Appendix G

Golden Hills Project Shadow Flicker Analysis

Shadow Flicker Analysis for the Golden Hills Wind Energy Facility Repowering Project

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Acronyms and Abbreviations

DECC	Department of Energy & Climate Change
DEM	digital elevation model
Hz	Hertz
NextEra	NextEra Energy Resources, LLC
NRC	National Research Council
NWS	National Weather Service
Project	Golden Hills Wind Energy Facility Repowering Project
USGS	United States Geological Survey

SECTION 1

Introduction

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 U.S. 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 a nuisance.

SECTION 2

Method for Predicting Shadow Flicker Effects

CH2M HILL conducted the shadow flicker analysis for the proposed Golden Hills Wind Energy Facility Repowering Project (Project) with a conceptual study layout of 48 turbines using the SHADOW calculation module of the WindPRO 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 farm 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 wind turbine, turbine hub height, turbine rotor width, turbine blade width, latitude and longitude, elevation data of the specific analysis area, 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 wind turbines and three (3) receptors on the Sweet property were provided by NextEra Energy Resources, LLC (NextEra).

The analysis was restricted to evaluating the effects to the three (3) receptors located within 2,000 meters of the proposed turbines. The WindPRO SHADOW calculation model was run based on the assumption that the project would use GE 1.7 XLE turbines with a hub height of 80 meters (262 feet) and rotor diameter of 100 meters (328 feet).

The model domain extended 2,000 meters (1.2 miles) in each direction from the proposed wind turbine locations. According to German guidelines, flickering is only an issue when at least 20 percent of the sun is covered by the blade. WindPRO uses the blade width included in the turbine specifications that are entered into the SHADOW calculation module to calculate the maximum distance from the turbine where flickering will occur. Beyond this maximum distance, the turbine will not contribute to shadow flicker impacts. However, WindPRO uses a fixed maximum distance default of 2,000 meters for the purpose of setting up the SHADOW calculation module. WindPRO then calculates the actual distance, or "zone of impact", based on the blade width included. The shadow flicker model made use of topographic data to account for elevation differences and topographic features in the line of sight when turbines are viewed from a receptor. For the lands within the project area, 5-foot contour data were available and were used for the modeling.

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.

As mentioned previously, the model was set to calculate shadow flicker only in the areas where 20 percent or more of the sun would be covered by the blade, creating detectable levels of flickering (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 the WindPRO program based on the width of the rotor blades. In this case, 985 meters (0.61 mile) was determined to be the maximum distance from the turbines within which shadows would fall that would entail coverage of 20 percent or more of the sun's surface.

The model focused on identifying the impacts on the three (3) receptors located within 985 meters of a proposed turbine, which is the calculated distance where the shadow flickering would be intense enough to be detectable and a potential source of concern. The three (3) receptors located within the calculated 985-meter zone of impact are included in Table 2. The orientation of each receptor was set on "greenhouse mode" for the model, which makes the very conservative 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.

Two runs of the WindPRO SHADOW calculation model were conducted. The first run provided a "worst case" assessment, and the second run, referred to as the "adjusted case assessment," took into account a number of factors that, under actual operating conditions, would reduce the amount of shadow flicker impact created.

2.1 Worst Case Assessment

The worst case WindPRO model run assumed that:

- There would be clear skies from sunrise to sunset;
- The turbines would be operating constantly; and
- The rotor would always be oriented perpendicular to the receptor, meaning the rotor plane (or axis of rotation) would be perpendicular to a line drawn between the sun and the receptor.

These assumptions generate model results that represent a substantial overestimation of the daily minutes and total annual hours of shadow flicker. The overestimation occurs because these assumptions do not account for times when shadows would not be created because of overcast conditions, the rotors would not be turning due both to wind conditions and time taken out for maintenance, and the rotors would not be perpendicular to the receptors of concern, and would thus be incapable of casting shadows on them.

2.2 Adjusted Case Assessment

To develop a more accurate assessment of the shadow flicker effects the Project would create, the model was run a second time using available information regarding sunshine conditions in the general Project area.

2.2.1 Probability of Sunshine

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 of the Project's western edge.

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

2.2.2 Predicted Turbine Operation and Rotation

In order to base the adjusted case assessment on a more accurate estimate of the numbers of hours that the turbines would be in operation, data was collected on “mechanical turbine availability”. Mechanical turbine availability is the percentage of time the turbines would be available to generate electricity versus the percentage of time that they would need to be off-line for maintenance purposes. Data was also collected on wind availability, to provide a basis for determining 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. The wind availability was collected using only the data available when the net capacity factor on the long-term time series was greater than five (5) percent.

