TECHNICAL MEMORANDUM

Summit Wind Repower Project Shadow Flicker Analysis

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Altamont Winds, LLC (Altamont Winds) proposes to repower an existing wind energy facility within the Altamont Pass Wind Resource Area of Alameda County, California. The Summit Wind Repower Project (Project) will replace old technology wind turbine generators (WTGs) with fewer and more efficient modern WTGs, and make improvements to related infrastructure within an existing wind facility. Up to 27 new WTGs are proposed to be installed, with an alternate location for one WTG (20a) for a total of 28 proposed WTG sites. This technical memorandum presents predicted shadow flicker exposure at receptors in the Project area from the Project's proposed WTG sites.

Introduction & Regulatory Requirements

Shadow flicker is the term used to refer to the alternating changes in light intensity that can occur at times when the rotating blades of wind turbines cast moving shadows on the ground or on structures. Shadow flicker occurs only when the wind turbines are operating during sunny conditions, and is most likely to occur early and late in the day when the sun is at a low angle in the sky. The intensity of shadow flicker is defined as "the difference or variation in brightness at a given location in the presence or absence of a shadow" (National Research Council [NRC], 2007). The intensity of the shadows cast by moving blades of wind turbines, and thus the perceived intensity of the flickering effect, is determined by the distance of the affected area from the turbine, with the most intense, distinct, and focused shadows occurring closest to the turbine (Department of Energy & Climate Change [DECC], 2009). The frequency of shadow flicker is a function of the number of blades making up the wind turbine rotor and rotor speed. Shadow flicker frequency is measured in terms of alternations per second, or Hertz (Hz).

There are two kinds of concerns that have been raised about shadow flicker in severe cases. One is that shadow flicker could have the potential to trigger epileptic seizures, and the other is that shadow flicker could become a source of annoyance to residents living near wind turbines. The Epilepsy Foundation notes that for a small minority (about 3 percent) of the 3 million people in the United States who are affected by epilepsy, there is a potential for epileptic seizures to be triggered by flashing light. These seizures have the potential to be triggered when the light flashes are in the range of 5 to 30 Hz. Because the frequency of the shadow flicker created by modern wind turbines is in the range of 0.6 to 1.0 Hz, the shadow flicker effects created by wind turbines do not have the potential to trigger epileptic seizures (Epilepsy Foundation, 2008).

The issue of annoyance is more subjective. There could be cases in which shadow flicker cast on residences located very close to wind turbines could be enough of a distraction for residents to be considered an annoyance.

In Alameda County, standards for acceptable levels of shadow flicker exposure were established in the Final Program Environmental Impact Report for the Altamont Pass Wind Resource Area, which includes the Project area. These standards were set forth as a part of Mitigation Measure AES-5:

"Mitigation Measure AES-5: Analyze shadow flicker distance and mitigate effects or incorporate changes into Project design to address shadow flicker

> *Where shadow flicker could result from the installation of wind turbines near residences (i.e., within 500 meters or about 1,600 feet in a broadly easterly or westerly direction, accounting for all seasons of the year), the Permittee shall prepare a graphic model and study to evaluate the potential for shadow flicker impacts on residences for review and acceptance by the Planning Director. No shadow flicker in excess of 30 minutes in a given day or 30 hours (net or total) in a given year will be permitted unless it has been mitigated subject to the approval of the Planning Director. If it is determined that existing setback requirements (see Safety Setbacks, Condition 24) are not sufficient to prevent shadow flicker impacts on residences, the County shall require the Permittee to increase the setback distances to ensure that residences are not affected.*
>
> *If any residence is nonetheless affected by shadow flicker within the 30-minute/30-hour thresholds due to unforeseen circumstances, the Permittee shall implement one or more measures to avoid or minimize the effect, such as providing opaque window coverings, window awnings, landscape buffers or a combination of these features to reduce flicker to acceptable limits for the affected receptor, or shutting down the turbine during the period shadow flicker would occur. Such measures shall be undertaken in consultation with the owner of the affected residence, and may be confirmed by preparation of a shadow flicker study at the Permittee's expense. If the shadow flicker study indicates that any given turbine would result in shadow flicker exceeding the 30-minute/30-hour thresholds and the affected property owner is not amenable to window coverings, window awnings, or landscaping and the turbine cannot be shut down during the period of shadow flicker, then the turbine operations would be limited to avoid shadow flicker to the satisfaction of the affected owner of the residence* (Alameda County Community Development Agency. 2014).

