SHADOW FLICKER ASSESSMENT
LAKE BENTON, MINNESOTA, USA

Submitted to

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1.0	11/10/2017	John Bosche	Initial issue
2.0	12/18/17	John Bosche	Added detailed analysis for 6 sites

Disclaimer

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Document 2.0

Report Standard:
ASSESSMENT

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Status:
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Key to Report Standard

Assessment: Full assessment of the subject of the report, including uncertainty analysis and review from senior-level staff

Review: A review of provided data to give an estimate of the resource, conditions or other information, and does not include detailed analysis, uncertainty evaluations or full review

Key to Classification

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EXECUTIVE SUMMARY

This report analyzes the potential for shadow flicker at the existing Lake Benton wind farm in west-central Minnesota, as well as an in-depth analysis for six receptors with high initial shadow flicker values.

Shadow flicker refers to rapid changes in the intensity of light at a receptor caused by rotating wind turbine blades. In other words, turbines project shadows on a location whenever the sun is behind the blades, and this shadow moves at the speed of blade rotation. If a window of a house falls in the path of such a shadow, observers inside the house notice rapid changes in the brightness of the room.

Our shadow flicker analysis is presented in this report. Modeling was performed using OpenWind software, which uses the National Renewable Energy Laboratory (NREL) solar declination code to calculate the sun vector minute-by-minute during the course of a year. The representative year used in this analysis is 2018. While there may be some variation depending on the year modeled, the overall results should be relatively consistent for all years.

A summary of the analysis for the in-depth receptors is presented below.

Receptor 1: Obstructions mostly mitigate shadow flicker, with a range of 6 hours to 11 hours per year expected.

Receptor 25: Obstructions mitigate shadow flicker, with a range of 1 to 2 hours per year expected.

Receptor 26: Obstructions mostly mitigate shadow flicker to about 5 hours per year, although northern windows could experience more shadow flicker with a range of 24 to 40 hours per year.

Receptor 37: The lack of tree and building obstructions shows no mitigation of shadow flicker. Including cloud cover, the expected range of shadow flicker is expected to be within 26 to 40 hours per year.

Receptor 40: Receptor 40 is a town hall, and not occupied on a daily basis. There are no building obstructions. Deciduous trees to the north and west provide some blockage. Expected shadow flicker ranges from 37 to 47 hours per year.

Receptor 64: No buildings provide blockage for shadow flicker, and many of the trees in line with turbines are scattered. This results in high uncertainty for this receptor, with a range of 18 to 43 hours per year of shadow flicker.

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1 INTRODUCTION

This report analyzes the potential for shadow flicker at the existing Lake Benton wind farm in west-central Minnesota, as well as an in-depth analysis for six receptors with high initial shadow flicker values.

Shadow flicker refers to rapid changes in the intensity of light at a receptor caused by rotating wind turbine blades. In other words, turbines project shadows on a location whenever the sun is behind the blades, and this shadow moves at the speed of blade rotation. If a window of a house falls in the path of such a shadow, observers inside the house notice rapid changes in the brightness of the room.

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Figure 1 presents the Project area, array, and residences/buildings considered in the shadow flicker analysis.

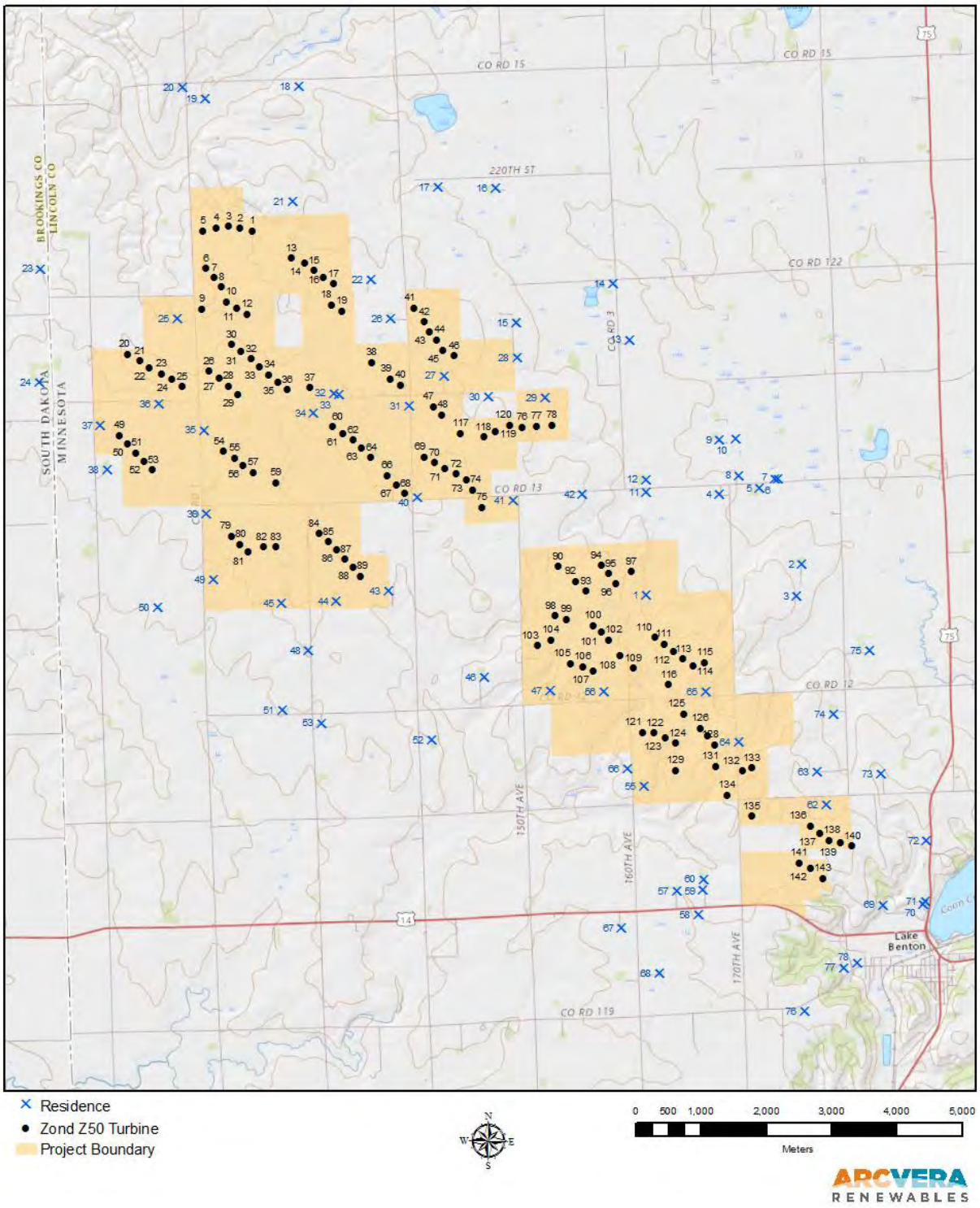


Figure 1. Lake Benton Zond Z50 (750 kW) Turbine Layout and Nearby Residences/Buildings

2 Project-Wide High-Level Analysis

The project wide analysis considered each receptor as a single point. No vegetation, weather patterns, or other obstructing features were considered. We evaluated 76 receptors within and adjacent to the Lake Benton turbines, as provided by Barr Engineering.

We used the following assumptions for the shadow flicker calculations:

- a maximum shadow propagation distance of 1000 meters
- minimum solar incidence angle of 3° above the horizon to cause shadow flicker
- elevations taken from the United States Elevation Data (NED) data set
- house receptor defined as a point 1.75 m above ground level
- no obstacles near receptors were considered, which also builds in conservatism
- topographic influence was included in analysis

Table 1 provides the hours per year of shadow flicker and the number of days per year for each residence.

Figure 2 provides a visual representation of shadow flicker from each turbine in hours per year. Figure 3 shows the impact on each residence in 15-hour bins per year.

Figure 4 shows a visual representation of the month and time of day of the shadow flicker. All times are in Central Standard Time (CST, UTC - 6).

Table 1. Modeled Shadow Hours/Year at Receptors for Sample Year 2018

Receptor Coordinates
(UTM Zone 14T, WGS84 Datum)

Receptor	Easting	Northing	Shadow Hours and Minutes per Year	Days per Year with Shadow Flicker
1	712177	4910103	41:23	155
2	714563	4910581	0:0	0
3	714481	4910092	0:0	0
4	713295	4911649	0:0	0
5	713914	4911748	0:0	0
6	714200	4911888	0:0	0
7	714143	4911891	0:0	0
8	713597	4911943	0:0	0
9	713294	4912492	0:0	0
10	713546	4912502	0:0	0
11	712182	4911685	0:0	0
12	712170	4911880	0:0	0
13	711928	4914027	0:0	0
14	711666	4914886	0:0	0
15	710191	4914282	0:0	0
16	709874	4916352	0:0	0
17	708991	4916371	0:0	0
18	706865	4917913	0:0	0
19	705418	4917733	0:0	0
20	705071	4917897	0:0	0
21	706763	4916153	17:18	83
22	707964	4914954	29:38	93
23	702908	4915115	0:0	0
24	702891	4913372	0:0	0
25	705002	4914343	47:3	169
26	708258	4914343	61:32	207
27	709078	4913473	8:32	32
28	710209	4913752	2:27	16
29	710634	4913132	20:29	71
30	709759	4913148	18:29	87
31	708545	4913004	32:19	107
32	707397	4913198	34:22	98
33	707478	4913188	27:32	80
34	707088	4912903	39:35	107
35	705406	4912639	25:08	39
36	704712	4913038	12:47	52
37	703822	4912712	53:53	142
38	703930	4912027	13:24	53
39	705435	4911357	19:5	55
40	708677	4911608	89:26	134
41	710141	4911563	26:06	103
42	711204	4911650	0:0	0
43	708231	4910174	6:35	29
44	707436	4910014	0:0	0
45	706599	4909986	0:0	0
46	709694	4908851	7:09	39
47	710703	4908637	10:38	50
48	707009	4909252	0:0	0
49	705554	4910342	0:0	0
50	704699	4909912	0:0	0
51	706609	4908344	0:0	0
52	708892	4907885	0:0	0
53	707200	4908142	0:0	0
55	712141	4907167	16:03	51
56	711531	4908618	3:40	25
57	712654	4905561	0:0	0
58	712975	4905204	0:0	0
59	713049	4905580	0:0	0
60	713063	4905745	0:0	0
62	714940	4906894	0:0	0
63	714798	4907387	2:26	16
64	713601	4907848	60:45	186
65	713087	4908623	28:24	75
66	711890	4907435	14:50	69
67	711804	4905002	0:0	0
68	712380	4904301	0:0	0
69	715809	4905350	0:0	0
70	716426	4905363	0:0	0
71	716453	4905411	0:0	0
72	716474	4906338	0:0	0
73	715769	4907359	0:0	0
74	715040	4908282	0:0	0
75	715592	4909252	0:0	0
76	714602	4903724	0:0	0
77	715209	4904389	0:0	0
78	715406	4904460	0:0	0

