a DNV company

# *Shadow Mapping for Desert Claim Project*

**CSRP0012-A**

***CONFIDENTIAL***

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**Prepared for:**

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# Approvals

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## Introduction

enXco, Inc. contracted with DNV Global Energy Concepts Inc. (DNV-GEC) to perform shadow mapping for the proposed Desert Claim wind power project located approximately 8 miles north of Ellensburg, Washington. This report summarizes the shadow impact findings for the project area and for individual residences in the project vicinity, and reflects the current 95-turbine layout and project boundary .

## Shadow Impacts

The shadows cast by the wind turbines will vary with several factors including turbine size, season, time of day, surrounding terrain, cloud cover, wind speed, and wind direction. The height of the sun in the sky varies by season, as does the time and location at which it rises and sets. In the winter, the sun rises late in the southeast, travels in a low arc across the southern sky, and sets early in the southwest. Because it is so low in the sky, it casts longer shadows. In the summer, the sun arcs through the sky at its highest angle and casts the shortest midday shadows. However, in the summer, the sun also rises earliest, sets latest, and covers a wider range of directions, from the northeast around the south to the northwest. Therefore, the summer sun casts shadows that span a broader direction range than in other seasons, and its early sunrise and late sunset create shadows earlier in the morning and later in the evening than in other seasons.

Shadows become less sharp (more diffuse) as the distance between the shadow-casting object and the observer grows. When considering shadows cast by relatively small objects at a long distance from the observer, at a sufficient distance no noticeable shadow forms at all because the object does not significantly block the sun's light. Instead, light diffracts (or bends) around the edges of the object, and the object itself becomes relatively small compared to the apparent size of the sun. The object becomes something that is silhouetted in front of the sun rather than something casting a shadow.

The part of the shadow where the light source is fully blocked is called the umbra; the part where the light source is only partially blocked is called the penumbra. On a sunny day, this phenomenon can be observed with the shadow of a flag pole. At its base the shadow has sharp edges because it is an umbra and has no penumbra. The shadow of the upper part of the pole has fewer and fewer sharp edges with more and more penumbra and less umbra.[1] At a sufficient distance, there is no umbra, and the pole becomes an object visible in the foreground of the sun.

Shadow flicker caused by wind turbines is defined as alternating changes in light intensity due to the moving blade shadows cast on the ground and objects, including windows at residences. The influence of shadow flicker on residences depends on the length and direction of shadows cast by wind turbines and the relative location of wind turbines and windows at the residence.

The sun is approximately 150 million km away from the earth, and the sun has a diameter of approximately 1.4 million km. Therefore, the diameter of the sun covers an arc 0.5° wide when viewed from earth. The maximum width of a wind turbine blade is approximately 4 m. (This is near the hub at the "maximum chord" position; the blade profile tapers to much less than 2 m as

[1] Source: University of Queensland, Australia. (http://www.uq.edu.au/_School_Science_Lessons/UNPh28.html).

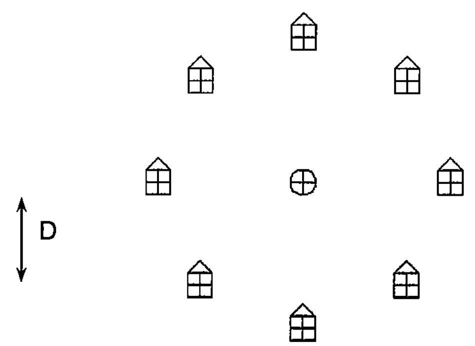
distance from the hub increases, and because the blade is relatively thin, from most viewpoints the blade is effectively well below 2 m wide.) Assume a 2-m wide blade section cuts across the disk of the sun, and further assume the blade must obscure more than half of the sun to make a clear shadow that could contribute to flicker. Given these assumptions, a blade covering more than 0.25° (half the width of the sun) can potentially cause flicker. Therefore, the outer edge of influence from this shadow can be considered as the distance at which a 2-m wide object represents 0.25°, which is approximately 458 m or about 1500 ft. In the case where smaller parts of the blade cast the shadow (such as farther "out" on the blade), the distance at which shadows become insignificant is much closer to the wind turbine. This is important to consider because the parts of the blade that reach near the overall height of the wind turbine are much slimmer than the portions of the blade located near the hub of the wind turbine, and it is the overall height that is used in the shadow analyses.

