

**Appendix G**  
**Shadow Flicker Report**

# Shadow Flicker Report

## Homestead Wind Project

Williams County, North Dakota

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## 1.0 PROJECT OVERVIEW

Homestead Wind, LLC (Homestead or Applicant), an indirect subsidiary of Apex Clean Energy Holdings, LLC (Apex), is proposing to construct an up to 256.5 megawatt (MW) wind energy generation facility in Williams County, North Dakota (hereafter referred to as the Project) (see Figure 1). The Project includes 81 turbine locations, although no more than 67 will be constructed. This report provides an assessment of the potential shadow flicker that could be experienced at occupied residences located around the proposed turbines.

Two wind turbine models are being considered for the Project (see Table 1). Therefore, this analysis evaluated the potential shadow flicker for each turbine model. In addition, for each turbine model, modeling considered all 81 turbine locations. This is a conservative approach since no more than 67 turbines will be constructed. Each wind turbine consists of three major mechanical components: the tower, nacelle, and rotor. The dimensions for both wind turbine models under consideration for the Project are provided in Table 1. The Project's turbine layout is depicted in Figure 2.

**Table 1. Homestead Wind Turbine Model Characteristics**

Turbine Model	Hub Height	Rotor Diameter	Total Height
Vestas V163	113 meters (371 feet)	163 meters (535 feet)	194.5 meters (638 feet)
GE 154	116 meters (381 feet)	154 meters (505 feet)	193 meters (634 feet)

\*conversions between metric and imperial/standard are rounded up to the nearest foot

The Project is located within Williams County, North Dakota, approximately 15 miles northwest of the City of Williston and 5 miles east of the North Dakota/Montana border. Elevations in the area range from approximately 2,150 feet above mean sea level (amsl) to 2,490 feet amsl. Land cover within the Project area is dominated by active agriculture, with farms and single-family residences generally occurring along the road frontage.

## 2.0 INTRODUCTION

Shadow flicker refers to the moving shadows that an operating wind turbine casts at times of the day when the turbine rotor is between the sun and a structure's position. Shadow flicker is most pronounced in northern latitudes during winter months because of the lower angle of the sun in the winter sky. However, it is possible to encounter shadow flicker anywhere for brief periods after sunrise and before sunset (U.S. Department of the Interior, 2005). During intervals of sunshine, wind turbine generators will cast a shadow on surrounding areas as the rotor blades pass in front of the sun, and if these moving shadows pass over a window they can cause a flickering effect. Shadow flicker does not occur when fog or clouds obscure the sun, or when turbines are not operating.

The distance between a wind turbine and a structure (occupied residence) affects the intensity of the shadows cast by the blades, and therefore the intensity of flickering. Shadows cast close to a turbine will be more intense, distinct, and focused. This is because a greater proportion of the sun's disc is intermittently

blocked by the turbine (BERR, 2009). Obstacles such as terrain, vegetation, and/or buildings occurring between structures and wind turbines may significantly reduce or eliminate shadow-flicker effects. At distances beyond roughly 10 rotor diameters shadow flicker effects are generally considered negligible (BERR, 2009; DECC, 2011; DOER, 2011).

The location and duration of shadow flicker can be predicted using computer modeling programs and input data regarding turbine characteristics and weather conditions. An “expected case” shadow flicker scenario is presented in this report based on a combination of real case data and conservative assumptions. The expected case aspects include sunshine frequency weather data (inclusion of percentage of monthly sunshine) and turbine rotor position (on-site wind direction data), while conservatively assumes that wind conditions allow continuous turbine operation. In addition, sunlight intensity and duration vary daily and seasonally, and obstacles that block shadows (terrain, vegetation, and buildings) exist in the landscape; these factors are not considered in the modeling, adding additional conservative measures.