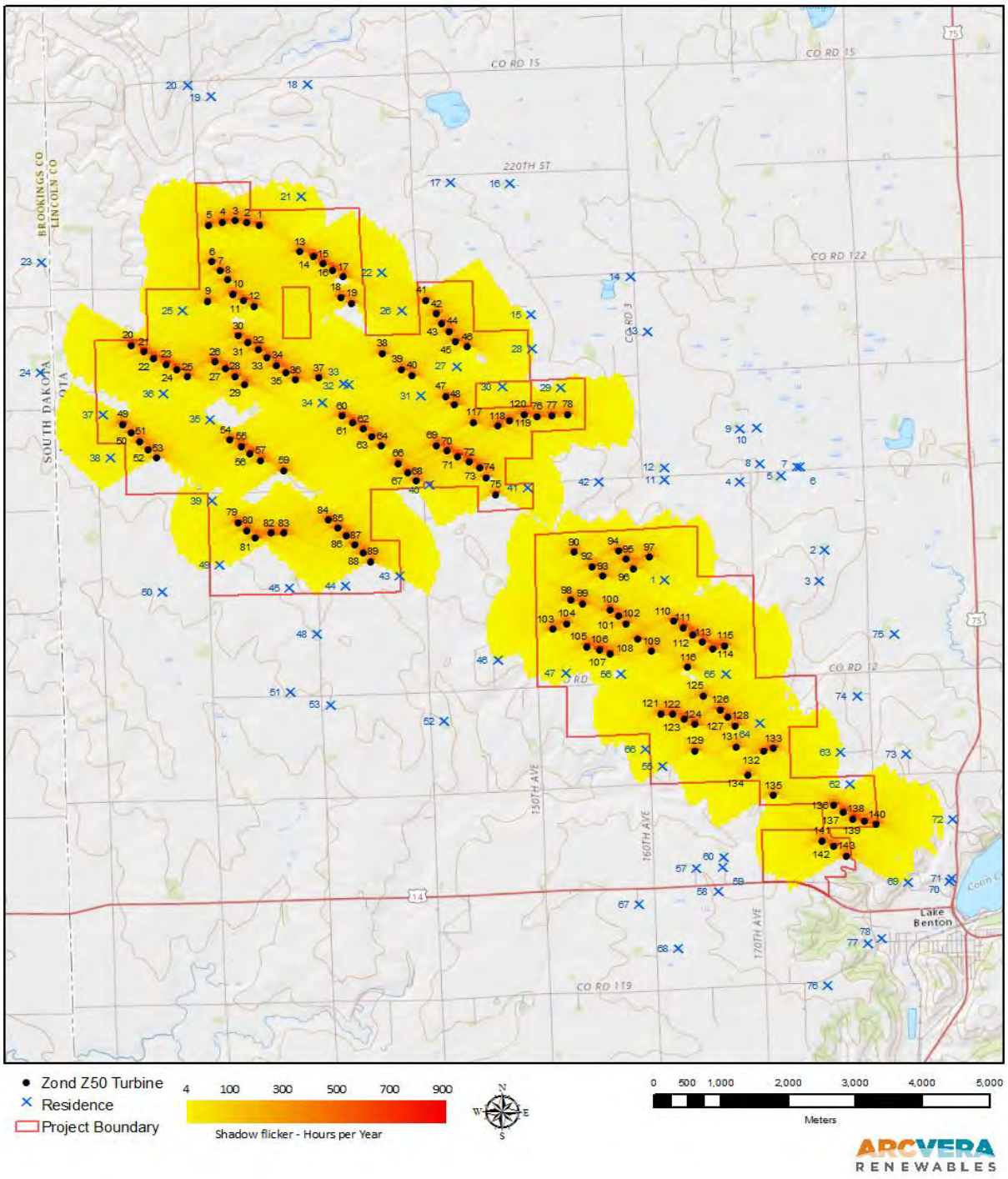


Figure 2. Lake Benton Modeled Shadow Hours/Year at Receptors

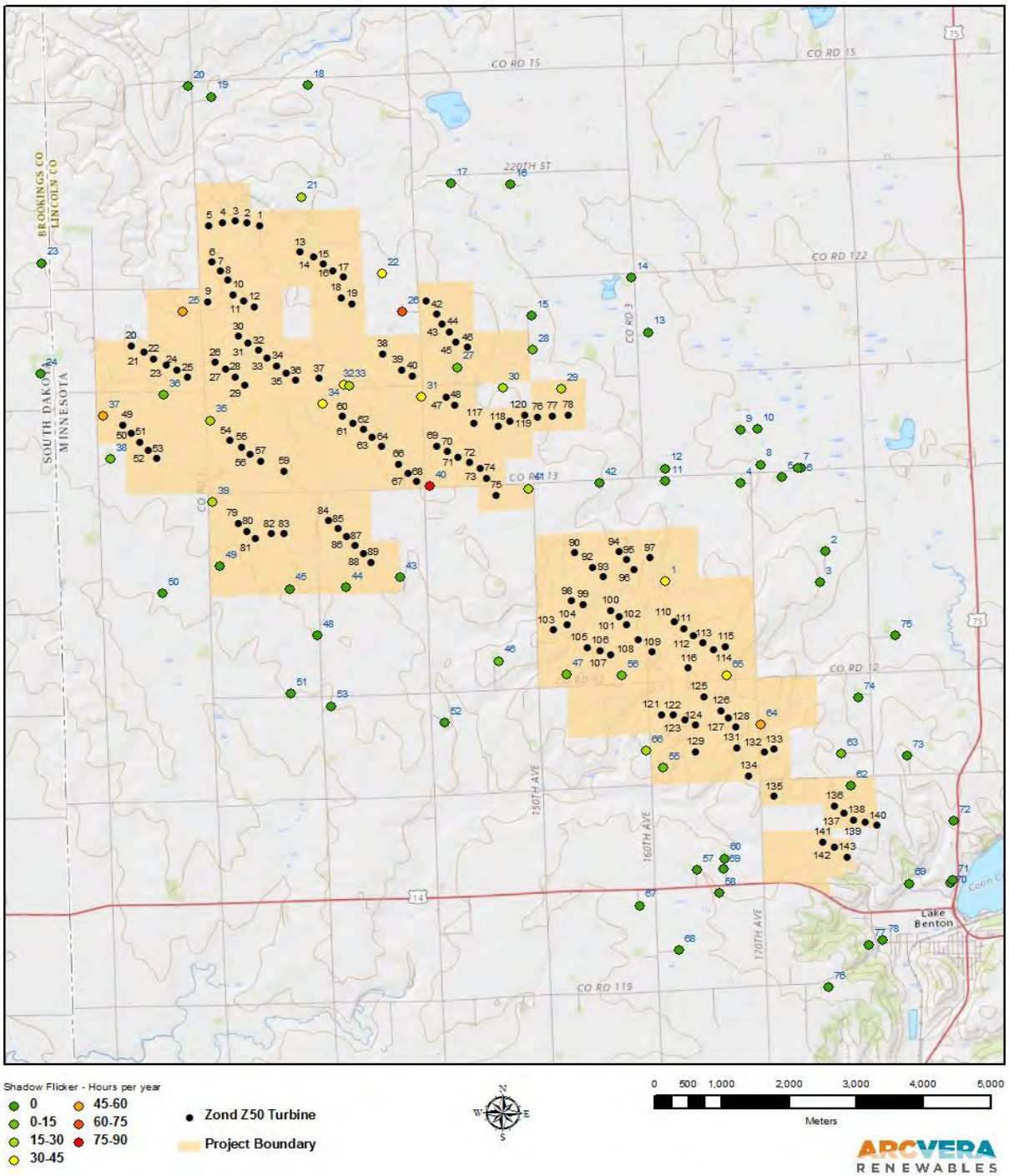


Figure 3. Lake Benton Shadow Flicker Receptor Impacts

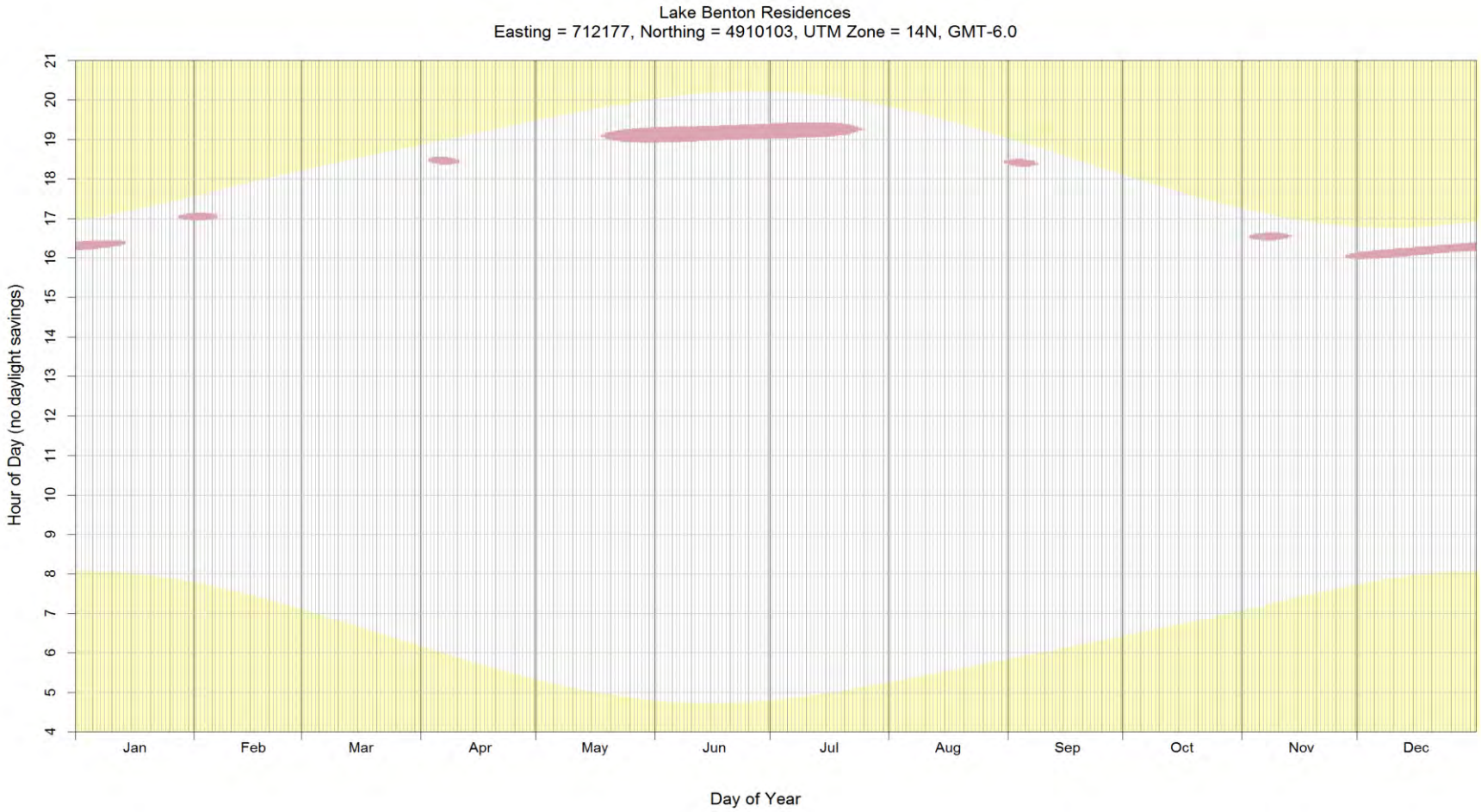


Figure 4. Lake Benton Shadow Flicker Monthly-Diurnal Impacts

Shadow flicker limits world-wide are generally based on Germany's standards, which limits shadow flicker exposure at residences, learning spaces, workplaces, and health care settings to 30 minutes/day or 30 hours/year in extreme cases. Actual amounts of shadow flicker at these locations cannot exceed 8 hours/year. Minnesota commissioned a review of policies for noise, shadow flicker and setbacks in 2011.[1] However, Minnesota does not currently have established limits.

The values in this represent extreme cases and do not take into account items such as weather phenomena, residence window orientation, and objects that could obstruct the shadow flicker effect. Six receptors were identified through this initial analysis as having the potential for shadow flicker that exceeds the thresholds defined above: Receptors 1, 25, 26, 37, 40, and 64. All but Receptor 40 are residences. Receptor 40 is the Hall for Drammen, Minnesota. The following sections analyze those six receptors considering those factors.

Clouds or other weather phenomena could reduce the intensity of sunshine and minimize the shadow cast by a rotating turbine. Most likely at least a quarter to one third of the days will be cloudy, foggy, rainy, etc., which will mitigate shadow flicker on those days. The National Centers for Environmental Information (NCEI) reports that out of all possible sunshine hours, Minneapolis-St. Paul has about 57% days with sunshine (based on 58 years of observation), which means that more than one third of the days in the region have cloud cover. About one third of the shadow flicker occurs from November-March, which will most likely have more cloud cover than the summer months. Table 2 shows the percent of possible sunshine per month for Minneapolis-St. Paul, along with the "full case" where cloud cover is not considered of shadow flicker for Lake Benton, and then reduced by the percentage of cloud cover.

[1] *International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns*. Minnesota Department of Commerce: Energy Facility Permitting, 2011

Table 2. Annual Possible Sunshine and Potential for Shadow Flicker Reduction

Month	Annual Average Possible Sunshine (%)	Annual Hours of Shadow Flicker -100% Sunshine	Annual Hours of Shadow Flicker Adjusted
Jan	53	78	37
Feb	59	30	12
March	57	36	15
April	56	53	23
May	62	72	27
June	67	107	35
July	74	88	23
Aug	69	58	18
Sept	62	46	17
Oct	51	30	15
Nov	37	60	38
Dec	38	112	69
Annual	57	771	331

In addition, wind direction can also be a factor – the direction a turbine is oriented can potentially mitigate (or exacerbate) shadow flicker (which will also depend on the position of the sun and time of day). Winds are primarily from the northwest and south in the project area, but are not uni-directional. This is accounted for in the model on a high-level basis.

For non-weather considerations, objects between the turbine and receptor can block or minimize shadow flicker, such as tree stands and tall hedges, other building, and structures. The direction residence windows face on a given "residence also can mitigate/exacerbate the shadow flicker effect.

The results in this analysis assume 100% sunshine for all daytime hours during the year with no obstructions and no considerations of window/residence orientation, which is an extreme, highly unlikely (if not impossible) scenario.

The maximum amount of shadow flicker at a receptor site is nearly 90 hours per year at site 40, which is the Township Hall for Drammen, Minnesota. Most shadow flicker occurs in the early mornings and evenings. The Township Hall would not be occupied in the early mornings. Occupation in the evening is sporadic. Ninety hours per year is the extreme case, and the Hall will most likely experience around 51 hours per year based on the NCEI data. Three other receptor points have 50 to 62 hours

per year of shadow flicker in the extreme case, which would potentially be between 30 and 35 hours per year given annual weather patterns. In total, 6 receptor points, the Township Hall, were further examined for their potential high shadow flicker.

3 DETAILED ANALYSES

The remaining sections of this report provide in-depth analyses for the top six receptors identified in the previous section. The analyses were aided by a site visit performed by Barr Engineering. Each analysis takes into account window location, surrounding structures, trees and other foliage, and weather patterns.

Windows were located using data from the site visit. Lower windows were assumed at a height of 1.75 m, and upper windows at 3.5 m.

Results are provided on a monthly and hourly basis. Results are provided in tiers: No Obstructions shows the shadow flicker analysis for each window as if they were standalone points, including the receptor building; Buildings Only takes into account the receptor buildings and any structures around the buildings that may block shadow flicker; Vegetation Only takes into account only the trees around the receptor - buildings are not considered, including the receptor building; All Obstructions takes into account all buildings and all vegetation. All Obstructions is considered the worst-case scenario. For Receptors 37 and 40 where buildings were not a factor, the Buildings Only step was excluded.

Finally, an Adjusted Estimate was made for each window. The adjusted estimate takes into account the density of deciduous trees and average sunshine for the month. The deciduous tree adjustment is somewhat pragmatic, based on the observed thickness of tree groves, observations of deciduous trees to evergreen trees, and an assumption that deciduous trees with no leaves can still block 10 to 60% of light[2]. Shadow blocked by buildings is assumed at 100%. This is considered the best-case scenario, and is intended to give a range from the All Obstructions case, and the actual shadow flicker experienced by each receptor is between the two values. The final adjusted value for each receptor was rounded upwards to the nearest 10 to account for uncertainty in the analysis.

3.1 Receptor 1

Receptor 1. Receptor 1 has multiple buildings and relatively dense groves of trees to the west of the building. The groves are largely deciduous trees (we have estimated 75%), which means that their shadow blocking will lessen during the winter months. However, most of the shadow flicker from the west and northwest turbines is during the spring and early summer months. We expect that shadow flicker will mostly be

[2] Multiple sources: Energy-Saving Landscaping for Your Passive Solar Home, North Carolina Solar Center, June 2001, https://nccleantech.ncsu.edu/wp-content/uploads/Energy_Landscape.pdf
Reducing Urban Heat Islands: Compendium of Strategies, Trees and Vegetation, Climate Protection Partnership Division in the U.S., Environmental Protection Agency's Office of Atmospheric Programs, 2014, https://www.epa.gov/sites/production/files/2014-06/documents/treesandvegcompendium.pdf

mitigated during this time. Shadow flicker in the late fall and winter months during the evening from the Turbines 100 and 101 to the southwest will be minimally mitigated. The window with the most potential to be affected by shadow flicker is the west-facing bay window. While all west-facing windows have similar results, the bay window is larger and has more potential exposure.

We expect that from the "no obstructions" analysis, shadow flicker hour will be reduced from obstructions alone by approximately 74%, resulting in approximately 650 minutes per year of shadow flicker as an average for all windows at the receptor, or about 11 hours per year. Once annual cloud cover data and an estimation of deciduous tree density is considered, the estimate is an 86% reduction, or approximately 350 minutes per year, or just less than 6 hours per year.

Table 3 presents the results of the detailed analysis for Receptor 1. Figures 5 and 6 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 7 and 8 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 3. Receptor 1 Overall Results

Shadow Flicker (min)	2483	Estimated from overall analysis
Shadow Flicker (min)	2,476	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	2,525	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	-73.8	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	649	
Shadow reduction (%)	-85.9	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	350	