The prevailing wind direction for the project site is from the northwest. The lateral extent of the blade shadow depends on wind direction, as the wind turbines yaw to face into the wind during operation. For example, during northwesterly winds, the turbine rotor will face to the northwest, and a relatively small shadow would be cast on a receptor if the sun is in line with the plane of the rotor. This would occur early in the morning in the summer (sun from the northeast) and late in the afternoon in the winter (sun from the southwest). In these cases, the rotor shadow will be in the shape of a narrow ellipse. On other occasions, the sun will be perpendicular to the rotor plane, and cast a larger area of moving blade shadows on the ground. In these cases, the ellipse will be wider. Generally, a southern or northern wind will have minimum shadow impact because the widest shadows would be cast at midday. At midday, shadows are also the shortest (closest to the wind turbine) due to the sun's position high in the sky.

Shadow flicker impacts were calculated for the Desert Claim project area using WindPRO software. This model generates site-specific results, taking site location (latitude/longitude), elevation, and monthly average cloud cover into account. The model also takes wind direction into account by modeling the average amount of time per year the turbine is yawed in various directions. Obstruction objects such as trees or buildings are not accounted for in the model. As the sun approaches the horizon, it is less intense and therefore the shadow influence is reduced. The model did not calculate shadow influence when the sun is at or below an angle of 4° above the horizon. This 4° assumption corresponds to approximately 30 minutes after sunrise and 30 minutes before sunset.

The assumptions applied in the WindPRO model are generally conservative, and err on the side of over-predicting shadow impacts. Cloud cover tends to be greater in the mornings and evenings than it is midday. Similarly, shadows are longer (although more diffuse) when the sun is lower in the sky. Since cloud cover data were available as monthly averages rather than by time of day, the model results will be conservative. The model assumes that the turbines are always operating. In reality, no flickering effect occurs in calm or very low winds, when the rotor is stationary or turning too slowly to cause flicker. Obstructing objects such as trees, silos, or buildings may block shadow impacts on some receptors; these factors are not reflected in the model results.

To address shadow flicker generally, theoretical houses have been assumed to be located at eight compass points around a representative turbine, as illustrated in Figure 1. A model was built with houses at distances of 750 ft (230 m), 1000 ft (305 m), and 1500 ft (458 m) from the turbine. Each house is assumed to have a generic 1 m by 1 m square window located 1 m above ground level and facing the turbine. It is likely that many houses will have windows that are not perpendicular to turbines, which will decrease the shadow impact on these houses. The model was run with an 80-m hub height and an approximately 92-m rotor diameter, which is representative of the REpower MM92. The results assume the turbine is yawed to various directions according to the annual direction distribution of the wind regime at the Desert Claim site. The results also take elevation differences, but not other structures or vegetation into account.




Turbine is in center with window receptors perpendicular to the turbine at eight compass points.

**Figure 1. Sample Layout for Shadow Flicker (D = 750, 1000, and 1500 ft)**

A review of Washington cloud cover data from the National Climatic Data Center yielded long-term data from Stampede Pass and Yakima. Stampede Pass is approximately 40 miles west of the project site, in the Cascade Mountains. Stampede Pass data are likely to be influenced by mountain weather that is not representative of the project site. Yakima is 28 miles south of Ellensburg, and approximately 36 miles south of the project site (see Figure 2). The cloud cover in Yakima is expected to be slightly less than the cloud cover in Ellensburg; however, it is the most representative site available. These data include mean monthly cloud cover data averaged over a 50-year period. Monthly data are presented as mean days per month characterized as "Clear," "Partly Cloudy," and "Cloudy" between sunrise and sunset. "Clear" is defined as 0-2 eighths of the sky being obstructed by cloud cover, "Partly Cloudy" specifies clouds in 3-6 eighths of the sky, and "Cloudy" represents 7-8 eighths of the sky being cloud covered. From these data, monthly sunshine probabilities were derived (as 100% minus percent cloud cover) and applied in the model (see Table 1).