### **3.0 METHODS**

#### **3.1 Shadow Flicker Analysis**

This shadow flicker analysis evaluated the potential impact of 81 wind turbines for the two different turbine models listed in Table 1. A maximum distance of potential effect of 10 rotor diameters from the turbine locations based on the wind turbine model (1,630 meters for the Vestas V163 and 1,540 meters for the GE 154) was used for these analyses to ensure that all potentially impacted residences were assessed. While at distances beyond roughly 10 rotor diameters shadow flicker effects are generally considered negligible, this analysis evaluates receptors within one mile of Project parcels which represent a larger area than the 10 rotor diameters since that distance is measured from turbine locations, which are sited interior of parcels.

The shadow flicker analysis for the proposed Project used *WindPRO 4.1* software and associated Shadow module. *WindPRO* is a widely accepted modeling software package developed specifically for the design and evaluation of wind power projects. Input variables and assumptions used for shadow flicker modeling calculations for the proposed Project include:

- The latitude and longitude coordinates of 81 proposed wind turbine sites (provided by the Applicant).
- The latitude and longitude coordinates of 29 residences located in the vicinity of the proposed turbines (within one mile of the boundary of Project parcels; provided by the Applicant).
- USGS DEM Elevation Data.
- The rotor diameter and hub height for both turbine models under consideration.
- Annual wind rose data (provided by the Applicant), which is depicted in Table A1 of Attachment A (to determine the approximate directional frequency of rotor orientation throughout the year).
- To account for the occurrence of cloudy conditions, the average monthly percent of available sunshine for the nearest National Oceanic and Atmospheric Administration (NOAA) weather station in Williston, North Dakota was used. Data were obtained from NOAA’s “Comparative Climatic Data for the United States through 2023” (see Table A2 of Attachment A) (<http://www.ncdc.noaa.gov>).

- No allowance was made for wind being below or above generation speeds. Blades are assumed to be moving during all daylight hours when the sun's elevation is more than 3 degrees above the horizon. Shadow flicker is generally considered imperceptible when the sun is less than 3 degrees above the horizon (due to the scattering effect of the atmosphere on low angle sunlight) (States Committee for Pollution Control, 2002).

The model calculations include the cumulative sum of shadow flicker hours for all Project turbines. This omni-directional approach reports total shadow flicker results at a receptor regardless of the presence or orientation of windows at that particular residence (i.e., it assumes shadows from all directions can be perceived at a residence, which may or may not be true). A receptor in this "greenhouse" model is defined as a one square meter area located one meter above ground; actual house dimensions are not taken into consideration.

Because the shadow flicker analysis conducted for the proposed Project was based on the conservative assumptions that 1) all turbines will be constructed, 2) the turbines are in continuous operation during daylight hours, and 3) that shadow flicker can be perceived at a receptor structure regardless of the presence or orientation of windows or the screening effects of all surrounding trees and buildings, the analysis presented herein is a conservative projection of the shadow-flicker effects.

### **3.2 Shadow Flicker Threshold**

No State or Williams County, or local standards exist for allowable frequency or duration of shadow flicker from wind turbines. The North Dakota Public Utilities Commission has not promulgated any standards on shadow flicker and Williams County Zoning Ordinance does not identify any standards on shadow flicker. However, 30 hours of shadow flicker per year is a commonly cited target for wind projects, and Homestead applied this target to the design of the Project for all occupied residences.

## **4.0 RESULTS**

Output from the model includes the following information:

- Calculated shadow-flicker time (total hours per year when shadow flicker is expected) at each of the 29 occupied residences.
- Shadow isolines, which are used to create maps showing turbine locations, receptors, and projected shadow-flicker duration (hours per year) without taking into consideration the effect of screening provided by vegetation and structures (see Figures 3 and 4).

These data are presented in the tables included in Attachment B.

A summary of the projected shadow flicker at each of the residences is presented in Table 2 below.