Figure 5. Receptor 1 Aerial Image with Line of Site from Turbines

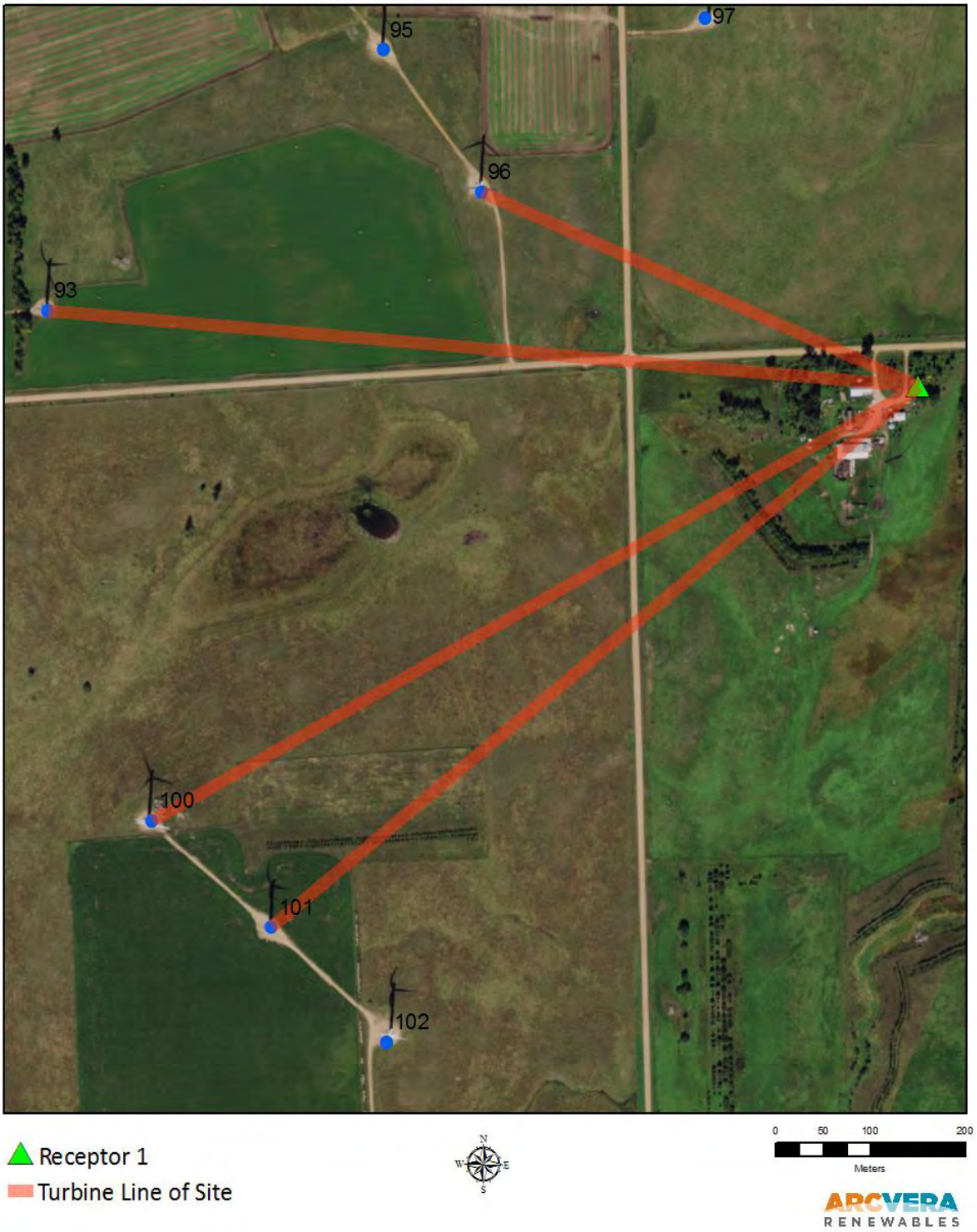


Figure 6. Receptor 1 Broad Aerial Image with Line of Site from Turbines

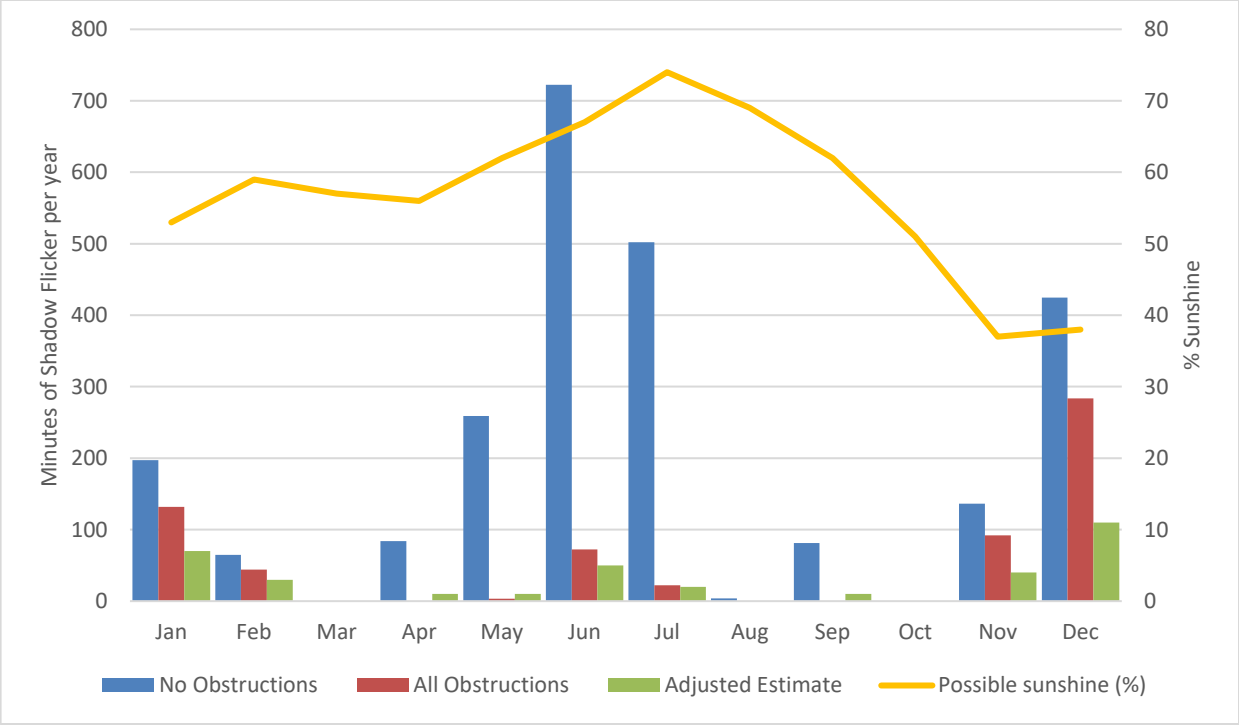


Figure 7. Receptor 1 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

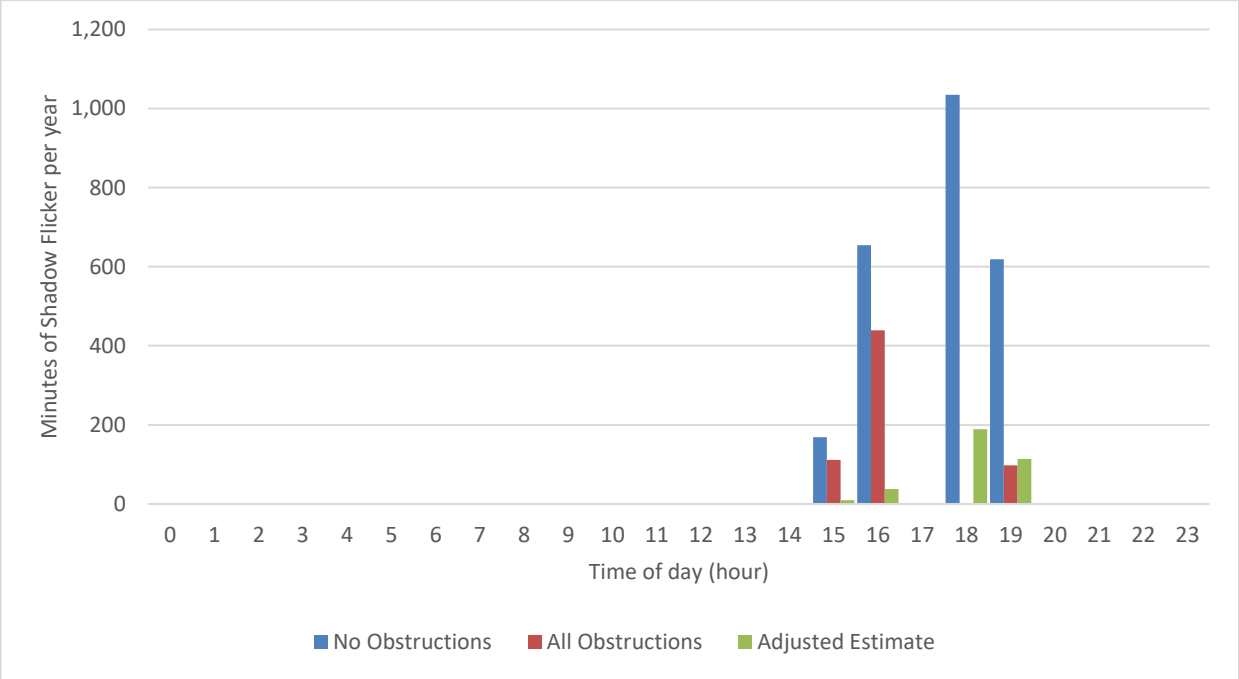


Figure 8. Receptor 1 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

3.2 Receptor 25

Receptor 25 has multiple buildings and large groves of trees that should mitigate most shadow flicker from the turbines in questions. Most of the windows were difficult to determine location and size due to the tree coverage. Given that the site visit was in a late fall month, the shadow flicker should not penetrate the tree groves. A higher base for the deciduous density was used for Receptor 25.

We expect that from the "no obstructions" analysis, shadow flicker hour will be reduced from obstructions alone by approximately 98%, resulting in approximately 60 minutes per year of shadow flicker as an average for all windows at the receptor, or about 1 hour per year. The adjustment based on cloud cover and foliage cover in fall and winter is similar, raising the estimate slightly due to deciduous trees losing part of their ability to block sunlight in the winter to approximately 97% reduction from the "no obstructions" case, or about 80 minutes per year. The southeast windows are expected to experience the most shadow flicker, but not more than 2 hours per year.

Table 4 presents the results of the detailed analysis for Receptor 25. Figures 9 and 10 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 11 and 12 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 4. Receptor 25 Overall Results

Shadow Flicker (min)	2,823	Estimated from overall analysis
Shadow Flicker (min)	2,568	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	2,762	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	-97.6	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	61	
Shadow reduction (%)	-96.9	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	80	

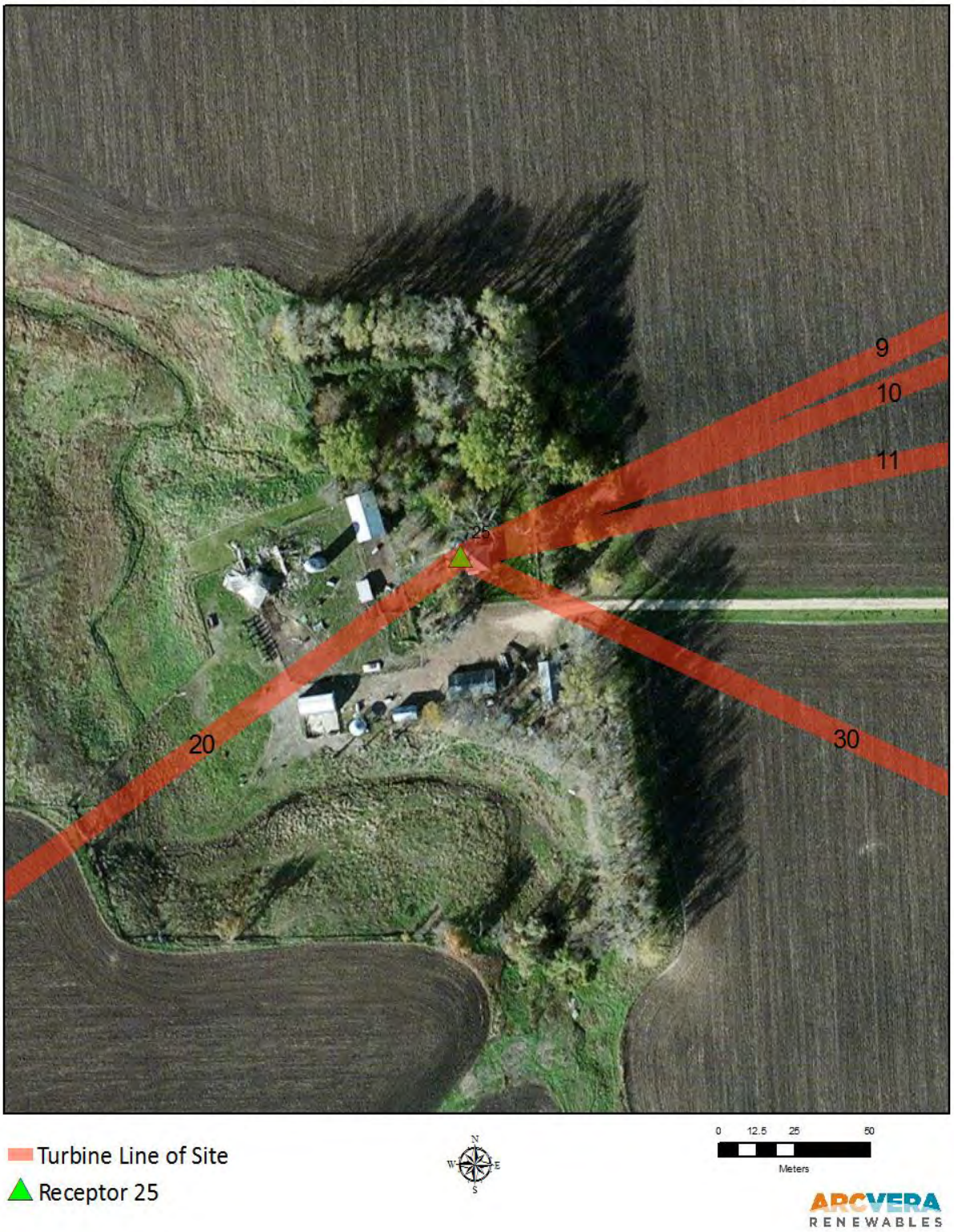


Figure 9. Receptor 25 Aerial Image with Line of Site from Turbines

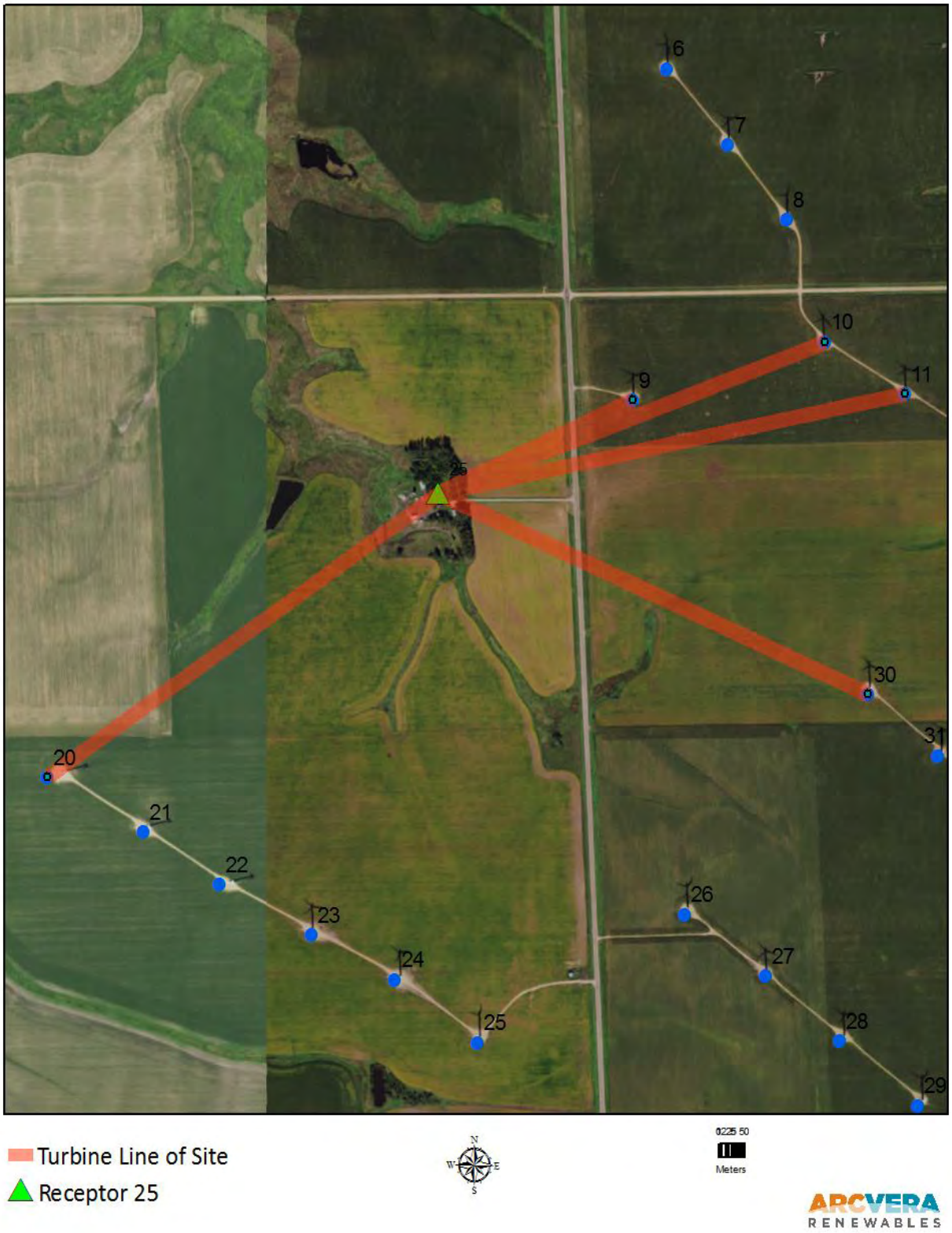


Figure 10. Receptor 25 Broad Aerial Image with Line of Site from Turbines

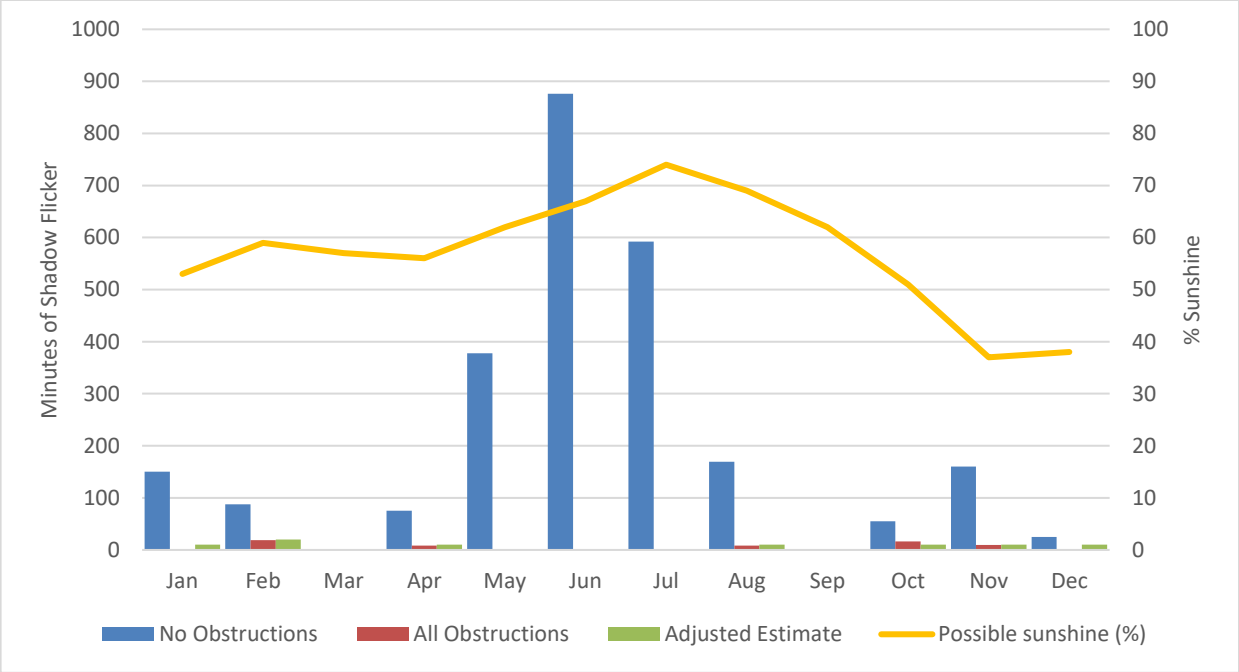


Figure 11. Receptor 25 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

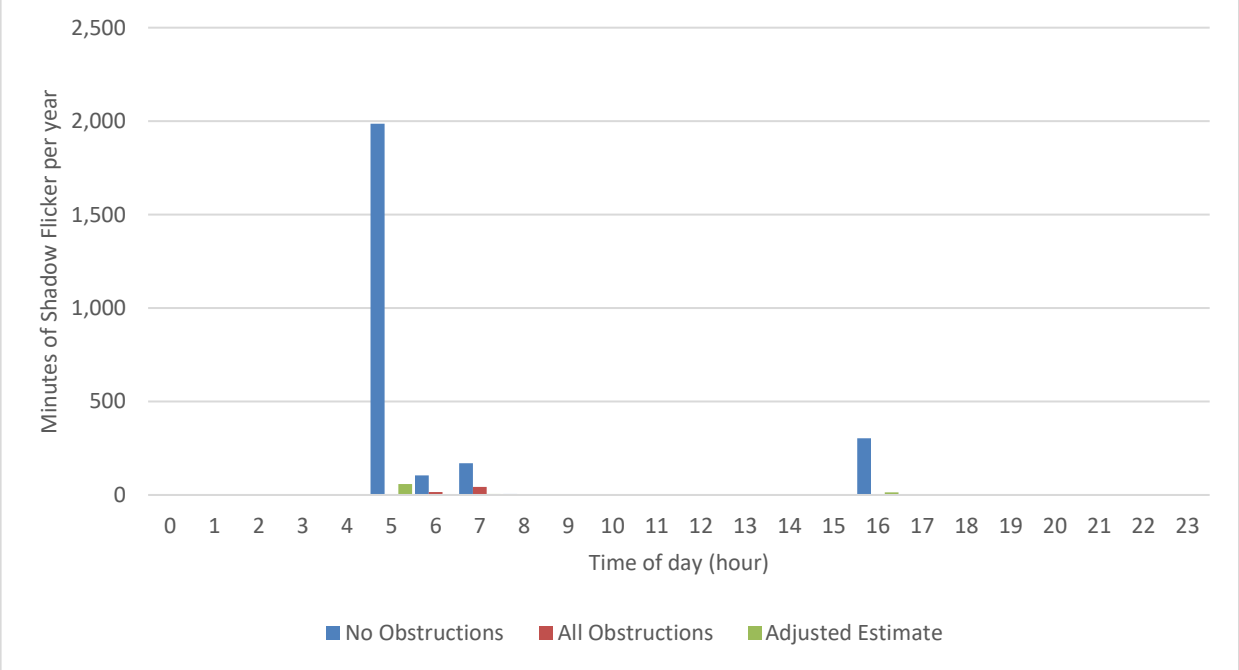


Figure 12. Receptor 25 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

3.3 Receptor 26

Receptor 26 has multiple buildings and large groves of trees that should mitigate most shadow flicker from the turbines in question. Windows on the west side were not able to be determined due to tree coverage. For this analysis, we assumed two windows on the upper and lower levels, similar to the primary windows on the eastern side. The large barn to the northeast of the house shown in aerial imagery is no longer present. All other structures were accounted for.

