees or structures have been accounted for. This means that the "realistic" estimates are still inherently conservative values. Also, the realistic shadow flicker hours predicted by windPRO assumes an availability factor of 100% which is very unlikely to be the case. Freeborn Wind expects actual availability factors will be 95-98%, but, with a conservative approach to estimating shadow flicker totals, the realistic estimates are not discounted accordingly.

A total of 254 residential structures within the project vicinity were analyzed and standard resolution realistic shadow flicker maps and individual maps were generated for each turbine array.

The 254 shadow receptors were then modeled as greenhouse-mode receptors and the estimated shadow flicker was calculated for the array using a 2,000 meter distance limit. Of the 254 receptors, the number that registered no shadow flicker hours was 141 (55%).

Table 3 contains the shadow flicker distribution of the 254 residential structures within 2,000 meters of any turbine location along with a breakdown of how many are non-participating.

Table 3: Residential structures realistic shadow flicker distribution

Realistic Shadow Flicker (hrs/year)	Vestas V116 2.0-80	
	Total # structures	# non-participating
0	141	106
0 to 5	64	42
5 to 10	16	9
10 to 15	8	2
15 to 20	11	5
20 to 25	5	5
25 to 30	2	1
30+	7	4

6. *CONCLUSIONS*

The conservative results of this study indicate that, of the 254 receptors modeled, three measured more than 30 hours per year at participating landowners' occupied residences with four measuring over 30 hours per year at non-participating landowners' occupied residences. The shadow flicker impact on the receptors was calculated from turbines within 2,000 meters with reductions due to turbine operational direction and sunshine probabilities included. This shadow flicker analysis is based on a number of conservative assumptions including:

- No credit was taken for the blocking effects of trees or buildings.
- The receptors were omni-directional rather than modeling specific facades of buildings.

The overall effect of using these conservative assumptions indicate that realistically, the number of hours of shadow flicker that would be observed will be less than those predicted by this study.

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Report Update

EAPC bears no responsibility to update this report for any changes occurring subsequent to the final issuance of this report.

Revision History

Revision No.	Revision Purpose	Date	Revised By
0	Original	5/31/2017	J. Haley

APPENDIX A: WIND TURBINE COORDINATES

Freeborn
V116 2.0-80 WTG Layout
UTM NAD83 Zone 15

WTG	Easting (m)	Northing (m)	Elevation AMSL (m)
3	487,247	4,832,825	381.8
4	489,056	4,833,446	384
6	484,004	4,830,617	381
7	485,113	4,830,489	381
8	486,717	4,831,330	381.1
9	487,241	4,831,317	384
11	489,833	4,831,840	387
12	490,469	4,831,839	386.1
13	485,425	4,829,628	384
14	485,788	4,829,695	384
16	490,164	4,831,189	385
17	490,522	4,830,572	384
18	484,510	4,827,756	383.5
19	484,265	4,827,106	384.1
20	483,581	4,823,771	382.7
21	483,960	4,823,928	384
22	479,426	4,821,633	372
23	480,104	4,821,522	382.5
24	482,852	4,821,909	383
25	480,494	4,820,188	387.8
26	481,859	4,819,789	390
27	482,528	4,819,780	393
28	487,432	4,820,561	374
29	488,362	4,819,958	372
30	489,983	4,819,704	378
31	490,675	4,820,134	375
32	493,766	4,820,864	366
33	494,074	4,821,063	363
34	494,648	4,821,310	363
37	484,905	4,818,449	381.7
38	486,855	4,818,414	375.3
39	487,344	4,818,521	375
40	488,572	4,818,424	372
41	488,991	4,818,572	374.8
42	489,927	4,818,322	376.5
43	490,247	4,818,593	378
44	490,576	4,818,879	377.7
45	484,890	4,816,488	375.9
46	485,179	4,816,948	375.3
47	486,502	4,816,891	377.6
48	486,789	4,817,202	375.2

Freeborn
V116 2.0-80 WTG Layout
UTM NAD83 Zone 15
continued

WTG	Easting (m)	Northing (m)	Elevation AMSL (m)
49	488,270	4,816,483	375
201	487,607	4,815,875	372
204	486,303	4,815,858	376.9
208	490,686	4,815,722	368.7
212	485,930	4,815,697	375
213	485,548	4,815,465	378
215	488,455	4,815,708	372
218	489,041	4,815,714	369
315	487,251	4,815,708	372

