DNV·GL

GLACIER RIDGE WIND PROJECT

Shadow Flicker Report

RES Americas

Document No.: 10026534-HOU-R-02
Issue: B, **Status**: FINAL
Date: 15 August 2016

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Project name:	Glacier Ridge Wind Project	
Report title:	Shadow Flicker Report	
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Date of issue:	15 August 2016	
Document No.:	10026534-HOU-R-02	
Issue:	B	
Status:	FINAL	

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Task and objective:

Shadow flicker analysis of the Glacier Ridge wind project.

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Keywords:
Shadow flicker, Glacier Ridge, North Dakota

Version	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	13 July 2016	Initial issue	A. Shomer	A. Nercessian	M. Cookson, B. Moreira
B	15 August 2016	Minor layout change	A. Shomer	A. Nercessian	S. Dokouzian/B. Moreira

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EXECUTIVE SUMMARY

An analysis has been conducted to predict the duration of shadow flicker to be experienced at receptors in the vicinity of the Glacier Ridge Wind Project (the "Project") in North Dakota. This analysis was undertaken for a total of 99 Vestas V126-3.45MW wind turbines (including 12 alternates), at a hub height of 285 feet (87 m) and rotor diameter of (413 feet) 126 m. The impact of the adjacent operational Ashtabula I and III wind projects has also been taken into consideration when applicable.

128 receptors have been identified by DNV GL in the vicinity of the Project using aerial imagery. Of these 128 receptors, 47 potentially affected receptors within 4921 feet (1500 m) of a turbine have been included in this report.

The receptor that is predicted to experience the most hours of shadow flicker in one year as well as the highest predicted minutes of shadow flicker in a single day is receptor 57. The predicted duration of shadow flicker at this receptor is 44 hours per year when taking into account long-term average monthly cloud cover and annual wind rose, some of the most impacting real-life attenuations, as well as 89 minutes in a single day on May 16 without consideration of cloud cover or wind rose statistics.

There are certain simplifications and conservative assumptions inherent within the model that may result in an overestimation of shadow flicker duration.

1 INTRODUCTION

DNV KEMA Renewables, Inc. ("DNV GL") has been commissioned by RES Americas (the "Customer" or "RES") to independently assess the impact of the shadow flicker effects in the vicinity of the proposed Glacier Ridge Wind Project (the "Project"). The proposed Glacier Ridge wind project is located in Barnes County, North Dakota, approximately 45 miles (72 km) west of Fargo. The current layout consists of 99 Vestas V126-3.45MW wind turbines (including 12 alternate locations) with a maximum blade tip height of 492 feet (150 m), a hub height of 285 feet (87 m) and a rotor diameter of 413 feet (126 m).

The purpose of this shadow flicker analysis is to calculate the predicted shadow flicker duration from the proposed Project at nearby receptor locations. This report includes a brief presentation of the Project site, a description of the shadow flicker assessment methodology, results of the analysis including a map illustrating areas prone to shadow flicker, and concluding comments.

1.1 Shadow flicker definition

Shadow flicker is defined as the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and a viewer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative positions of the sun throughout the year, the wind turbines at the site, and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations in vicinity of the Project.

It should be noted, as described in Section 3, that there are certain simplifications and conservative assumptions inherent within the model that may result in an overestimation of shadow flicker duration.

2 DESCRIPTION OF THE WIND FARM SITE

2.1 Site description

The proposed Project is located in northern Barnes County, North Dakota, approximately 45 miles west of West Fargo, ND.

The proposed wind farm is situated in relatively simple terrain, consisting of flat farm land, with wind turbine base elevations ranging from 1345 feet to 1509 feet. The ground cover on and near the site is primarily comprised of farm land and open fields with some forested areas. Dwellings are interspersed throughout the Project site.

2.2 Wind farm layout

The proposed turbine layout supplied by the Customer [1] considered 99 Vestas V126-3.45MW wind turbines of which 87 are to be built (12 are alternates). The precise coordinates of each turbine are presented in Appendix A.

NExtEra Energy Resources owns the operational wind farms Ashtabula I and Ashtabula III, located immediately to the north west of the Glacier Ridge project. Ashtabula I and III respectively consist of 131 GE sle 1.5 MW and 39 GE xle 1.6 MW wind turbine generators at a hub height of 262 feet (80 m). The locations were obtained from RES and confirmed with Google Earth imagery.

These turbines were considered in an alternate simulation and only in cases where receptors experience flicker from both Glacier Ridge and Ashtabula wind turbines during the year.

2.3 Receptors locations

A list of 128 receptors to be considered as shadow flicker receptors was identified on site by RES [4] and validated by DNV GL using available aerial imagery. Of the 128 total identified receptors, shadow flicker duration was calculated for 46 receptors located within 4921 feet (1500 m) (10 times the tip height, as explained in Section 3.2) of a turbine.

Maps of turbine locations and receptor locations are included in Figure 4-1 to Figure 4-8. The IDs and coordinates of these receptors are listed in Appendix B.

2.4 Applicable regulations

There are no applicable local or state requirements with regard to exceedance limits of shadow flicker in the jurisdictions associated with this Project. However, past projects in North Dakota have modeled maximum levels of 30 hours/year. DNV GL considers these levels as best practices that should ideally be applied to wind farms.

DNV GL can recommend shadow flicker mitigation measures to the Customer upon request.

3 SHADOW FLICKER ASSESSMENT

3.1 Overview

Shadow flicker may occur under certain combinations of circumstances with regards to the sun's position and wind direction; when the sun passes behind the rotating blades of a wind turbine, a moving shadow is cast in front of or behind the turbine. When viewed from a stationary position, the moving shadows cause periodic flickering of the sunlight, otherwise known as the "shadow flicker" phenomenon.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends on a number of variables, namely:

- Orientation of the building relative to the turbine;
- Wind direction: the shape and intensity of the shadow are determined by the position of the sun relative to the blades (the turbine rotor continuously yaws to face the wind so the rotor plane will always be perpendicular to the wind direction;
- Distance from turbine: the farther the observer from the turbine, the less pronounced the effect;
- Turbine height and rotor diameter: a larger turbine rotor diameter will cast a larger shadow, meaning a larger area will be prone to incidences of shadow flicker;
- Time of year and day: position of sun relative to the horizon;
- Weather conditions: cloud cover reduces the occurrence of shadow flicker;
- Vegetation and other obstacles that help to mask shadows;
- Operational status of turbines.