**Table 2. Summary of Expected Shadow Flicker**

Hours/Year	Number of Receptors		
	Non-Participating Residence	Participating Residence	Total
<i>V163 with 113-meter hub height</i>			
0	11	2	13
0 – 1	0	0	0
1 – 10	5	2	7
10 – 20	2	3	5
20 – 30	1	3	4
Over 30	0	0	0
<b>Max Hours/Year</b>	20:26	29:55	--
<i>GE154 with 116-meter hub height</i>			
0	13	2	15
0 – 1	0	0	0
1 – 10	5	2	7
10 – 20	1	5	6
20 – 30	0	1	1
Over 30	0	0	0
<b>Max Hours/Year</b>	19:01	24:25	--

As these results indicate, all occupied residences will receive less than 30 hours of shadow flicker per year for both turbine models (V163 and GE154), even when modeling all 81 turbine locations, although no more than 67 will be built. At most residence locations, shadow flicker will occur primarily in the early morning or late afternoon.

Attachment B provides the results of the predicted shadow flicker at each receptor. The times of day and duration of shadow flicker experienced by each structure will vary throughout the calendar year based on the position of the sun in the sky and the direction of prevailing winds.

## 5.0 DISCUSSION

As outlined above, results of the shadow flicker analysis for the Project indicate that no residences, participating and non-participating, are modeled to receive over 30 hours of shadow flicker per year.

In addition, the shadow flicker calculations presented herein do not take into account the actual location and orientation of windows, or the screening effects associated with existing, site-specific conditions and obstacles such as trees (i.e., does not take into account the results of a viewshed analysis) and/or buildings. Further, this analysis assumes turbine rotors are continuously in motion and that each receptor location is occupied year-round.

Given these assumptions, the predicted shadow-flicker frequency represents a conservative scenario, and almost certainly overstates the actual frequency of shadow flicker that would be experienced at any given residence location. In addition, many of the modeled shadow flicker hours are expected to be low intensity because they would occur during the early morning or late afternoon hours when the sun is low in the sky. As the sun sinks too low on the horizon and the distance to the sun becomes too long, the shadow dissipates before it reaches the ground (or the receptor) (EMD, 2021).

## **6.0 CONCLUSIONS**

WindPRO predicted that no occupied residences will receive more than 30 hours/year of shadow flicker under the Vestas V163 scenario or under the GE154 scenario from the Project, even when modeling all 81 turbine locations, although no more than 67 will be constructed. More generally, the assumptions underlying the shadow flicker analysis are conservative. The analysis does not take into account important real-world factors, including the actual location and orientation of windows and the screening effects associated with existing, site-specific conditions and obstacles such as trees and/or buildings. Also, the analysis assumes turbine rotors are in continuous motion. Given these assumptions, the predicted shadow-flicker frequency represents a conservative scenario and likely overstates the actual frequency of shadow flicker that would be experienced at any given receptor location.