**Table 1. Cloud Cover Data for Yakima, Washington**

| | Sunrise to Sunset, Mean Cloud Cover (Eighths of Sky Covered) | % Sunshine During Daylight Hours |
|---|---|---|
| January | 6.3 | 21% |
| February | 5.9 | 26% |
| March | 5.4 | 33% |
| April | 5.2 | 35% |
| May | 4.7 | 41% |
| June | 4.2 | 48% |
| July | 2.5 | 69% |
| August | 2.7 | 66% |
| September | 3.1 | 61% |
| October | 4.5 | 44% |
| November | 5.8 | 28% |
| December | 6.2 | 23% |
| **Average** | **4.7** | **41%** |

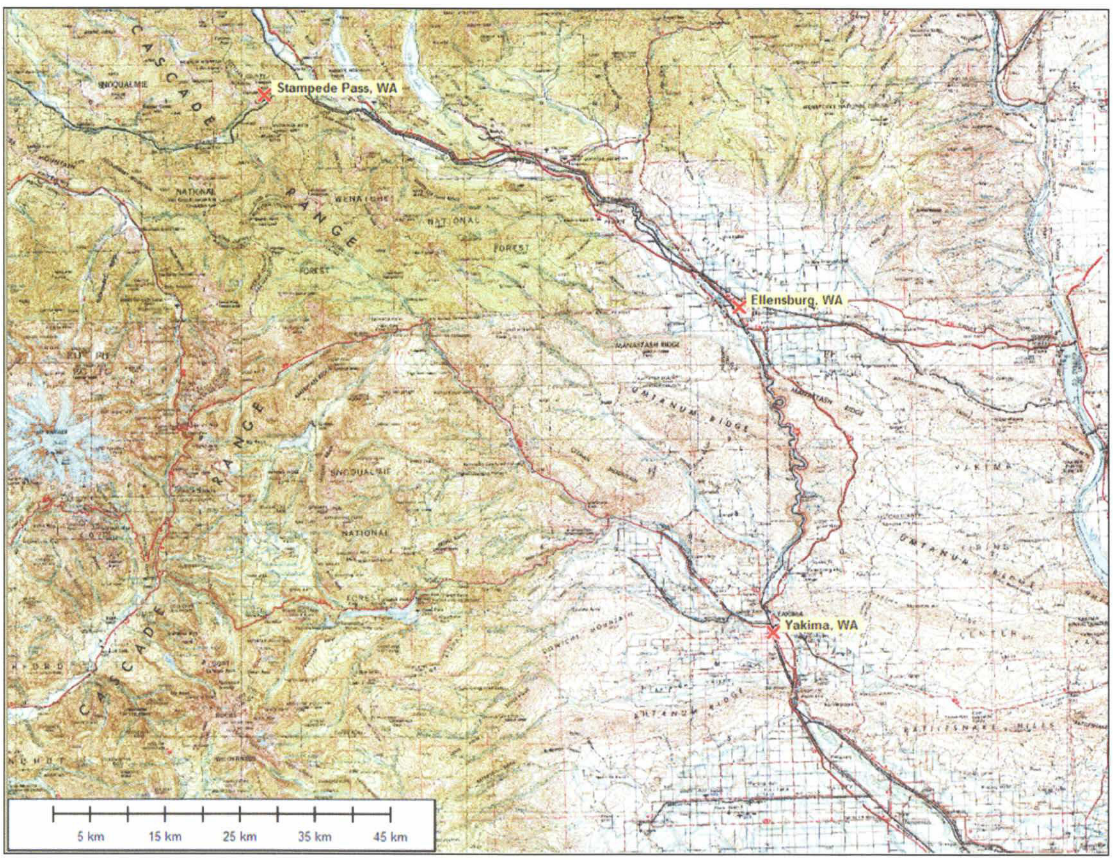



**Figure 2. Cloud Cover Data Locations Relative to Ellensburg**

For those receptors that have potential shadow flicker impacts, Exhibit A graphically indicates the days of the year and hours of the day in which shadow flicker impacts could occur. The shaded area on each plot illustrates the time of shadow impact. Generally, the results show that houses to the south of a turbine do not have impacts, and that houses farther away from a turbine would have fewer hours of impact. Also, with the exception of short midday impacts in the winter due to low sun angles, the results show that houses 1000 ft away have impacts limited to mornings and evenings, when the sun angle is low and shadows tend to be more diffuse.

Table 2, Table 3, and Table 4 provide a summary of shadow flicker impacts for houses 750 ft (230 m), 1000 ft (305 m), and 1500 ft (458 m) from a turbine, respectively.