3.2 Assessment methodology

The number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which takes into account the sun's position, topography of the wind farm site and wind turbine specifications such as rotor diameter and hub height.

Shadow flicker has been calculated at the subject receptors (i.e. residences) at a height of 6.5 feet (2 m) to represent ground floor windows. Rather than facing a particular direction, shadow flicker receptors (windows) are simulated as horizontal planes, meaning they experience shadow flicker over 360°, often referenced as the "greenhouse" scenario; this assumption therefore represents a worst case scenario. Simulations with WindFarmer Analyst have been carried out with a resolution of 1 minute; if shadow flicker occurs in any 1-minute period, the model registers this as 1 minute of shadow flicker.

It is generally accepted that shadow flicker from wind turbines does not occur beyond a distance, D, from a given wind turbine. The UK wind industry considers this distance to be equivalent to 10 rotor diameters [2], while the Danish wind industry suggests a value of between 1640 feet and 3281 feet (500 and 1000 m) [3]. DNV GL has adopted a conservative approach and has assumed the length, D, that a shadow can be cast to be defined as follows:

D = 10 x (hub height + rotor radius)

Beyond this distance, a viewer does not perceive the turbine blade to be chopping the light, but rather as an object passing in front of the sun.

The annual hours of shadow flicker at receptors has been calculated in two steps:

1) A "worst case" or astronomical worst-case, which represents the number of hours of annual shadow flicker that does not take into account attenuating factors, such as cloud cover or the site specific wind rose.

2) An "expected case" that does consider cloud cover and the site specific wind rose in order to get a more realistic estimate, as described below. It shall be noted that additional attenuation factors are still present but were not considered, and therefore the "expected case" is still conservative.

Shadow flicker calculations can be adjusted using average monthly cloud coverage, which is based on historical meteorological data and statistics. According to data gathered from the Bismarck, Fargo, and Williston National Oceanic and Atmospheric Administration (NOAA) stations, monthly cloud cover can be estimated and applied as a percentage decrease in flicker duration. These cloud cover percentages are shown in Table 3-1.

Table 3-1 Monthly cloud cover percentage (%) reduction (Bismarck, Fargo, and Williston)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Percentage	33.5	34.3	32.8	35.0	37.9	41.6	55.9	54.3	47.2	41.9	30.7	32.8

*Fargo station is located 50 miles east of the project

Further, the annual site-specific wind rose was used in order to consider the probability of the turbines being oriented in a given direction. This produces a more accurate estimate of shadow flicker duration at residences. The directional wind frequency that was measured on site was provided by RES [5] and is shown in Table 3-2. This is based on 6 years of data collected at the mast and can be considered representative of the long term distribution.

Table 3-2 Site specific directional frequencies (%) at mast M2

Sector (°)	0	30	60	90	120	150	180	210	240	270	300	330
Percentage	9.6	8.0	4.6	3.6	5.8	10.3	8.7	6.1	7.0	8.8	14.8	12.8

Note: The sectors are defined as 30° sectors centered at the given value

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in the calculations of shadow flicker duration. Similarly, turbine operational shut-down has not been considered in this analysis. Consideration of these factors could lead to a reduction of the levels of shadow flicker predicted.

3.3 Simplifications and conservative assumptions

Shadow flicker duration calculated in the manner described above has several limitations and may over-estimate the annual number of hours of shadow flicker experienced at a specified location for several reasons, namely:

- The modeling of the wind turbine blades as discs rather than individual blades results in an overestimate of shadow flicker duration.

  Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependent on the thickness of the turbine blade and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade [6].
- Additionally, the orientation of windows on a given house has not been taken into account, i.e. the model assumes that a window is always facing the turbine(s).
- Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine. The length of the shadow cast by a wind turbine is dependent on the degree that direct sunlight is diffused, which in turn is dependent on the amount of dispersants (humidity, smoke and other aerosols) in the path between the light source (sun) and the receiver [6].
- The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.
- Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce shadow flicker occurrence.

In light of the reasons listed above, it is likely that the shadow flicker durations presented in Section 4, Appendix B and Appendix C can be regarded as conservative.

4 RESULTS AND CONCLUSION

An analysis has been conducted to determine the duration of shadow flicker predicted for receptors in the vicinity of the Glacier Ridge Wind Project in North Dakota. This analysis was undertaken specifically for the Vestas V126-3.45MW wind turbine with a blade tip height of 492 feet (150 m).

Detailed maps illustrating predicted "expected case" shadow flicker duration at receptors lying within 4921 feet (1500 m) of the Glacier Ridge Wind Project is presented in Figure 4-1 through Figure 4-8. These maps take into account average monthly cloud cover and annual site wind rose. For illustrative purposes shadow flicker is shown when occurring 30 hours or more per year.

The receptor that is predicted to experience the most hours of shadow flicker in one year as well as the highest predicted minutes of shadow flicker in a single day is receptor 57. The predicted duration of shadow flicker at this receptor is 44 hours per year when taking into account average monthly cloud cover and annual wind rose as well as 89 minutes in a single day on May 16 without consideration of cloud cover or wind rose statistics.

Of the 128 dwelling locations provided by the Customer, 47 are within a distance of 4921 feet (1500 m). The results of the shadow flicker assessment are presented for all receptor locations in the Project area (in terms of minutes on worst day and total hours per year) in tabular format in Appendix B.

Results for the "expected case" in hours per year take into account the average monthly cloud cover from the NOAA meteorological stations at Bismarck, Fargo, and Williston and the annual site specific wind rose. It should be noted that the predicted level of exposure for minutes on worst day assumes no cloud cover or wind rose statistics.

There are four (4) receptors with a predicted annual shadow flicker level that exceeds 30 hours per year.

Three (3) of the receptors are predicted to incur additional cumulative shadow flicker impact from the neighboring Ashtabula I and III projects. Two (2) of these receptors are below 30 hours per year predicted annual shadow flicker. One (1) receptor (R119) exceeds 30 hours per year predicted annual shadow flicker and is included in the four (4) receptors mentioned above. The cumulative shadow flicker for these receptors was calculated in an alternate simulation and is shown in Appendix C.

As described in Section 3, certain conservative assumptions have been made in this analysis, which likely results in an overestimation of the shadow flicker impacts that may be experienced at each receptor.