Method for Predicting Shadow Flicker Effects

CH2M conducted the shadow flicker analysis for the proposed Project with a layout of 28 WTG sites using the SHADOW calculation module of the WindPRO 3.0 software. WindPRO is a comprehensive software package developed for the design, development, and assessment of wind farm projects, as well as for the evaluation of energy, environmental, visual, electrical, and economic effects of wind energy projects. To calculate shadow flicker levels at nearby residences and other structures, referred to as receptors, the WindPRO SHADOW calculation module takes into account the location of each receptor, the orientation of each side of the receptor, the location of each WTG, hub height, rotor diameter, blade width, latitude and longitude, elevation data of the specific analysis area including proposed turbine pad elevations, and data on the sun's path through the sky on each day of the year (EMD International A/S [EMD], 2008). The locations of proposed WTGs as well as the 27 occupied receptors located nearby were provided by Altamont Winds for use in this analysis. The shadow flicker model made use of topographic data, including proposed turbine pad elevations, to account for the minor elevation differences and topographic features in the line of sight when WTGs are viewed from a receptor. For the area within the Project and its vicinity1-meter LIDAR data were available and were used for the modeling (NOAA 2006). The locations of the WTGs and receptors included in the modeling are indicated on map presented as Figure 1.

The Project consists of up to 27 WTGs of either General Electric (GE) or Vestas turbine models including an alternate location for one WTG (20a) for a total of 28 proposed WTG sites. Therefore, a 28 WTG -site WindPRO SHADOW calculation model was run for both the GE and Vestas turbine models under consideration for the Project.

As the sun approaches the horizon, sunshine becomes less intense, and, therefore, the shadow influence is reduced. To take this phenomenon into account, the standard practice in shadow flicker analysis is to calculate shadow flicker for only the times when the sun is at an angle of 3 or more degrees above the horizon (EMD, 2008; Osten and Pahlke, 1998). In conducting this analysis, the 3-degree threshold was observed.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. The intensity of shadow flicker tapers off with increasing distance from the turbine. Generally, shadow flicker is most intense and noticeable within 1,000 meters (3,274 feet) of the turbine. With increased distance from the turbine, the shadow flickering becomes less perceptible. Research has established that the threshold at which shadow flicker is no longer perceptible is the point at which less than 20 percent of the sun would be covered by the blade (EMD, 2008; Osten and Pahlke, 1998). The distance threshold defining the area within which 20 percent or more of the sun is covered is determined by WindPRO based on the width of the blades. Based on the blade widths assumed for the turbines modeled, WindPRO calculated that the actual maximum distance from the turbines within which shadows would fall that would entail coverage of 20 percent or more of the sun's surface would be 1,667 meters (5,469 feet or 1.04 mile). This calculated distance where the shadow flickering would be intense enough to be detectable and a potential source of concern is also referred to as the zone of potential impact.

The orientation of each of the 27 receptors ion the Project vicinity was set on "greenhouse mode" for the model, which makes the assumption that the receptor has windows on all of its sides and, therefore, would be affected by shadow flicker that falls on any side of the structure; the "greenhouse mode" represents a worst-case scenario for each receptor.

An important variable that the WindPRO Shadow calculation model takes into account is the probable hours when the sunny conditions required for shadows to be created will be present in the Project area. To adjust the model to take into account the probable hours of sunshine in the Project area, cloud coverage data were necessary. Because detailed meteorological data, specifically data that would allow the extraction of convective mixing height and fraction of cloud cover per hour, were not available for the Project area itself, research was conducted to locate a nearby meteorological station that collects the required data. The research revealed that the nearest station where the data are collected is located at the Livermore Airport, which is approximately 9 miles west southwest of the Project's southwestern corner.

To calculate the monthly probabilities of sunshine, hourly National Weather Service (NWS) meteorological data collected from the Livermore Airport monitoring station (WBAN #23285) were used for the analysis. Five years of hourly observations between January 1, 2008 and December 31, 2012 were obtained from the NWS automated surface observation system (ASOS). The data at the Livermore Airport are 96.5-percent complete for the 5-year period and is the nearest complete data available which represents the climate conditions to the Project area. The second closest NWS meteorological station to the Project site would be from the Stockton Airport, which is located approximately 25 miles northeast from the Project.