**Table 2. Potential Shadow Flicker Summary, 750 ft from Turbine 38**

| Direction from Turbine | Days of Potential Impact per Year | Max Hours per Day[1] | Mean Hours per Day[2] | Total Annual Hours |
|---|---|---|---|---|
| North | 92.00 | 1.62 | 0.13 | 11.90 |
| Northeast | 169.00 | 1.52 | 0.17 | 28.58 |
| East | 166.00 | 1.50 | 0.47 | 77.67 |
| Southeast | 0.00 | 0.00 | 0.00 | 0.00 |
| South | 0.00 | 0.00 | 0.00 | 0.00 |
| Southwest | 0.00 | 0.00 | 0.00 | 0.00 |
| West | 178.00 | 1.48 | 0.39 | 68.85 |
| Northwest | 160.00 | 1.53 | 0.23 | 36.03 |

1. Not reduced to account for cloud cover or turbine yaw direction; assumes sky is always clear and turbine is facing the sun.
2. Mean hours per day calculated only on days with potential impact. Days without impact are not factored into the average. Mean hours per day would be much lower if days with no potential impact were factored in.

**Table 3. Potential Shadow Flicker Summary, 1000 ft from Turbine 38**

| Direction from Turbine | Days of Potential Impact per Year | Max Hours per Day[1] | Mean Hours per Day[2] | Total Annual Hours |
|---|---|---|---|---|
| North | 30.00 | 0.62 | 0.04 | 1.28 |
| Northeast | 137.00 | 1.20 | 0.13 | 18.42 |
| East | 107.00 | 1.15 | 0.34 | 35.92 |
| Southeast | 0.00 | 0.00 | 0.00 | 0.00 |
| South | 0.00 | 0.00 | 0.00 | 0.00 |
| Southwest | 0.00 | 0.00 | 0.00 | 0.00 |
| West | 99.00 | 1.15 | 0.33 | 32.23 |
| Northwest | 128.00 | 1.20 | 0.17 | 22.13 |

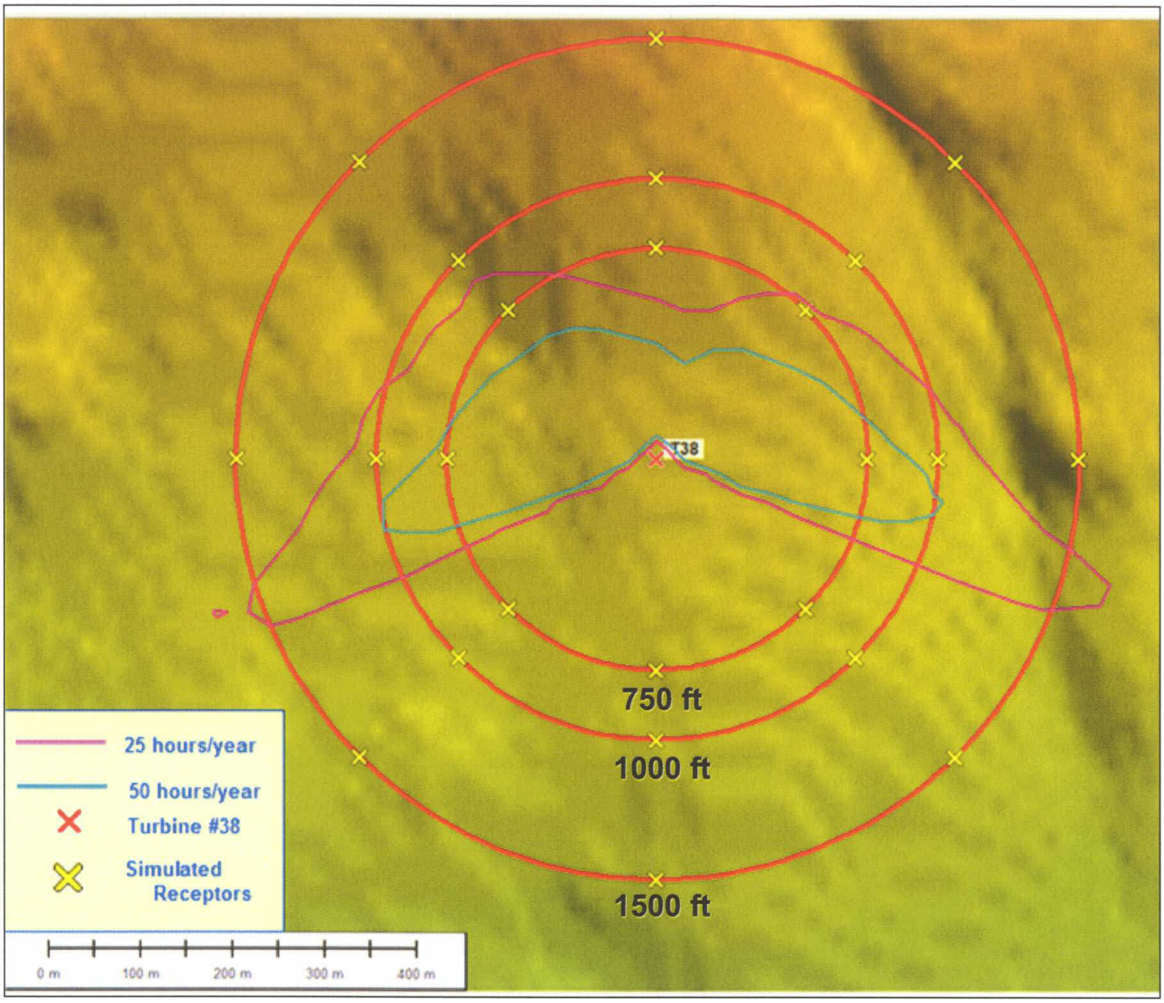
1. Not reduced to account for cloud cover or turbine yaw direction; assumes sky is always clear and turbine is facing the sun.
2. Mean hours per day calculated only on days with potential impact. Days without impact are not factored into the average. Mean hours per day would be much lower if days with no potential impact were factored in.

