Pronghorn Flats Wind Farm
Shadow Flicker Analysis
Banner and Kimball Counties, NE

June 10,

2020

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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.

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Executive Summary

EAPC was hired by Orion Wind Resources, LLC (OWR) to provide a shadow flicker analysis on dwellings in the vicinity of the proposed Pronghorn Flats Wind Farm (PFWF) near Scottsbluff in Banner and Kimball Counties, NE. The planned wind farm consists of up to 43 wind turbines. Coordinates of the locations of these wind turbines as well as 30 dwellings within 2,000 meters (1.25 miles) of a wind turbine were provided by PFWF. A windPRO model was built combining digital elevation data with the project turbine layout and dwelling locations supplied by PFWF to generate shadow flicker models for the site. The resulting models were then used to perform shadow flicker calculations for the area.

The wind turbine model evaluated for this report was the General Electric (GE) 3.03-140-98, which is a 3.03 megawatt (MW) capacity generator with a rotor diameter of 140 meters and a hub height of 98 meters above ground level (AGL).

The model is based on other conservative assumptions as well. No credit was taken for the blocking effects of trees or buildings. The receptors were omni-directional rather than modeling specific facades of buildings, and the study assumes 100% turbine availability.

While there are no rules in Nebraska that limit the number of shadow flicker hours allowed, it is generally accepted practice to limit the number of hours to less than 30 hours per year at any dwelling.

The results of this study indicate that of the 30 dwellings modeled, the highest amount of shadow flicker per year on any dwelling within 2,000 meters (1.25 miles) of a wind turbine is 28 hours and 15 minutes for the GE 3.03-140-98 m hub height layout modelled. All dwellings located within the project area would experience less than 30 total hours of shadow flicker in any given year.

1. windPRO is the world's leading software tool for designing and analyzing wind farms, including noise and shadow flicker.

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 passes 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 hence the term "flicker." In this case, with a maximum rotational speed of 15.7 rpm for the GE 3.03-140-98, the frequency would be 0.78 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.

This flickering effect is most noticeable within approximately 1,000 meters of the turbine and becomes more and more diffused as the distance increases. Based on the width of the blades for the GE 3.03-140-98 turbine, beyond 1,600 meters (5,250 ft) the shadow flicker effects become indistinguishable. 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 which will make the shadow flicker prediction more conservative (higher than in reality).

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.

Methodology

This shadow flicker analysis was performed utilizing windPRO, which 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 x 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 utilize the highest precision available 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 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 since it assumes that all windows are always in direct line of sight with the turbines and the sun.

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 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 distinguishable since the amount of atmosphere that the light must pass through is 15 times greater than when the sun is directly overhead.

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)

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. The table of wind turbine coordinates can be found in Appendix A.

Turbine Specifications: A wind turbine's total height and rotor diameter and blade width are 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. The wider the blade is, the farther the shadow will persist. 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.

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 all participating and non-participating occupied structures found to be located in the vicinity of the wind farm.

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, 44 years' worth of monthly sunshine probability data were retrieved for North Platte, NE, 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 below in Table 1.

Table 1: North Platte, NE monthly sunshine probabilities

North Platte, NE Monthly Sunshine Probabilities (1965-2009)												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunshine %	60	62	65	66	68	72	76	75	73	70	60	67
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 was provided by PFWF 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, 3-meter resolution 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.

Wind Turbines from Adjacent Projects: OWR is not aware of any other operating energy conversion facilities, existing or under construction, within or adjacent to the proposed project area.

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.

Results

The results of this study indicate that for the 30 dwellings modeled, the highest non-participating dwelling would experience 28 hours and 15 minutes of shadow flicker per year and the highest participating dwelling would experience 25 hours and 43 minutes of shadow flicker per year for the GE 3.03-140-98 m hub height layout modelled. The distribution of shadow flicker impacts is shown below in Table 2. The full tables of results can be found in Appendix B.

Table 2: Pronghorn Flats dwellings cumulative realistic shadow flicker distribution.

Realistic Shadow Flicker (hrs/year)	Number of Non-Participating Dwellings	Number of Participating Dwellings
0	11	2
0 to 5	2	0
5 to 10	4	1
10 to 15	1	0
15 to 20	0	3
20 to 25	2	2
25 to 30	1	1
30+	0	0

It is important to note that no credit was taken for any potential shading effects from any type of trees, shrubs or other obstacles that would reduce the number of shadow flickering hours at the structures, and the receptors are modeled as "greenhouses".