We expect that from the "no obstructions" analysis, shadow flicker hour will be reduced from obstructions alone by approximately 91%, resulting in approximately 300 minutes per year of shadow flicker as an average for all windows at the receptor, or about 5 hours per year. The adjustment based on cloud cover and foliage cover in fall and winter is similar, raising the estimate slightly due to deciduous trees losing part of their ability to block sunlight in the winter to approximately 90% reduction from the "no obstructions" case, or about 310 minutes per year. The northern windows on the second story above the garage are expected to experience the most the most shadow flicker, with a range of 24 to 40 hours per year. The shadow flicker for these two windows primarily happens in the morning from May through July. The two windows are relatively small, so the impact of shadow flicker is not expected to be extreme.

Table 5 presents the results of the detailed analysis for Receptor 26. Figures 13 and 14 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 15 and 16 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 5. Receptor 26 Overall Results

Shadow Flicker (min)	3,692	Estimated from overall analysis
Shadow Flicker (min)	3,177	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	3,526	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	-90.5	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	301	
Shadow reduction (%)	-90.5	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	310	

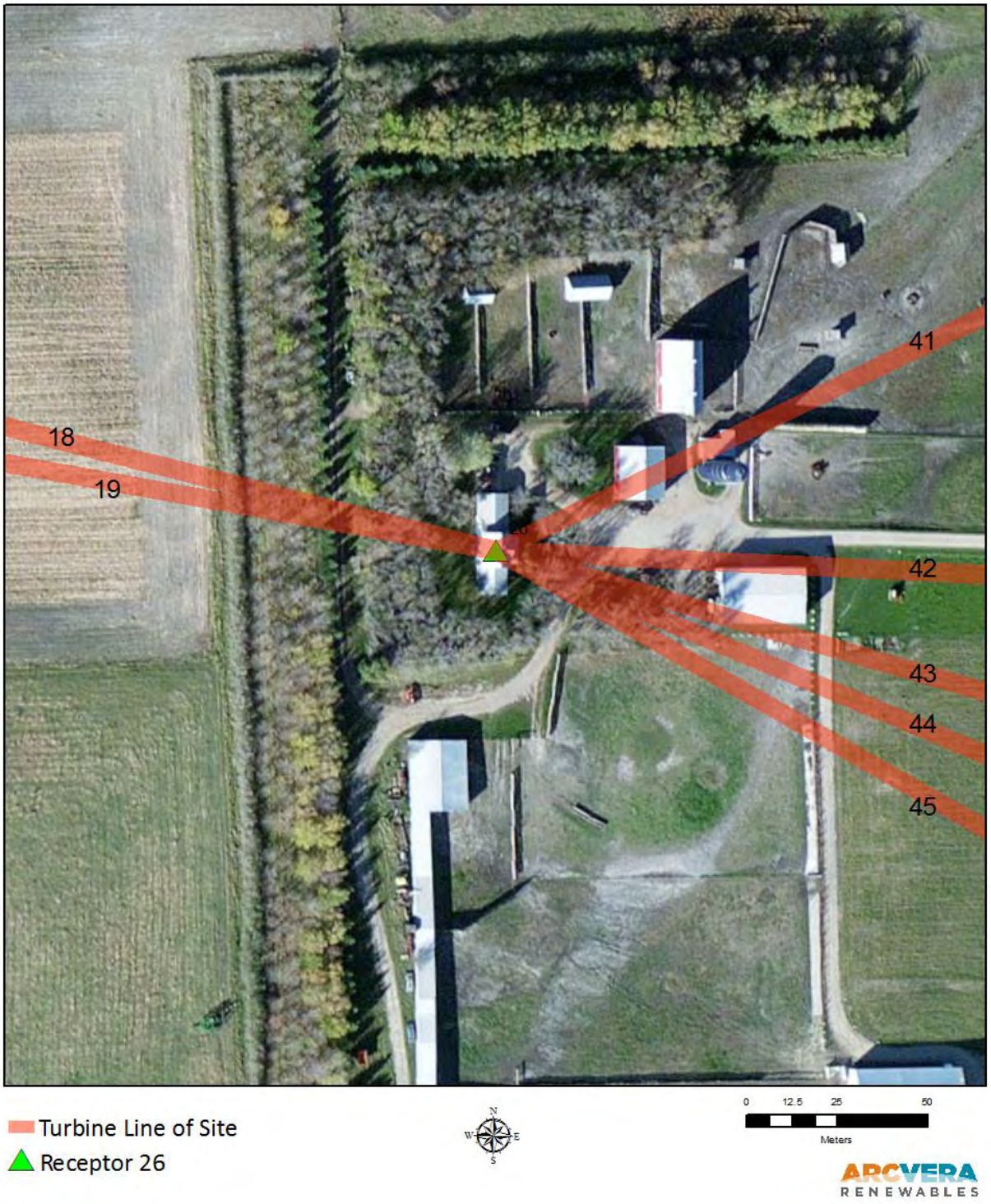


Figure 13. Receptor 26 Aerial Image with Line of Site from Turbines

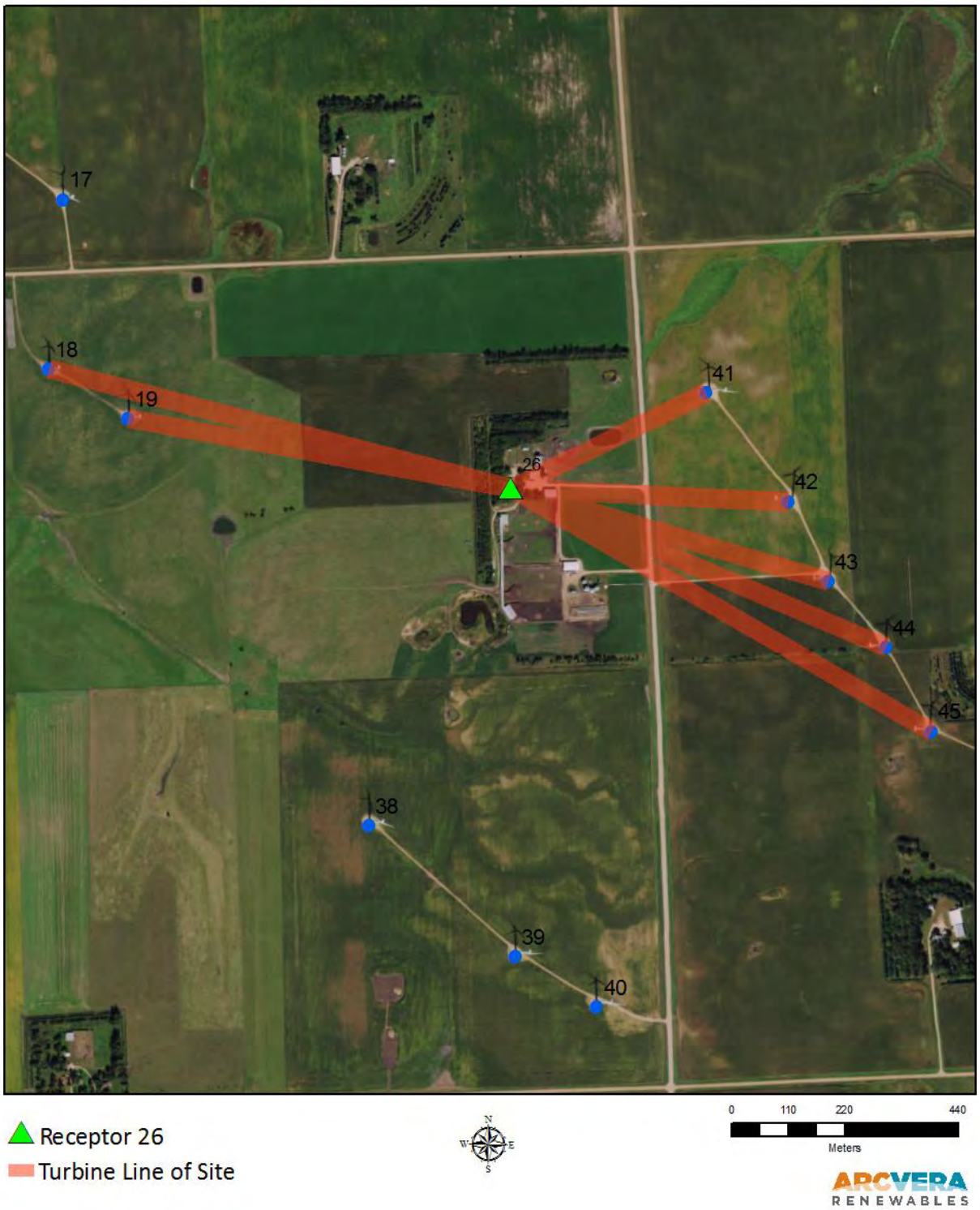


Figure 14. Receptor 26 Broad Aerial Image with Line of Site from Turbines

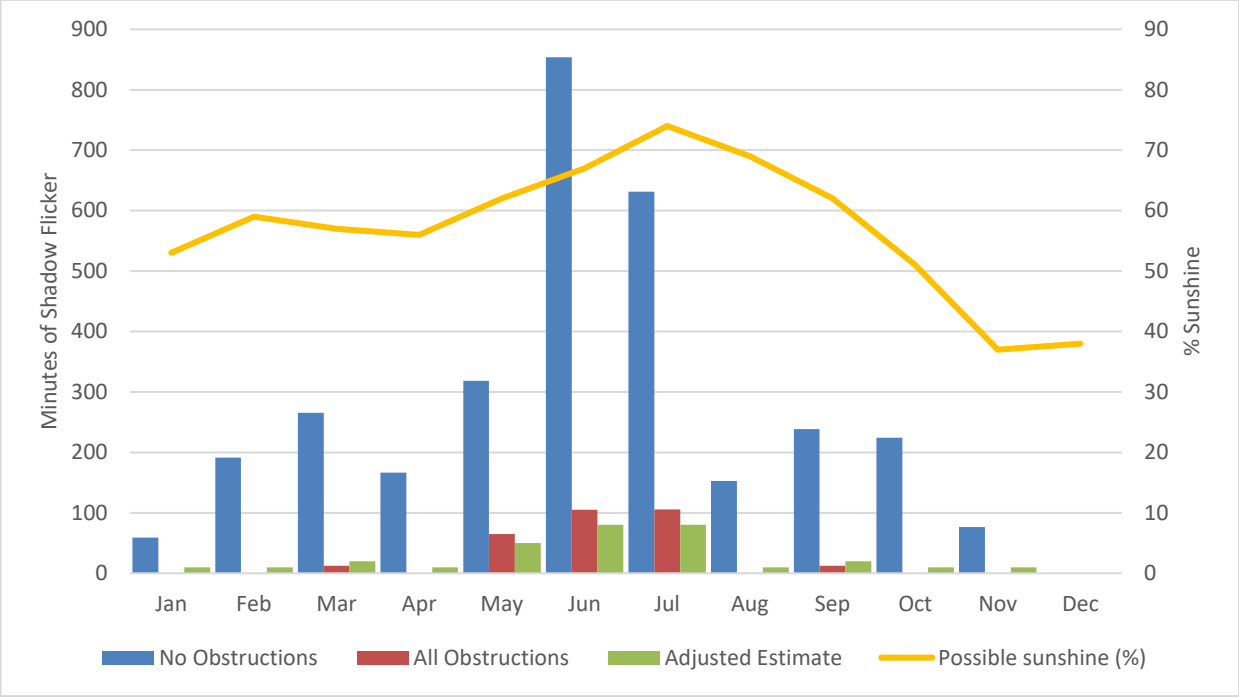


Figure 15. Receptor 26 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

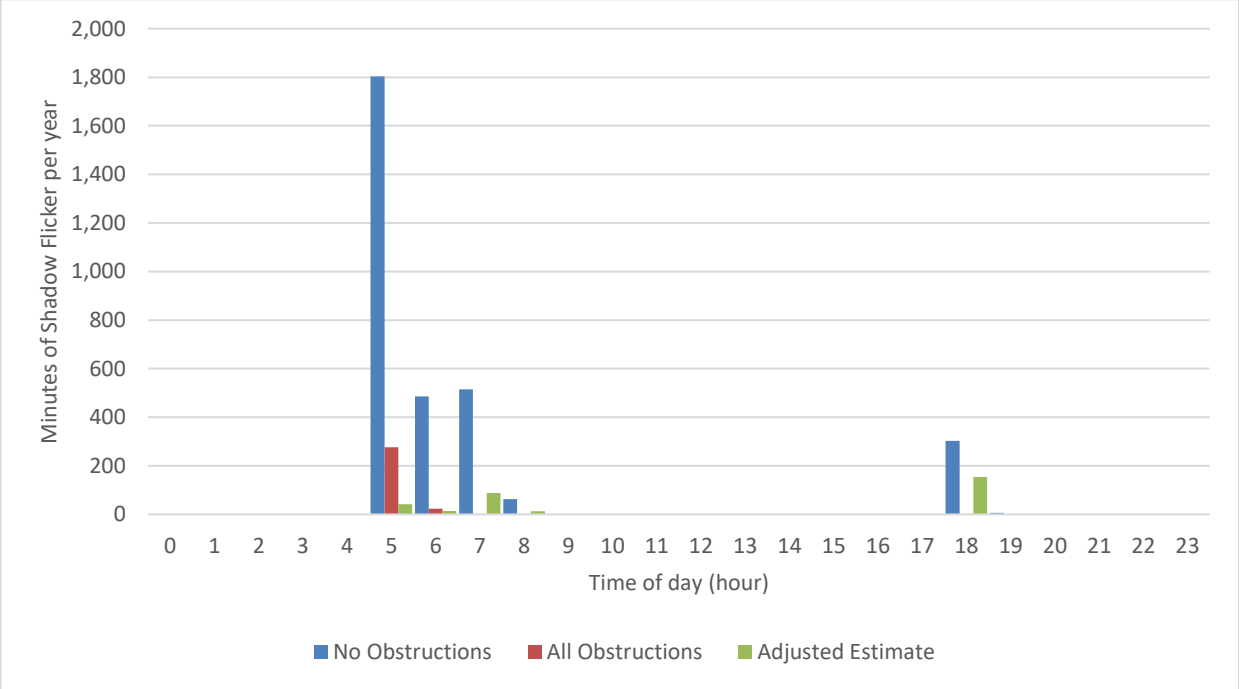


Figure 16. Receptor 26 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

3.4 Receptor 37

Receptor 37 has no buildings or trees that could mitigate shadow flicker from the row of turbines to the southeast. Many of the structures in the aerial imagery around the receptor are gone, as well as the tree near the building that would have provided quite a bit of blocking. The site visit photos for Receptor 37 clearly show the exposure of the building to the southeast.

The risk of shadow flicker for this receptor is evident in that there is no difference from the "no obstructions" analysis to the "all obstructions" case. The receptor building itself does not supply any blocking for its own windows. When accounting percent sunshine on a monthly basis, shadow flicker is reduced by more than 50% to approximately 1,570 minutes, or approximately 26 hours per year. The worst case, not accounting for any weather patterns is approximately 54 hours per year. Because there will not be a year where the receptor experiences 100% sunshine, the actual amount of shadow flicker experienced by the receptor will most likely be between 26 and 40 hours per year.