APPENDIX B: SHADOW RECEPTOR COORDINATES & REALISTIC SHADOW HOURS

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
52	Non-Participant	491,123.15	4,834,254.35	387.3	0:00
53	Non-Participant	491,241.93	4,834,213.05	387.4	0:00
54	Non-Participant	490,749.64	4,834,865.83	387.0	0:00
55	Non-Participant	490,708.04	4,834,733.98	387.0	0:00
56	Non-Participant	490,414.36	4,834,881.43	387.0	0:00
57	Non-Participant	490,353.75	4,834,700.94	387.0	0:00
58	Non-Participant	489,695.42	4,834,897.59	384.0	0:00
59	Non-Participant	489,611.05	4,834,901.79	384.0	0:00
60	Non-Participant	489,297.75	4,834,976.71	387.0	0:00
61	Non-Participant	489,200.99	4,834,880.85	384.0	0:00
62	Non-Participant	489,095.27	4,834,878.01	384.0	0:00
63	Non-Participant	488,872.72	4,834,743.01	384.0	0:00
64	Non-Participant	488,546.96	4,834,785.37	384.0	0:00
65	Non-Participant	488,402.71	4,834,902.97	384.0	0:00
66	Non-Participant	487,727.73	4,834,885.50	384.0	0:00
67	Non-Participant	487,110.60	4,834,670.39	387.0	0:00
68	Non-Participant	486,699.94	4,834,669.48	390.0	0:00
69	Non-Participant	486,453.75	4,833,834.60	384.0	0:00
70	Non-Participant	485,711.70	4,832,179.71	381.0	3:17
71	Non-Participant	485,736.63	4,832,667.14	381.0	0:58
72	Non-Participant	487,896.57	4,832,301.66	390.3	0:18
73	Non-Participant	487,929.62	4,832,232.14	390.7	1:37
74	Non-Participant	487,999.40	4,833,133.39	390.0	8:03
75	Non-Participant	488,002.98	4,833,156.28	389.3	7:54
76	Participant	487,929.49	4,833,979.89	389.6	2:01
77	Participant	488,159.28	4,833,937.56	389.7	3:49
78	Non-Participant	487,703.95	4,832,994.94	390.0	16:21
79	Non-Participant	490,705.79	4,834,021.92	390.9	0:00
80	Non-Participant	490,667.26	4,833,970.60	390.0	0:00
81	Participant	491,227.31	4,833,962.15	393.0	0:00
82	Non-Participant	491,226.47	4,833,797.43	391.1	0:00
83	Non-Participant	491,097.22	4,833,803.34	391.9	0:00
84	Participant	491,371.38	4,832,825.45	384.0	0:00
85	Participant	490,881.93	4,832,287.35	387.0	8:29
86	Participant	490,127.39	4,832,569.03	393.0	0:00
87	Participant	489,445.42	4,832,495.30	389.8	3:03
88	Participant	489,251.97	4,832,379.16	387.0	9:19
89	Non-Participant	488,643.01	4,832,486.60	390.0	2:55
90	Participant	487,807.67	4,831,759.15	390.0	11:58