**Table 4. Potential Shadow Flicker Summary, 1500 ft from Turbine 38**

| Direction from Turbine | Days of Potential Impact per Year | Max Hours per Day[1] | Mean Hours per Day[2] | Total Annual Hours |
|---|---|---|---|---|
| North | 0.00 | 0.00 | 0.00 | 0.00 |
| Northeast | 98.00 | 0.83 | 0.09 | 8.83 |
| East | 65.00 | 0.78 | 0.22 | 14.35 |
| Southeast | 0.00 | 0.00 | 0.00 | 0.00 |
| South | 0.00 | 0.00 | 0.00 | 0.00 |
| Southwest | 0.00 | 0.00 | 0.00 | 0.00 |
| West | 62.00 | 0.78 | 0.22 | 13.55 |
| Northwest | 88.00 | 0.85 | 0.11 | 9.97 |

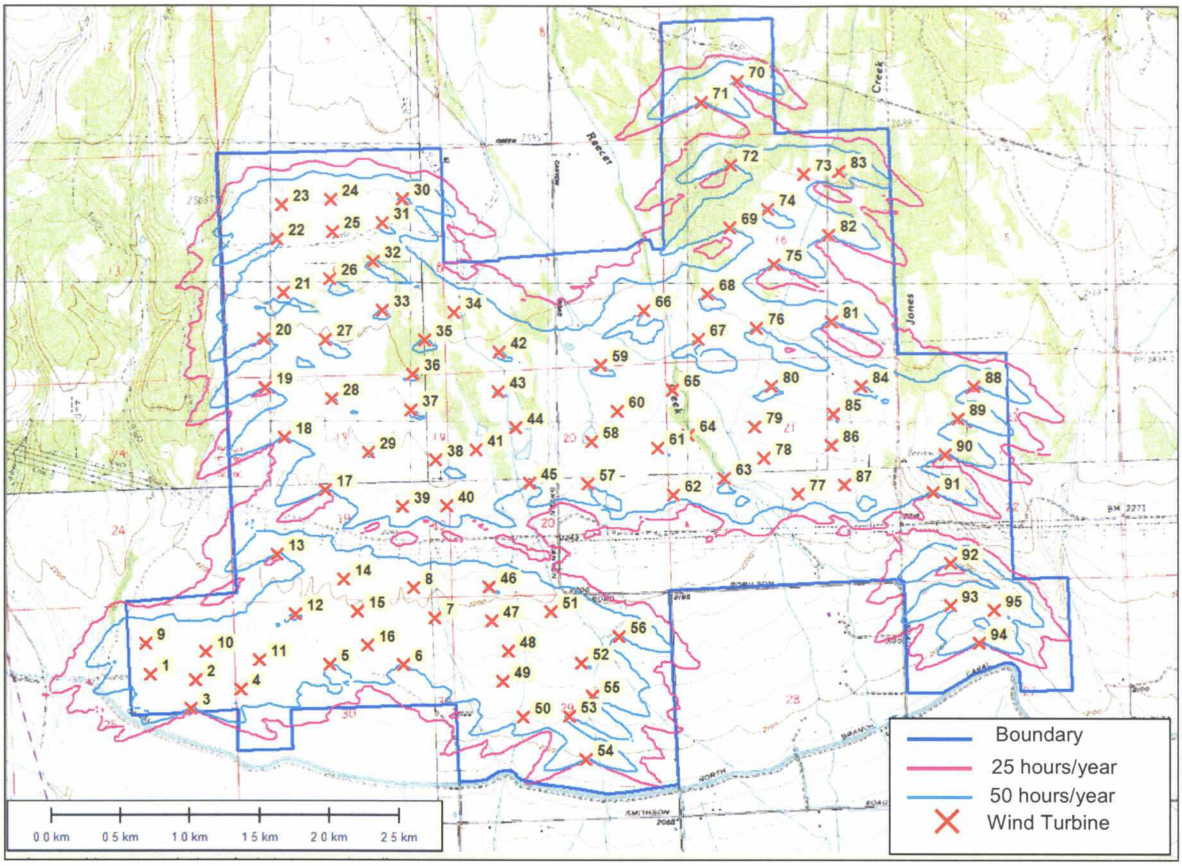
1. Not reduced to account for cloud cover or turbine yaw direction; assumes sky is always clear and turbine is facing the sun.
2. Mean hours per day calculated only on days with potential impact. Days without impact are not factored into the average. Mean hours per day would be much lower if days with no potential impact were factored in.