This predicted number of operational hours was calculated using the equation below, which incorporates an expected mechanical turbine availability of 97.07 percent and a wind availability of 93.84 percent:

- (Total hours per year)*(mechanical turbine availability)*(wind availability) = predicted annual operational hours
- (8,760 hours)*(0.9707)*(0.9384) = 7,979.5 annual operational hours
- The 7,979.5 annual operational hours equates to the turbines operating at 91 percent per year.

2.2.3 Evaluation of the Adjusted Case Assessment Results

The adjusted case assessment assumes that the sun would be unobstructed by clouds long enough to have the potential to permit shadow flicker effects to be created anywhere from 55 percent to 95 percent of the time during daylight hours on a monthly basis, averaging out to approximately 75 percent of the time when considered on an annual basis. The adjusted case assessment also assumes that the turbines would have the potential to operate 91 percent of the time during daylight hours (7,979.5 operation hours per year, compared to the 8,760 hours assumed by the worst case assessment). This adjustment from the worst case assessment allows the model to generate predictions of the number of hours of shadow flicker experienced at receptors that are more accurate in respect to the actual shadow flicker conditions that would be experienced, as opposed to the hours of shadow flicker predicted by the worst case assessment. However, the results of the adjusted case assessment still represent an overestimation of total hours of shadow flicker effect.

A key variable that was not taken into account in the adjusted case modeling is wind direction. Wind direction determines how much of the time the blades are turned in a direction that would cast shadows on the receptors being evaluated. The data required to permit this variable to be factored into the modeling were not available. If data had been available for analysis, some of the estimated hours and minutes of the predicted shadow flicker exposure may have been lower than the numbers calculated using the adjustments related to cloud cover, mechanical turbine availability, and wind availability (or speed).

2.2.4 Additional Factors

Other factors that could also affect the total amount of predicted shadow flicker, but were not able to be taken into account in the adjusted case assessment due to uncertainty or unavailable data include the following:

- Presence of haze or particulate matter in the air could reduce the intensity of light and reduce distances at which shadows can be cast.
- Shadows created by portions of the rotor closest to the hub are more intense and can be perceived at a longer distance than shadows created by blade tips. The WindPRO model treats shadows created by all parts of the blade as if they were shadows created by blade portions closest to the hub. As a result, this could overstate distances at which shadows can be seen and might also overstate shadow effects.
- 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 adjusted case assessment, it is important to note that these results are also upper limit projections, and that the actual hours and minutes of shadow flicker predicted to be experienced at receptors in proximity to the project are likely to be substantially lower than those that the modeling results indicate.

SECTION 3

Analysis Results

The shadow flicker modeling results for the three (3) receptors located on the Sweet property and within the 985-meter zone of impact, meaning 985 meters from a proposed turbine, are presented in Table 2. The three (3) receptors are identified with an ID that corresponds to the receptor locations labeled in Figure 1. For each receptor, the table presents the modeling results in terms of the following conditions:

- The total potential shadow flicker during all daylight hours (in hours per year) based on the adjusted case calculations which take overcast conditions into account;
- The predicted maximum minutes per day of shadow flicker. These values are only based on the worst case assessment due to limitations of the WindPRO software, and therefore do not take overcast conditions into account.
- Identification of the turbines that would contribute to shadow flicker effects at that receptor
- The distance to the nearest turbine that contributes to shadow flicker effects at the receptor
- The months in which shadow flicker occurs

Table 3 provides a list of the all 48 turbines and indicates the total number of hours of shadow flicker experienced at receptors that would be generated by that particular turbine. Only three (3) of the 48 turbines are predicted to generate shadow flicker effects. All turbines are identified with a number that corresponds to the turbine locations labeled in Figure 1.

The results of the modeling are also communicated in graphic form in Figure 1. The information provided on this figure consists of butterfly diagrams that indicate the distribution of annual hours of potential shadow flicker effect around each turbine, and the locations of the receptors in the project area in relationship to these shadow flicker patterns.

The modeling results indicate that all three (3) receptors located on the Sweet property and within 985 meters of the proposed turbines have the potential to experience shadow flicker effects. A review of the annual shadow flicker exposure data indicates that these three (3) receptors could experience from 33 minutes up to approximately 13 hours per year of shadow flickering. On a daily basis, the maximum shadow flicker effects for the three (3) receptors have the potential to last between 18 and 76 minutes (or 1 hour and 16 minutes).

Receptor H33 could likely experience minimal shadow flicker effects. There will only be a total of approximately 30 minutes of shadow flicker per year, and on the day of maximum shadow flicker exposure, the duration of the flickering would be no more than 18 minutes.

Receptor H35 could experience an approximate total of up to 10 hours and 45 minutes of shadow flicker effects over the course of one year. The flickering would occur during the months of April, May, June, July, and August. On the day of maximum shadow flicker exposure, the flickering would occur for no more than one hour and 9 minutes.