## 7.0 REFERENCES

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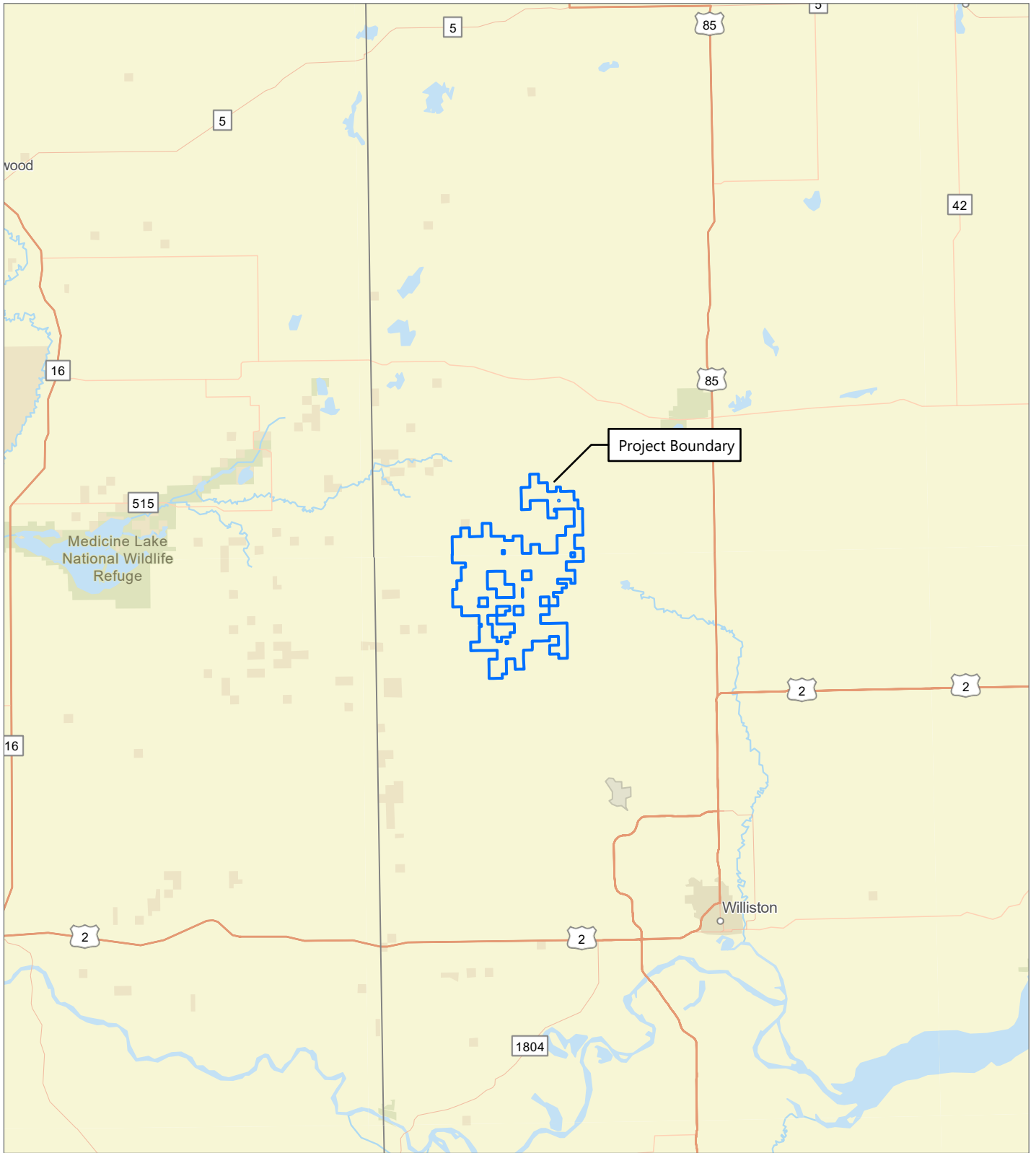
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[http://www.umwelt.sachsen.de/umwelt/download/laerm\\_licht\\_mobilfunk/WEA-Schattenwurf-Hinweise\\_LAI.pdf](http://www.umwelt.sachsen.de/umwelt/download/laerm_licht_mobilfunk/WEA-Schattenwurf-Hinweise_LAI.pdf) (Accessed September 2019).