Table 6 presents the results of the detailed analysis for Receptor 37. Figures 17 and 18 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 19 and 20 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 6. Receptor 37 Overall Results

Shadow Flicker (min)	3,233	Estimated from overall analysis
Shadow Flicker (min)	3,243	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	3,280	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	0.0	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	3,243	
Shadow reduction (%)	-51.6	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	1,570	

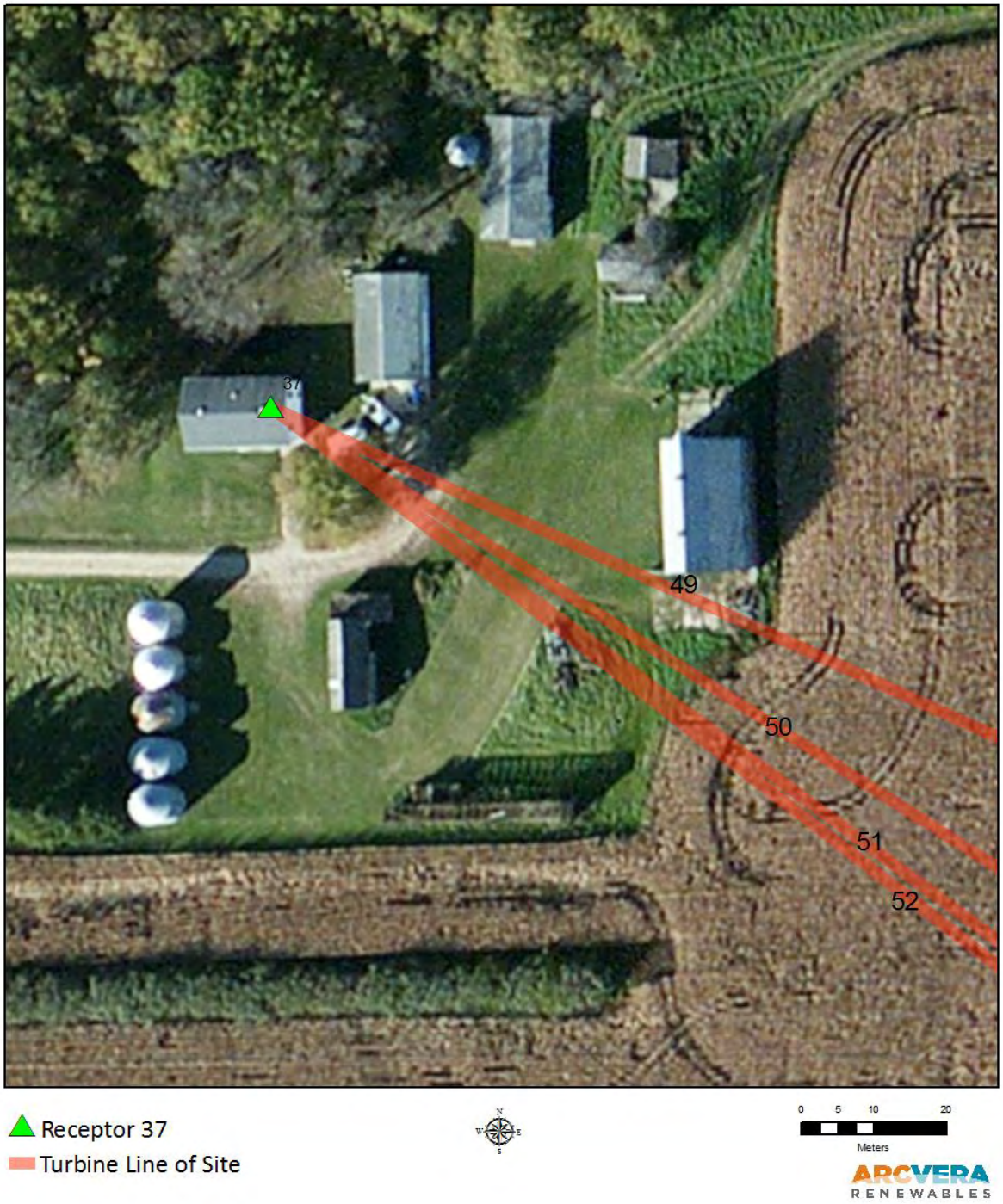


Figure 17. Receptor 37 Aerial Image with Line of Site from Turbines

Figure 18. Receptor 37 Broad Aerial Image with Line of Site from Turbines

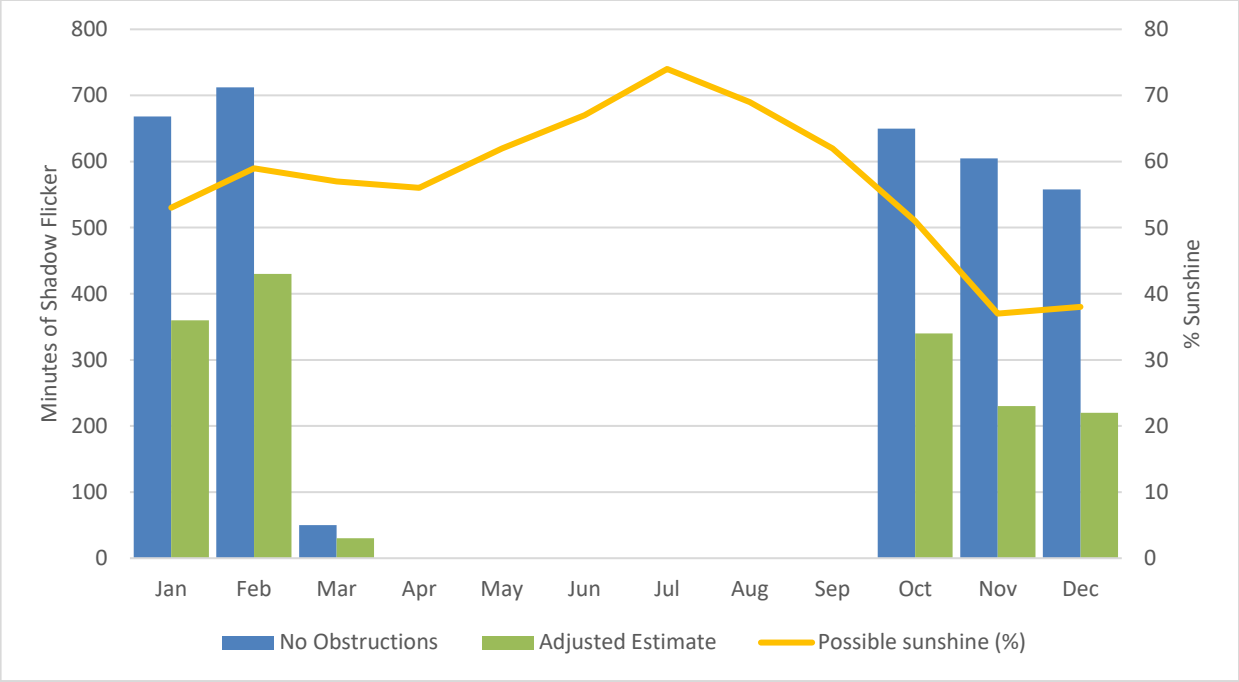


Figure 19. Receptor 37 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

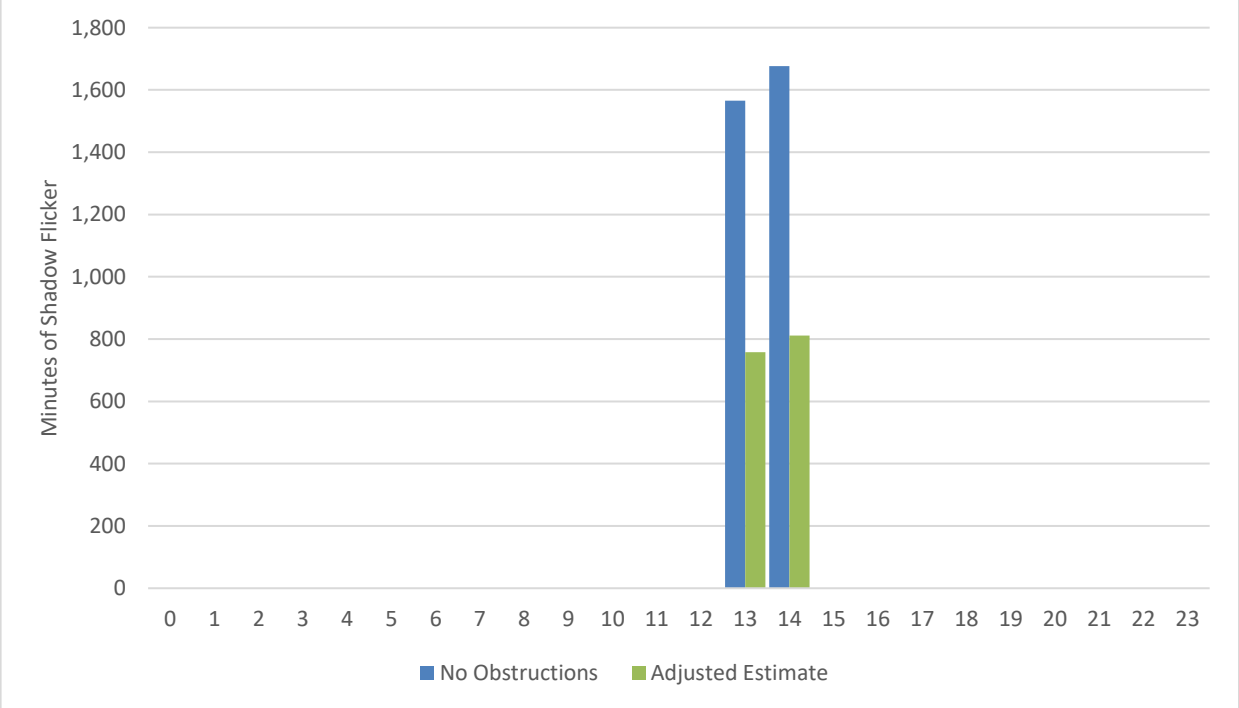


Figure 20. Receptor 37 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

3.5 Receptor 40

As previously noted, Receptor 40 is a Town Hall that is not occupied on a daily basis. For that reason, the receptor analysis was simplified, with points representing blocks of windows on the respective sides of the building. There are no other structures around the receptor, although there are some trees to the north and northeast.

We expect that from the "no obstructions" analysis, shadow flicker hour will be reduced from obstructions alone by approximately 43%, resulting in approximately 2830 minutes per year of shadow flicker as an average for all windows at the receptor, or about 47 hours per year. The adjustment based on cloud cover and foliage cover in fall and winter reduces that to approximately 2,190 minutes per year, or 37 hours per year. The shadow flicker happens primarily from May to July in the evening.

Table 7 presents the results of the detailed analysis for Receptor 40. Figures 21 and 22 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 23 and 24 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 7. Receptor 40 Overall Results

Shadow Flicker (min)	3,645	Estimated from overall analysis
Shadow Flicker (min)	4,979	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	5,699	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	-43.2	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	2,828	
Shadow reduction (%)	-56.0	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	2,190	

