APPENDIX M – SHADOW FLICKER ANALYSIS

SHADOW FLICKER ANALYSIS REPORT

Sweetland Wind Project
Hand County, South Dakota

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TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

The Sweetland Wind Farm, LLC (the Project) is a proposed wind power electric generation facility expected to consist of up to 71 wind turbines in Hand County, South Dakota. The Project is being developed by Scout Clean Energy, LLC (SCE). Epsilon Associates, Inc. (Epsilon) has been retained by SCE to conduct a shadow flicker modeling study for the Project. This report presents results of the study.

Shadow flicker modeling was conservatively conducted for 86 turbines, including 15 alternates. All wind turbines for this Project are proposed to be General Electric (GE) 2.82-127 units. The purpose of this assessment is to predict the expected annual duration of shadow flicker at modeled locations in the vicinity of the Project due to the operation of the proposed wind turbines and to evaluate the Project with respect to the shadow flicker requirements in the Hand County Development Agreement (Development Agreement).

Using the Project specific data provided by SCE, the annual expected duration of shadow flicker was modeled at all occupied residences in the vicinity of the Project. The maximum expected annual flicker resulting from the operation of the proposed and alternate wind turbines is 55 hours, 23 minutes. This occurs at a participating receptor. The maximum expected annual flicker at a non-participating receptor is 9 hours, 16 minutes. The maximum expected annual flicker at a receptor with pending participation is 14 hours, 49 minutes. There is a total of four receptors predicted to have over 30 hours of annual flicker and all four receptors are participating. It is Epsilon's understanding that waivers will be acquired for these receptors. Therefore, the Project meets the requirements with respect to shadow flicker in the Development Agreement.

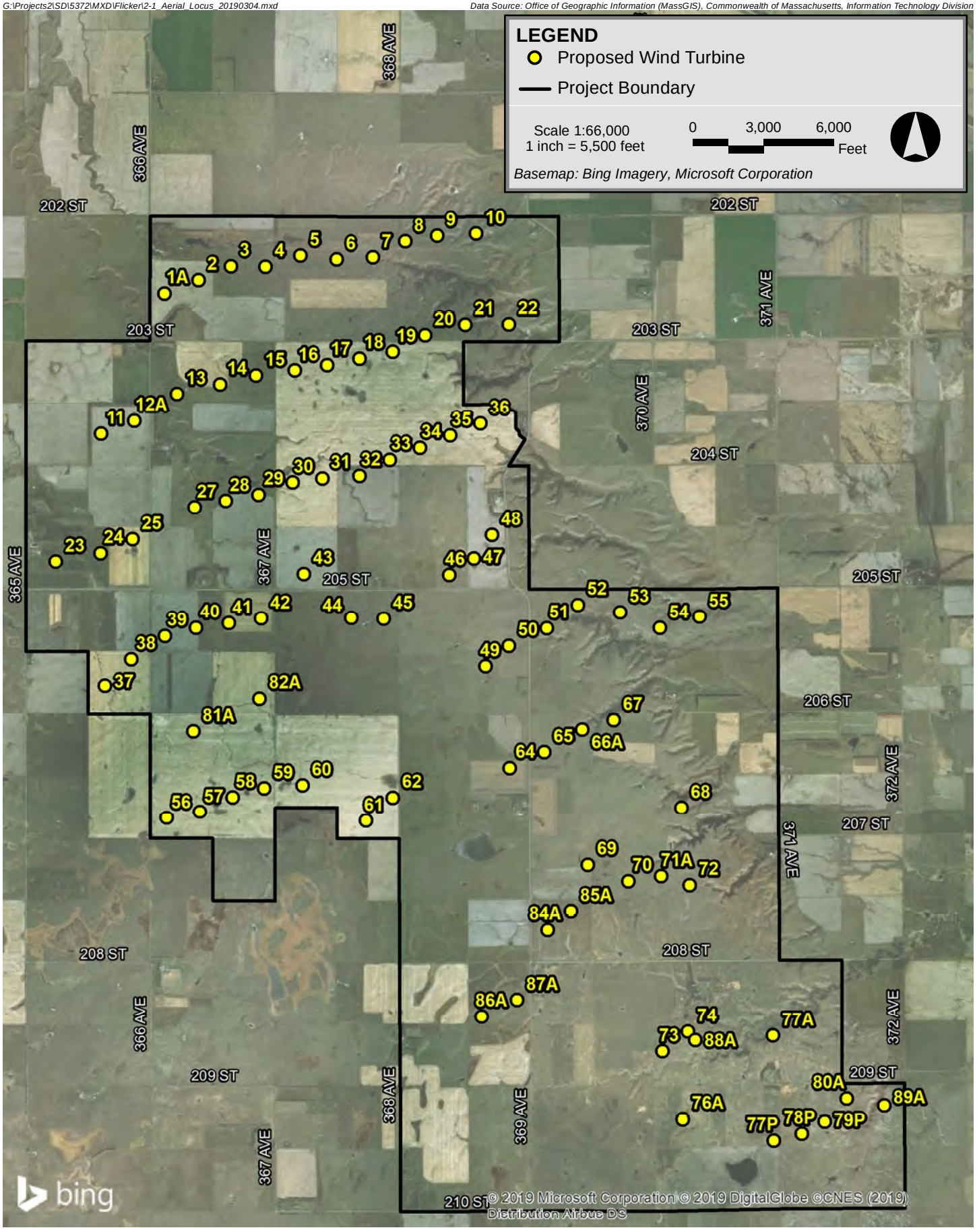
The modeling results are conservative in that modeling receptors were treated as "greenhouses", i.e. there was a window on each side of a building, and the surrounding area was assumed to be without vegetation or structures ("bare earth").