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## FIGURES

**Figure 1. Regional Project Location**



## Homestead Wind Project

Williams County, North Dakota

*Shadow Flicker Analysis*

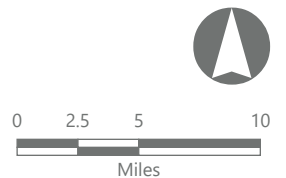
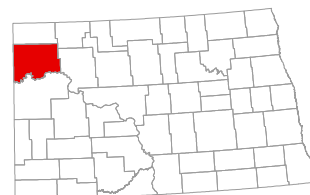
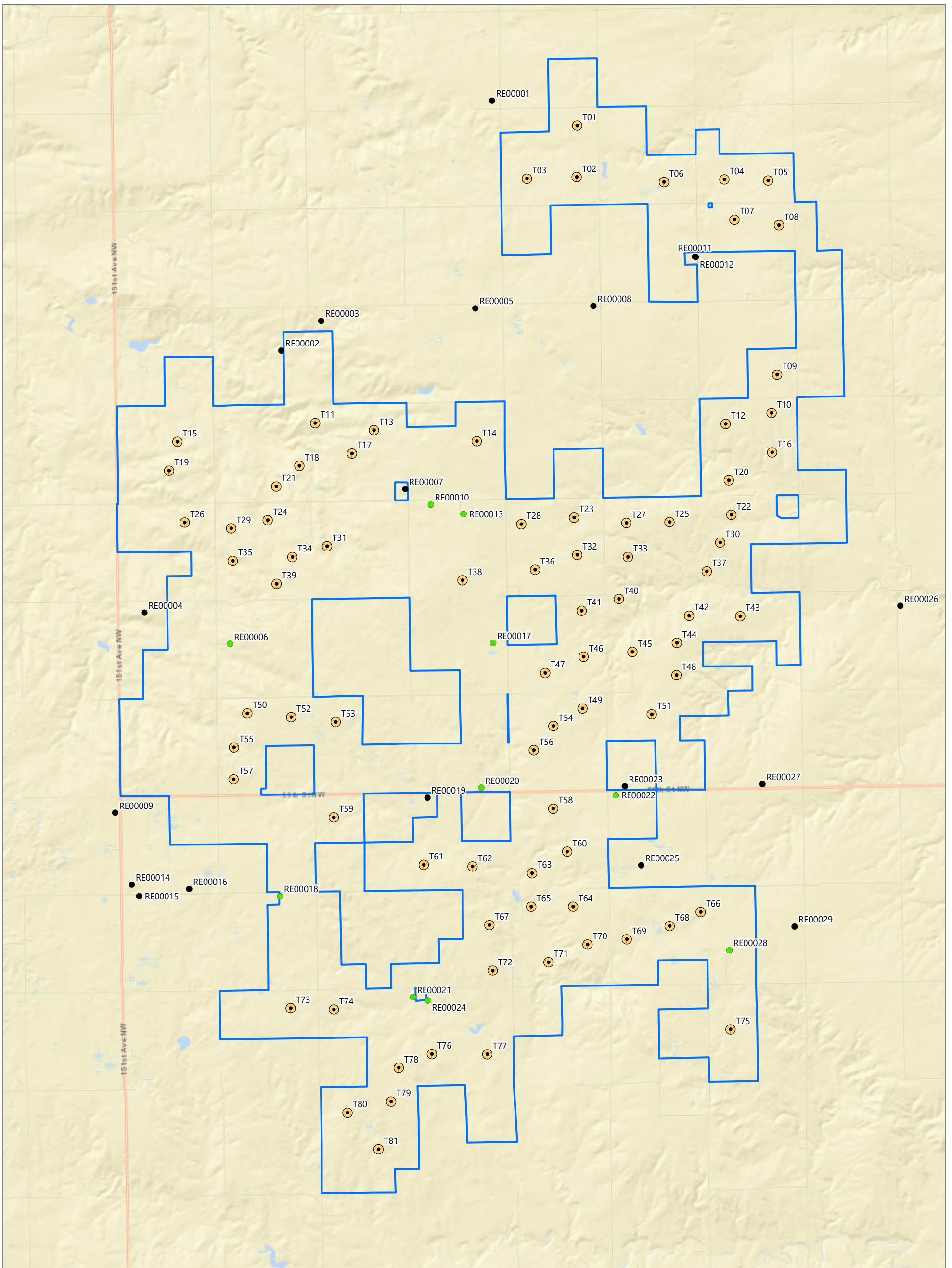