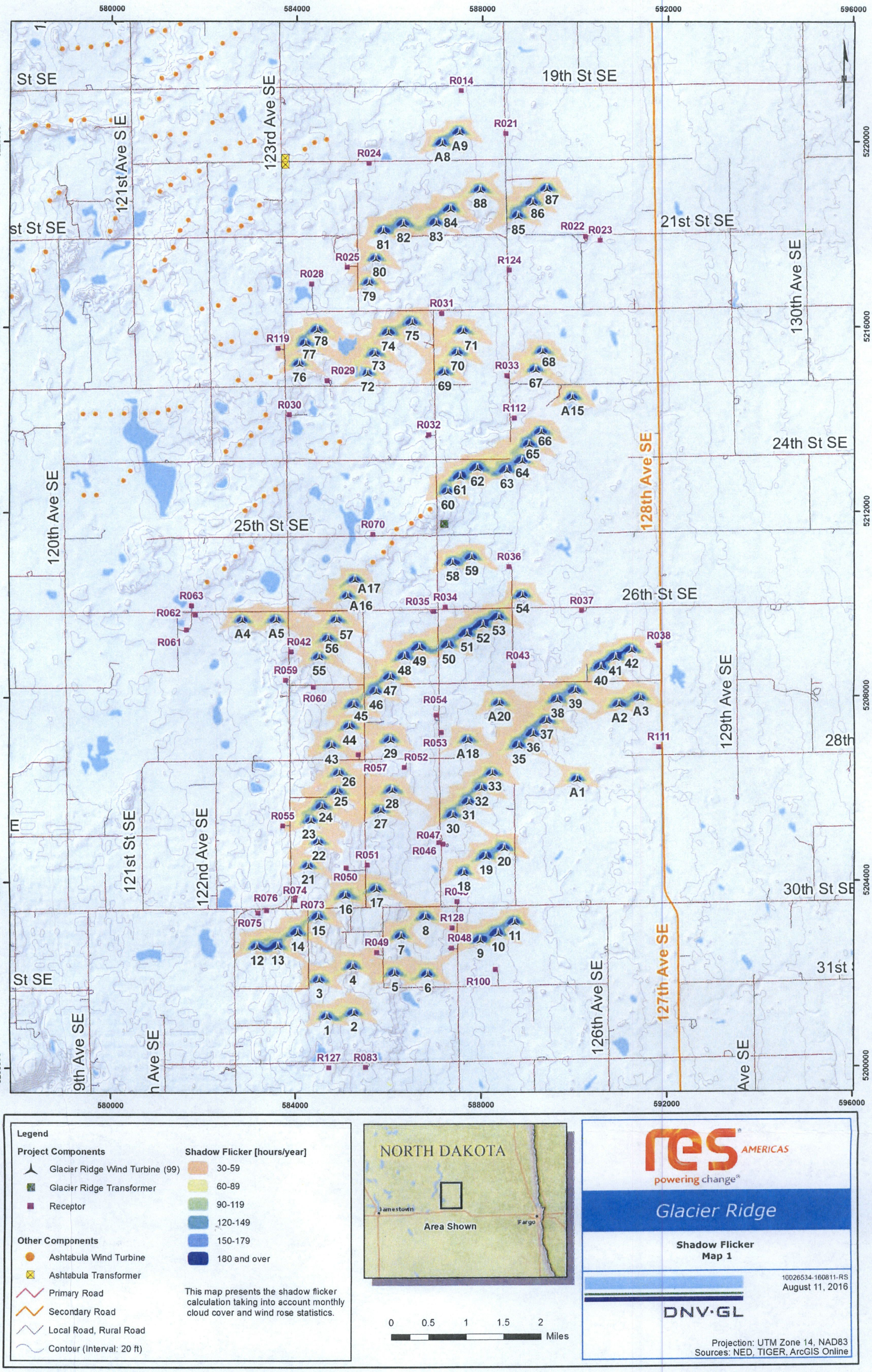

Figure 4-1 Modeled hours of shadow flicker at Glacier Ridge Wind Project

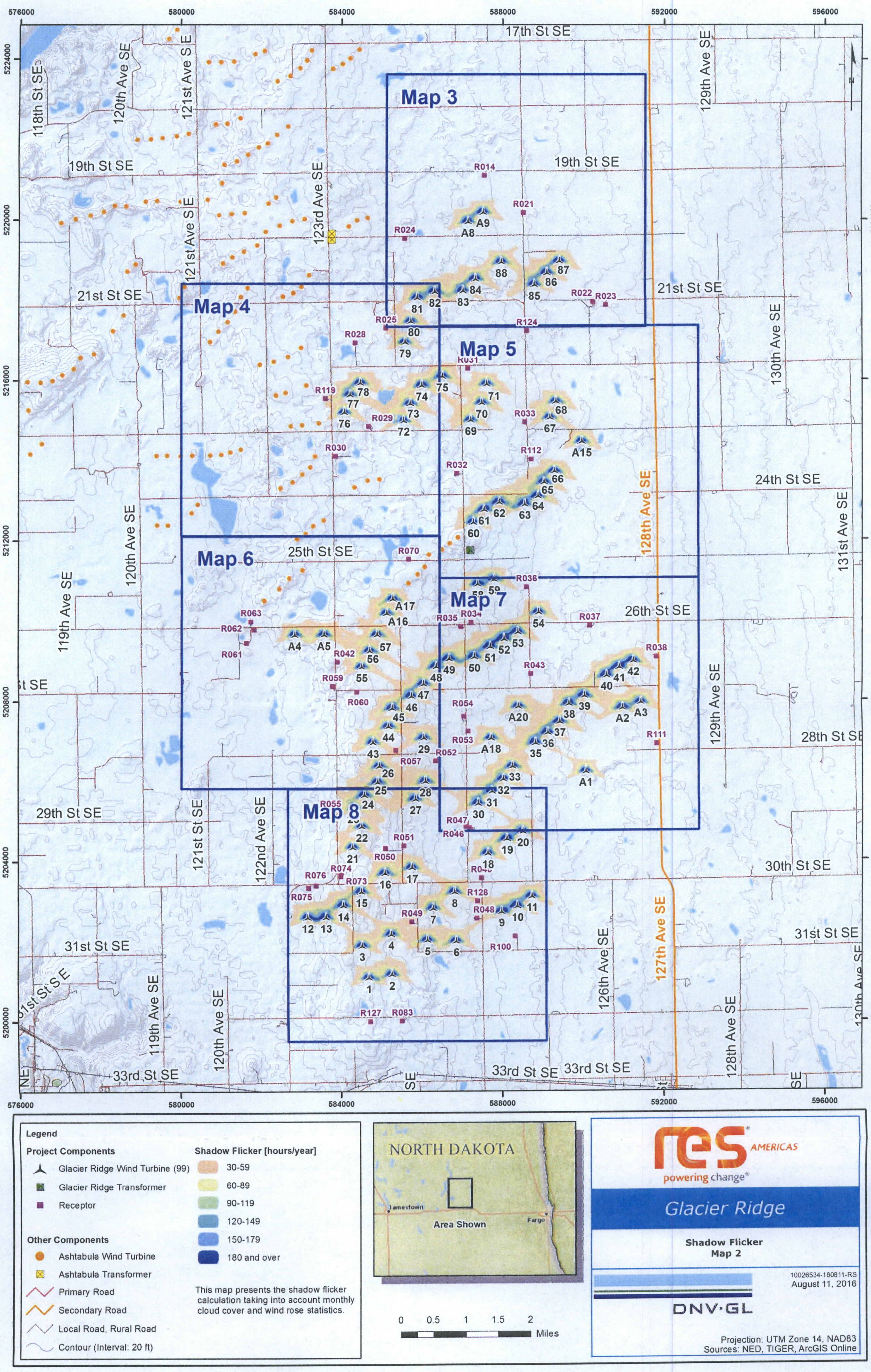

Figure 4-2 Modeled hours of shadow flicker at Glacier Ridge Wind Project

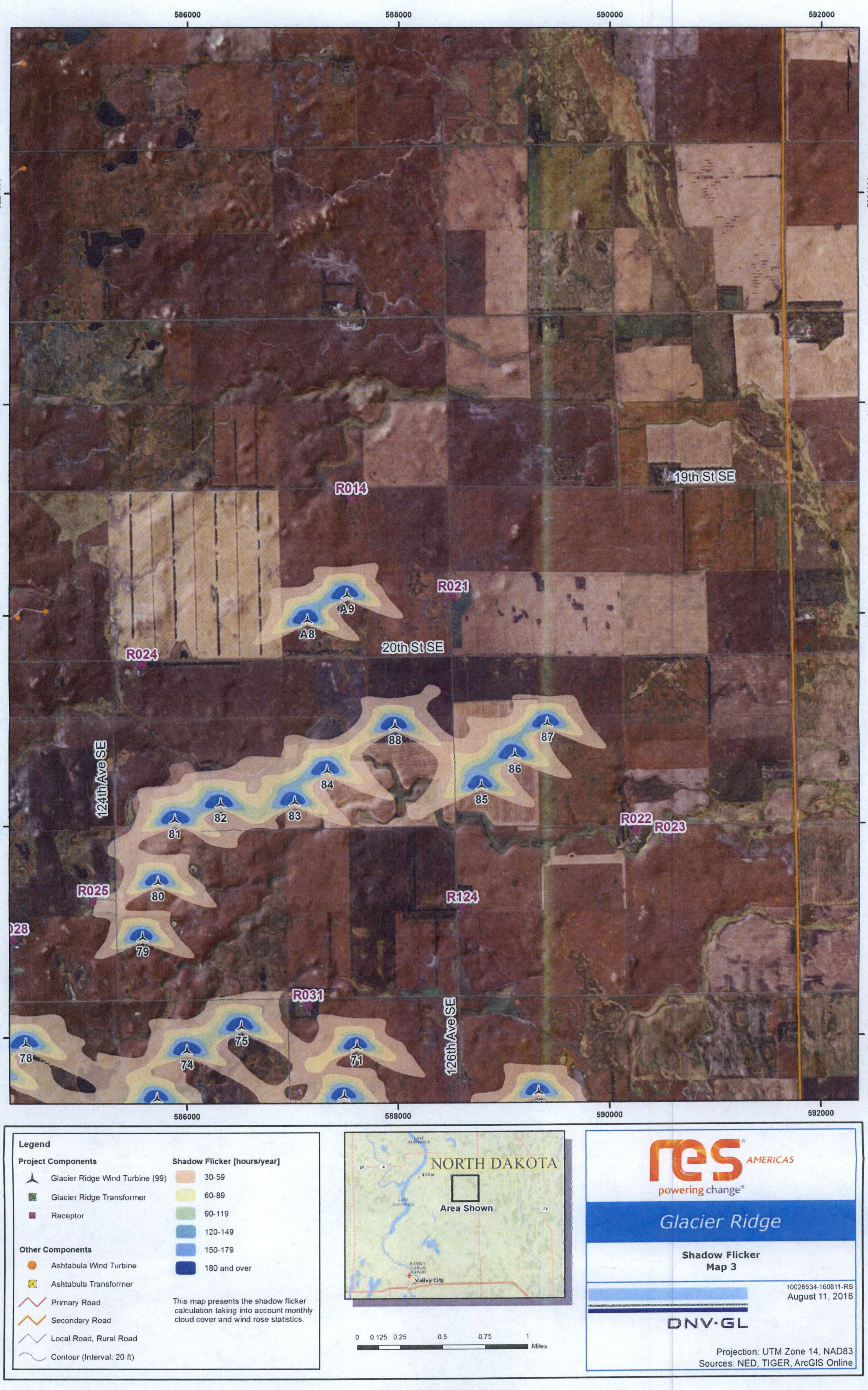

Figure 4-3 Modeled hours of shadow flicker at Glacier Ridge Wind Project

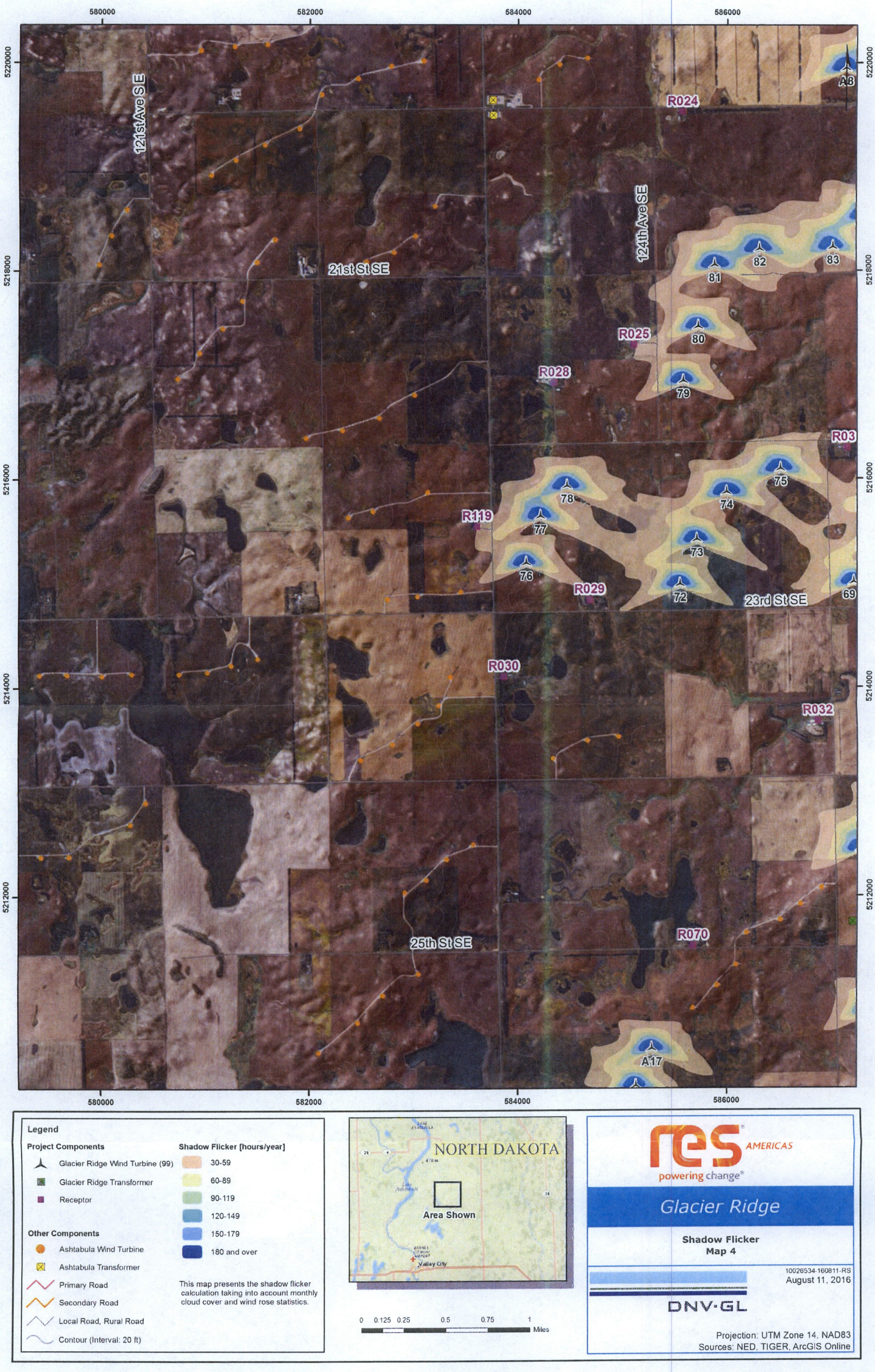

Figure 4-4 Modeled hours of shadow flicker at Glacier Ridge Wind Project

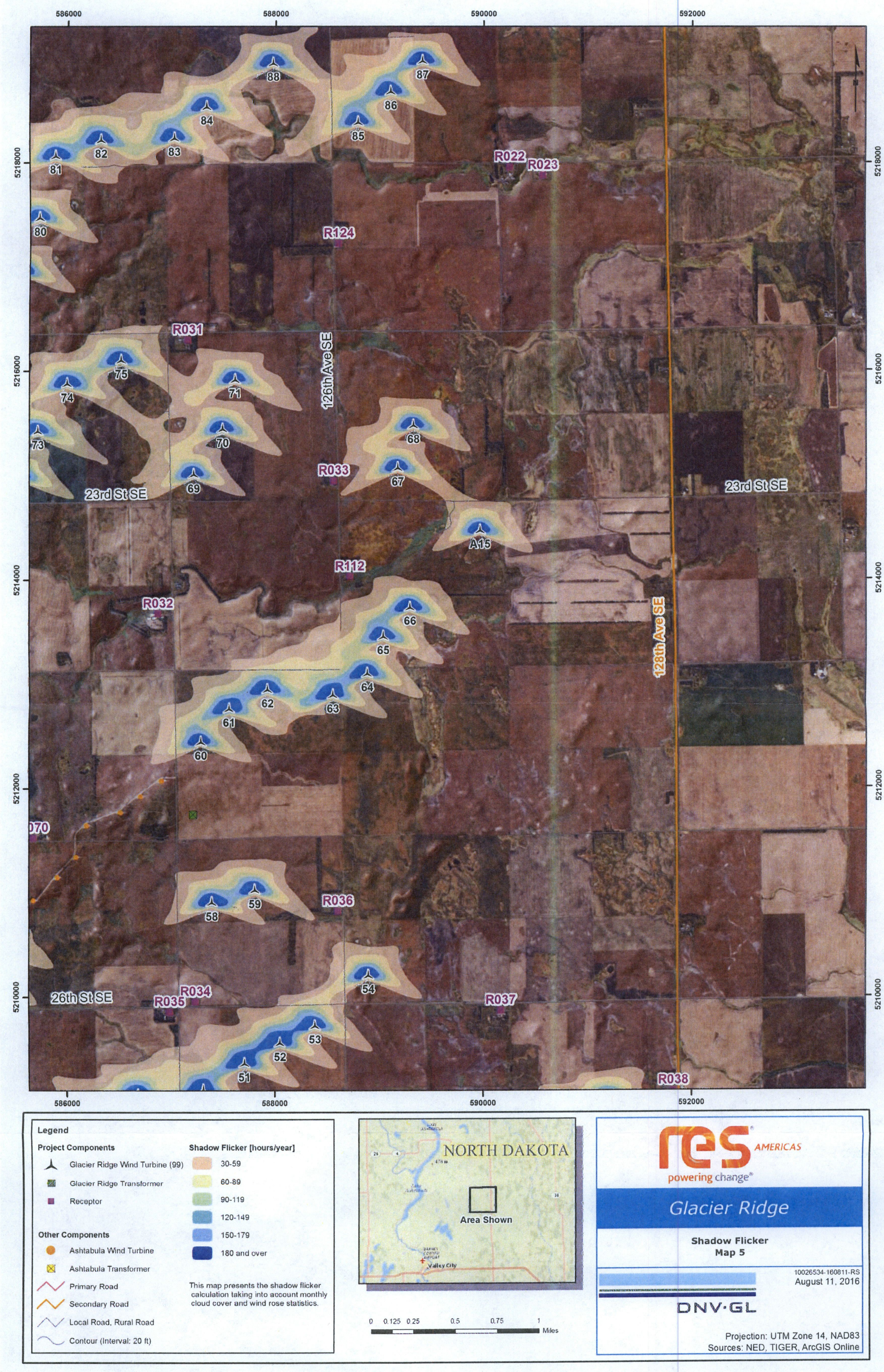

Figure 4-5 Modeled hours of shadow flicker at Glacier Ridge Wind Project

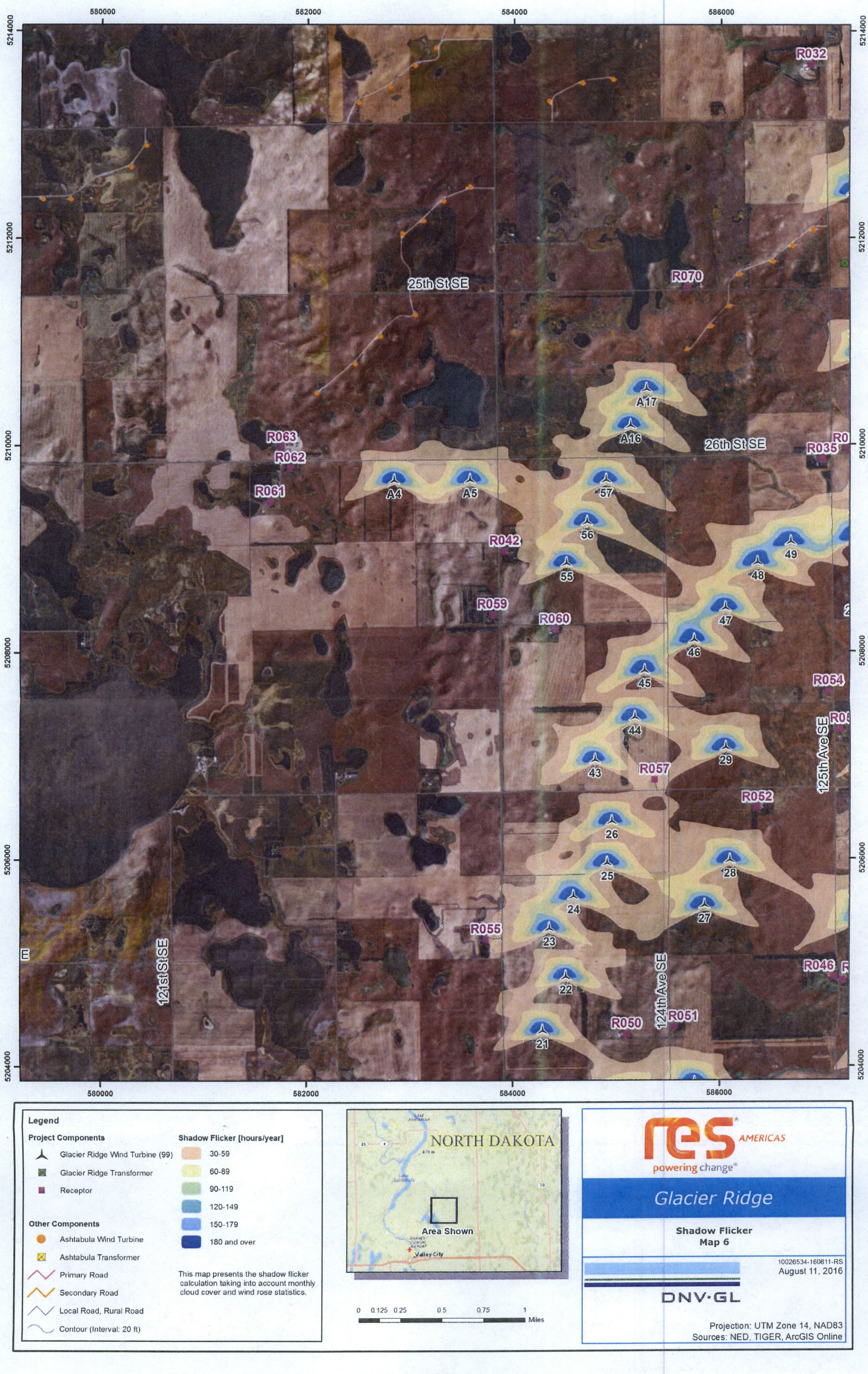

Figure 4-6 Modeled hours of shadow flicker at Glacier Ridge Wind Project