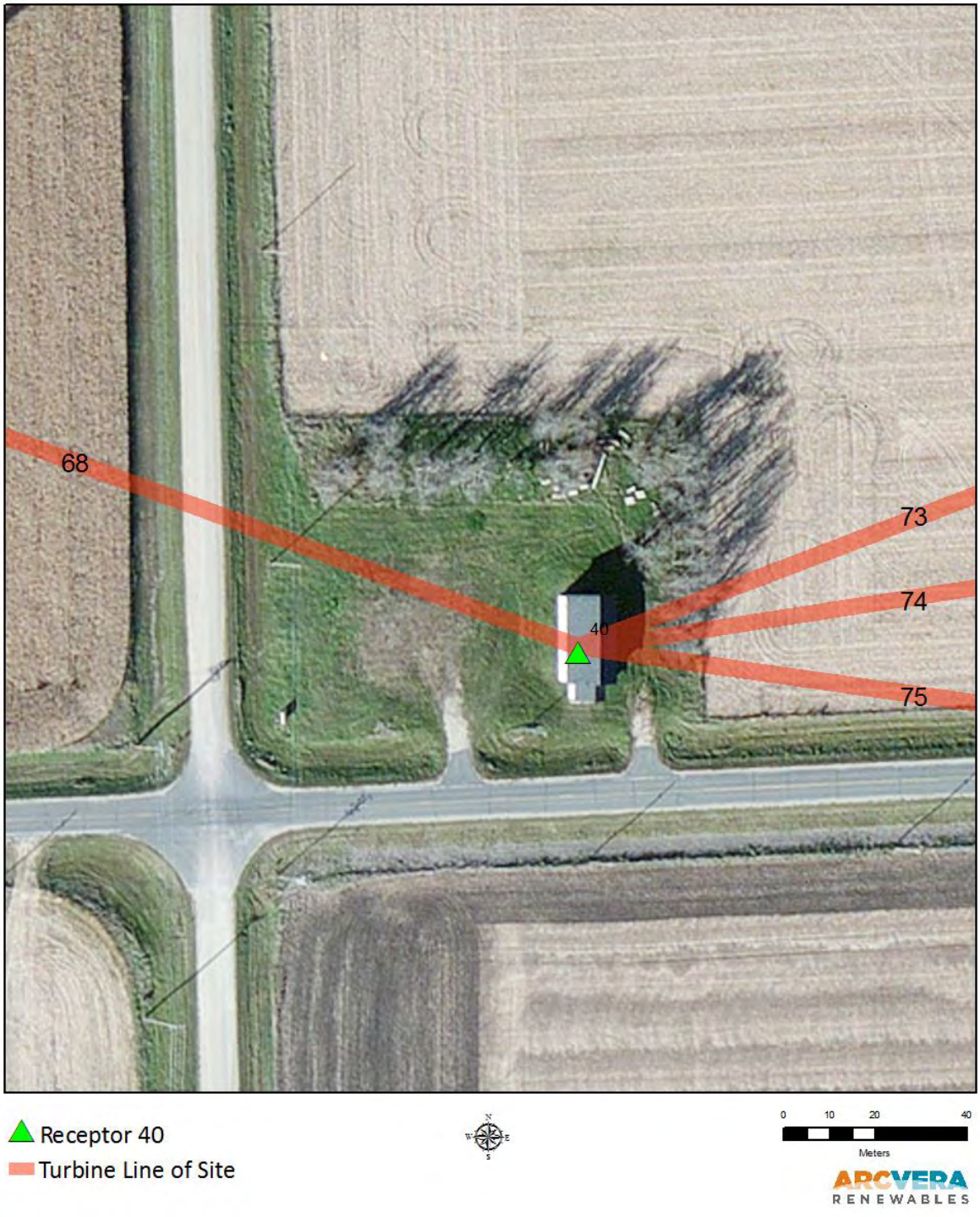


Figure 21. Receptor 40 Aerial Image with Line of Site from Turbines

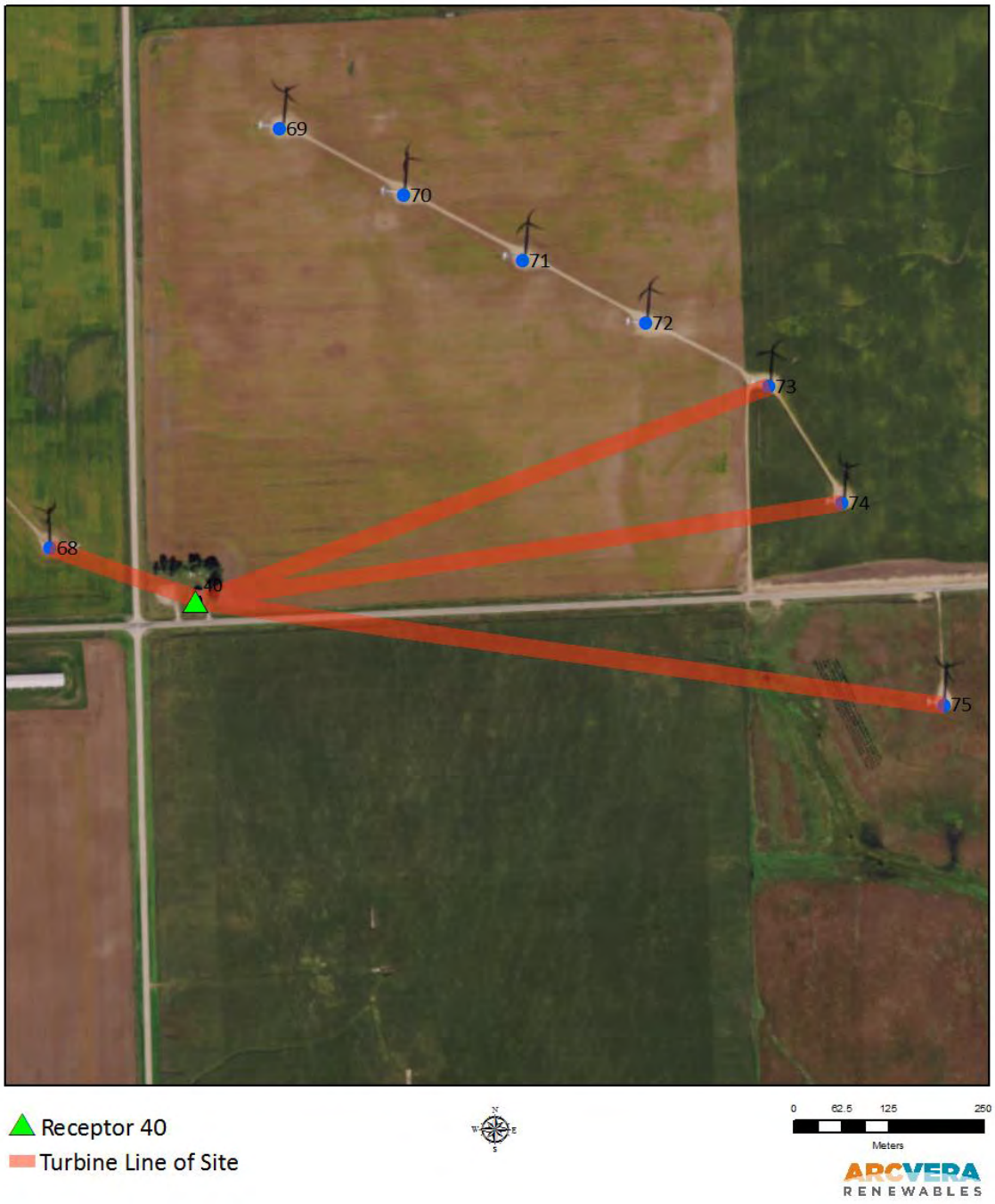


Figure 22. Receptor 40 Broad Aerial Image with Line of Site from Turbines

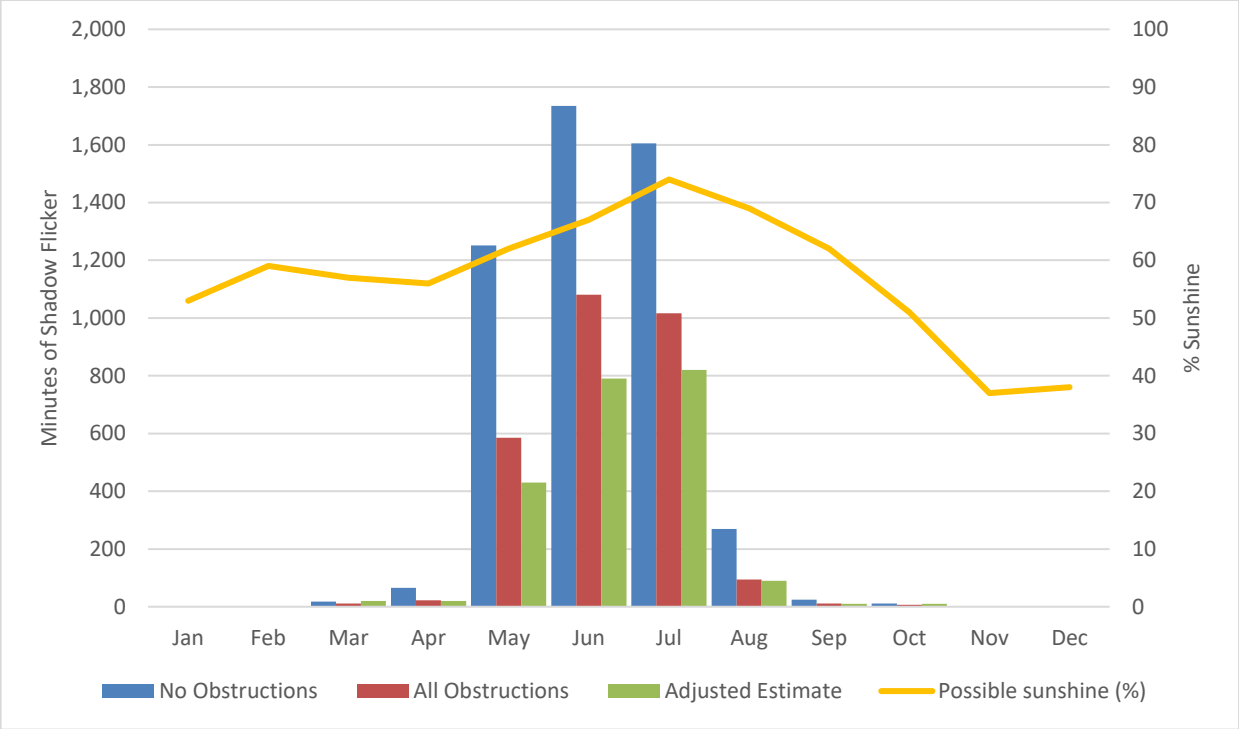


Figure 23. Receptor 40 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

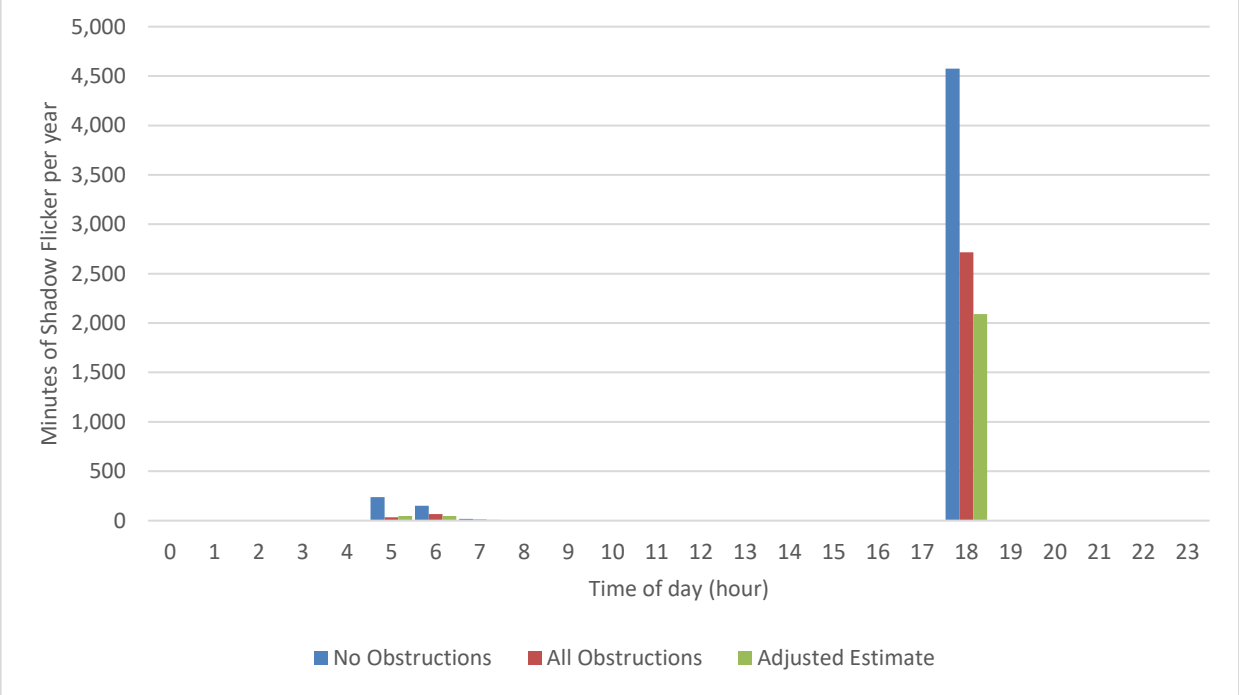


Figure 24. Receptor 40 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

3.6 Receptor 64

Receptor 64 has no buildings that could block shadow flicker from the turbines to the west, but there are scattered and large groves of trees that will mitigate some shadow flicker.

We expect that from the "no obstructions" analysis, shadow flicker hour will be reduced from obstructions alone by approximately 42%, resulting in about 2,030 minutes per year of shadow flicker as an average for all windows at the receptor, or about 34 hours per year. The adjustment based on cloud cover and foliage cover in fall and winter reduces the shadow flicker to approximately 21 hours per year.

The windows with the highest amount of shadow flicker are windows for the garage. Excluding those windows lowers the shadow flicker estimate to a range of approximately 24 hours per year to 30 hours per year. Given the placement and patchy nature of many of the trees around the receptor, accurate numbers are difficult to determine. A few feet variance in the estimate of tree location or size could affect the amount of shadow flicker greatly. In addition, the large deciduous tree on the west side of the house has few lower branches, and may not provide much blockage. The uncertainty involved with Receptor 64 is quite high, potentially up to 25%, meaning that shadow flicker experienced by the receptor could be as high as 43 hours per year, or as low as 15 hours per year.

Table 8 presents the results of the detailed analysis for Receptor 40. Figures 25 and 26 present aerial views of the receptor with a line of site from each turbine with the potential to cause shadow flicker. Figures 27 and 28 show shadow flicker for the No Obstructions case, the All Obstructions case, and the Adjusted Estimate on a monthly and hourly basis, respectively. The monthly chart also shows the average sunshine per month as a reference.

Table 8. Receptor 64 Overall Results

Shadow Flicker (min)	3,645	Estimated from overall analysis
Shadow Flicker (min)	3,479	Detailed analysis, no obstructions, mean from all windows
Shadow Flicker (min)	3,630	Detailed analysis, no obstructions, max from all windows
Shadow reduction (%)	-41.7	Without cloud cover or deciduous tree factors
Shadow Flicker (min)	2027	
Shadow reduction (%)	-64.6	Includes cloud cover and deciduous tree factors
Shadow Flicker (min)	1,230	

Figure 25. Receptor 64 Aerial Image with Line of Site from Turbines

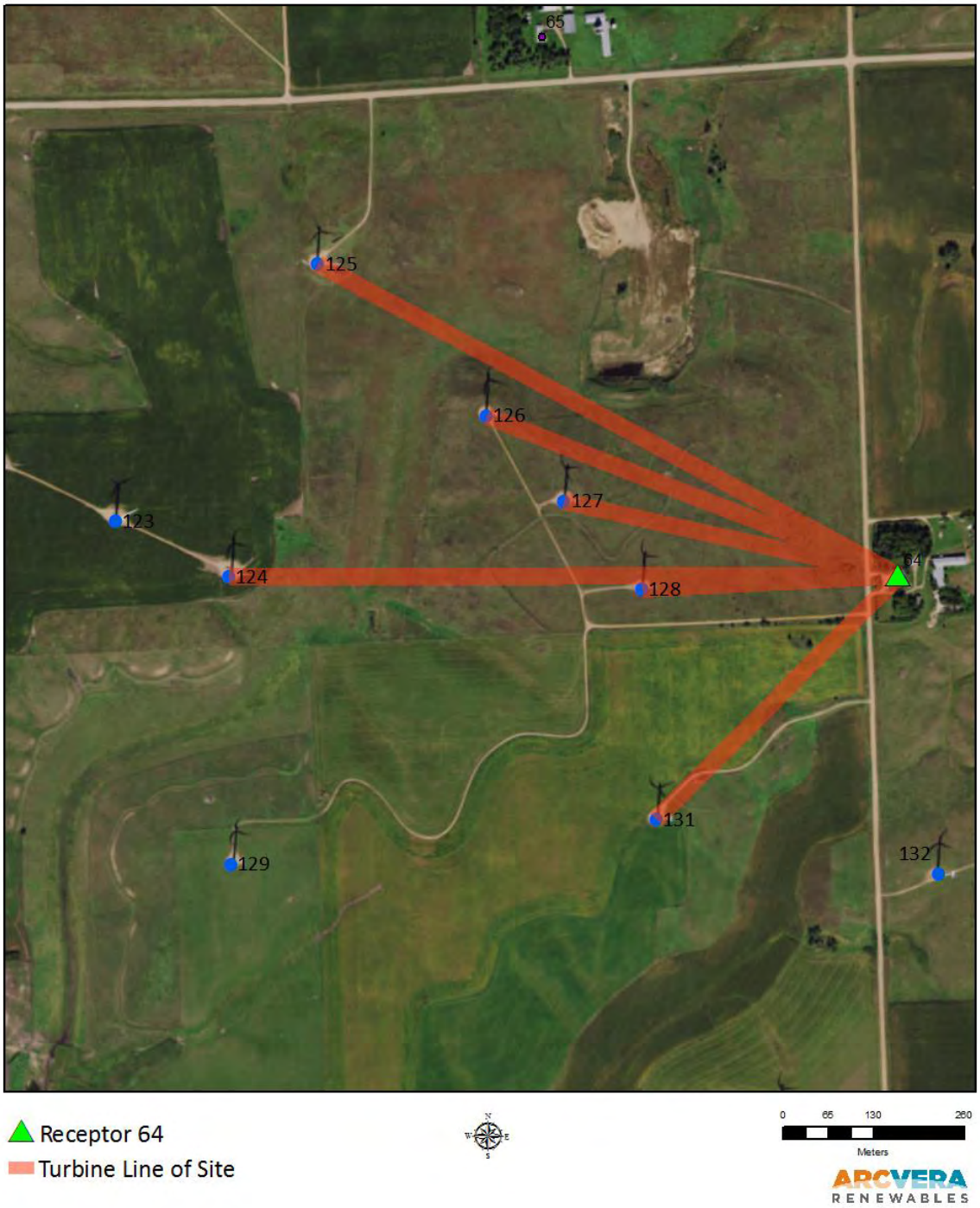


Figure 26. Receptor 64 Broad Aerial Image with Line of Site from Turbines

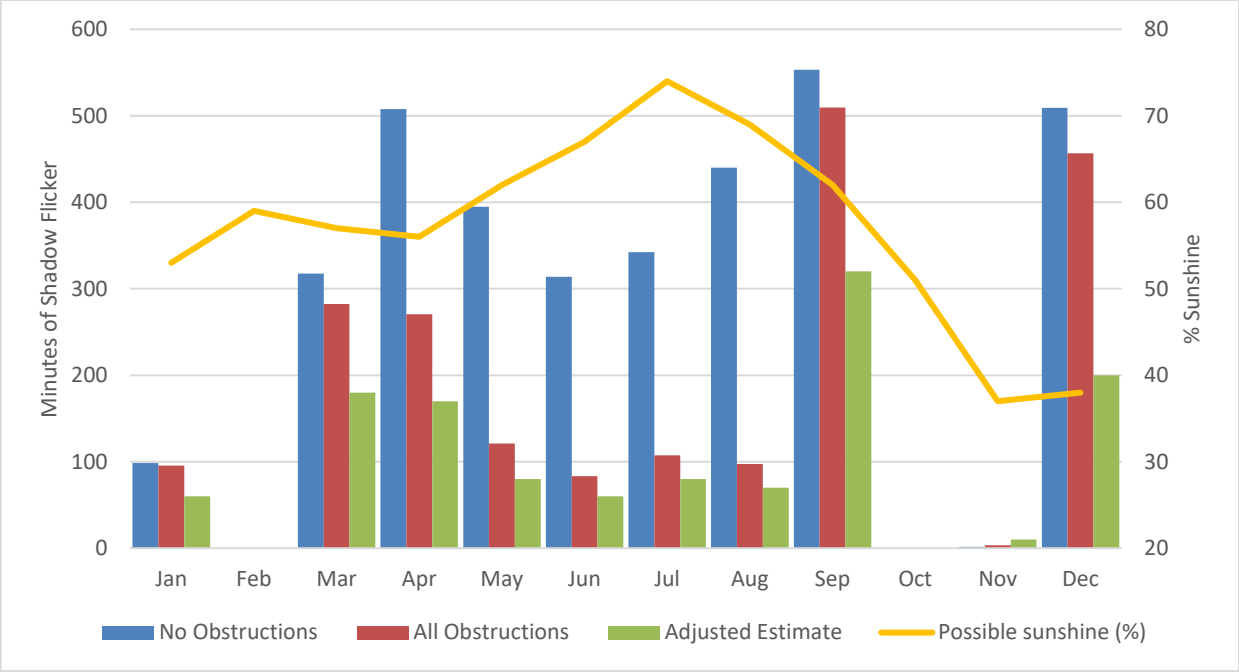


Figure 27. Receptor 64 Monthly Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

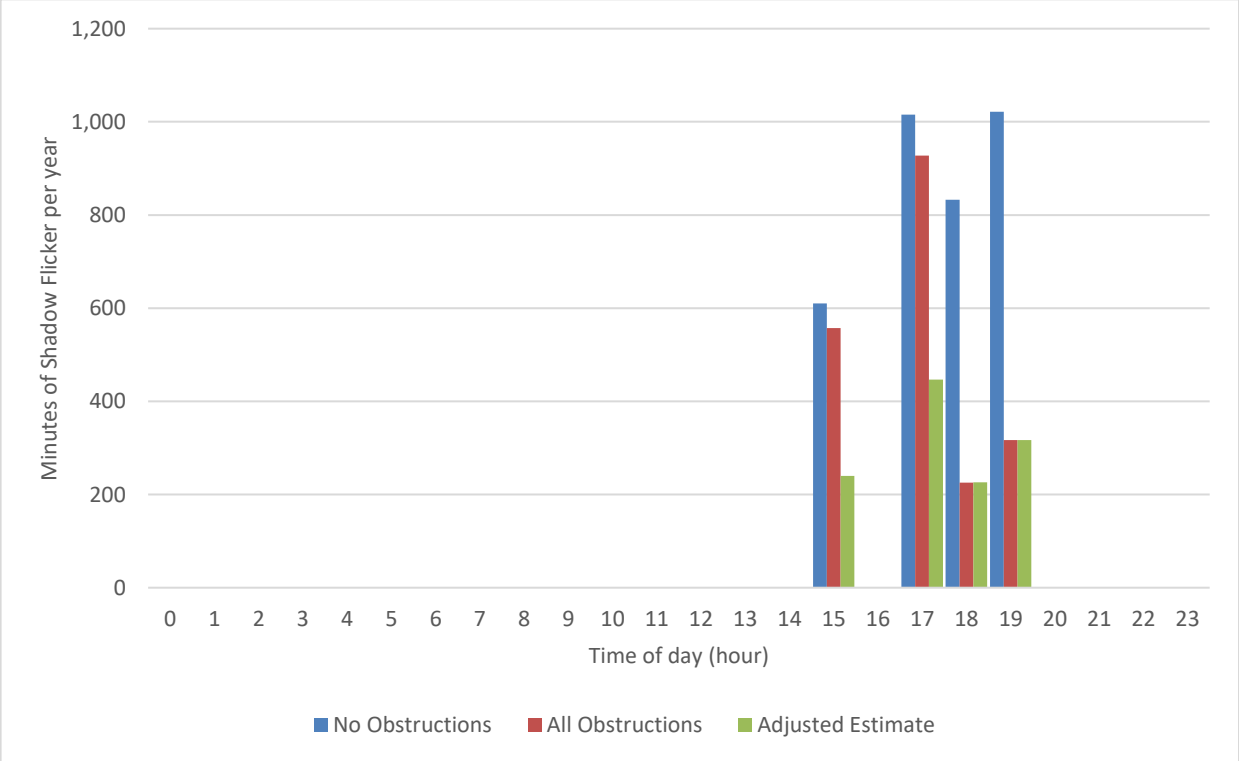


Figure 28. Receptor 64 Time of Day Shadow Flicker, No Obstructions, All Obstructions, and Adjusted Estimate

APPENDIX A: Site Visit Documentation

RECEPTOR 1

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering

Receptor Site 1

Type	House
Orientation	N/S
Stories	Story & a half (old portion, with west dormer). New is largely garage
Shadow flicker from	Generally west