The realistic shadow flicker results are shown in Appendix B. The map for the realistic flicker can be found in Appendix C.

Conclusions

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 assume an availability factor of 100% which is very unlikely to be the case. Actual availability factors will likely be in the range of 95-98%, however, with a conservative approach to estimating shadow flicker totals, the realistic estimates are not discounted accordingly.

The shadow flicker impact on dwellings within 2,000 meters (1.25 miles) of a wind turbine was calculated by taking into account turbine operational time, turbine operational direction and sunshine probabilities. This shadow flicker analysis is based on a number of conservative assumptions including:

- The turbines are operating at 100% availability.
- No credit was taken for the blocking effects of trees, shrubs, window coverings or other structures.
- The receptors were omni-directional rather than modeling specific facades of houses.

The results of this study indicate that for the 30 dwellings modeled, the highest amount of shadow flicker per year on any dwelling within 2,000 meters (1.25 miles) of a wind turbine is 28 hours and 15 minutes for the GE 3.03-140-98 m hub height layout modelled.

The overall effect of these conservative assumptions is that the number of hours of shadow flicker that would be observed should be less than those predicted by this study.

APPENDIX A – Table of Wind Turbine Coordinates

Table A-1: Pronghorn Flats Wind Farm
43 GE 3.03-140-98m HH WTG's UTM
NAD83 Zone 13

WTG	Turbine Type	Easting (m)	Northing (m)	Base Elev. AMSL (m)
1	GE 3.04-140-98	584,353	4,593,073	1,611
2	GE 3.04-140-98	584,060	4,592,357	1,599
3	GE 3.04-140-98	581,945	4,592,354	1,614
4	GE 3.04-140-98	581,185	4,592,008	1,617
5	GE 3.04-140-98	580,639	4,591,557	1,614
6	GE 3.04-140-98	589,829	4,590,897	1,572
7	GE 3.04-140-98	585,782	4,590,801	1,598
8	GE 3.04-140-98	582,240	4,590,725	1,599
9	GE 3.04-140-98	589,212	4,590,689	1,575
10	GE 3.04-140-98	583,820	4,590,676	1,592
11	GE 3.04-140-98	580,400	4,590,520	1,609
12	GE 3.04-140-98	588,603	4,590,473	1,575
13	GE 3.04-140-98	583,675	4,590,025	1,594
14	GE 3.04-140-98	588,311	4,589,994	1,581
15	GE 3.04-140-98	586,205	4,589,712	1,599
16	GE 3.04-140-98	582,026	4,589,469	1,598
17	GE 3.04-140-98	588,219	4,589,136	1,596
18	GE 3.04-140-98	589,355	4,588,063	1,586
19	GE 3.04-140-98	589,091	4,587,642	1,570
20	GE 3.04-140-98	590,892	4,587,562	1,581
21	GE 3.04-140-98	580,433	4,587,531	1,614
22	GE 3.04-140-98	581,970	4,587,504	1,604
23	GE 3.04-140-98	582,091	4,586,408	1,605
24	GE 3.04-140-98	590,476	4,586,398	1,564
25	GE 3.04-140-98	580,104	4,586,388	1,614
26	GE 3.04-140-98	582,495	4,585,270	1,599
27	GE 3.04-140-98	580,637	4,584,913	1,611
28	GE 3.04-140-98	581,457	4,584,856	1,603
29	GE 3.04-140-98	579,995	4,584,828	1,613
30	GE 3.04-140-98	588,894	4,584,354	1,571
31	GE 3.04-140-98	583,813	4,584,321	1,598
32	GE 3.04-140-98	581,549	4,583,761	1,612
33	GE 3.04-140-98	581,143	4,583,285	1,606
34	GE 3.04-140-98	588,328	4,583,260	1,574
35	GE 3.04-140-98	583,474	4,582,687	1,612
36	GE 3.04-140-98	582,750	4,582,562	1,597
37	GE 3.04-140-98	585,133	4,581,926	1,591
38	GE 3.04-140-98	581,694	4,581,844	1,598
39	GE 3.04-140-98	583,966	4,581,564	1,596
40	GE 3.04-140-98	584,718	4,581,506	1,593

Table A-1: Pronghorn Flats Wind Farm
43 GE 3.03-140-98m HH WTG's UTM
NAD83 Zone 13

continued

WTG	Turbine Type	Easting (m)	Northing (m)	Base Elev. AMSL (m)
41	GE 3.04-140-98	588,013	4,581,065	1,587
42	GE 3.04-140-98	583,297	4,581,056	1,589
43	GE 3.04-140-98	588,971	4,580,778	1,581