The AERMET meteorological data processor, developed by the U.S. Environmental Protection Agency to read and extract parameters from NWS data and process for the purposes of air dispersion modeling, was used to calculate the monthly probabilities of sunshine. For this analysis, AERMET (Version 14134) extracted the fraction of cloud cover for each hour and calculated the convective mixing height based on the station latitude and time zone. The total daytime hours for each month were determined based on the convective mixing height, which is generated only during daytime hours. For each hour, a cloud cover fraction of seven tenths and below was considered sunny. The total number of sunny hours (or sun hours) was divided by the total number of daytime hours in the month (or possible sun hours) to determine each month's sunshine probability. The monthly sunshine probabilities that were derived through this analysis and were used in calculating the Project's likely shadow flicker effects are summarized in Table 1.

Table 1. Average Sunshine Probability Per Month (Recorded Sun Hours/Possible Sun Hours) for Livermore Airport, California

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.66	0.62	0.67	0.79	0.80	0.88	0.92	0.92	0.93	0.83	0.73	0.64

Note: The ratios presented in Table 1 are fractions of the valid available data only. A value of 1.0 would indicated continuously sunny conditions (no periods of clouds) and a value of 0.0 would indicate continuously cloudy conditions (no periods of sunshine).

Based on the analysis of the available cloud cover data, the assumption was made that the sun would be unobstructed by clouds long enough to have the potential to permit shadow flicker effects to be created anywhere from 62 to 93 percent of the time during daylight hours on a monthly basis. Although consideration of the hours of sunny versus cloudy conditions allows the model to generate predictions of the number of hours of shadow flicker experienced at receptors that are generally accurate in respect to the actual shadow flicker conditions that would be experienced, these modeling results likely still represent an overestimation of total hours of shadow flicker effect. The modeling's estimates of hours of potential shadow flicker impact are somewhat larger than what is likely to be actually experienced because there are additional variables that the modeling did not take into account. Three of the variables that were not taken into account are: wind direction, which determines how much of the time the blades are turned in a direction that would cast shadows on the receptors being evaluated; mechanical turbine availability, which identifies the percentage of time the turbines would be available to generate electricity versus the percentage of time that they would need to be offline for maintenance purposes; and wind availability, which is used to identify the percentage of time when wind speeds would be high enough to spin the blades but low enough to allow the turbines to operate safely. All of these factors reduce the time period that shadow flicker may be present.

Other factors that could also affect the total amount of predicted shadow flicker, but were not taken into account in the modeling include:

- Presence of haze or particulate matter in the air that tends to reduce the intensity of light and reduce distances at which shadows can be cast.
- Potential structures and vegetation located between receptors and the turbines, which would block shadows created by the rotating turbine blades and thus prevent shadow flicker from occurring at receptors.
- The model assumes that the receptors are in the "greenhouse mode," in which the receptor is assumed to be all windows—a worst case scenario. Receptors normally have much less window than wall space on any given side.

Therefore, in reviewing and interpreting the results of the modeling, it is important to note that these results are upper limit projections, and that the actual hours and minutes of shadow flicker predicted to be experienced at receptors in proximity to the Project may be less than those that the modeling results indicate.

Analysis Results & Conclusion

The shadow flicker modeling results for the 27 receptors evaluated are presented in Table 2. Results represent the greatest predicted shadow flicker exposure from the GE and Vestas turbine models. Consistent with standard industry practice, the number of predicted hours and minutes of flickering on the day with the maximum amount of flickering has not been adjusted to take cloud cover into account, providing a worst-case prediction. The predicted number of hours and minutes of solar flicker on an annual basis have been adjusted to reflect cloud cover conditions, providing a more realistic (although still overstated) estimate of potential shadow flicker exposure.

Figure 1 provides a graphic representation of the patterns of total annual shadow flicker exposure around each of the WTG sites and the relationship of each of the receptors to these patterns. None of the receptors are located in the areas of heaviest shadow flicker exposure, and only one (receptor B) is located in an area with more than 30 hours of predicted shadow flickering per year (in the zone with 35.00 to 44.99 hours of predicted annual flicker).

