SHADOW FLICKER ASSESSMENT

CROCKER WIND PROJECT

CLARK COUNTY, SOUTH DAKOTA

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1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

Crocker Wind Farm, LLC ('Crocker') is developing the Crocker Wind Farm ('Project') in eastern South Dakota. Currently, the Project is proposed to consist of up to 77 GE 2.72-116 turbines with a hub height of 90 meters.

To support the development of the Project, Geronimo Energy, LLC ('Geronimo') completed – on behalf of Crocker - a shadow flicker analysis to estimate levels of flicker potentially associated with the operation of the Project.

1.2 DESCRIPTION OF SHADOW FLICKER AND MODELING

Rotating wind turbine blades may cast shadows during periods when the sun is shining and the turbine is operating. Such shadows may occasionally fall upon homes or other occupied structures (known as receptors) in and near the wind farm area. Expected shadow flicker impacts of the Project have been evaluated by the WindPRO software package, which incorporates the proposed turbine layout, 88 receptors identified by review of aerial imagery, and site-specific meteorological data.

2. SHADOW FLICKER – DEFINITION AND CHARACTERISTICS

Like any tall structure, wind turbines will cast a shadow when the sun is visible. As wind turbines rotate, a flickering or flashing effect may occur when the shadows of the rotating blades cause rapid changes in light intensity at stationary locations such as homes (referred to as receptors). This change in light intensity is known as shadow flicker. Shadow flicker at a receptor may occur only when the following four conditions are met:

- The sun is shining with no cloud cover present;
- The turbine is operating;
- The turbine blades are positioned on a line between the sun and the receptor; and
- The receptor is close enough to the turbine to distinguish the shadow created by the blades.

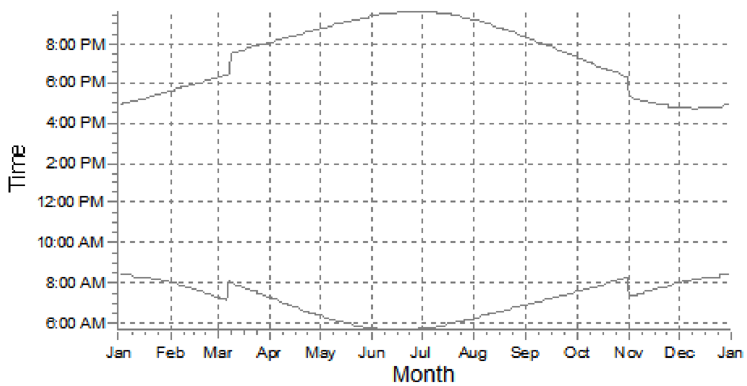
Shadow flicker intensity and frequency of occurrence at a given receptor are determined by several factors:

- **Cloud Cover and Visibility:** If the sun is obscured by clouds, the solar disk is not prominent enough to perceive shadow flicker. Similarly, atmospheric phenomena such as haze, fog, or smoke which would limit visibility also reduce the intensity of shadow flicker because it diffuses the light from the sun.
- **Local Topography:** Elevation differences between the receptor and the turbine location can either increase or decrease frequency of shadow flicker, compared to flat terrain. For example, a receptor may be shielded from the turbine by a prominent hill, wind break, or by other nearby buildings.
- **Wind Speed:** Shadow flicker will only occur if the turbine is operating, as discussed previously. Turbines are designed to operate above a specific wind speed (cut-in speed, generally 3 – 4 m/s for modern wind turbines) and below another specific wind speed (cut-out speed, generally 20 – 25 m/s for modern wind turbines).
- **Wind Direction:** Upwind wind turbines like those proposed at the Project seek to maximize energy production by orienting themselves with blades facing into the wind. The area affected by shadow flicker depends on the orientation of the plane of blade rotation relative to a line between the receptor and the sun. If the other conditions are such that shadow flicker is possible and the plane is close to parallel to the receptor-sun

line, the generation of flicker is negligible at the receptor. Alternatively, if the plane is close to perpendicular the generation of flicker at the receptor may be noticeable.

- **Maintenance:** It is occasionally necessary to shut down wind turbines for maintenance, during which time the turbine will not produce shadow flicker.

- **Sun Angle and Path:** On a given day, shadows cast by the sun are longest during the periods around sunrise and sunset and shortest during mid-day hours. Shadows are also longer in the summer than the winter, with the longest shadows occurring on the summer solstice and shortest shadows occurring on the winter solstice, as seen in the image below:



- **Position of Turbines Relative to Receptors:** The frequency of shadow flicker at a receptor decreases as the distance between the receptor and a wind turbine increases. The frequency is also affected by the location of a wind turbine relative to the receptor. For example, a wind turbine will never cast a shadow on a receptor located directly to its south, since it is never possible for the turbine to lie between the receptor and the sun. A receptor located to the west of the turbine, however, may experience shadow flicker during the early morning hours when the sun is in the eastern sky and low to the ground provided other conditions are met.