Receptor H34 could experience an approximate total of up to 13 hours and 16 minutes of shadow flicker effects over one year. The flickering would occur during the months of April, May, June, July, and August. On the day of maximum shadow flicker exposure, the flickering would occur for no more than one hour and 16 minutes.

Although the adjusted case assessment results took a real world factor into account (overcast conditions and operational hours), there are many attenuating variables that could lessen the amount of shadow flicker that are not accounted for in the model; therefore, the data generated by the adjusted case assessment represent an overestimation of the likely potential hours and minutes of shadow flicker effect. The actual levels of shadow flicker exposure at receptors would likely be lower than the modeling results indicated in Table 2. This is due in part to the fact that the WindPRO calculations assumed the turbines would be operating continuously, which is unrealistic during low or no-wind conditions.

In evaluating the implications of the shadow flicker impacts identified in Table, it is important to note that the impacts identified are likely to be upper limit predictions of the actual shadow flickering that would occur.

TABLE 2

Modeled Shadow Flicker Impacts on Receptors H33, H34, and H35

Receptor ID	Property Owner	Total Potential Shadow Flicker Adjusted for Overcast Conditions (hrs:min per year)	Maximum Daily Shadow Flicker (hrs:min per day)*	Turbines Contributing to Shadow Flicker	Distance to Nearest Turbine (meters [feet])	Months that Shadow Flicker Occurs
H33	Sweet	0:33	0:18	T-11	550 (1,803)	Mar, Sep, Oct
H34	Sweet	13:16	1:16	T-13, T-20	522 (1,713)	Apr, May, Jun, Jul, Aug
H35	Sweet	10:45	1:09	T-13, T-20	549 (1,802)	Apr, May, Jun, Jul, Aug

*WindPRO is unable to adjust the maximum daily shadow flicker effects for overcast conditions or operational hours.

Note: The data included in this analysis uses aggregated meteorological data and is based on a conservative modeling approach. Therefore, it is important to note that the results presented in this analysis would likely not be consistently observed on an annual basis, and that actual hours of shadow flicker would potentially vary.

TABLE 3
Potential Shadow Flicker per Wind Turbine

Turbine ID	Total Potential Shadow Flicker Adjusted for Overcast Conditions (hrs:min per year)
T-1	0:00
T-2	0:00
T-3	0:00
T-4	0:00
T-5	0:00
T-6	0:00
T-7	0:00
T-8	0:00
T-9	0:00
T-10	0:00
T-11	0:32
T-12	0:00
T-13	9:21
T-14	0:00
T-15	0:00
T-16	0:00
T-17	0:00
T-18	0:00
T-19	0:00
T-20	6:26
T-21	0:00
T-22	0:00
T-23	0:00
T-24	0:00
T-25	0:00
T-26	0:00
T-27	0:00
T-28	0:00
T-29	0:00
T-30	0:00
T-31	0:00
T-32	0:00
T-33	0:00
T-34	0:00
T-35	0:00
T-36	0:00
T-37	0:00
T-38	0:00
T-39	0:00
T-40	0:00
T-41	0:00

TABLE 3
Potential Shadow Flicker per Wind Turbine

Turbine ID	Total Potential Shadow Flicker Adjusted for Overcast Conditions (hrs:min per year)
T-42	0:00
T-43	0:00
T-44	0:00
T-45	0:00
T-46	0:00
T-47	0:00
T-48	0:00
TOTAL	**16:19**

Note: All wind turbines that were included in the model are listed in this table: turbines that are predicted to potentially cause shadow flicker, along with turbines that are not predicted to cause shadow flicker at the three (3) receptors located on the Sweet property and within 2,000 meters.