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
93	WNW	916
96	NW	505
100	SW	926
101	SW	882

Windows	Number	Approx size (height/width)	Notes
Facing west	2 upper, 2 lower + door	upper = 1' H x 1.5'W, lower ~2.5'Wx5', other lower is bay window, overall ~6' wide x 5'H, 1/4 top door window	
Facing north	1 upper, 2 lower	per = ~1.5'Wx3'H, lower ~2'Wx	mixed small trees on north side, also in driveway loop, mostly ~10 feet high
Facing south	0		South wall of new garage is incomplete, not yet sided, only housewrapped. No apparent windows or doors on south side

Obstructing Features	Approx. Height (m)	Approx. Dist. From House (m)	Notes
		45	bldgs are all ~ same height as home/garage ~ 20-25'
West barns/silos	6		
		80-120	lots of low brush, largely deciduous
W/NW trees	15-20m mixed		
SW barns/silos	6		
SW trees	6-7m	30-80	brushy trees, with outermost tier composed of 4-8m evergreens on slightly elevated ground/berm
Other structures		170-220	

Other notes and observations

Expansion is underway, addition of a 3 car attached garage to south side of home, appears to double the area. Photo from driveway has clear view inline with house of 100&101 - home base elev is much lower than turbine base. Trees on south removed to make way for expansion. Porch overhang is a good 4+ feet deep,

Facing Turbine 96 from Receptor 1

Facing Receptor 1 from Turbine 96

Facing Turbine 93 from Receptor 1

Facing Receptor 1 from Turbine 93

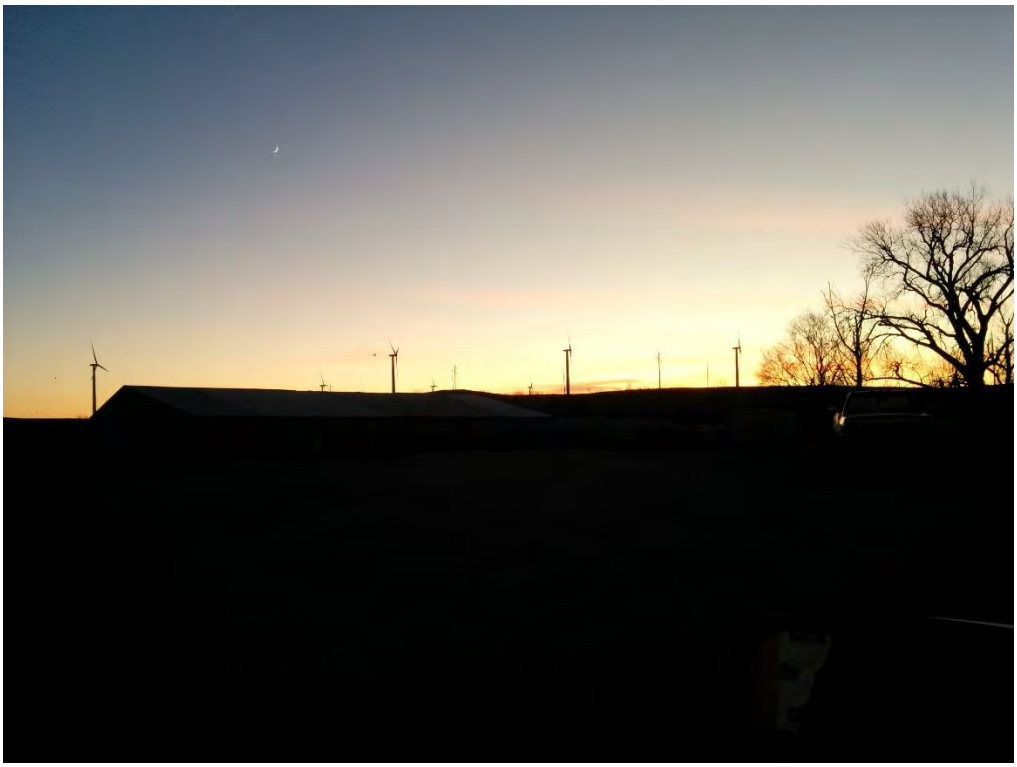
View of West Face of Receptor 1 from Road

Facing Turbine 101 from Receptor 1

Facing Receptor 1 from Turbine 101

Facing Turbine 100 from Receptor 1

Facing Receptor 1 from Turbine 100



View from Receptor 1 from Driveway in line with Windows of Home

Looking up Driveway at Receptor 1

RECEPTOR 25

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering *Note: This residence may be difficult to ascertain all windows due to long drive*

Receptor Site 25

Type	House
Orientation	E/W
Stories	2
Shadow flicker from	East and West

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
9	ENE	420
10	ENE	809
11	ENE	932
20	WSW	908
30	ESE	920

Windows	Number	Approx size (height/width)	Notes
Facing west	2 upper, 2 lower		view of house was limited due to long drive
Facing east			not visible - obscured almost completely by East trees/vegetation
Facing north			not visible - obscured completely by North trees/vegetation
Facing south	2 upper, 1 lower + door		could see 1/2 of home, assume other is match + door

Obstructing Features	Approx. Height (m)	Approx. Dist. From House (m)	Notes
S/SE trees	see note	30	Evergreen/Decid mix, evergreens ~2/3 height of deciduous: ~20m decid., ~10-15m evergreen
East trees	see note	10	Evergreen/Decid mix, evergreens ~2/3 height of deciduous: ~20m decid., ~10-15m evergreen, North end of the east side (N of driveway) are a little nearer to evenly 10-15m for both decid and evergreen
West trees	10	10	
SW structures	6.25	25	
SE Structures	5	30	
Silo	10	50	

Other notes and observations

estimation of dimensions of windows is challenging due to distance and heavy cover. Eastern window on South wall was slightly visible down driveway, appears to have old-style metal shade extended out over it. From alignment with turbine 9, thick vegetation obscures the house completely

Facing from Turbine 9 from Receptor 25

Facing Receptor 25 from Turbine 9

Facing from Turbine 20 from Receptor 25

Facing Receptor 25 from Turbine 20

Inline between Receptor 25 and Turbine 21

Inline between Receptor 25 and Turbine 20

RECEPTOR 26

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering *Note: This residence may be difficult to ascertain all windows due to long drive and trees*

Receptor Site 26

Type	House	
Orientation	N/S	
Stories		2
Shadow flicker from	East and West	

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
18	WNW	921
19	WNW	739
41	ENE	425
42	E	545
43	ESE	637
44	SE	787
45	SE	940

Windows	Number	Approx size (height/width)	Notes
Facing west	not visible		West side isn't clearly visible. Top of roof and some shingles visible through treetops from turbine #19, bulk is below evergreen portions and not visible.
Facing east	2 upper, 2 lower, plus 2 doors with glass		
Facing north	2 upper level	~1.5/Wx2.5'H	/lower level is garage
Facing south	2 upper, 2 lower	~1.5/Wx2.5'H, may be larger on lower level, not clearly visible	South face visibility limited, throuhg trees.

Obstructing Features	Approx. Height (m)	Approx. Dist. From House (m)	Notes
West trees	15		Rows of several varieties, including deciduous & evergreen. Evergreen ~60% of the height of decidouous
East trees	17		East trees appear to me mostly deciduous
North trees	15		Rows of several varieties, including deciduous & evergreen. Evergreen ~60% of the height of decidouous
South trees	~17		Appear largely deciduous, can't see the base but tops are in line with the east trees. There are a few evergreens mixed in on the south side
NE structures	NA		NE structure is gone
East structure	9		this is the ENE structure, in line with the silo&its lean-to shed
SE structures	7		This is for ESE structure
Other structures	20		Silo has a roughly 15m lean-to shed on its north side

Other notes and observations

Clear view of front door right down the driveway, some masking may fill in a bit with leaves, but it's a pretty clear view

Facing Receptor 26 from Turbine 19

Facing Turbine 41 from Receptor 26

Facing Receptor 26 from Turbine 41

Facing Receptor 26 from Turbine 41 from road

Facing Receptor 26 from Turbine 42

Facing Receptor 26 from Turbine 42 looking down driveway

Facing Receptor 26 from Turbine 42

Facing Receptor 26 from Turbine 43

Facing Receptor 26 from Turbine 43 on road

Facing Receptor 26 from Turbine 44

Facing Receptor 26 from Turbine 44 on road

Facing Receptor 26 from Turbine 45

RECEPTOR 37

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering

Receptor Site 37

Type	House
Orientation	N/S
Stories	1.5 - daylighted basement has full windows @ ground level
Shadow flicker from	South east

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
49	SE	326
50	SE	501
51	SE	680
52	SE	855

Windows	Number	Approx size (height/width)	Notes
Facing east	3 + door	3'Hx2'W upper windows (one is a double, 2 are singles), lower is slightly smaller. Door has pair of thin veritcal lights ~6"W x 3'H	
Facing south	3 upper, 2 lower	1 double, 1 single, match upstairs dimensions 3'Hx2'W	

Obstructing Features	Approx. Height (m)	Approx. Dist. From House	Notes
Building SE		NA	Building is gone
Trees south	3	76	appears to be a lilac hedge, with a few slightly taller trees sporadically
Tree next to house SE		NA	Tree is gone

Other notes and observations

All cover to the SE appears gone, the small barn and the tree on the SE corner both have been removed. There are non Lake Benton turbines to the W & NW as well

Facing Receptor 37 from Turbine 49

Facing Turbines 50 and 52 from Receptor 37

Facing Turbines 50 and 52 from Receptor 37

RECEPTOR 40

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering

Receptor Site 40

Type	Town hall
Orientation	N/S
Stories	One tall level, with basement windows
Shadow flicker from	East/West

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
68	WNW	210
73	ENE	807
74	ENE	862
75	ESE	990

Windows	Number	Approx size (height/width)	Notes
Facing west	6 upper, 7 lower, plus door	2' W x 6' H Upper, 1'Wx2'H basement, 2'Wx5'H on entry, half door	Many of western basement are obscured by ramp, one fully and one partially boarded over
Facing east	7 upper, 6 lower, 1 on entry	same dimensions as west face	
Facing north	None		Only an access panel on the north wall
Facing south	4 plus 1 in door	2'Wx6'H on main building, pair 2'Wx5'H on entry, half door window	

Obstructing Features	Approx. Height (m)	Approx. Dist. From House (m)	Notes
Trees East	15	10	Single row of trees
Trees North	15	15	Single row of trees, with several gaps

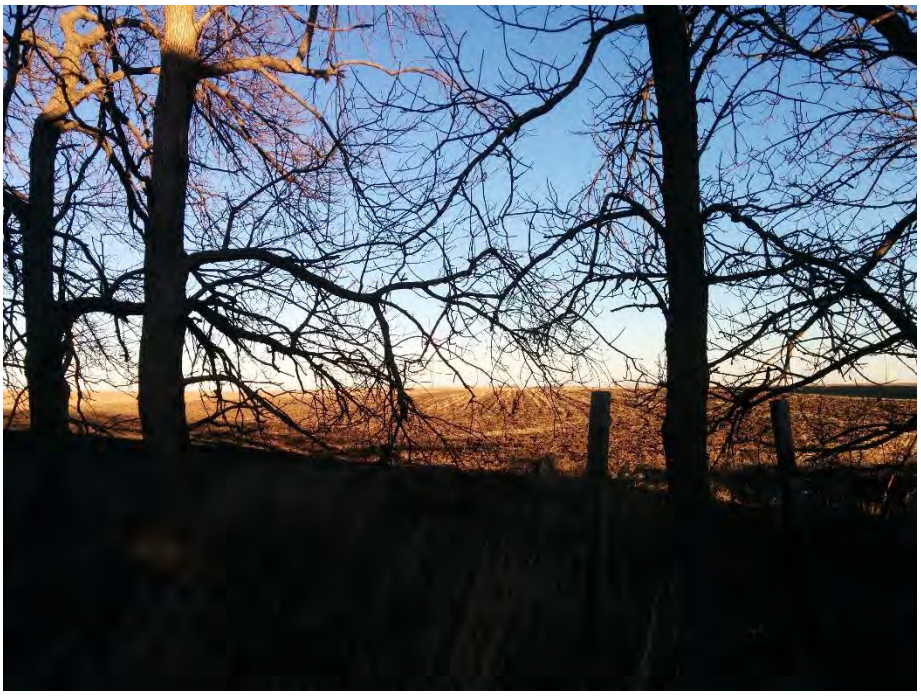
Other notes and observations

Upper level is divide into 3 main spaces, 1 window deep on north, 3 windows center, 3 windows south, plus lower entry has own windows on each side

North side of Township Hall

Facing north from Township Hall

Facing east-northeast from Township Hall



Facing east from east side of Township Hall

South side of Township Hall

Facing south from Township Hall

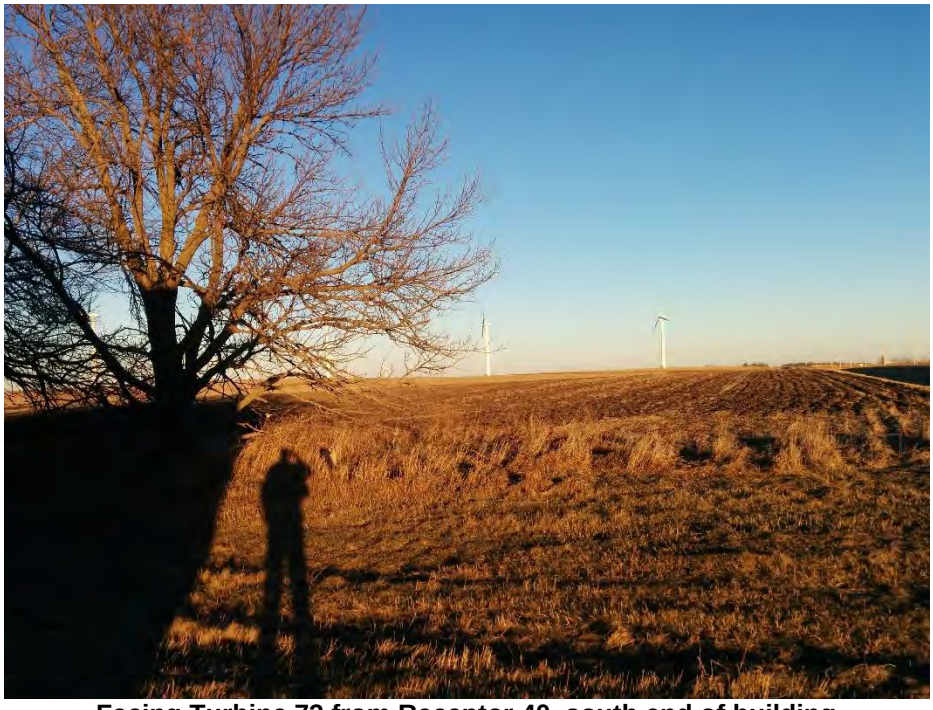
West face of Township Hall

East face of Township Hall

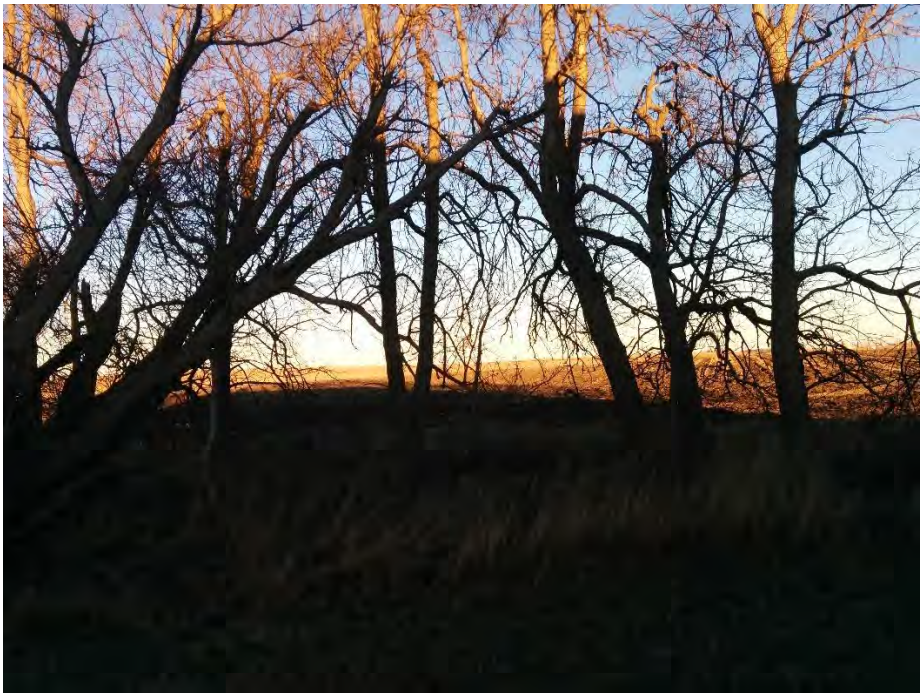
Facing west from Township Hall

Facing Turbine 68 from Receptor 40, south end of building

Facing Turbine 68 from Receptor 40, north end of building

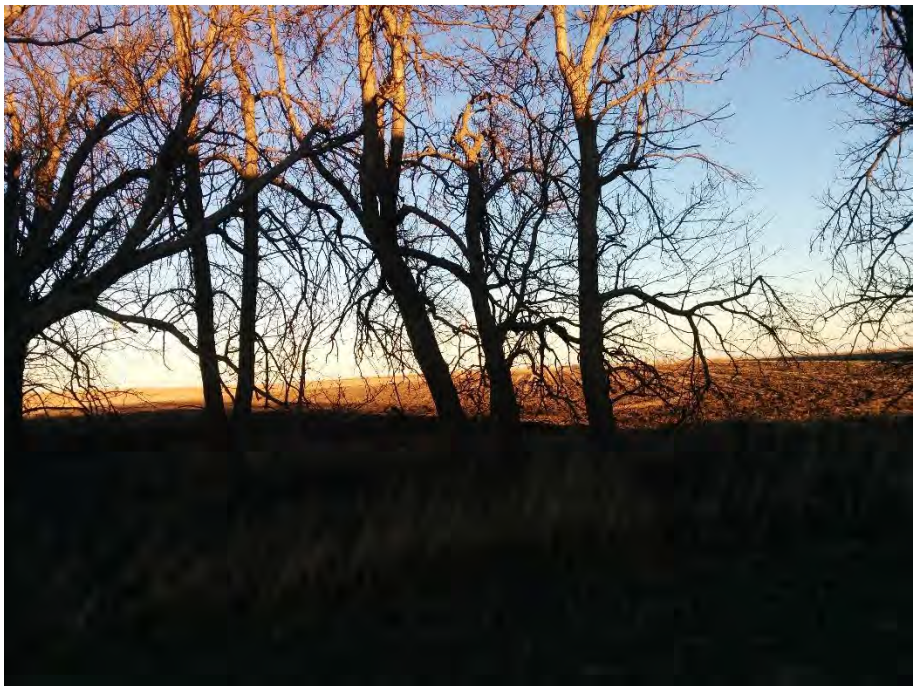


Facing Turbine 73 from Receptor 40, south end of building



Facing Turbine 73 from Receptor 40, north end of building

Facing Turbine 74 from Receptor 40, south end of building



Facing Turbine 74 from Receptor 40, north end of building

Facing Turbine 75 from Receptor 40, south end of building

Facing Turbine 75 from Receptor 40, north end of building

RECEPTOR 64

Shadow Flicker Site Visit Notes
Lake Benton, MN
Barr Engineering

Receptor Site 64

Type	House
Orientation	E/W
Stories	
Shadow flicker from	Generally west

Shadow Flicker Turbines	Turbine Direction from House	Turbine Distance to House (m)
124	W	962
125	NW	945
126	NW	632
127	WNW	495
128	W	373
131	SW	495