2.0 INTRODUCTION

The Project is located in Hand County, South Dakota, consisting of 71 GE wind turbines. A total of 15 alternate wind turbine locations are also proposed for the Project. The wind turbines will be GE 2.82-127 units with a rotor diameter of 127 meters. A total of 64 primary and 9 alternate wind turbines are proposed to have a hub height of 114 meters and a total of 7 primary and 6 alternate wind turbines are proposed to have a hub height of 89 meters. Figure 2-1 shows the locations of the 71 proposed and 15 alternate wind turbines and the Project boundary over aerial imagery in Hand County.

With respect to wind turbines, shadow flicker can be defined as an intermittent change in the intensity of light in a given area resulting from the operation of a wind turbine due to its interaction with the sun. While indoors, an observer experiences repeated changes in the brightness of the room as shadows cast from the wind turbine blades briefly pass by windows as the blades rotate. In order for this to occur, the wind turbine must be operating, the sun must be shining, and the window must be within the shadow region of the wind turbine, otherwise there is no shadow flicker. A stationary wind turbine only generates a stationary shadow similar to any other structure.

The wind turbines were modeled with the WindPRO software package using information provided by SCE. The expected annual duration of shadow flicker was calculated at discrete receptor points and shadow flicker isolines for the area surrounding the Project were generated. The results of this analysis are found within this report.



Sweetland Wind **Hand County, South Dakota**

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Figure 2-1
Aerial Locus Map

3.0 REGULATIONS

3.1 Federal Regulations

There are no federal shadow flicker regulations applicable to this Project.

3.2 South Dakota State Regulations

There are no state shadow flicker regulations applicable to this Project.

3.3 Hand County Regulations

Hand County currently has no zoning ordinance containing language regulating shadow flicker. However, the Hand County Development Agreement was executed on December 4, 2018 with Sweetland Wind Farm, LLC. The Project is therefore subject to the following shadow flicker requirement per the agreement:

> *Developer agrees to site Project wind turbines so as to limit shadow flicker resulting from Project wind turbines at currently occupied residences to 30 hours per year or less, unless waived in writing by the owner of the occupied residence.*

All receptors (occupied residences) have been evaluated in this analysis against the 30 hour per year limit.

4.0 SHADOW FLICKER MODELING

4.1 Modeling Methodology

Shadow flicker was modeled using a software package, WindPRO version 3.2.737. WindPRO is a software suite developed by EMD International A/S and is used for assessing potential environmental impacts from wind turbines. Using the Shadow module within WindPRO, worst-case shadow flicker in the area surrounding the wind turbines was calculated based on data inputs including:

- location of the wind turbines,
- location of discrete modeling points,
- wind turbine dimensions,
- shadow flicker calculation distance limits, and
- terrain data.