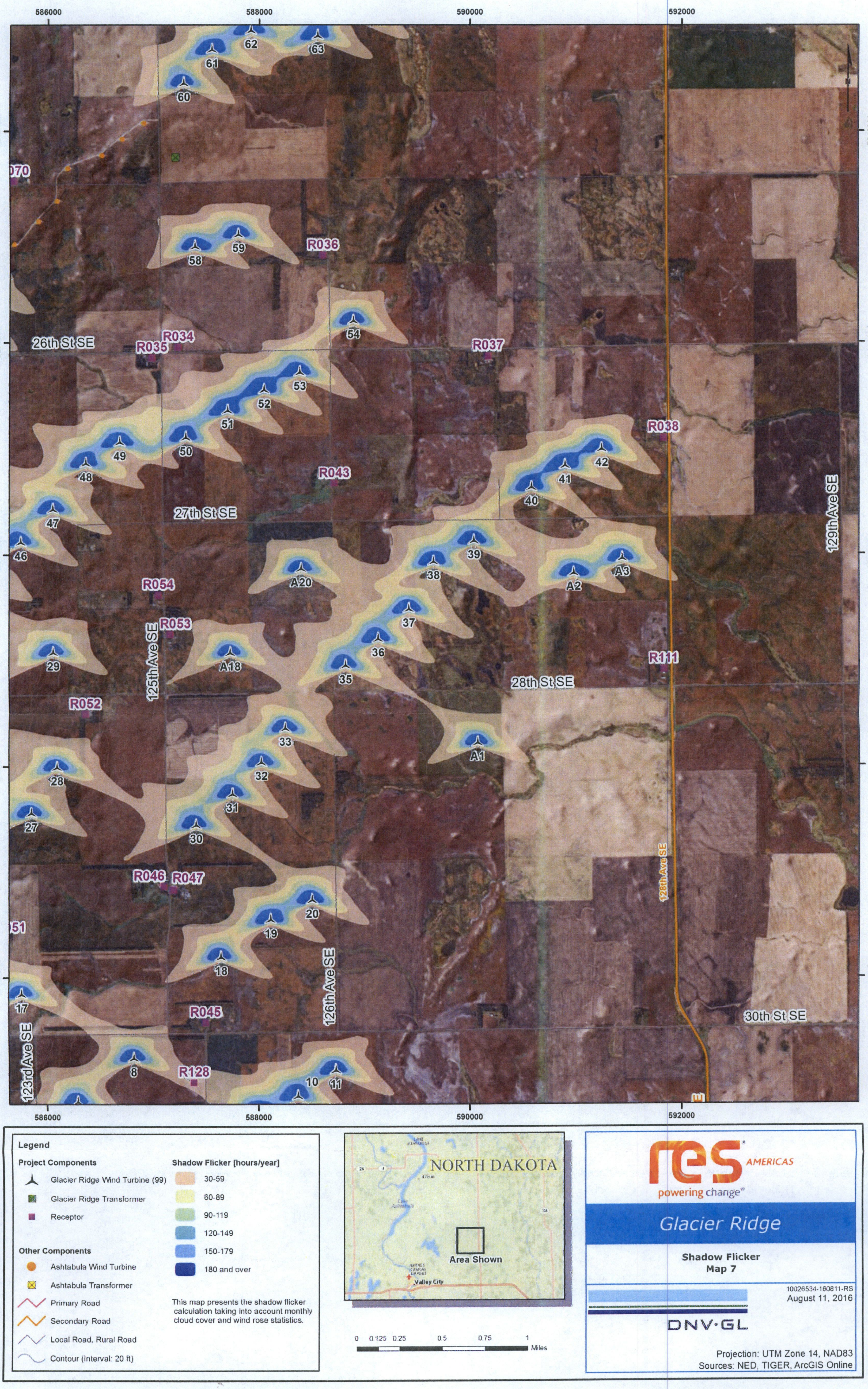

Figure 4-7 Modeled hours of shadow flicker at Glacier Ridge Wind Project

Figure 4-8 Modeled hours of shadow flicker at Glacier Ridge Wind Project

5 REFERENCES

[1] Turbine layout locations sent by email, by RES, to B. Moreira, DNV GL, 15 August 2016, "PUSAevg144_wAlternates_NorthDakota_NAD83_USft.csv".

[2] Department for Business Enterprise & Regulatory Reform, UK, "Onshore Wind: Shadow Flicker", http://webarchive.nationalarchives.gov.uk/20090609003228/http:/www.berr.gov.uk/whatwedo/energy/sources/renewables/planning/onshore-wind/shadow-flicker/page18736.html