SECTION 4

References

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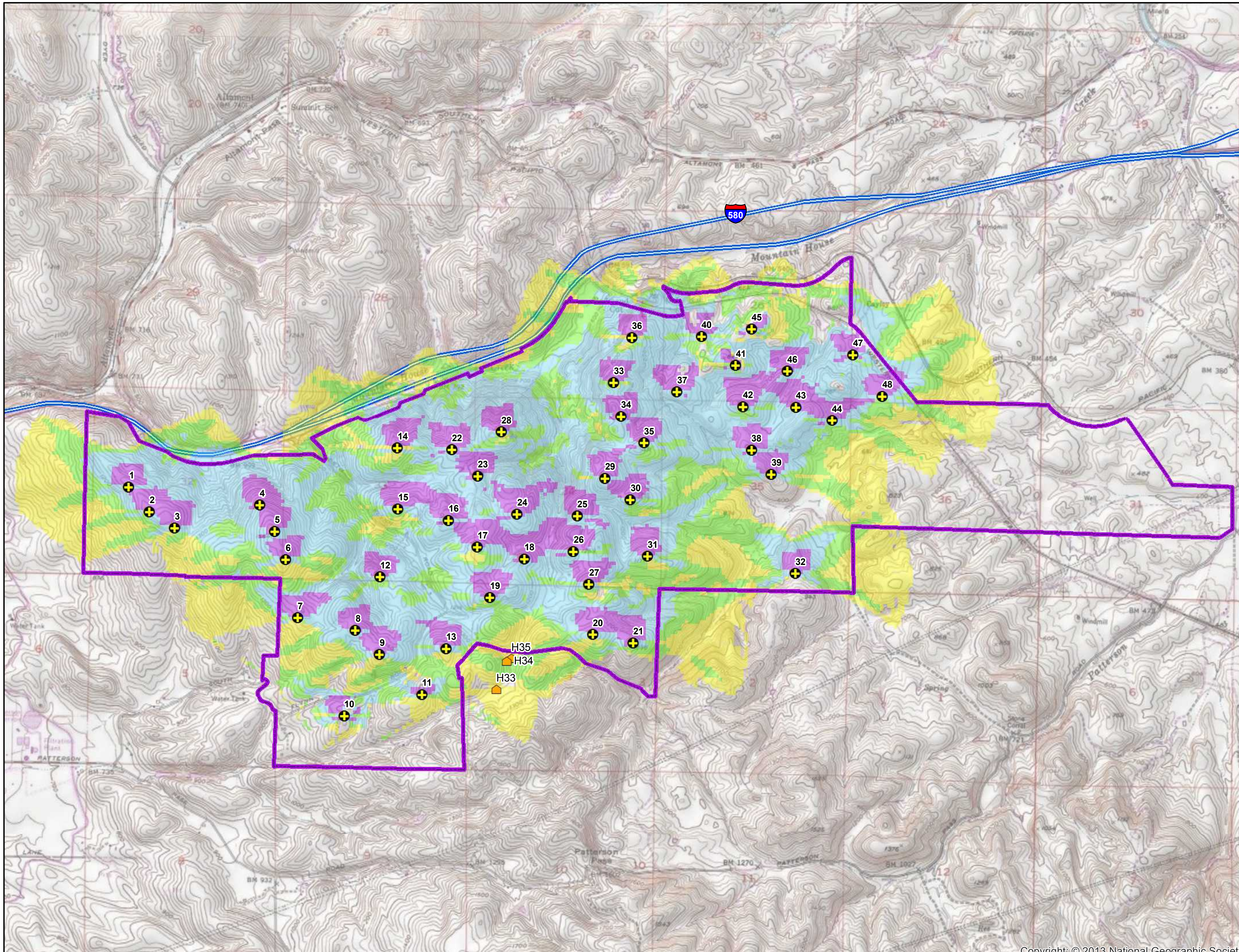
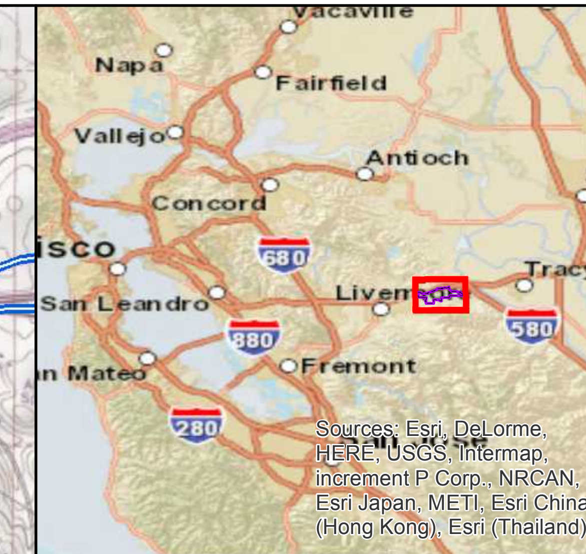
Osten, Tjado, and Thomas Pahlke (Osten and Pahlke). 1998. Schattenwurf von windenergieanlagen: wird die gebraeuschabstrahlung der MW-Anlagen in den Schatten gestellt? (Shadow impact on the surrounding of wind turbines). *DEWI Magazin*, Nr. 13, August 1998. Pp 6-12.

Figure 1
Shadow Flicker Results





LEGEND

Golden Hills Project Boundary

Proposed Turbine Locations

Receptors on the Sweet Property

Total Potential Hours of Shadow Flicker based on the Adjusted Case Assessment

Hours per Year

0.01- 10

10 - 30

30 - 100

100+

N

0 2,500

Feet

FIGURE 1
Shadow Flicker Results
Golden Hills Wind Energy Facility Repowering Project