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
91	Participant	488,305.53	4,831,307.25	390.0	3:40
92	Participant	488,025.27	4,830,990.60	390.0	16:37
93	Participant	488,742.25	4,830,847.36	396.0	1:50
94	Participant	489,027.17	4,830,750.93	393.0	3:41
95	Non-Participant	489,119.50	4,830,895.23	388.0	4:24
96	Participant	489,845.51	4,830,871.29	384.0	8:27
97	Non-Participant	491,644.47	4,830,960.95	384.0	3:01
98	Non-Participant	491,882.26	4,830,026.01	379.7	2:26
104	Non-Participant	491,425.20	4,829,146.63	381.0	0:00
105	Non-Participant	490,812.63	4,829,139.30	378.0	0:00
106	Non-Participant	490,347.76	4,829,156.99	381.1	0:00
107	Non-Participant	489,534.37	4,829,244.89	389.8	0:00
108	Non-Participant	489,844.38	4,828,725.17	388.8	0:00
109	Non-Participant	489,338.33	4,829,061.40	389.2	0:00
110	Non-Participant	488,613.46	4,829,366.84	387.9	0:00
111	Participant	487,587.70	4,829,959.51	391.9	0:00
112	Participant	488,447.41	4,830,073.94	393.0	0:00
113	Non-Participant	487,565.67	4,830,393.37	393.0	0:00
114	Participant	487,743.93	4,830,937.50	390.0	4:41
115	Non-Participant	486,656.54	4,830,605.74	384.0	2:01
116	Participant	486,310.06	4,829,680.27	386.5	18:29
117	Non-Participant	486,435.35	4,829,125.38	389.0	9:50
118	Non-Participant	486,678.04	4,829,278.05	387.0	15:34
119	Participant	487,527.40	4,829,082.74	389.4	0:00
120	Non-Participant	487,871.02	4,829,342.90	386.2	0:00
122	Participant	486,409.12	4,827,770.02	387.0	0:00
123	Non-Participant	486,379.87	4,828,148.20	384.0	0:00
124	Non-Participant	486,125.35	4,827,902.78	389.3	0:34
125	Non-Participant	486,064.35	4,827,547.23	390.0	0:44
127	Participant	486,310.36	4,828,379.94	386.5	0:00
128	Non-Participant	486,394.76	4,828,457.37	384.0	0:00
129	Participant	485,993.08	4,829,249.94	387.0	0:08
130	Non-Participant	484,448.10	4,829,649.13	384.0	4:27
131	Participant	484,601.60	4,830,442.75	381.0	40:28
132	Participant	484,706.45	4,831,066.19	381.0	6:14
133	Non-Participant	483,497.85	4,830,757.15	381.0	16:19
134	Non-Participant	482,567.17	4,830,728.83	381.0	1:09
143	Participant	482,881.74	4,828,998.71	381.0	0:00

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
144	Non-Participant	483,315.98	4,829,217.54	381.2	0:00
145	Non-Participant	483,455.02	4,829,144.60	383.8	0:00
146	Non-Participant	483,580.39	4,829,459.16	381.0	0:00
147	Non-Participant	482,672.03	4,830,086.02	381.0	2:02
157	Non-Participant	478,805.82	4,821,087.46	369.0	2:29
158	Participant	478,664.43	4,821,178.37	369.0	4:37
159	Non-Participant	478,647.12	4,821,112.56	369.0	1:33
160	Non-Participant	478,269.39	4,821,160.64	371.1	3:31
161	Non-Participant	478,097.73	4,821,320.15	369.3	1:41
162	Non-Participant	477,938.79	4,821,351.61	372.0	1:02
163	Non-Participant	477,446.49	4,821,472.33	378.0	0:00
164	Non-Participant	477,497.07	4,821,175.76	372.0	0:00
165	Non-Participant	478,205.31	4,821,084.62	369.2	3:33
166	Non-Participant	478,270.15	4,820,910.22	370.3	0:04
169	Non-Participant	478,677.58	4,819,587.54	372.0	0:00
170	Non-Participant	478,722.33	4,819,550.94	370.8	0:00
183	Non-Participant	490,036.52	4,816,332.37	368.7	6:34
186	Non-Participant	489,569.19	4,816,363.33	366.6	6:07
188	Participant	488,365.48	4,816,989.51	372.9	0:53
189	Participant	487,425.11	4,816,361.88	377.4	15:11
190	Non-Participant	486,385.80	4,816,496.91	375.0	5:49
194	Participant	482,988.83	4,816,361.50	384.0	0:00
197	Non-Participant	481,231.87	4,817,992.25	387.0	0:00
198	Participant	480,912.06	4,817,974.60	384.2	0:00
199	Participant	480,808.87	4,817,981.68	384.0	0:00
202	Participant	479,835.67	4,818,613.97	379.3	0:00
203	Non-Participant	479,817.51	4,819,314.12	379.1	0:00
204	Non-Participant	479,816.45	4,819,887.61	381.0	18:04
205	Participant	481,387.94	4,819,516.00	390.0	11:48
206	Non-Participant	481,529.19	4,818,591.73	387.0	0:00
207	Participant	481,510.64	4,819,469.39	389.3	4:11
208	Non-Participant	479,919.60	4,818,496.63	378.1	0:00
209	Participant	480,843.89	4,819,595.90	392.6	3:27
210	Non-Participant	482,125.01	4,817,998.55	387.0	0:00
211	Non-Participant	482,314.07	4,817,878.95	387.0	0:00
212	Participant	482,517.87	4,817,958.33	387.0	0:00
213	Non-Participant	483,193.45	4,816,759.08	384.0	0:00
214	Participant	483,202.77	4,817,284.22	387.0	0:00