Figure 2. Proposed Project Layout



## Homestead Wind Project

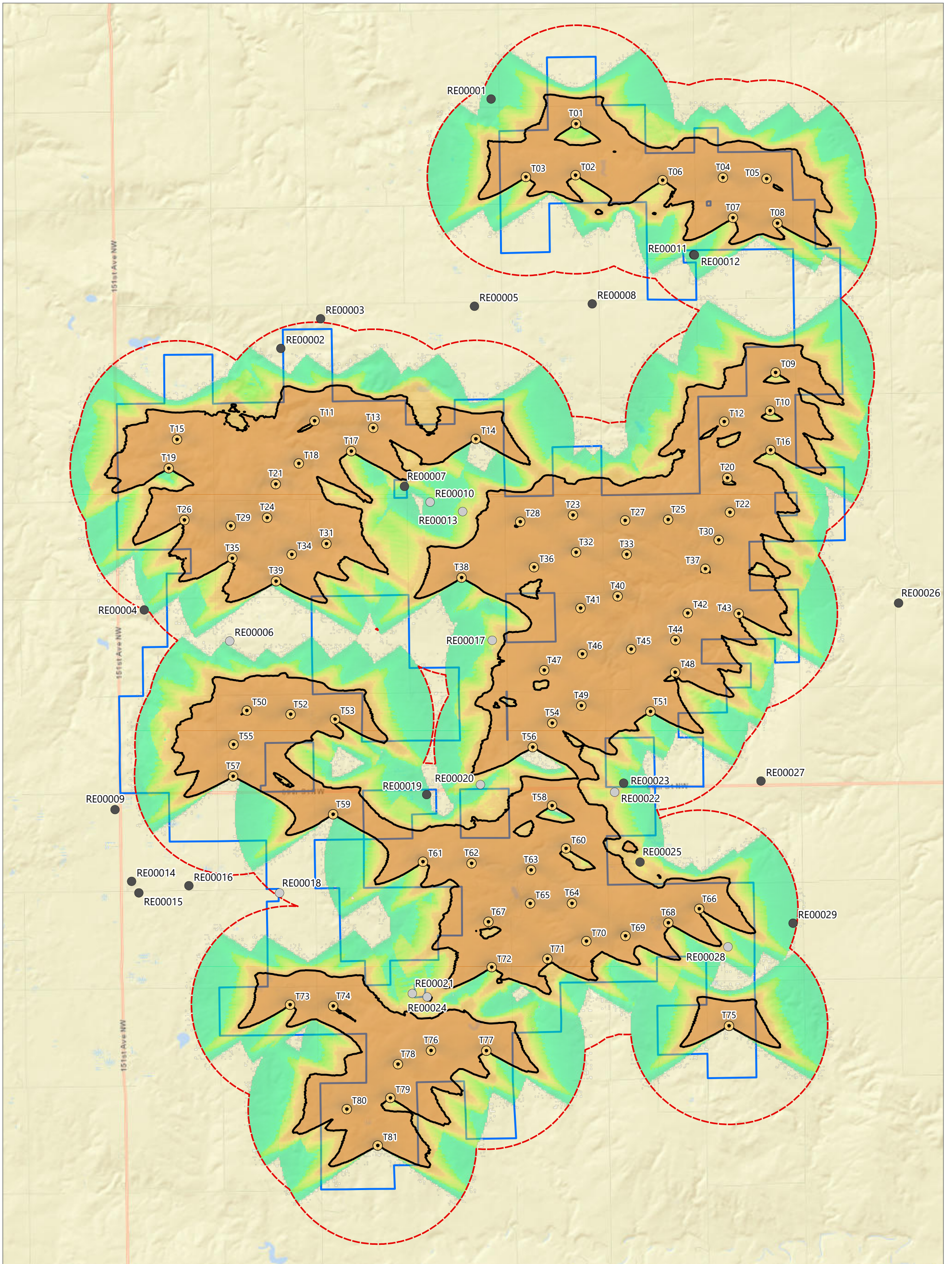
Williams County, North Dakota

### Shadow Flicker Analysis

- Non-Participant
- Participant
- Wind Turbine
- Project Boundary



**Figure 3. Projected Shadow Flicker – Vestas V163**



**Homestead Wind Project**

Williams County, North Dakota

**Shadow Flicker Analysis**

- Wind Turbine
  - Non-Participating Residence < 30 hours/year
  - Participating Residence < 30 hours/year
  - Project Boundary
  - 10 Rotor Diameter from Wind Turbine
  - Shadow Flicker Isoline 30 hours/year
- Shadow Flicker (hours/year)
- < 1
  - 1 - 10
  - 10 - 20
  - 20 - 30
  - > 30