[3] Danish Wind Industry Association, "Shadow variations from Wind turbines", http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/env/shadow/shadow2.htm

[4] Receptor locations sent by email, by RES, to B. Moreira, DNV GL, 20 June 2016, "houses 5_31_16

[5] Wind Rose data sent by email, by RES, to B. Moreira, DNV GL, 20 June 2016, "Wind Roses for DNV-GL Noise.xlsx"

[6] Freud H-D, Kiel F.H., "Influences of the opaqueness of the atmosphere, the extension of the sun and rotor blade profile on the shadow impact of wind turbine", DEWI Magazine No. 20 pp 43-51, Feb 2002.

APPENDIX A – TURBINE LAYOUT

Turbine ID	Easting [m][1]	Northing [m][1]
A1	590076	5206196
A2	590981	5207795
A3	591439	5207934
A4	582849	5209629
A5	583584	5209635
A8	587150	5219922
A9	587524	5220163
A15	589971	5214442
A16	585134	5210160
A17	585288	5210512
A18	587730	5207044
A20	588406	5207838
T1	584691	5201066
T2	585268	5201144
T3	584526	5201860
T4	585247	5202145
T5	586148	5202000
T6	586861	5201974
T7	586290	5202798
T8	586821	5203209
T9	587992	5202713
T10	588380	5202851
T11	588737	5203096
T12	583173	5202575
T13	583626	5202581
T14	584061	5202873
T15	584510	5203216
T16	585095	5203673
T17	585763	5203813
T18	587646	5204166
T19	588117	5204521
T20	588513	5204705
T21	584292	5204315
T22	584515	5204835
T23	584354	5205304
T24	584587	5205613
T25	584913	5205936
T26	584956	5206337

Turbine ID	Easting [m][1]	Northing [m][1]
T27	585852	5205522
T28	586096	5205960
T29	586058	5207046
T30	587407	5205414
T31	587750	5205710
T32	588027	5206010
T33	588256	5206335
T35	588827	5206922
T36	589136	5207175
T37	589425	5207453
T38	589657	5207903
T39	590041	5208102
T40	590586	5208607
T41	590902	5208814
T42	591247	5208969
T43	584793	5206931
T44	585178	5207338
T45	585273	5207795
T46	585749	5208090
T47	586053	5208401
T48	586364	5208835
T49	586685	5209034
T50	587313	5209079
T51	587708	5209332
T52	588051	5209527
T53	588391	5209693
T54	588900	5210177
T55	584516	5208832
T56	584714	5209233
T57	584898	5209633
T58	587395	5210877
T59	587807	5210994
T60	587285	5212419
T61	587554	5212735
T62	587925	5212919
T63	588559	5212869
T64	588889	5213074
T65	589041	5213426
T66	589298	5213703
T67	589180	5215042