Windows	Number	Approx size (height/width)	Notes
Facing west	2	~2'x2'	In west wall of garage, no windows on West face of home
Facing south	5	Patio door to deck, 1 roughly 4'Hx8'wide 4-panel window, 1 ~4'Wx4'H 2-pane windows in western half (up & down). Lower east window is obscured in under the new deck. Also garage service door with top half window tucked into alcove, and top panels of garage doors are glass.	
Facing north	3	Door with ~1'Wx2'H side lights (future north deck access?, no deck there now), garage service door may have a little window on top	

Obstructing Features	Approx. Height (m)	Approx. Dist. From House	Notes
Trees NW	14.5	16	
Trees south	10.7	26	
Trees west	18.4	10	This is a quite tall deciduous tree, there's a little ~3-4m tree next to it slightly southward
Trees SW	5.5	40-70	Southwest trees are evergreens in a line along the road. Some scattered ~1m bushes in the loop of the driveway
Trees along E/W road to south	5	78-150	Trees are pretty patchy and all deciduous

Facing Turbine 126 from Receptor 64

Facing Turbine 127 from Receptor 64

Facing Receptor 64 from Turbine 128

Facing Turbine 128 from Receptor 64

Facing Turbine 131 from Receptor 64

Facing Receptor 64 from Turbine 131

Facing Receptor 64 from Turbine 127

resourceful. naturally.
engineering and environmental consultants

BARR

December 5, 2017

Sarah Beimers
Manager of Government Programs and Compliance
MnHPO - Compliance Unit
Minnesota Historical Society
345 Kellogg Boulevard West
St. Paul, Minnesota 55102-1906

RE: Lake Benton Power Partners, LLC Site Permit Amendment

Dear Ms. Beimers:

Lake Benton Power Partners, LLC (LBPP) operates an existing 107.25 Megawatt (MW) wind energy generation facility located in Lincoln County, Minnesota (refer to attached figure), that it purchased from AES Corporation in 2015. The Minnesota Environmental Quality Board (EQB) issued a Large Wind Energy Conversion System (LWECS) Site Permit (Public Utilities Commission [PUC] Docket: IP6908/WS-13-294, EQB Permit: LWECS-1-1997) to the original owner on October 31, 1995, and made subsequent amendments on June 19, 1997 and November 1, 2017. As a result of the most recent permit amendment, the permit expires on November 1, 2039. The facility includes 139 Zond turbines (Z 750 model) and commenced commercial operation in 1997.

LBPP is proposing to conduct facility upgrades for the purpose of increasing efficiency and reliability, and extending the life of the wind energy facility. The facility's nameplate capacity of 107.25 MW will not change. The proposed upgrades will consist of retrofitting the existing wind turbines by exchanging old equipment for new components. To accomplish these improvements, a request to amend the existing LWECS site permit will be submitted to the Minnesota Public Utilities Commission (PUC) in December, 2017. Specifically, LBPP will seek the following changes to the existing permit:

- Increase the rotor diameter from 48 to 50 meters;
- Adjust the permitted wind access buffer setbacks to current PUC guidelines; and
- Approve an exception for those turbines that do not meet the current PUC setback guidelines.

LBPP retained Barr Engineering Co. (Barr) to assist with the Site Permit amendment process for the facility. The purpose of this letter is to inform your organization of the proposed turbine retrofits and the pending PUC Site Permit amendment. LBPP plans to conduct the retrofit activities within existing access roads and construction pads and previously surveyed areas. Therefore, no impacts to historic properties are anticipated to occur as a result of the proposed Project.

If you have comments regarding this proposed Site Permit amendment, please contact Rachael Shetka at Barr at the address listed below, by e-mail at RShetka@barr.com or by phone at (218) 529-7155.

Sincerely,

Rachael Shetka

Rachael Shetka
Senior Environmental Specialist

Attachments: Site Location Map

Turbine Location

Met Tower Location

Project Boundary (2007)

Municipal Boundary

Civil Township

County Boundary

Miles

2.5 0 2.5

Kilometers

5 0 5

Figure 1

SITE LOCATION
Lake Benton Wind Project
ALLETE Clean Energy
Lincoln County, Minnesota

resourceful. naturally.
engineering and environmental consultants

BARR

December 5, 2017

Ms. Cynthia Warzecha
Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul, M 55155

RE: Lake Benton Power Partners, LLC Permit Amendment
Natural Heritage Information System Rare and Unique Resource Review

Dear Ms. Warzecha:

Barr Engineering Co. (Barr) is assisting Lake Benton Power Partners, LLC (LBPP), a subsidiary of ALLETE Clean Energy, Inc., with a Minnesota Public Utilities Commission Site Permit Amendment for an existing wind energy generation facility. The facility is located in Lincoln County, Minnesota (Figure 1, attached).

LBPP is proposing to conduct facility upgrades for the purpose of increasing efficiency and reliability, and extending the life of the wind energy facility. The proposed upgrades consist of retrofitting the existing wind turbines by replacing equipment with new components (referred to herein as "the Project"). The turbine retrofits will include replacing equipment within the nacelle (gearboxes, generators, and switchgear) as well as replacing the rotors and blades.

Barr maintains a license agreement (LA-898) with the Minnesota Department of Natural Resources to access the Natural Heritage Information System (NHIS) database. Barr completed a review of threatened and endangered plant and wildlife species within one mile of the proposed Project area in November 2017 (Figures 2a and 2b, attached). According to the NHIS database, there are records for the Poweshiek skipperling (*Oarisma poweshiek*), Dakota skipper (*Hesperia dacotae)*, and Ottoe skipper (*Hesperia ottoe)* occurring within one mile of the Facility.

The Dakota skipper is known to occur within two types of native prairies: moist bluestem and upland prairie that is relatively dry and often found on ridges and hillsides. The Poweshiek skipperling is known to occur within high quality tallgrass prairies in both upland and wetland areas. The Ottoe skipper is known to occur in native dry-mesic to dry prairie with mid-height grasses.

Native plant communities (MBS) and sites with high biodiversity significance (DNR MBS) have been mapped within project boundary, and the existing site turbines 1, 13, and 14 are within a site with high biodiversity significance and adjacent to native plant communities (see Figure 2a). These areas may contain suitable habitat for the Dakota skipper, Poweshiek skipperling, and Ottoe skipper.

Based on this desktop review, we would like to discuss the project with you in further detail. Please contact me at (218) 529-7155.

Sincerely,

Rachael Shetka

Rachael Shetka
Senior Environmental Specialist

cc: Tim Sweeney, ALLETE Clean Energy, Inc.

Attachments: Figure 1 - Site Location
Figures 2a and b – Unique Natural Features

Turbine Location

Met Tower Location

Project Boundary (2007)

Municipal Boundary

Civil Township

County Boundary

Miles

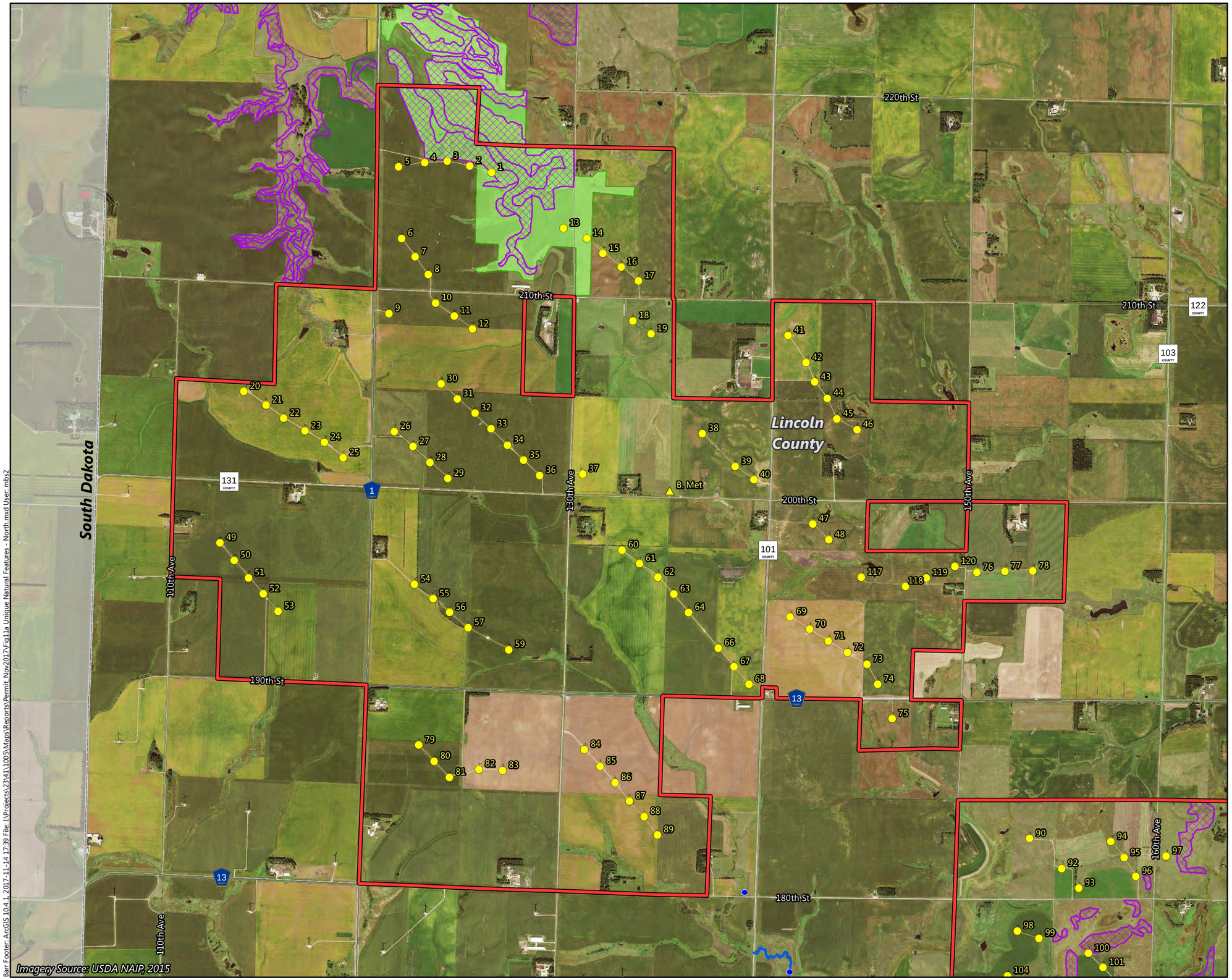
2.5 0 2.5

Kilometers

5 0 5

Figure 1

SITE LOCATION
Lake Benton Wind Project
ALLETE Clean Energy
Lincoln County, Minnesota



Turbine Location
Met Tower Location
Project Boundary (2007)

Native Plant Community (MBS)
Site with High Biodiversity Significance (DNR MBS)

NHIS Rare Natural Features (DNR)
Vertebrate Animal
Invertebrate Animal
Municipal Boundary
County Boundary

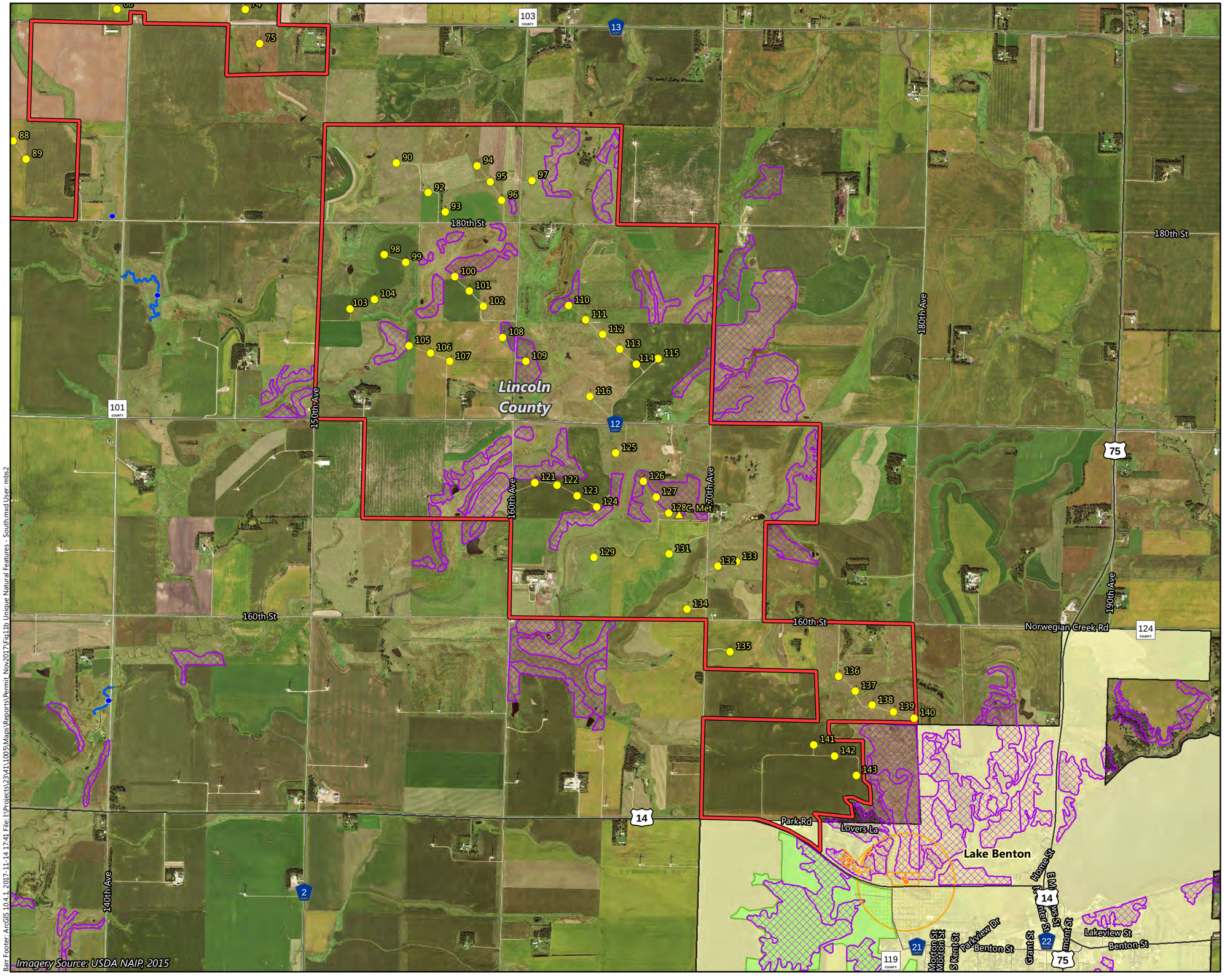
Feet
2,500 0 2,500

Meters
800 0 800

Figure 2a

UNIQUE NATURAL FEATURES - NORTH
Lake Benton Wind Project
ALLETE Clean Energy
Lincoln County, Minnesota

Barr Footer: ArcGIS 10.4.1 2017-11-14 17:39 File: I:\Projects\23141\100\Maps\Reports\Permit_Nov2017\Fig11a Unique Natural Features - North.mxd User: mbs2



Feet
2,500 0 2,500

Meters
800 0 800

Figure 2b

UNIQUE NATURAL FEATURES - SOUTH
Lake Benton Wind Project
ALLETE Clean Energy
Lincoln County, Minnesota