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
215	Participant	483,073.07	4,818,358.10	389.8	0:00
216	Non-Participant	483,174.49	4,818,814.06	390.0	0:00
217	Participant	483,142.74	4,820,544.16	387.0	1:08
218	Non-Participant	481,832.04	4,821,123.15	390.0	1:15
219	Non-Participant	481,768.22	4,821,490.14	390.1	4:00
220	Participant	481,504.94	4,820,122.46	392.7	30:52
221	Non-Participant	480,777.76	4,821,245.63	393.0	22:34
222	Participant	480,813.67	4,820,952.79	396.0	1:11
223	Participant	479,901.51	4,821,098.94	377.0	0:00
224	Participant	479,892.21	4,820,682.07	376.9	13:07
225	Non-Participant	479,820.41	4,820,309.37	377.3	9:23
227	Participant	479,805.59	4,821,315.76	375.9	0:00
228	Non-Participant	479,810.15	4,821,948.31	377.5	24:02
229	Participant	479,879.69	4,821,931.52	379.5	16:05
230	Participant	479,903.61	4,822,170.56	380.0	0:00
231	Non-Participant	479,813.69	4,822,791.85	373.9	0:00
232	Non-Participant	479,887.65	4,822,797.42	374.6	0:00
233	Participant	479,820.91	4,822,863.18	372.9	0:00
234	Non-Participant	479,896.04	4,823,328.27	379.2	0:00
235	Non-Participant	479,376.19	4,822,736.46	372.0	0:00
236	Non-Participant	479,220.98	4,822,953.69	375.0	0:00
237	Non-Participant	479,140.54	4,822,922.44	370.6	0:00
238	Non-Participant	478,974.57	4,823,097.87	372.0	0:00
240	Non-Participant	478,768.59	4,823,419.67	371.2	0:00
241	Non-Participant	478,715.52	4,823,342.29	369.6	0:00
243	Non-Participant	493,118.85	4,822,721.17	372.0	0:00
245	Non-Participant	493,967.35	4,822,718.96	369.0	0:00
246	Non-Participant	494,170.56	4,822,801.06	368.5	0:00
247	Participant	494,342.80	4,822,622.38	368.4	0:00
248	Participant	494,430.70	4,822,653.85	367.3	0:00
249	Non-Participant	495,170.52	4,822,718.52	363.7	0:00
250	Non-Participant	495,302.60	4,822,811.41	363.1	0:00
253	Non-Participant	496,467.38	4,821,140.97	362.9	0:00
254	Non-Participant	496,563.22	4,821,118.93	363.3	0:00
257	Non-Participant	495,436.75	4,819,575.33	363.0	0:00
258	Non-Participant	495,394.43	4,819,572.49	363.0	0:00
259	Non-Participant	494,975.14	4,819,281.53	363.9	0:00
260	Non-Participant	495,026.94	4,819,307.04	363.4	0:00