Receptor B, is the only receptor located in an area where the Alameda County standard for maximum annual shadow flicker exposure of over 30 hours per year has the potential to be exceeded. The total predicted annual shadow flicker at this receptor would be 37 hours, 51 minutes per year. This receptor is located on land under lease from Altamont Winds and is considered a participant of the Project. There are four receptors (receptors A, B, J and T), located in an area where the Alameda County standard for maximum daily shadow flicker exposure of over 30 minutes per day has the potential to be exceeded.

Should mitigation of the shadow flicker effects on receptors located on the properties of non-participating landowners become necessary, the following measures could be undertaken:

- Residents could be provided with technical and financial assistance to install awnings or window coverings on windows on the sides of their residences that would be exposed to flicker.
- Residents could also be provided with technical and financial assistance to install trees or shrubs that are strategically located to screen any shadow flickering with the potential to affect outdoor use areas around their residences.

In cases where there is potential for shadow flicker effects to exceed adopted standards and where window coverings and landscape plantings would not be sufficient to reduce the shadow flicker effects to levels that are consistent with the standards, consideration can be given to programming specific WTGs to modify their operation on sunny days during the days and times they would be expected to create excessive levels of shadow flicker.

Table 2. Summary of Predicted Shadow Flicker Exposure at Receptors in the Project Area

Receptor ID	**Receptor Status**	**Maximum Daily Shadow Flicker (hrs:min per day)***	**Total Predicted Annual Shadow Flicker Exposure (hrs:min per year)**
A	Participating	**0:31**	13:56
B	Participating	**1:28**	**37:51**
C	Non-Participating	0:24	5:08
D	Non-Participating	0:23	3:51
E	Non-Participating	0:24	5:30
F	Non-Participating	0:23	7:57
G	Non-Participating	0:26	9:37
H	Non-Participating	0:30	11:48
I	Non-Participating	0:27	8:52
J	Non-Participating	**0:31**	15:05
K	Non-Participating	0:24	5:51
L	Non-Participating	0:23	8:09
M	Non-Participating	0:29	9:48
N	Non-Participating	0:26	13:37
O	Non-Participating	0:24	4:56
P	Participating	0:29	9:59
Q	Non-Participating	0:22	6:38
R	Non-Participating	0:00	0:00
S	Non-Participating	0:21	6:55
T	Participating	**0:41**	4:44
U	Non-Participating	0:00	0:00
V	Non-Participating	0:00	0:00
W	Non-Participating	0:00	0:00
X	Non-Participating	0:18	1:10
Y	Participating	0:27	15:33
Z	Non-Participating	0:00	0:00
AA	Participating	0:13	3:41

*****Not adjusted to reflect potential cloud or fog conditions
Bold represents exceedance of Alameda County Shadow Flicker Standard

References

Alameda County Community Development Agency. 2014. Altamont Pass Wind Resource Area Repowering Final Program Environmental Impact Report. Certified November, 2014.

Alameda County Community Development Agency. 2016. Conditional Use Permit (PLN2014-00056) for the Summit Wind Repower Project. Resolution No. Z-16-01. January 14, 2016.

Department of Energy & Climate Change (DECC). 2009. *Onshore Wind: Shadow Flicker*. Available at website: http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/planning/on_off_wind/shadow_flicker/shadow_flicker.aspx. Accessed on November 19, 2009.

EMD International A/S (EMD). 2008. *WindPRO 2.6 User's Guide*. First Edition. Pages 8–9 and 254–263. January.