APPENDIX B – Tables of Shadow Flicker Results

Table B-1: Pronghorn Flats Wind Farm Shadow Flicker Tabular Results Sorted by Receptor ID
Realistic case shadow results at occupied structures
Results using 43 GE 3.03-140-98m HH WTG's
UTM NAD83 Zone 13

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Shadow Flicker (hrs/year)
1-NP	NP	589357	4592764	1,568.6	0:00
2-NP	NP	589396	4592754	1,568.2	0:00
3-NP	NP	589326	4592481	1,570.7	0:00
4-NP	NP	586575	4592140	1,579.0	0:00
5-NP	NP	581470	4590430	1,605.0	28:15
6-NP	NP	583071	4590125	1,597.6	24:19
7-NP	NP	584822	4588968	1,595.2	5:10
8-NP	NP	584844	4588871	1,596.0	0:00
9-NP	NP	587967	4587899	1,570.0	7:51
10-NP	NP	588099	4587891	1,569.0	10:34
11-NP	NP	584805	4586738	1,584.0	0:00
12-NP	NP	578853	4586557	1,617.2	3:23
13-NP	NP	587999	4586245	1,569.0	0:00
14-NP	NP	589242	4586129	1,564.4	4:01
15-NP	NP	578528	4585772	1,611.0	0:00
16-NP	NP	578486	4585724	1,611.0	0:00
17-NP	NP	588339	4584816	1,571.6	21:35
18-NP	NP	587902	4584603	1,572.3	6:03
19-NP	NP	580120	4584359	1,611.1	5:57
20-NP	NP	589353	4579990	1,579.2	0:00
21-NP	NP	587533	4579776	1,567.3	0:00
1-P	P	583141	4591710	1,599.9	4:36
2-P	P	579933	4591328	1,622.4	25:43
3-P	P	584726	4590540	1,590.0	21:12
4-P	P	590621	4586911	1,572.0	0:00
5-P	P	580727	4586498	1,608.0	19:48
6-P	P	580760	4586498	1,608.0	18:21
7-P	P	580820	4586479	1,608.0	16:31
8-P	P	579851	4585838	1,612.6	0:00
9-P	P	581771	4585740	1,605.0	23:45

Table B-2: Pronghorn Flats Wind Farm Shadow Flicker Tabular Results Sorted by hr/yr
Realistic case shadow results at occupied structures
Results using 43 GE 3.03-140-98m HH WTG's
UTM NAD83 Zone 13

