Subject: Shadow-Flicker Modeling
Wild Horse, WA.

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1. Introduction

Wind Engineers (WEI) was requested by Zilkha Renewable Energy (Zilkha) to evaluate the predicted shadow flicker impacts at the proposed Wild Horse Wind Power Project near Kittitas, WA. The proposed wind project consists of 136 wind turbines at 65 m hub height. The shadow flicker impacts at the potential receptors have been evaluated. Because the distance between wind turbines and residences is larger than 1,000 meters there are no significant impacts at any of the residences. An example of the potential shadow-flicker area is shown below using the WindPro software, a widely-accepted modeling software package developed specifically for the design and evaluation of wind power projects. The typical 'butterfly' shape is here slightly distorted by the terrain effects. WEI personnel did not visit the site for this assessment.

This Project Briefing provides a brief explanation of shadow flicker, the modeling approach employed and other relevant explanations.

2. Shadow Flicker Background

Shadow flicker caused by wind turbines is defined as alternating changes in light intensity caused by the moving blade casting shadows on the ground and stationary objects, such as a window at a dwelling. No flicker shadow will be cast when the sun is obscured by clouds/fog or when the turbine is not rotating. Shadow flicker is not the sun seen through a rotating wind turbine rotor nor what an individual might view moving through the shadows of a wind farm.

The spatial relationships between a wind turbine and receptor, as well as wind direction are key factors related to shadow flicker duration. At distances of greater than 1,000 feet between wind turbines and receptors, shadow flicker usually only occurs at sunrise or sunset when the cast shadows are sufficiently long. For situations where the rotor plane is in-line with the sun and receptor (as seen from the receptor), the cast shadows will be very narrow (blade thickness), of low intensity, and will move quickly past the stationary receptor. When the rotor plane is perpendicular to the sun-receptor “view line”, the cast shadow of the blades will move within a circle equal to the turbine rotor diameter.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Some details are outlined below:

1. A wind turbine blade is narrow at the blade tip with increasing width up to the rotor hub. When a turbine is located sufficiently close to a receptor such that the wider blade portion covers most of the sun’s disk (as seen by the receptor) the flicker intensity will increase. At greater distances a lower intensity will occur since the blades cover a smaller portion of the sun’s disk.
2. The shadow flicker intensity is lowest when the cast shadow passing over a receptor originates from the rotor tip. This intensity increases as the cast shadow moves in along the blade length to a maximum at the hub/nacelle, to then diminishes as it moves back out along the opposite blade side.
3. Low shadow flicker impacts are usually indicative of greater receptor-turbine separation distances and incident shadows of low intensity originating from the rotor tips.
4. Low visibility weather conditions (still sunlight) will result in lower shadow flicker intensity.
5. At longer wind turbine–receptor distances the cast shadow is “out of focus”. This does not contribute to lower intensity but the flickering is less distinct.
6. Shadows are fainter in a lighted room. Consequently, switching lights on will lower the intensity of incident shadow flicker.
7. Covering a window (curtains, blinds or shutters) will prevent shadow flicker.
8. Screening, such as trees, will reduce or prevent shadow flicker.

The WindPro software program uses a very conservative model for evaluating shadow flicker. None of the above aspects are directly considered in the WindPro shadow flicker model – only flicker or no flicker is considered. Consequently, it is likely that all receptors would experience less shadow flicker impact than modeled. It is further likely that marginally affected receptors may not experience shadow flicker at all. At times when shadow-flicker does occur, the intensity is likely to be very low.

The shadow-flicker frequency is related to the rotor speed. Typical blade pass frequencies for the types of turbines under consideration for the Wild Horse Project are 0.6 to 1.0 Hz (less than 1 alternation per second).

In terms of health and safety, such low frequencies are harmless. Frequencies higher than 3 Hz but below 10 Hz are widely used in strobe lights found in discotheques and the Epilepsy Foundation has made a statement that frequencies below 10 Hz are not likely to trigger epilepsy seizures.

3. Modeling Approach

As previously stated, a near worst case approach is adopted when reporting shadow flicker results from the WindPro model. Additional general site and receptor-specific assessments that would likely reduce shadow flicker impacts are presented below.

1. Obstacles (terrain, trees, buildings, etc.) located between the receptor and wind turbine will significantly reduce (or eliminate) the duration and/or intensity of the shadow flicker.
2. The model applies a minimum sun angle of 3º and considers the topographic characteristics of the surrounding terrain out to approximately 2 miles (3.2 km) from the project boundary. Higher elevations may exist outside the modeled boundary which obstruct the sun at or above the 3º angle, this reducing the impact. This is likely to occur during dusk/twilight time periods.
3. Cloud or fog cover conditions are modeled as an average number of hours per day. The typical daily or hourly variation is not captured by the model. In most areas increased cloud cover (or fog) is more likely to occur in the morning and evening hours at a time when the model predicts the longest cast shadow.
4. Wind turbine operation (run hours) is also modeled as an average (hours per day) when wind patterns clearly change over the course of a day. In addition, the model considers the calm winds (where turbines do not run) distributed equally on a daily basis. Both situations would tend to increase the shadow flicker estimation.