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
278	Non-Participant	494,446.31	4,820,117.16	366.0	0:00
279	Non-Participant	494,361.19	4,820,178.26	366.0	0:00
280	Participant	494,443.05	4,820,713.37	363.0	12:33
282	Non-Participant	494,338.60	4,821,604.01	366.0	31:12
283	Non-Participant	492,743.92	4,822,125.51	369.0	0:00
285	Non-Participant	492,707.14	4,821,448.81	370.7	3:31
286	Non-Participant	492,732.22	4,820,638.28	371.9	4:31
287	Non-Participant	492,724.36	4,819,671.66	369.1	0:00
288	Participant	493,023.36	4,819,573.95	367.9	0:00
289	Non-Participant	492,804.97	4,819,213.63	369.0	0:00
293	Non-Participant	492,137.91	4,817,869.85	370.3	0:00
295	Non-Participant	491,784.79	4,818,080.56	372.0	1:18
296	Participant	491,095.62	4,817,515.55	375.0	0:00
297	Non-Participant	491,102.73	4,817,161.39	373.2	0:00
299	Participant	490,398.79	4,817,681.63	372.0	0:00
300	Participant	490,744.23	4,818,140.10	375.0	7:35
301	Non-Participant	491,180.07	4,817,942.05	373.9	2:32
302	Participant	490,763.42	4,819,365.86	378.0	17:45
303	Participant	491,127.87	4,820,087.20	378.0	27:33
305	Participant	491,061.42	4,820,555.14	378.0	9:52
306	Non-Participant	491,257.94	4,821,420.39	375.0	0:00
307	Non-Participant	490,183.64	4,821,121.17	378.0	0:00
308	Non-Participant	490,451.48	4,821,641.19	379.3	0:00
309	Non-Participant	490,086.12	4,821,979.52	381.0	0:00
312	Non-Participant	489,503.51	4,821,705.40	378.0	0:00
313	Non-Participant	489,079.52	4,821,180.09	375.0	0:00
314	Non-Participant	489,306.45	4,820,961.03	376.3	1:06
315	Non-Participant	489,484.43	4,819,590.84	375.0	34:35
316	Non-Participant	489,606.26	4,819,098.81	376.1	24:19
317	Non-Participant	489,398.64	4,818,872.71	375.0	34:29
318	Non-Participant	489,543.44	4,817,818.32	375.0	0:53
319	Participant	488,944.73	4,817,952.75	372.0	9:58
320	Non-Participant	488,304.42	4,817,959.28	372.0	6:07
321	Non-Participant	488,450.99	4,817,336.86	372.0	0:38
322	Non-Participant	487,887.83	4,817,759.02	372.0	2:59
323	Participant	487,707.51	4,818,164.12	372.0	13:58
324	Non-Participant	487,989.02	4,819,491.07	372.0	0:00
325	Non-Participant	487,904.25	4,819,630.05	372.0	0:00