Turbine ID	Easting [m][1]	Northing [m][1]
T68	589331	5215446
T69	587217	5214981
T70	587494	5215412
T71	587614	5215885
T72	585554	5214964
T73	585717	5215393
T74	586001	5215847
T75	586517	5216070
T76	584083	5215171
T77	584221	5215618
T78	584475	5215910
T79	585585	5216917
T80	585730	5217440
T81	585888	5218030
T82	586321	5218182
T83	587027	5218200
T84	587333	5218498
T85	588794	5218350
T86	589109	5218643
T87	589415	5218939
T88	587977	5218917

1 Coordinate system is UTM Zone 14N, NAD83 datum.

APPENDIX B – RECEPTOR LOCATIONS AND ASSOCIATED SHADOW FLICKER

Receptor ID	UTM Easting[1] [m]	UTM Northing[1] [m]	Layout pUSAevg144 results					Turbine IDs contributing to the events	Closest turbine	
			Days per year	Worst day	Minutes on Worst day	Total Hours in Year [hrs/yr]				
						Astronomical Worst case	Expected Case with monthly cloud cover and wind rose		Distance [feet]	Turbine ID
57	585372	5206769	219	16-May	89	185	44	T26 T29 T43	1967	T26
128	587393	5203011	236	13-Mar	52	137	38	T7 T8 T9 T10 T11	1985	T8
49	585767	5202491	204	13-Feb	86	142	32	T3 T4 T5 T6 T7 T8 T15	1989	T7
119	583617	5215549	236	18-Jan	51	130	31	T76 T77 T78	1968	T76
55	583742	5205228	210	16-Apr	47	117	30	T22 T23 T24 T25	2022	T23
25	585118	5217293	181	20-Jan	51	114	27	T79 T80	1967	T79
48	587383	5202578	160	14-Aug	75	97	24	T5 T6 T7 T9 T10 T11	2047	T9
31	587158	5216301	154	5-Jan	50	99	23	T71 T74 T75	2025	T71
29	584690	5214845	122	4-Jun	63	77	21	T72 T73 T76	2261	T76
33	588565	5214953	193	15-Apr	47	79	20	A15 T67 T68 T69 T70	2038	T67
42	583918	5208982	163	7-Mar	47	68	17	A4 T55 T56 T57	2023	T55
74	584004	5203615	142	22-Jan	47	75	17	T15 T16	2114	T15
53	587162	5207247	165	8-Mar	54	66	16	A18 A20 T29 T33	1980	A18
54	587053	5207619	176	8-Jan	35	60	14	A18 A20 T29 T46	2914	A18
73	584021	5203718	110	2-Jan	45	59	14	T15 T16	2151	T21
50	585108	5204313	136	19-Jan	36	57	13	T17 T21	2100	T16
45	587501	5203580	135	21-Oct	52	57	13	T7 T8 T10 T11	1981	T18
38	591832	5209102	91	14-Mar	48	47	12	T40 T41 T42	1968	T42
75	583392	5203391	130	21-Jan	36	51	11	T14 T15	2766	T13
112	588722	5214037	104	6-Feb	45	44	10	A15 T66	2185	T66
51	585569	5204380	111	18-May	27	32	9	T21 T22	1967	T17
36	588612	5210827	84	23-Apr	36	33	9	T58 T59	2334	T54
46	587109	5204862	121	15-Oct	26	31	9	T19 T20 T27	2056	T30
35	586989	5209860	143	22-Jan	34	40	9	T51 T52 T53	2774	T50

Receptor ID	UTM Easting[1] [m]	UTM Northing[1] [m]	Layout pUSAevg144 results					Turbine IDs contributing to the events	Closest turbine	
			Days per year	Worst day	Minutes on Worst day	Total Hours in Year [hrs/yr]			Distance [feet]	Turbine ID
						Astronomical Worst case	Expected Case with monthly cloud cover and wind rose			
43	588746	5208670	139	6-Jan	25	33	8	T38 T39 T50 T51	2948	A20
76	583205	5203338	75	30-Oct	31	25	6	T14 T15	2506	T12
37	590176	5209874	79	15-Aug	21	20	5	T42 T54	4215	T41
34	587238	5209958	74	9-Feb	30	21	5	T52 T53	2569	T51
47	587199	5204831	63	26-Feb	29	17	4	T19 T20	2031	T30
60	584400	5208230	65	29-Oct	30	17	4	T45 T46	2011	T55
21	588531	5220177	60	30-Mar	28	17	4	A8 A9	3304	A9
62	581853	5209784	36	14-Mar	29	13	3	A4	3307	A4
59	583799	5208374	48	17-Jun	25	15	3	T55	2793	T55
28	584354	5216931	53	14-Sep	21	10	3	T79 T80	3372	T78
63	581753	5209984	34	26-Feb	26	10	3	A4	3779	A4
32	586878	5213678	59	21-Nov	22	11	3	T62	3808	T61
61	581643	5209458	33	12-Apr	24	9	2	A4	3997	A4
52	586360	5206498	51	19-Mar	20	10	2	A18 T26	1968	T28
22	590255	5217954	42	20-Jun	15	7	2	T86	4247	T87
100	588329	5202120	24	20-Mar	18	5	1	T6	2238	T9
14	587562	5221104	0	-	0	0	0		3089	A9
30	583920	5214126	0	-	0	0	0		3472	T76
70	585680	5211529	0	-	0	0	0		3574	A17
83	585526	5200014	0	-	0	0	0		3802	T2
111	591834	5206916	0	-	0	0	0		3581	A3
124	588614	5217226	0	-	0	0	0		3735	T85
127	584738	5200004	0	-	0	0	0		3488	T1

APPENDIX C – CUMULATIVE SHADOW FLICKER RESULTS OF RECEPTORS AFFECTED BY NEIGHBORING LAYOUT

Receptor ID	UTM Easting[1] [m]	UTM Northing[1] [m]	Including Ashtabula turbines					Turbine IDs contributing to the events	Closest turbine	
			Days per year	Worst day	Minutes on Worst day	Total Hours in Year [hrs/yr]			Distance [feet]	Turbine ID
						Astronomical Worst case	Expected Case with monthly cloud cover and wind rose			
119	583617	5215549	236	17-Jan	67	149	36	T76 T77 T78 Ash-N59 Ash-N60 Ash-N70	1896	Ash-N61
29	584690	5214845	123	4-Jun	63	80	22	T72 T73 T76 Ash-N72	2260	T76
28	584354	5216931	58	20-Sep	24	13	3	T79 T80 Ash-N58	3373	T78

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