Figure 3 shows shadow flicker contours for a typical sole turbine (Turbine 38) on typical project terrain. The simulated receptor points on Figure 3 correspond to the measurement locations used to generate the results in Table 2, Table 3, and Table 4. Lines represent equal number of hours per year of shadow flicker. Almost all of the area with 50 or more annual hours of shadow flicker falls within 1000 ft of a turbine. Generally, the potential shadow flicker impacts at a distance of 1000 ft or greater from a turbine are limited to receptors located to the east to east-southeast or west to west-southwest of a turbine. Figure 4 shows a map of the entire project area with shadow flicker contours resulting from the additive shadow flicker effects of all turbines at the project. Less than 25 hours per year of potential shadow impacts are predicted outside the project boundary to the north or south. Some areas within about 1000 ft to the east or west of the project boundary have impacts exceeding 25 hours per year.




(lines represent equal number of hours per year of shadow flicker)

**Figure 3. Shadow Flicker around a Typical Turbine (#38)**




(lines represent area with equal hours per year of shadow flicker)

**Figure 4. Shadow Contour Map of Desert Claim Project Area**

## Impacts on Identified Receptors

Next, DNV-GEC calculated the theoretical duration of shadow flicker at the nine residences that are located within 2500 feet of a turbine using WindPRO software. The residences are shown on a map in Figure 5. Shadows beyond about 1500 ft are not expected to cause shadow flicker because they will diffuse at that distance or greater, but the model did calculate a theoretical duration of shadow flicker. There are no residences located within 1500 feet of a turbine; therefore, it is DNV-GEC's best approximation that no shadow flicker impacts are expected at any of the residences.

Greenhouse-style windows are assumed, that is, the receptors are assumed to have windows facing each turbine. This is a conservative approximation and will tend to over-estimate impacts. Each set of results assumes the cloud cover data presented in Table 1, and assumes the turbine is yawed to various directions according to the annual direction distribution of the wind regime at the Desert Claim site. The results also take into account elevation differences, but not other structures or vegetation, and assume the turbines are always operating.

Table 5 shows the theoretical maximum shadow flicker effect, assuming perceptible flicker occurs beyond 1500 ft from a turbine. Exhibit A shows the corresponding calendar graphs for each receptor. At distances of 1500 ft and greater, the shadow flicker hours are limited to early and late in the day, when shadows are diffuse, and the turbine will generally appear as a distant object in front of the rising or setting sun, not an object casting a noticeable shadow. The resulting shadow flicker hours are due to the cumulative effect of shadow flicker from one or more turbines on a specific residence.