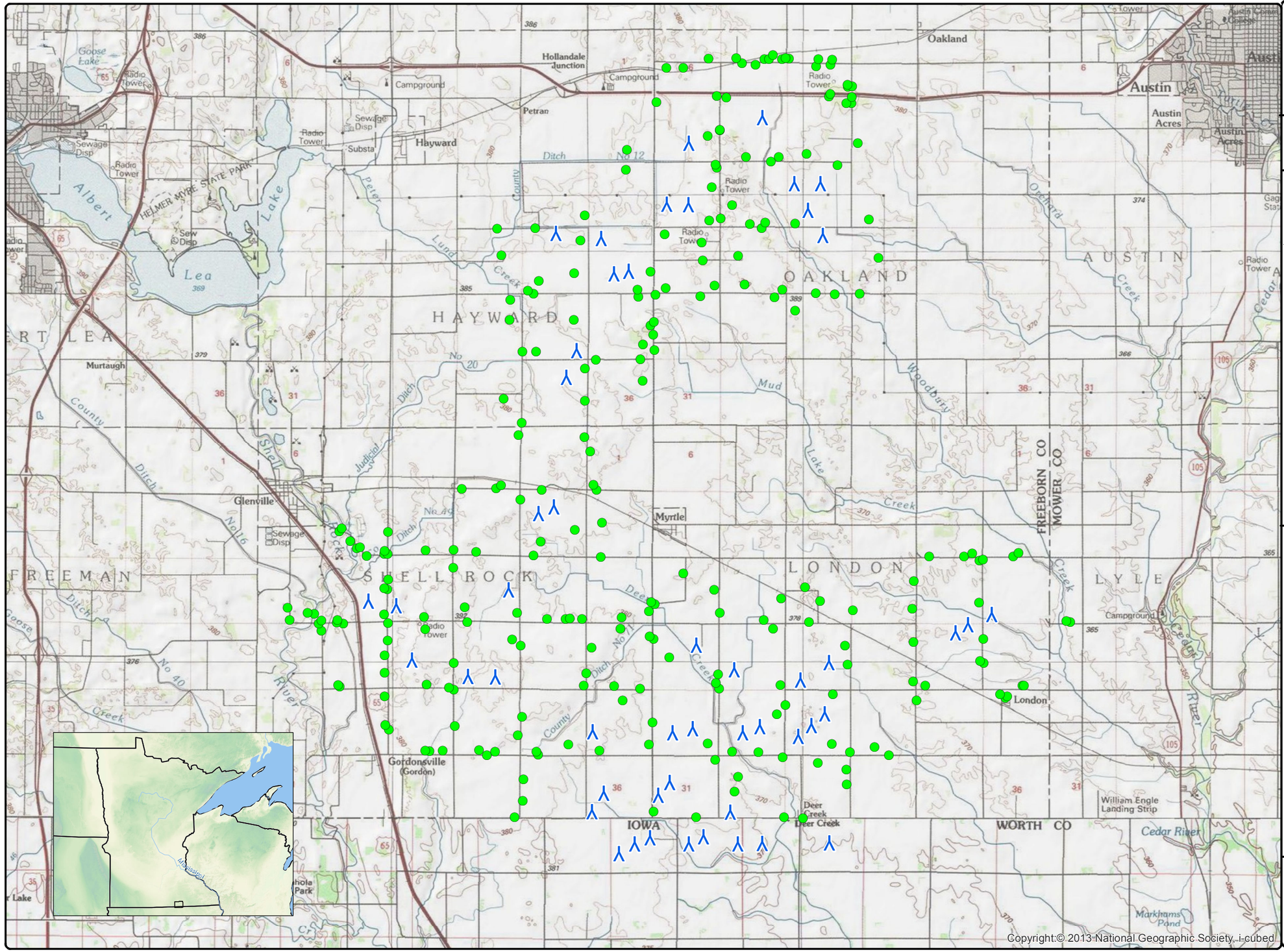
Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
326	Non-Participant	487,959.48	4,819,851.46	372.0	45:23
327	Non-Participant	488,005.25	4,821,349.03	375.0	0:00
328	Participant	487,868.07	4,821,914.04	379.9	0:00
331	Non-Participant	487,112.21	4,822,314.27	382.4	0:00
333	Non-Participant	486,328.79	4,821,619.07	375.0	0:00
334	Non-Participant	486,420.74	4,821,570.97	375.0	0:00
335	Non-Participant	486,765.95	4,820,261.51	375.0	18:34
336	Non-Participant	486,358.09	4,818,672.87	378.0	20:21
337	Non-Participant	486,275.16	4,818,132.19	378.0	22:02
338	Participant	485,063.44	4,817,982.65	381.0	0:00
339	Non-Participant	484,302.26	4,818,132.05	384.0	12:22
340	Participant	483,562.37	4,817,886.03	387.0	1:49
341	Non-Participant	483,529.20	4,817,963.43	387.0	1:24
346	Non-Participant	481,696.41	4,824,377.09	384.0	0:00
347	Participant	481,492.40	4,822,446.38	387.0	1:58
348	Non-Participant	480,817.41	4,822,885.54	378.9	0:00
349	Non-Participant	482,052.32	4,822,841.45	384.0	0:00
350	Participant	481,497.82	4,822,891.83	381.6	1:58
352	Non-Participant	483,051.40	4,821,347.90	384.0	0:00
353	Non-Participant	483,783.27	4,821,199.51	384.1	0:00
355	Participant	484,240.30	4,821,199.51	381.8	4:04
356	Non-Participant	484,341.74	4,821,205.21	382.3	1:54
357	Participant	484,639.21	4,821,202.93	382.3	0:00
358	Non-Participant	484,870.27	4,820,492.46	387.0	0:00
359	Non-Participant	484,746.34	4,819,871.72	387.0	0:00
360	Non-Participant	484,675.68	4,819,574.25	384.0	0:00
361	Non-Participant	485,426.76	4,819,567.41	384.0	0:00
362	Non-Participant	485,631.58	4,819,217.79	384.0	1:35
363	Non-Participant	486,054.76	4,819,497.88	381.0	1:52
364	Non-Participant	486,289.08	4,820,776.02	375.9	2:10
365	Non-Participant	486,384.85	4,820,713.85	377.9	2:50
366	Participant	486,273.59	4,821,385.28	375.0	3:00
367	Participant	485,609.12	4,821,242.82	384.0	0:00
369	Participant	485,572.65	4,820,956.74	384.0	0:00
372	Participant	485,095.10	4,822,716.49	378.0	0:00
381	Non-Participant	486,120.86	4,827,025.83	387.0	0:00
383	Non-Participant	486,019.43	4,829,077.35	384.3	0:00
384	Participant	484,438.60	4,828,506.72	384.0	0:00