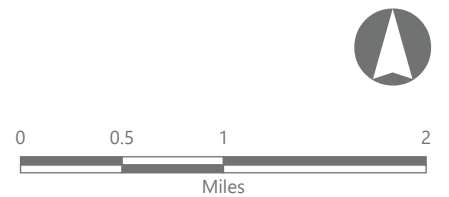
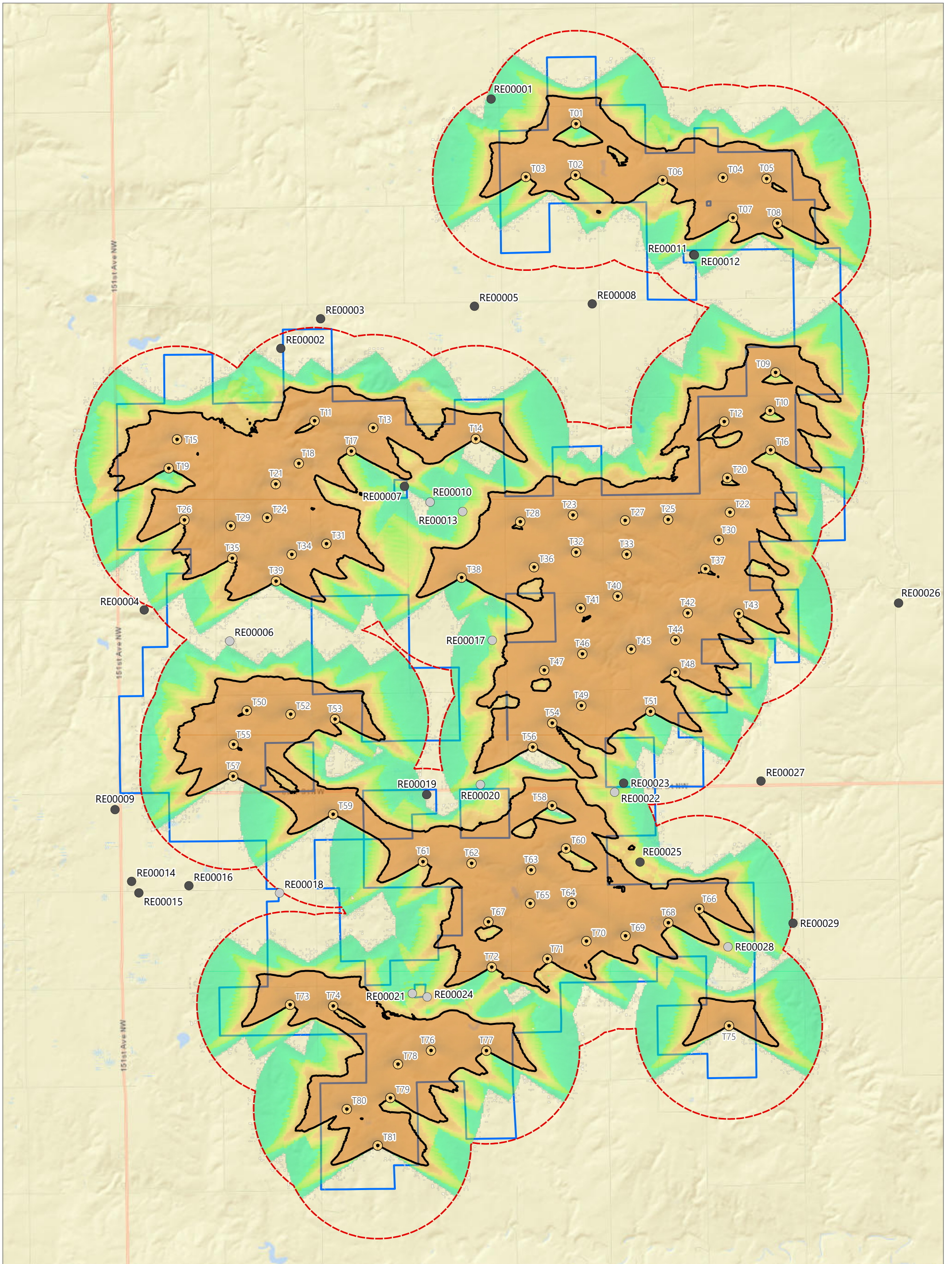