Receptor ID	Participation Status	Easting (m)	Northing (m)	Elevation AMSL (m)	Shadow Flicker (hrs/year)
5-NP	NP	581470	4590430	1,605.0	28:15
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17-NP	NP	588339	4584816	1,571.6	21:35
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9-NP	NP	587967	4587899	1,570.0	7:51
18-NP	NP	587902	4584603	1,572.3	6:03
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1-NP	NP	589357	4592764	1,568.6	0:00
2-NP	NP	589396	4592754	1,568.2	0:00
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4-NP	NP	586575	4592140	1,579.0	0:00
8-NP	NP	584844	4588871	1,596.0	0:00
11-NP	NP	584805	4586738	1,584.0	0:00
13-NP	NP	587999	4586245	1,569.0	0:00
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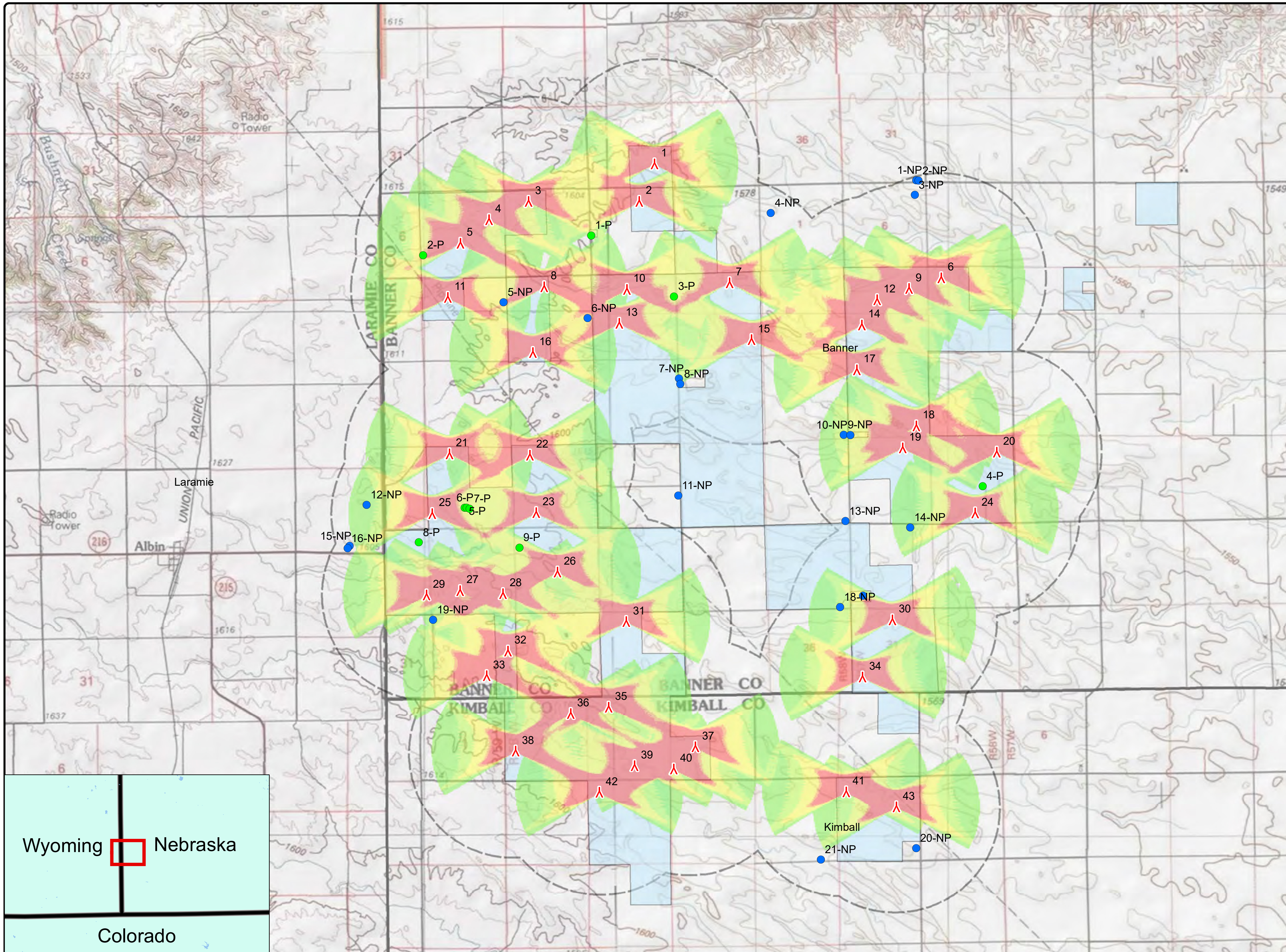
16-NP	NP	578486	4585724	1,611.0	0:00
20-NP	NP	589353	4579990	1,579.2	0:00
21-NP	NP	587533	4579776	1,567.3	0:00
2-P	P	579933	4591328	1,622.4	25:43
9-P	P	581771	4585740	1,605.0	23:45
3-P	P	584726	4590540	1,590.0	21:12
5-P	P	580727	4586498	1,608.0	19:48
6-P	P	580760	4586498	1,608.0	18:21
7-P	P	580820	4586479	1,608.0	16:31
1-P	P	583141	4591710	1,599.9	4:36
4-P	P	590621	4586911	1,572.0	0:00
8-P	P	579851	4585838	1,612.6	0:00

APPENDIX C – Shadow Flicker Map



0 0.5 1 2 Mile

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Pronghorn Flats Wind Farm
Shadow Flicker Iso-Lines

Client

Orion Renewable Energy

Project Description

43 GE 3.03-140-98 m HH WTGs.
Realistic shadow flicker map.

Assumes statistical reduction due to sunshine probability, turbine orientation and operation probability. Sensors in "greenhouse" mode. No obstacles assumed.

Location: Banner County, NE
Project #: 20202880

Issue Dates

#	Description	Date
1	Original	2020.05.22

Drawn By: AS *Checked By:* JH

Legend

- Banner County Turbine Array
- Participants
- Non Participants

Shadow Flicker

Hours per year

- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- >30
- Participating Land Parcels
- 2 km Turbine Buffer
- County Lines