Freeborn
Real case shadow flicker results at dwellings within two kilometers of project WTGs
Results using Vestas V116 2.0 - 80 m hub height WTGs
UTM NAD83 Zone 15
continued

Shadow Receptor #	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Real Case Shadow (hrs/year)
386	Participant	484,976.57	4,827,525.03	385.6	32:30
387	Participant	484,713.29	4,827,322.16	390.0	15:20
388	Participant	484,712.15	4,826,536.88	390.0	0:00
390	Non-Participant	484,698.47	4,825,637.63	390.0	0:00
391	Non-Participant	484,836.38	4,825,292.29	390.0	0:00
392	Non-Participant	484,918.38	4,824,485.48	389.5	2:40
393	Participant	484,991.26	4,824,353.96	387.4	2:16
394	Participant	485,129.30	4,823,556.04	381.0	4:11
395	Participant	484,461.41	4,823,382.10	384.0	13:17
397	Non-Participant	482,937.05	4,820,708.01	387.0	0:23
399	Participant	483,455.00	4,822,750.82	381.0	0:00
400	Non-Participant	483,632.82	4,823,089.19	381.0	0:00
401	Non-Participant	483,134.76	4,824,113.81	387.0	27:11
402	Participant	483,657.90	4,824,353.15	388.6	1:59
403	Non-Participant	482,658.35	4,824,464.85	384.0	7:01
404	Non-Participant	482,544.38	4,824,393.04	384.0	3:53
405	Non-Participant	483,168.91	4,826,001.88	383.6	0:00
406	Non-Participant	483,085.75	4,825,693.48	384.6	0:00
407	Non-Participant	482,726.41	4,826,582.46	381.0	1:06
408	Non-Participant	483,180.35	4,827,734.74	381.0	4:10
409	Non-Participant	483,516.57	4,827,733.61	381.0	10:54
410	Participant	482,870.34	4,828,502.93	381.0	0:00
418	Non-Participant	489,526.06	4,834,877.29	384.0	0:00
419	Non-Participant	491,131.31	4,834,199.17	389.2	0:00
422	Non-Participant	494,847.48	4,819,356.53	363.0	0:00

APPENDIX C: FREEBORN WIND ENERGY PROJECT SITE OVERVIEW



0 0.75 1.5 3 Mile

EAPC WIND ENERGY

www.eapc.net | 701.775.3000

Freeborn Shadow Analysis
Shadow Flicker Results
Vestas V116 2.0 MW 80 m HH

Client

Merjent

Project Description

Freeborn wind farm project site overview. Project consists of 42 wind turbines with in MN with an additional 8 turbines included from the turbine array in Iowa, and 254 occupied residences within 2 km of the wind turbines.