Based on these data, the model was able to incorporate the appropriate sun angle and maximum daily sunlight for this latitude into the calculations. The resulting worst-case calculations assume that the sun is always shining during daylight hours and that the wind turbine is always operating. The WindPRO Shadow module can be further refined by incorporating sunshine probabilities and wind turbine operational estimates by wind direction over the course of a year. The values produced by this further refinement, also known as the "expected" shadow flicker, are presented in this report.

The proposed wind turbine layout for the Project dated February 6, 2019 was provided by SCE. Of the 86 conservatively modeled wind turbines, 15 are alternative wind turbine locations. Locations of the turbines are shown in Figure 4-1 and the coordinates are provided in Appendix A. All wind turbines are GE 2.82-127 units with a rotor diameter of 127 meters. A total of 64 primary and 9 alternate wind turbines are proposed to have a hub height of 114 meters and a total of 7 primary and 6 alternate wind turbines are proposed to have a hub height of 89 meters. The hub height of each wind turbine in the layout is included in Appendix A. Each wind turbine has the following characteristics based on the technical data provided by SCE:

		GE 2.82-127
♦ Rated Power	=	2,820 kW
♦ Hub Height	=	89 or 114 meters
♦ Rotor Diameter	=	127 meters
♦ Cut-in Wind Speed	=	3 m/s
♦ Cut-out Wind Speed	=	30 m/s

To-date, there are no federal, state, or local regulations regarding the maximum radial distance from a wind turbine to which shadow flicker should be analyzed applicable to this Project. In the United States, shadow flicker is commonly evaluated out to a distance of ten

times the rotor diameter. According to the Massachusetts Model Bylaw for wind energy facilities, shadow flicker impacts are minimal at and beyond a distance of ten rotor diameters.[1] Defining the shadow flicker calculation area has also been addressed in Europe where the ten times rotor diameter approach has been accepted in multiple European countries.[2] Some jurisdictions conservatively require a larger calculation area. The New Hampshire Site Evaluation Committee through rulemaking docket 2014-04 adopted rules on December 15, 2015 outlining application requirements and criteria for energy facilities, including wind energy facilities. As part of these revised regulations, Site 301.08(a)(2) requires an evaluation distance of at least 1 mile from a wind turbine.[3] Section 16-50j-94, part (g), of the Regulations of Connecticut State Agencies identifies the components required in a shadow flicker evaluation report which includes the calculation of shadow flicker from each proposed wind turbine to any off-site occupied structure within a 1.25 mile radius.[4] For this Project, ten times the rotor diameter of the proposed wind turbine corresponds to a distance of 0.79 miles (1,270 m). Conservatively, this analysis includes shadow flicker calculations out to 1.25 miles (2,012 m) from each wind turbine in the model for the proposed layout.

A modeling receptor dataset was provided by SCE for occupied residences in Hand County within ~4 miles of any proposed wind turbine on January 2, 2019. A total of 41 receptors from this dataset were input into the model.[5] These were all modeled as discrete points and are shown on Figure 4-1. Each modeling point was assumed to have a window facing all directions ("greenhouse" mode) which yields conservative results. Participation status for each of the 41 modeling receptors was assigned based on the parcel data provided by SCE on January 7, 2019. Parcels identified as Wind Lease and Easement Agreement ('Controlled Land') and Good Neighbor Agreements ('GNA') within the dataset have been considered participating parcels. Participating parcels within the Project boundary are indicated on Figure 4-1.[6] Parcels containing wind turbines that were not identified as 'Controlled Land' or 'GNA' have been given "pending participation" status and are indicated as such on the figure. All other parcels are considered non-participating properties. All receptors are

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1 Massachusetts Department of Energy Resources, "Model As-of-Right Zoning Ordinance or Bylaw: Allowing Use of Wind Energy Facilities" 2009.

2 Parsons Brinckerhoff, "Update of UK Shadow Flicker Evidence Base" Prepared for Department of Energy and Climate Change, 2011.

3 State of New Hampshire Site Evaluation Committee Site 300 Rules (2015), available at http://www.gencourt.state.nh.us/rules/state_agencies/site100-300.html Accessed in January 2019.