Figure 4. Projected Shadow Flicker – GE 154



## Homestead Wind Project

Williams County, North Dakota

### Shadow Flicker Analysis

- Wind Turbine
- Non-Participating Residence < 30 Hours/Year
- Participating Residence < 30 Hours/Year
- Project Boundary
- 10 Rotor Diameter from Wind Turbine
- Shadow Flicker Isoline
- 30 hours/year

Shadow Flicker (hours/year)

- < 1
- 1 - 10
- 10 - 20
- 20 - 30
- > 30



**ATTACHMENT A**  
Windrose and Sunshine Data

**Table A1. Wind Rose Data**

SECTOR	N	NNE	NE	ENE	E	ESE	SE	SSE
Frequency	3.53	3.08	3.65	4.01	4.18	5.72	7.01	7.4
Hours of Operation	309	270	320	351	366	501	614	648

SECTOR	S	SSW	SW	WSW	W	WNW	NW	NNW
Frequency	6.49	5.04	4.29	7.41	9.49	10.97	10.43	7.3
Hours of Operation	569	442	376	649	831	961	914	639

Source: Wind rose data provided by Apex Clean Energy, LLC

**Table A2. Sunshine Probability Data**

Month	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Sunshine Probability <sup>2</sup>	0.51	0.57	0.61	0.59	0.63	0.68	0.77	0.75	0.67	0.56	0.43	0.47

Source: NOAA Comparative Climatic Data for the United States through 2023 – Williston, North Dakota. Defined by NOAA as the total time that sunshine reaches the surface of the earth, expressed as the percentage of the maximum amount possible from sunrise to sunset with clear sky conditions.

## **ATTACHMENT B**

Tabular Shadow Flicker Results

Receptor ID	Receptor Status	X Coordinate	Y Coordinate	Projected Expected Case Annual Shadow Flicker (hh:mm/year)	
				Vestas V163	GE 154
RE00001	Non-Participating	583805	5374610	3:50	3:37
RE00002	Non-Participating	580330	5370488	0:00	0:00
RE00003	Non-Participating	580988	5370978	0:00	0:00
RE00004	Non-Participating	578073	5366165	0:00	0:00
RE00005	Non-Participating	583530	5371184	0:00	0:00
RE00006	Participating	579485	5365651	0:00	0:00
RE00007	Non-Participating	582373	5368208	10:18	6:24
RE00008	Non-Participating	585477	5371224	0:00	0:00
RE00009	Non-Participating	577590	5362865	0:00	0:00
RE00010	Participating	582797	5367948	4:47	2:28
RE00011	Non-Participating	587152	5372037	5:03	4:42
RE00012	Non-Participating	587166	5372032	5:18	4:55
RE00013	Participating	583335	5367791	14:21	13:22
RE00014	Non-Participating	577864	5361679	0:00	0:00
RE00015	Non-Participating	577984	5361489	0:00	0:00
RE00016	Non-Participating	578810	5361608	0:00	0:00
RE00017	Participating	583824	5365663	17:08	12:28
RE00018	Participating	580309	5361487	0:00	0:00
RE00019	Non-Participating	582740	5363113	3:11	0:00
RE00020	Participating	583628	5363278	6:53	5:43
RE00021	Participating	582503	5359825	16:45	10:59
RE00022	Participating	585847	5363153	22:41	11:42
RE00023	Non-Participating	585995	5363302	12:40	6:48
RE00024	Participating	582749	5359769	29:55	24:25
RE00025	Non-Participating	586266	5361998	20:26	19:01
RE00026	Non-Participating	590539	5366279	0:00	0:00
RE00027	Non-Participating	588265	5363337	0:00	0:00
RE00028	Participating	587720	5360597	21:40	19:59
RE00029	Non-Participating	588795	5360988	3:45	0:00