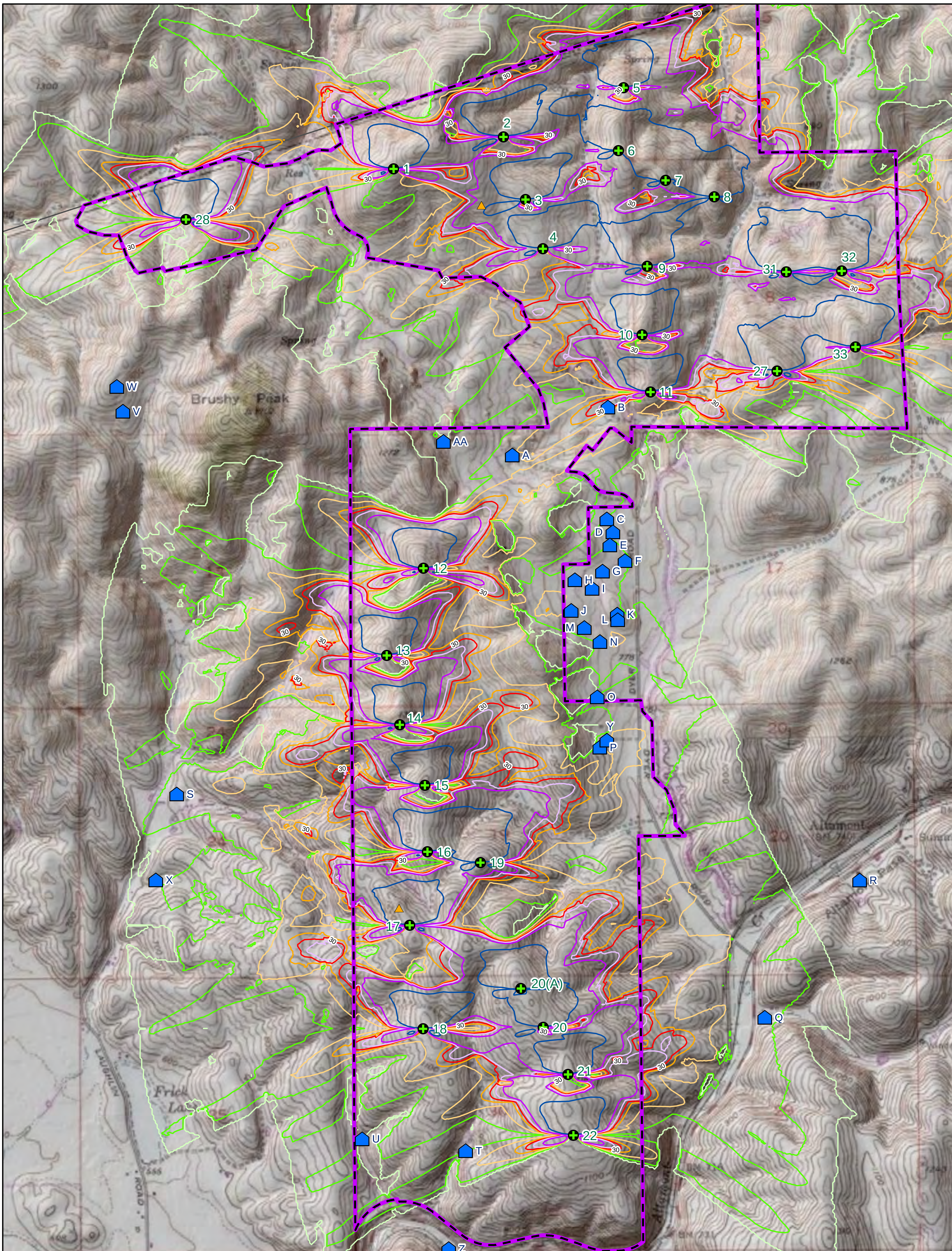
Epilepsy Foundation. 2008. *Photosensitivity and Epilepsy*. Available at website: http://www.epilepsyfoundation.org/about/photosensitivity/index.cfm. Accessed on June 24, 2008.

National Research Council (NRC). 2007. *Environmental Impacts of Wind-Energy Projects.* National Academies Press.

NOAA. 2006. LIDAR data. Available at: https://coast.noaa.gov/dataservices/Metadata/TransformMetadata?u=https://coast.noaa.gov/data/Documents/Metadata/Lidar/harvest/ca2006_usgs_alameda_m1474_metadata.xml&f=html

Osten, Tjado, and Thomas Pahlke. 1998. "Schattenwurf von Windenergieanlagen: Wird die Gebraeuschabstrahlung der MW-Anlagen in den Schatten Gestellt? (Shadow Impact on the Surrounding of Wind Turbines)." *DEWI Magazin*, Nr. 13, August 1998, pages 6–12.

Figure 1



LEGEND

Project Boundary

Proposed Turbine

Proposed Met Tower

Receptors

Total Potential Annual Hours of Shadow Flicker

0.01

5

15

25

30

35

45

100

N

0 2,000

Feet

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Shadow Flicker Results (Hours Per Year)

Summit Wind Repower Project

Alameda County, California

ch2m.