4 State of Connecticut CSC Wind Regulations (2014), available at https://www.cga.ct.gov/aspx/CGARegulations/CGARegulations.aspx?Yr=2014&Reg=2012-054&Amd=E Accessed in January 2019.

5 The original dataset contained 42 receptors; however, it was later determined that one of the receptors was not an occupied residence, as confirmed by the Hand County Tax Assessor on February 1, 2019. This receptor was excluded from the model.

6 Participating parcels that extend beyond the Project boundary have been excluded from figures.

indicated as either participating, pending participation, or non-participating on Figure 4-1. The model was set to limit calculations to 2,012 meters from a wind turbine, the equivalent of 1.25 miles. Consequently, shadow flicker at any of the 41 modeling receptors greater than the corresponding limitation distance from a wind turbine was zero. In addition to modeling discrete receptors, shadow flicker was calculated at grid points in the area surrounding the modeled wind turbines to generate flicker isolines. A 20-meter spacing was used for this grid.

The terrain height contour elevations for the modeling domain were generated from elevation information derived from the National Elevation Dataset (NED) developed by the U.S. Geological Survey. Conservatively, obstacles, i.e. buildings and vegetation, were excluded from the analysis. This is effectively a "bare earth" scenario which is conservative. When accounted for in the shadow flicker calculations, such obstacles may significantly mitigate or eliminate the flicker effect depending on their size, type, and location. In addition, shadow flicker durations were calculated only when the angle of the sun was at least 3° above the horizon.

Monthly sunshine probability values were input for each month from January to December. These numbers were obtained from a publicly available historical dataset for Huron, South Dakota from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI).[7] Table 4-1 shows the percentage of sunshine hours by month used in the shadow flicker modeling. These values are the percentages that the sun is expected to be shining during daylight hours.

The number of hours the wind turbines are expected to operate for the 16 cardinal wind directions was input into the model. The number of operational hours per wind direction sector was provided by SCE for a 114-meter height, which were conservatively used in the model for all wind turbines. Operational hours at an 89-meter height would be fewer. These hours per wind direction sector are used by WindPRO to estimate the "wind direction" and "operation time" reduction factors. Based on this dataset, the wind turbines would operate 90% of the year due to cut-in and cut-out specifications of the proposed unit. Table 4-2 shows the distribution of operational hours for the 16 wind directions.

[7] NCEI (formerly NCDC), http://www1.ncdc.noaa.gov/pub/data/ccd-data/pctpos15.dat. Accessed in February 2019.

Table 4-1 Monthly Percent of Possible Sunshine

Month	Possible Sunshine
January	62%
February	62%
March	62%
April	59%
May	66%
June	69%
July	76%
August	74%
September	69%
October	59%
November	51%
December	51%

Table 4-2 Operational Hours per Wind Direction Sector

Wind Sector	Operational Hours
N	546
NNE	333
NE	234
ENE	231
E	261
ESE	398
SE	646
SSE	759
S	624
SSW	461
SW	348
WSW	363
W	384
WNW	695
NW	903
NNW	695
Annual	7,881