Location: Freeborn County, Minnesota

Project #: 20172210

Issue Dates

1	Original	2017.5.31
#	*Description*	*Date*

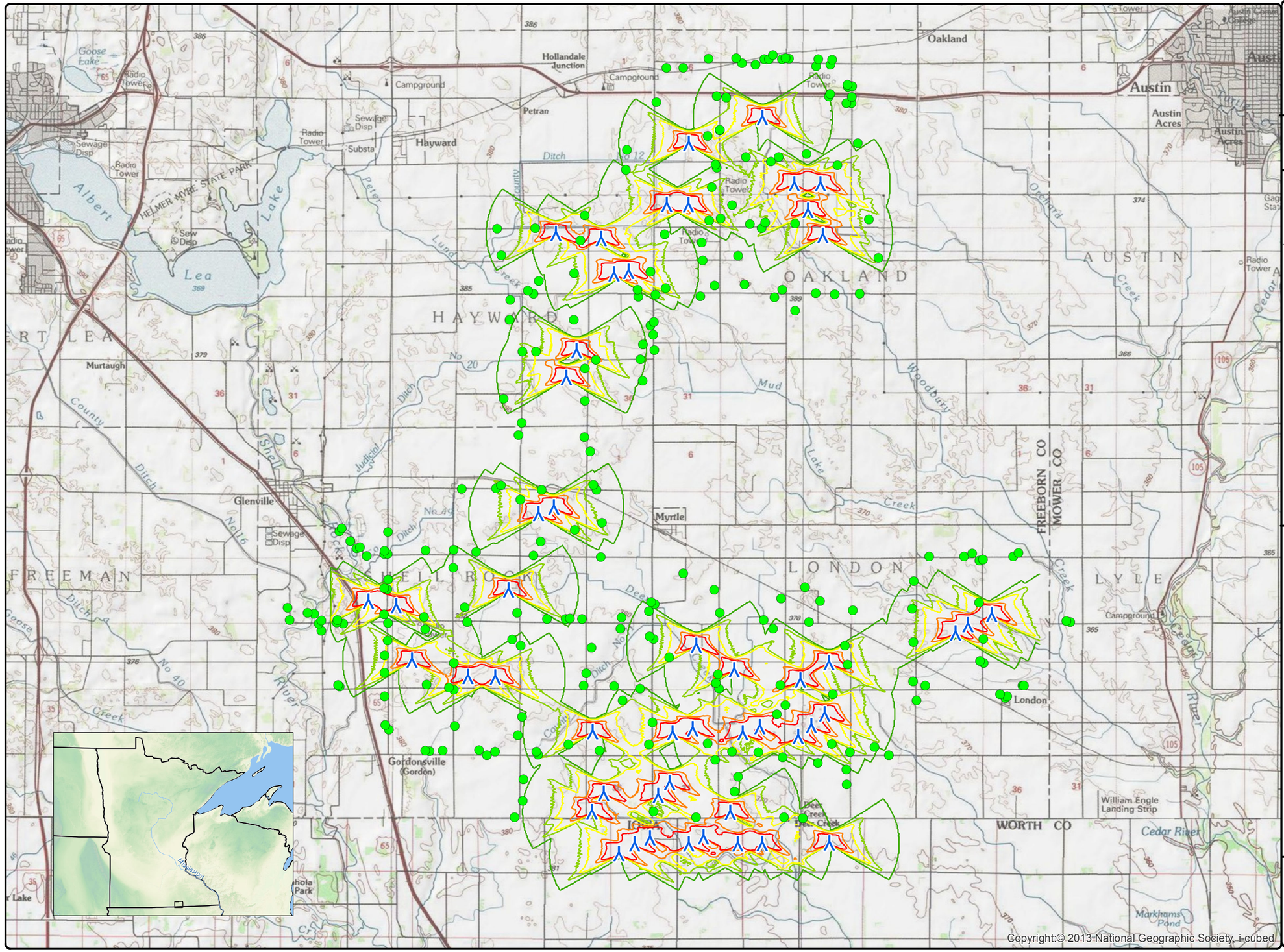
Drawn By: JH | *Checked By: JH*

Legend

- 50 V116-2.0-80
- Occupied Residences

N W E S

APPENDIX D: V116 2.0-80 LAYOUT STANDARD RESOLUTION SHADOW FLICKER MAP



0 0.75 1.5 3 Mile

EAPC WIND ENERGY

www.eapc.net | 701.775.3000

Freeborn Shadow Analysis
Shadow Flicker Results
Vestas V116 2.0 MW 80 m HH

Client

Merjent

Project Description

Shadow Flicker for Vestas V116 80 m HH WTGs. Realistic shadow flicker map and data at receptors (hrs/yr) within at least 2 km of turbines. Assumes statistical reduction due to sunshine probability, turbine orientation and operation probability. Sensors in "greenhouse" mode. No obstacles assumed.

Location: Freeborn County, Minnesota

Project #: 20172210

Issue Dates

#	Description	Date
1	Original	2017.5.31

Drawn By: JH *Checked By: JH*

Legend

- 50 V116-2.0-80
- Occupied Residences

Shadow Flicker hrs/yr

- 0
- 5
- 10
- 30
- 50

N W E S