The shadow-flicker model requires the following input:

- Turbine locations (coordinates)
- Shadow flicker receptor locations (coordinates)
- USGS 1:24,000 topographic map
- USGS Digital Elevation Model (height contours)
- Rotor diameter
- Hub height
- Joint wind speed and direction frequency distribution
- Sunshine hours (monthly averages)

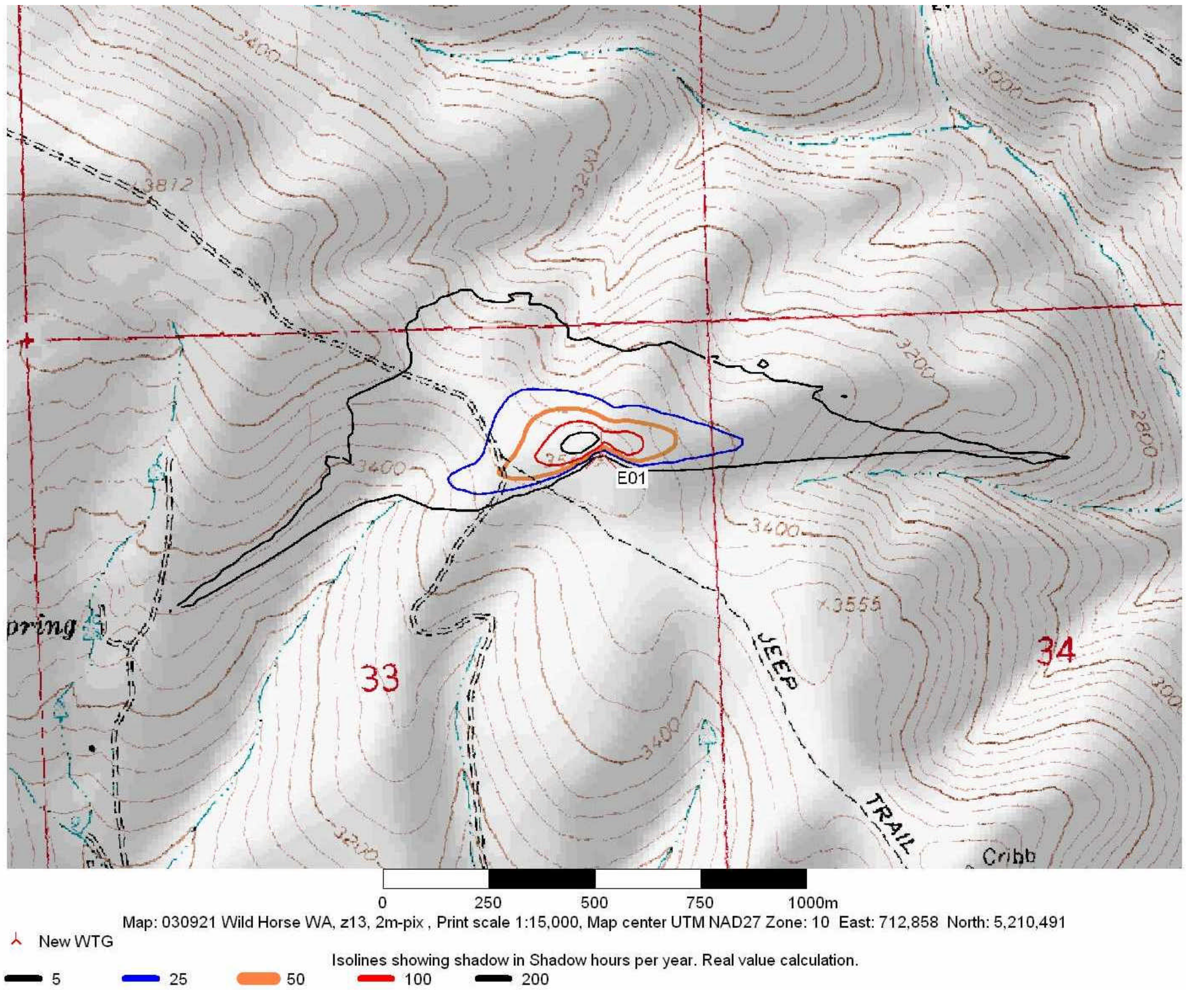
The model calculates the shadow flicker time for either a) each receptor b) everywhere (defined areas) or both. A receptor is defined as a 1 m² window at the residence whose azimuth has been estimated (north, south, east, west or 90, 180, 270 degrees from the nearby access road). The sun's path is calculated by the software from the turbine location and the cast shadow derived over the day. The turbine run-time and direction (seen from the receptor) are calculated from the site's long-term wind speed and direction distribution. Finally, a cloud cover assumption (monthly average sunshine hours) is applied to arrive at the estimated annual flicker impact at each receptor.

For the example below, a map with line contours showing the number of hours of shadow-flicker was preferred, thus computations for 25 by 25 meter squares were required. The output for the map and for tabulated data (not shown) is:

- Turbine locations and elevations
- Calculated shadow-flicker time at selected receptors
- Tabulated and plotted time of day with shadow flicker at selected receptors
- Listing of turbines causing shadow flicker at each selected receptor
- Map showing turbine locations, selected shadow-flicker receptors and line contours indicating projected shadow-flicker time (hours per year).

4. Results

There is no significant impact on any of the potential shadow-flicker receptors. The closest receptor is more than one mile away from a wind turbine and at that distance – even if the angle is ideal for producing shadow flicker, the shadow-flicker intensity will be extremely low and hardly noticeable even under ideal conditions for producing shadow flicker.
The plot below shows the details of a typical shadow-flicker area.



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