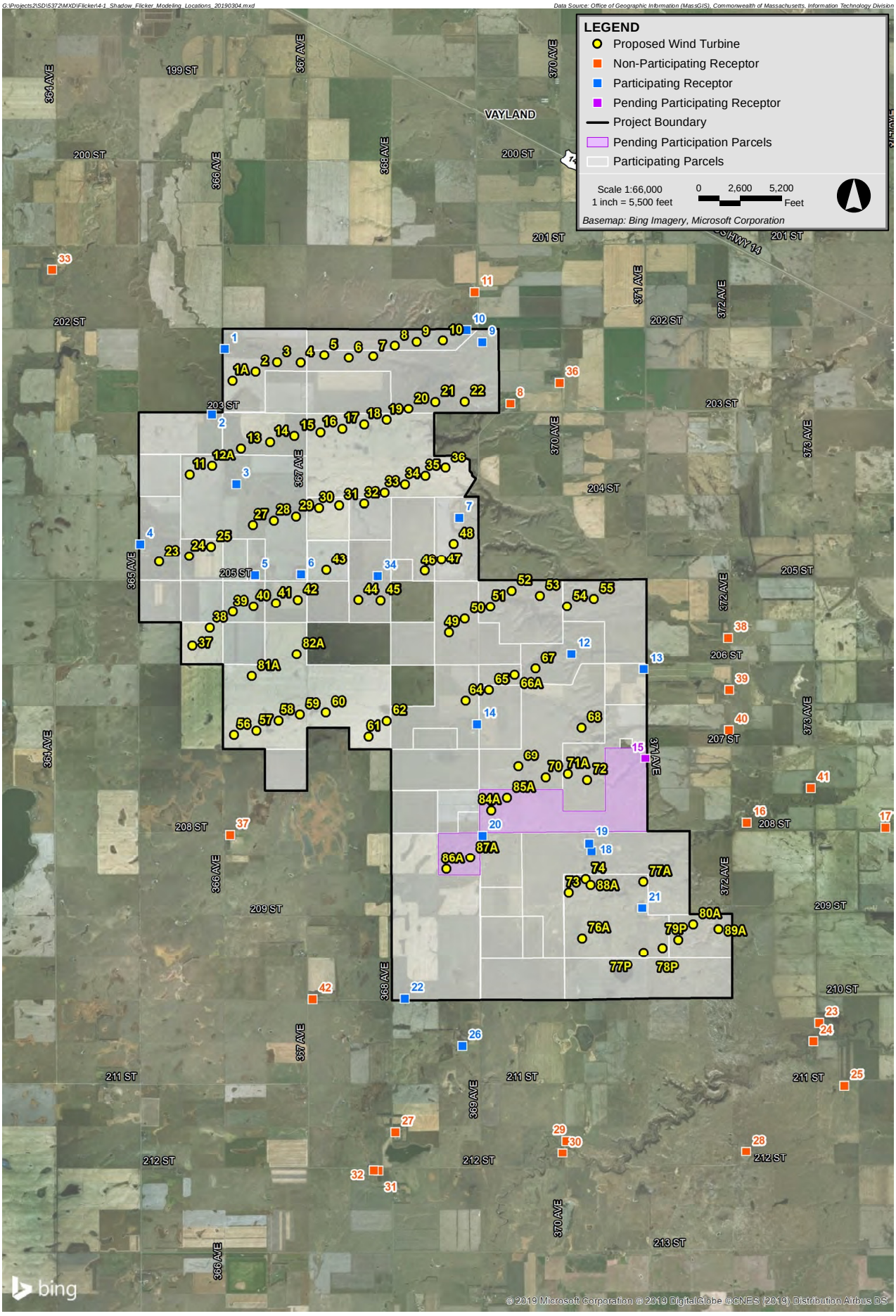

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Figure 4-1
Shadow Flicker Modeling Locations

4.2 Results

Following the modeling methodology outlined in Section 4.1, WindPRO was used to calculate shadow flicker at the 41 discrete receptor points in Hand County and generate shadow flicker isolines based on the grid calculations.

Table B-1 in Appendix B presents the shadow flicker modeling results for the 41 receptors. The predicted expected annual shadow flicker duration ranged from 0 hours, 0 minutes per year to 55 hours, 23 minutes per year. Many of the receptors in Hand County (20) were predicted to experience no annual shadow flicker. Seven (7) locations were predicted to experience some shadow flicker but less than 10 hours per year. The modeling results showed that 10 locations would be expected to have 10 to 30 hours of shadow flicker per year, and four (4) locations would be expected to have over 30 hours of shadow flicker per year. Figure 4-2 displays the modeled flicker isolines over aerial imagery in relation to modeled wind turbines and receptors.