- **Distance from Turbines to Receptors:** It is generally accepted that shadow flicker from wind turbines is not perceptible beyond distances of 1500 meters (4921 feet), because the shadow is sufficiently diffuse that the shadow is not seen as a solid obstruction.

Currently, shadow flicker impacts are not regulated by state and federal law; however, a general threshold of 30 hours of shadow flicker exposure is often used as a reference within the wind industry based on a standard goal which has been derived from a German court case in which it was determined that 30 hours of actual observed shadow flicker at a neighbor's property was tolerable [1].

3. SHADOW FLICKER MODELING

Computer models are frequently employed to predict the expected amount of shadow flicker at locations within or around a wind farm. One such model is built into EMD WindPRO 2.9.285, an industry standard software package for the design, assessment, and optimization of wind farms. The WindPRO SHADOW module is able to incorporate the sun's position, topography of the wind farm site, locations of receptors, wind turbine specifications, and the observed wind direction distribution to calculate shadow positions and orientations at one-minute intervals for a calendar year.

3.1 MODEL INPUTS

Crocker has identified 77 primary and 7 alternate positions for turbine placement in the Project area. Appendix C displays the proposed turbine positions within the wind farm area as well as the receptor locations. Appendix A provides the turbine coordinates.

Possible receptor locations were identified from 2016 aerial imagery provided by the Farm Service Agency's (FSA) National Agricultural Imagery Program (NAIP). The locations were further refined by field visits to determine if the buildings were still occupiable and to identify any new buildings since the 2015 photo was taken. A total of 88 receptors were identified within one mile of the project, as seen in Appendix C.

Historical sunshine frequencies (in terms of mean sunlight hours per day) for each calendar month were provided by the WindPRO station database. The nearest site in the database to the Crocker Project is at the National Weather Service (NWS) weather station at Huron, SD. Table 1 lists the percentage of possible sunshine hours that was used in the shadow flicker modeling.

Table 1 – Percent of possible sunshine hours per month at Huron, SD

Average Sunshine Hours Per Day											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
52%	54%	58%	63%	65%	66%	74%	78%	68%	59%	51%	51%

Wind direction data collected by an on-site meteorological tower was used in the analysis. The wind direction observations were binned into twelve 30-degree sectors to determine the relative frequency of wind direction at the site. In order to more accurately reflect the anticipated operating conditions in the wind farm, wind speeds outside the operating range of the wind turbines have been removed. An additional downtime of 5% was added to reflect typical observed levels of downtime in modern wind farms. Table 2 below shows the hourly distribution for the 12 sectors and their number of corresponding hours per direction on an annual basis that was used by the shadow flicker model.

Table 2 - Wind turbine operating hours by direction, Crocker Wind Farm

Operating Hours by Direction													
Sector	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Frequency (%)	8.5	6.1	5.4	6.7	8.5	11.5	14.9	7.7	5.0	6.1	9.1	10.6	100.0
Hrs/Year	675	480	430	531	678	916	1180	607	394	484	725	837	7937

Finally it was assumed that no shadows would be cast if the sun angle was less than 3 degrees above the horizon, since the depth of the atmospheric column at these angles substantially increases scattering of solar radiation and renders shadows, like those analyzed in this report, incoherent.

Geronimo initially assessed the wind turbine/receptor interaction using the following assumptions:

- Receptors assumed to be transparent in all directions (known as ‘greenhouse’ mode);
- Flat terrain without obstacles which would reduce shadow flicker occurrences;
- Obstructions such as trees and outbuildings not considered

The first run of the model with this configuration indicated four receptors (all participants) would exceed the target 30 hours per year of shadow flicker. A second run of the model was completed which made the following additional assumptions:

- Terrain effects were included, potentially shielding some receptors from flicker impacts
- Aerial imagery near the affected receptors was reviewed, and tree stands were drawn in and added to the model. Trees were assumed to be 40 feet in height based on site visits.

The model was run again with these assumptions, and the results are presented in section 3.2 below.

3.2 MODEL RESULTS

Summary statistics are as follows, for participating and non-participating landowners:

Table 3 - WindPRO shadow flicker results

Value	Hours / Year
Average - Participant	5.4
Average - Non Participant	0.4
Max - Participant	18.9
Max - Non Participant	7.5

Calculated flicker impacts for each receptor are provided in Appendix B. The model predicts no residences to receive shadow flicker in excess of 30 hours per year.