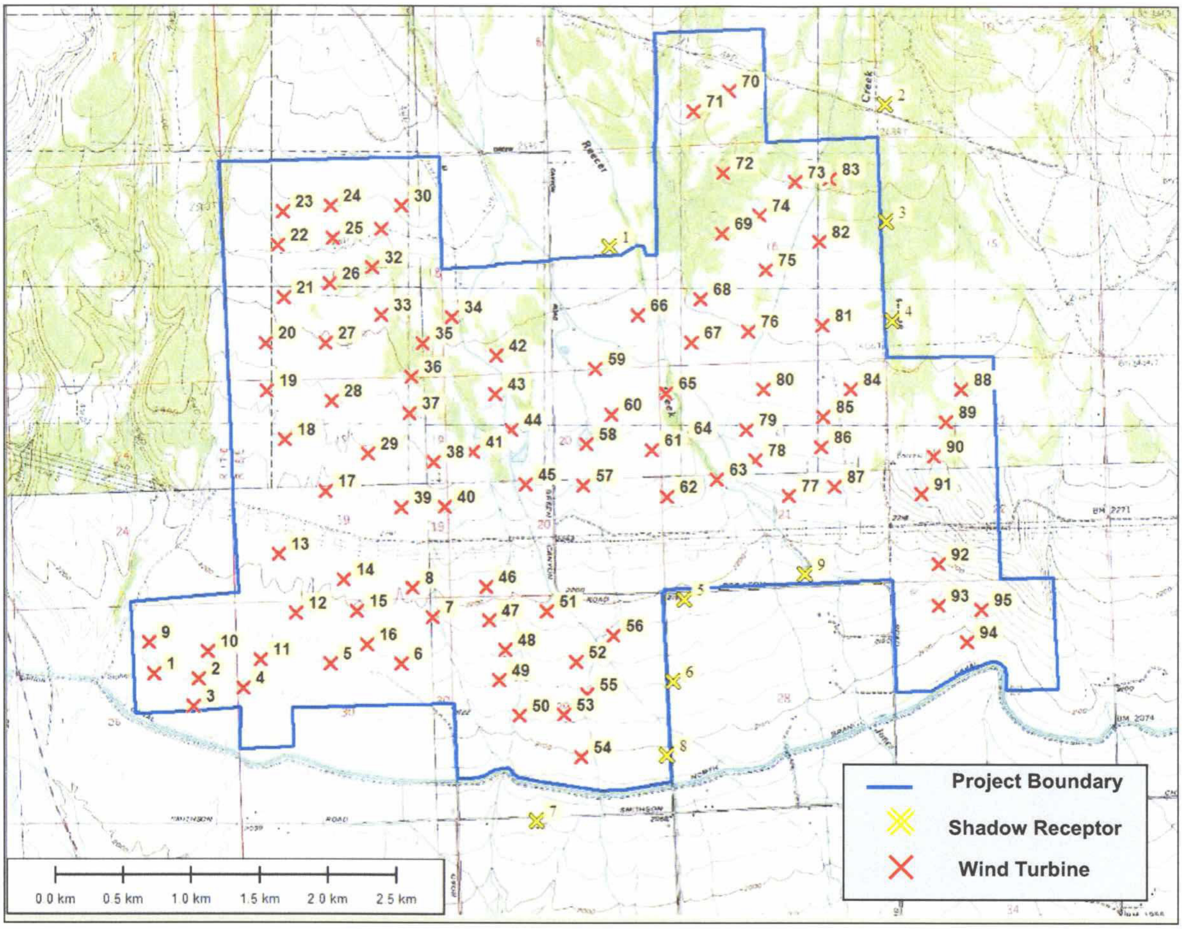


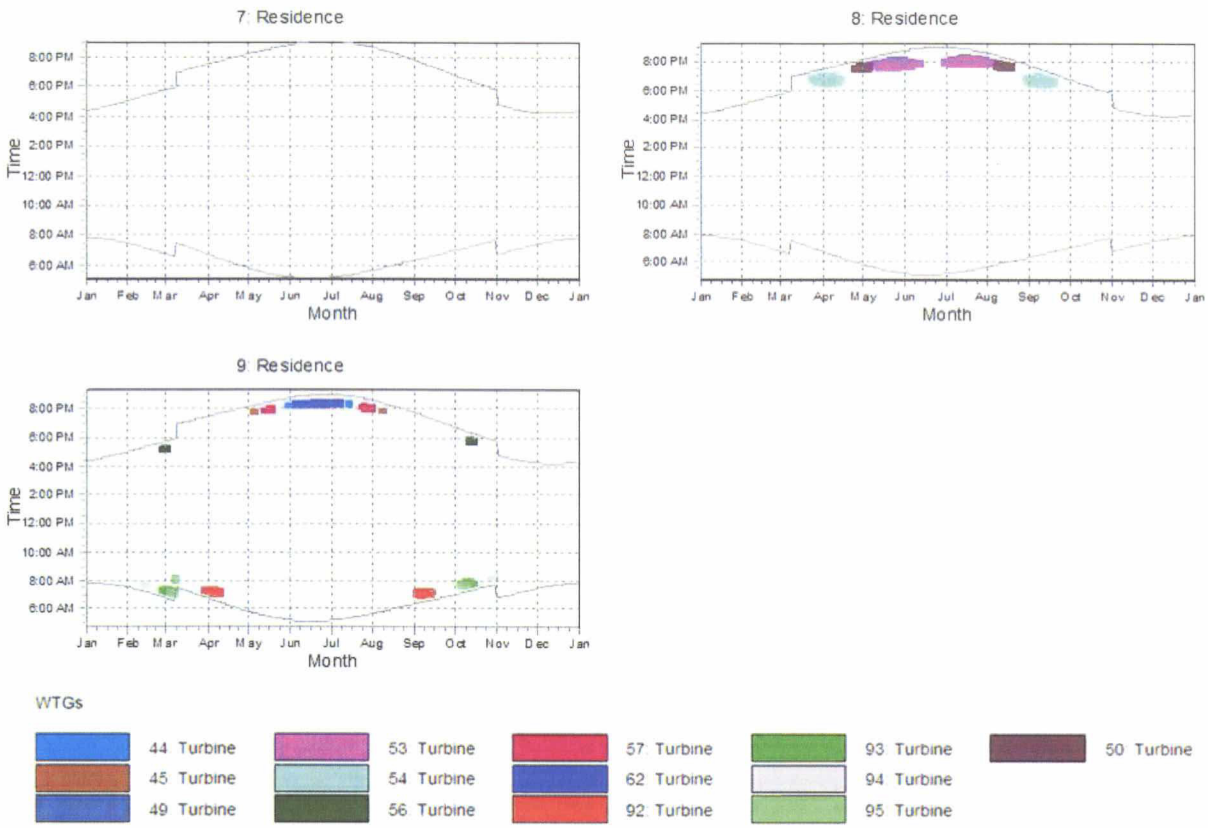

**Figure 5. Desert Claim Shadow Receptors**

**Table 5. Theoretical Shadow Flicker Duration, No Distance Diffusion Limit**

| Receptor | Days of Potential Impact per Year | Max Hours per Day[1] | Mean Hours per Day[2] | Total Annual Hours |
|---|---|---|---|---|
| 1 | 222 | 0.60 | 0.07 | 14.87 |
| 2 | 57 | 0.15 | 0.01 | 0.85 |
| 3 | 205 | 0.70 | 0.13 | 26.03 |
| 4 | 194 | 0.70 | 0.10 | 19.85 |
| 5 | 215 | 0.50 | 0.05 | 10.12 |
| 6 | 242 | 0.57 | 0.08 | 20.17 |
| 7 | 0 | 0.00 | 0.00 | 0.00 |
| 8[3] | 145 | 0.57 | 0.13 | 18.70 |
| 9[3] | 113 | 0.32 | 0.05 | 5.27 |

1. Not reduced to account for cloud cover or turbine yaw direction; assumes sky is always clear and turbine is facing the sun.
2. Mean hours per day calculated only for days identified in column titled "Days per Year." Other days are not factored into the result. Mean hours per day would be much lower if other days were factored into the result.
3. Project participant residence located within Project area.

## Exhibit A: Shadow Calendar Maps for Desert Claim, No Distance Diffusion Limit


7: Residence
8: Residence
9: Residence
Time
Month
8:00 PM
6:00 PM
4:00 PM
2:00 PM
12:00 PM
10:00 AM
8:00 AM
6:00 AM
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
WTGs
44: Turbine
45: Turbine
49: Turbine
53: Turbine
54: Turbine
56: Turbine
57: Turbine
62: Turbine
92: Turbine
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50: Turbine