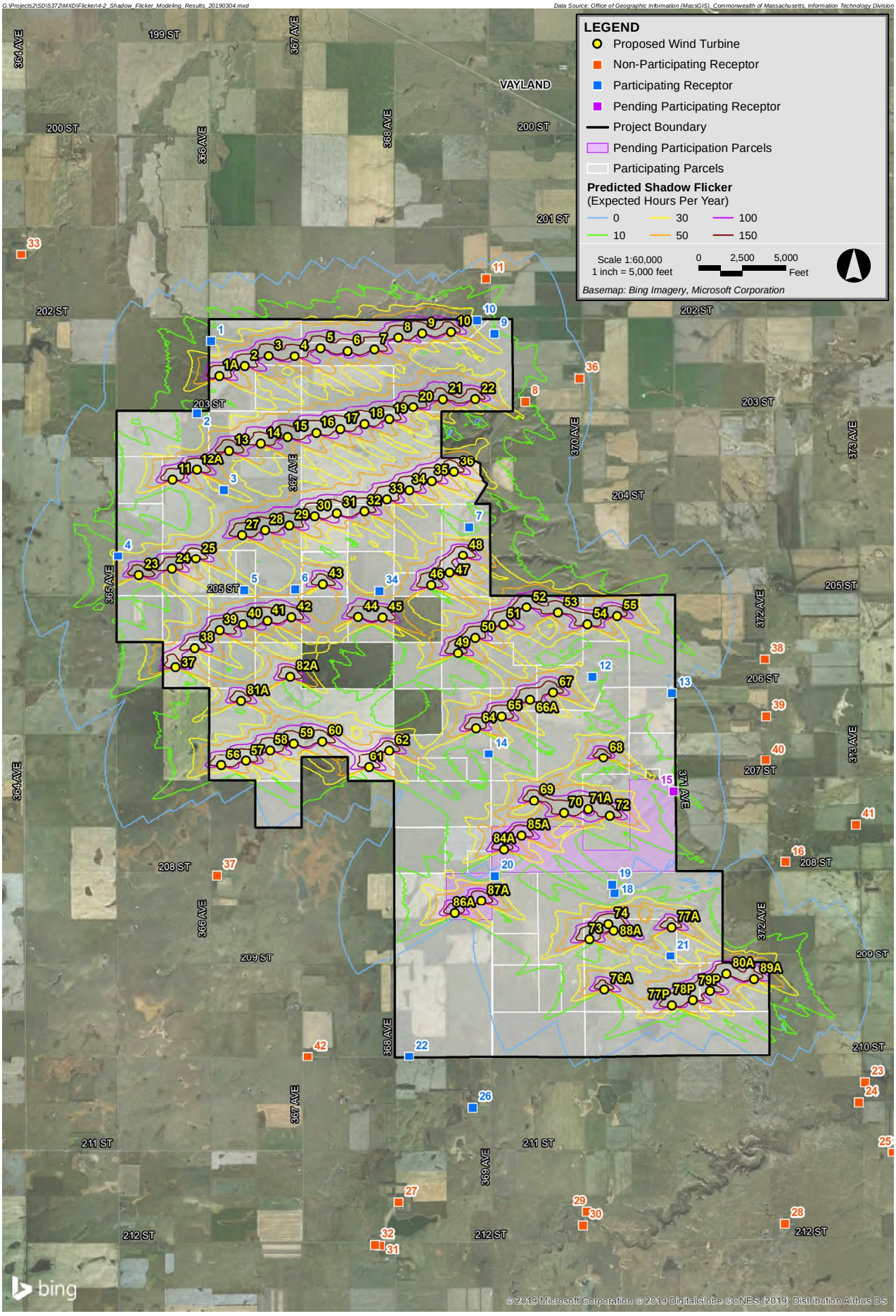

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Figure 4-2
Shadow Flicker Modeling Results

5.0 EVALUATION

The Sweetland Wind Project is limited to 30 hours per year of shadow flicker at occupied residences, as per the Development Agreement. The maximum expected annual flicker resulting from the operation of the proposed and alternate wind turbines is 55 hours, 23 minutes. This occurs at a participating receptor. The maximum expected annual flicker at a non-participating receptor is 9 hours, 16 minutes. The maximum expected annual flicker at a receptor with pending participation is 14 hours, 49 minutes. There is a total of four receptors predicted to have over 30 hours of annual flicker and all four receptors are participating (#6-Eric Fanning, #4-Jeremy & Marci Stevens, #21-Wayne & Joan Horsley, and #34-Dale G Christiansen). It is Epsilon's understanding that waivers will be acquired for these receptors. Therefore, the Project meets the requirements with respect to shadow flicker in the Development Agreement.

6.0 CONCLUSIONS

A shadow flicker analysis was conducted to determine the duration of shadow flicker in the vicinity of the proposed Project within Hand County, SD. Shadow flicker resulting from the operation of the proposed wind turbine layout and alternate wind turbine locations was calculated at 41 occupied residences, and isolines were generated from a grid encompassing the area surrounding the wind turbines. The maximum expected annual flicker resulting from the operation of the proposed and alternate wind turbines is 55 hours, 23 minutes. This occurs at a participating receptor. The maximum expected annual flicker at a non-participating receptor is 9 hours, 16 minutes. The maximum expected annual flicker at a receptor with pending participation is 14 hours, 49 minutes. There is a total of four receptors predicted to have over 30 hours of annual flicker and all four receptors are participating. It is Epsilon's understanding that waivers will be acquired for these receptors. Therefore, the Project meets the requirements with respect to shadow flicker in the Development Agreement.

The modeling results are conservative in that modeling receptors were treated as "greenhouses" and the surrounding area was assumed to be without vegetation or structures ("bare earth").

Appendix A
Wind Turbine Coordinates

Table A-1: Wind Turbine Coordinates (Layout 190206)

Wind Turbine ID	Hub Height (m)	Coordinates NAD83 UTM Zone 14N (meters)	
		X (Easting)	Y (Northing)
1A	89	511012.21	4921687.08
2	114	511453.33	4921859.46
3	114	511870.19	4922038.85
4	114	512321.24	4922032.65
5	114	512774.51	4922174.47
6	114	513244.56	4922123.89
7	114	513710.73	4922151.63
8	114	514128.93	4922358.66
9	114	514543.93	4922430.56
10	114	515045.88	4922458.48
11	114	510193.66	4919873.20
12A	89	510620.94	4920044.27
13	114	511176.44	4920385.98
14	114	511733.46	4920510.93
15	114	512198.31	4920625.64
16	114	512699.15	4920693.91
17	114	513119.71	4920762.30
18	114	513540.47	4920848.10
19	114	513970.65	4920934.88
20	114	514387.31	4921145.50
21	114	514905.57	4921284.73
22	114	515470.08	4921288.61
23	114	509603.78	4918211.78
24	114	510183.19	4918322.66
25	114	510600.13	4918502.72
27	114	511405.11	4918917.06
28	114	511804.96	4919001.75
29	114	512229.95	4919082.95
30	114	512672.33	4919240.36
31	114	513058.38	4919293.06
32	114	513537.27	4919326.90
33	114	513931.55	4919533.22
34	114	514321.46	4919691.24
35	114	514711.34	4919849.29
36	114	515101.21	4920007.25
37	114	510243.63	4916605.53
38	114	510579.50	4916943.29
39	89	511017.08	4917250.36
40	114	511418.75	4917354.69
41	114	511845.57	4917412.66
42	89	512265.78	4917475.42
43	114	512815.20	4918054.27
44	114	513429.64	4917481.64
45	89	513853.67	4917471.46
46	89	514702.38	4918039.82
47	114	515021.66	4918255.13
48	89	515255.92	4918559.94
49	114	515168.17	4916854.45

Table A-1: Wind Turbine Coordinates (Layout 190206)

Wind Turbine ID	Hub Height (m)	Coordinates NAD83 UTM Zone 14N (meters)	
		X (Easting)	Y (Northing)
50	114	515469.25	4917120.17
51	114	515962.07	4917348.53
52	114	516365.98	4917651.25
53	114	516911.45	4917557.34
54	114	517426.35	4917351.11
55	114	517943.89	4917497.10
56	114	511042.17	4914893.71
57	114	511469.67	4914971.97
58	114	511894.42	4915162.79
59	114	512305.67	4915277.95
60	114	512803.14	4915317.02
61	114	513621.17	4914858.56
62	114	513970.70	4915157.35
64	114	515484.40	4915543.47
65	89	515930.55	4915748.62
66A	89	516423.31	4916038.94
67	114	516827.22	4916161.87
68	114	517706.12	4915026.43
69	114	516494.56	4914281.40
70	114	517021.22	4914069.27
71A	114	517443.63	4914133.45
72	114	517815.36	4914019.51
73	114	517461.35	4911864.45
74	89	517789.29	4912125.25
76A	114	517721.01	4910983.29
77A	114	518892.06	4912070.45
77P	114	518901.20	4910709.17
78P	114	519264.70	4910797.24
79P	114	519563.99	4910955.49
80A	89	519848.54	4911253.43
81A	114	511384.00	4916015.74
82A	89	512244.18	4916438.26
84A	114	515973.83	4913442.12
85A	114	516278.60	4913679.95
86A	114	515116.95	4912318.92
87A	89	515575.65	4912534.49
88A	114	517882.92	4912011.96
89A	114	520332.80	4911161.95

Appendix B
Shadow Flicker Modeling Results: Occupied Residences

Table B-1: Shadow Flicker Modeling Results at Occupied Residences

Modeling ID	Description	Participation Status	Coordinates NAD83 UTM Zone 14N (meters)		Expected Shadow Flicker Hours per Year
			X (Easting)	Y (Northing)	(HH:MM/year)
1	Dale& Leanna Resel	Participating	510861.20	4922299.80	24:33
2	Dale& Leanna Resel	Participating	510617.45	4921033.54	12:18
3	John& Kimberly Fanning	Participating	511084.98	4919693.62	23:21
4	Jeremy& Marci Stevens	Participating	509240.44	4918553.74	45:27
5	James& Renae Aalbers	Participating	511442.82	4917952.72	23:31
6	Eric Fanning	Participating	512329.39	4917967.20	55:23
7	Jason D Resel	Participating	515363.03	4919055.61	5:43
8	Lyle& Rebecca Resel	Non-Participating	516342.30	4921246.06	9:16
9	James Major	Participating	515803.65	4922429.04	14:06
10	36891 St	Participating	515499.23	4922661.77	23:31
11	Steve Runge	Non-Participating	515658.09	4923385.39	7:05
12	Craig& Cheryl Van Asperen	Participating	517511.88	4916440.42	12:06
13	Cole Mehling	Participating	518901.01	4916154.62	2:11
14	Karen& Clinton Haigh	Participating	515701.85	4915097.07	7:26
15	Gilbert& Stephanie Rodgers	Pending Participation	518930.64	4914440.16	14:49
16	Reynolds Family Farms LLC	Non-Participating	520879.37	4913213.26	0:00
17	L Brewer 37386	Non-Participating	523539.62	4913117.77	0:00
18	Jay Anderberg	Participating	517896.23	4912672.02	5:14
19	Jay Anderberg cabin	Participating	517856.16	4912818.41	13:50
20	Jeremy& Marci Stevens	Participating	515809.40	4912961.25	11:31
21	Wayne& Joan Horsley Residence	Participating	518872.55	4911572.32	40:35
22	Travis Letsche	Participating	514315.01	4909824.50	0:00
23	Robert Duxbury	Non-Participating	522266.31	4909368.02	0:00
24	Paul Duxbury	Non-Participating	522159.03	4909019.95	0:00
25	Dean Duxbury	Non-Participating	522748.18	4908152.95	0:00
26	Leon& Lori Boomsma	Participating	515422.97	4908930.39	0:00
27	Scot Parmely	Non-Participating	514136.35	4907279.00	0:00
28	Non-valuated property	Non-Participating	520868.09	4906901.58	0:00
29	Non-valuated property	Non-Participating	517417.40	4907112.62	0:00
30	M Anson	Non-Participating	517347.17	4906873.43	0:00
31	Joe Jensen	Non-Participating	513813.93	4906527.92	0:00
32	Howard Jensen	Non-Participating	513722.68	4906535.03	0:00
33	Kevin& Marcie Bertsch	Non-Participating	507556.69	4923810.27	0:00
34	Dale G Christiansen	Participating	513798.02	4917935.51	35:17
36	Larry& Deanne Rowen	Non-Participating	517289.54	4921647.66	1:19
37	Robert& Patricia Moriarty	Non-Participating	510971.00	4912975.40	0:00
38	Jerrit Mehling	Non-Participating	520521.55	4916748.02	0:00
39	Deborah A Mehling Rev Trust	Non-Participating	520543.07	4915750.09	0:00
40	Gregory Roy Mehling	Non-Participating	520533.48	4914986.86	0:00
41	Kenneth& Dieanne Wedge	Non-Participating	522108.26	4913867.58	0:00
42	Daniel W Jensen	Non-Participating	512549.23	4909816.85	0:00