4. MITIGATION

In the event that Crocker receives complaints about flicker from the Project, impacts can be re-evaluated and mitigation measures will be taken if necessary. Such mitigation measures include but are not limited to planting of additional vegetation near receptors and installation of curtains or blinds in the windows of affected receptors.

Crocker plans to address any post-construction shadow flicker concerns on a case-by-case basis. If shadow flicker concerns are reported to Crocker, project representatives will implement the following procedure:

- Log the contact in Crocker's complaint database to track resolution efforts;
- Prepare site-specific assessment of shadow flicker impacts, noting the time of day, season, and expected duration of future flicker impacts;
- Meet with landowner to discuss site-specific assessment, educate landowners on landowner driven mitigation strategies (e.g. modification of interior lighting) and discuss concerns;
- Assess the residence to determine if on-site mitigation measures, including but not limited to, installation of exterior or interior screening, are appropriate for the level of impact and effectively address the concern;
- Work with landowner to develop a mitigation plan; and
- Implement the mitigation plan.

Crocker's goal is to resolve all flicker related complaints the project may receive satisfactorily. Crocker has preference for the least intrusive methodology for mitigating any effects first by engaging with the landowner through education, and will go to more intrusive measures in the event that education is not sufficient in resolving the matter with the landowner.

5. CONCLUSION

An analysis of potential shadow flicker impacts from the Crocker Wind Farm on nearby receptors indicates that the effects are expected to be minor and well within tolerances that do not present concerns for nuisance. No residences are expected to experience over 30 hours per year of shadow flicker.

6. REFERENCES

1. WindPower. 2003. Danish Wind Industry Association. Shadow Casting From Wind Turbines. http://guidedtour.windpower.org/en/tour/env/shadow/index.html.

APPENDIX A – TURBINE LAYOUT

Turbine ID	X	Y	Status
1	590446	4995368	Primary
2	590826	4995399	Primary
3	590462	4994532	Primary
4	590855	4994574	Primary
7	590325	4992719	Primary
12	588367	4993133	Primary
13	589506	4992367	Primary
14	589170	4992179	Primary
15	588544	4991795	Primary
16	588796	4992048	Primary
17	588196	4991533	Primary
19	587987	4991224	Primary
20	588910	4990931	Primary
21	589243	4991122	Primary
23	586613	4989565	Primary
25	587518	4989827	Primary
28	586966	4990561	Primary
47	593136	4990460	Alternate
48	593455	4990714	Alternate
51	589815	4990311	Primary
52	589526	4989977	Primary
53	587806	4987122	Primary
54	588146	4987232	Primary
55	588519	4987316	Primary
59	592709	4988584	Alternate
69	590874	4991609	Primary
71	590045	4991307	Primary
72	588098	4988758	Alternate
77	590206	4994221	Primary
86	585866	4990367	Primary
87	585455	4990192	Primary

88	585058	4990096	Primary
89	586955	4993047	Primary
90	587393	4993196	Primary
91	587601	4993573	Primary
92	587904	4993894	Primary
93	588385	4994106	Primary
94	588666	4994332	Primary
95	585865	4993126	Primary
96	586215	4993311	Primary
99	587704	4988626	Alternate
100	587352	4988518	Alternate
101	587479	4987004	Primary
102	585141	4987001	Primary
155	589951	4995233	Primary
158	588128	4995289	Primary
166	593055	4995948	Primary
177	594145	4997168	Primary
178	594854	4997989	Primary
179	595007	4998682	Primary
180	594540	4998788	Primary
181	593942	4998652	Primary
182	594154	4999135	Primary
184	593745	4998184	Primary
185	593500	4997892	Primary
186	593442	4997536	Primary
187	593045	4997421	Alternate
189	592505	4996430	Primary
190	592161	4996366	Primary
191	591793	4996200	Primary
192	591487	4996743	Primary
194	592535	4996808	Primary
196	592552	4997736	Primary
197	592271	4998045	Primary
198	592527	4998310	Primary
199	592182	4998619	Primary
204	590293	4999012	Primary

205	589685	4999053	Primary
206	589971	4998678	Primary
207	589710	4997974	Primary
210	589797	4996996	Primary
211	590628	4996420	Primary
212	590518	4995975	Primary
213	589046	4987458	Primary
214	589425	4987382	Primary
215	590078	4999950	Primary
216	590363	5000214	Primary
218	590797	5000295	Primary
220	591403	4999167	Primary
221	592152	4999950	Primary
222	592588	5000305	Primary
223	593819	5000160	Primary
224	594210	5000303	Primary
230	591342	4997941	Primary

APPENDIX B – SHADOW FLICKER MODEL CALCULATIONS

Table 4 - Shadow flicker model results (hours/year)

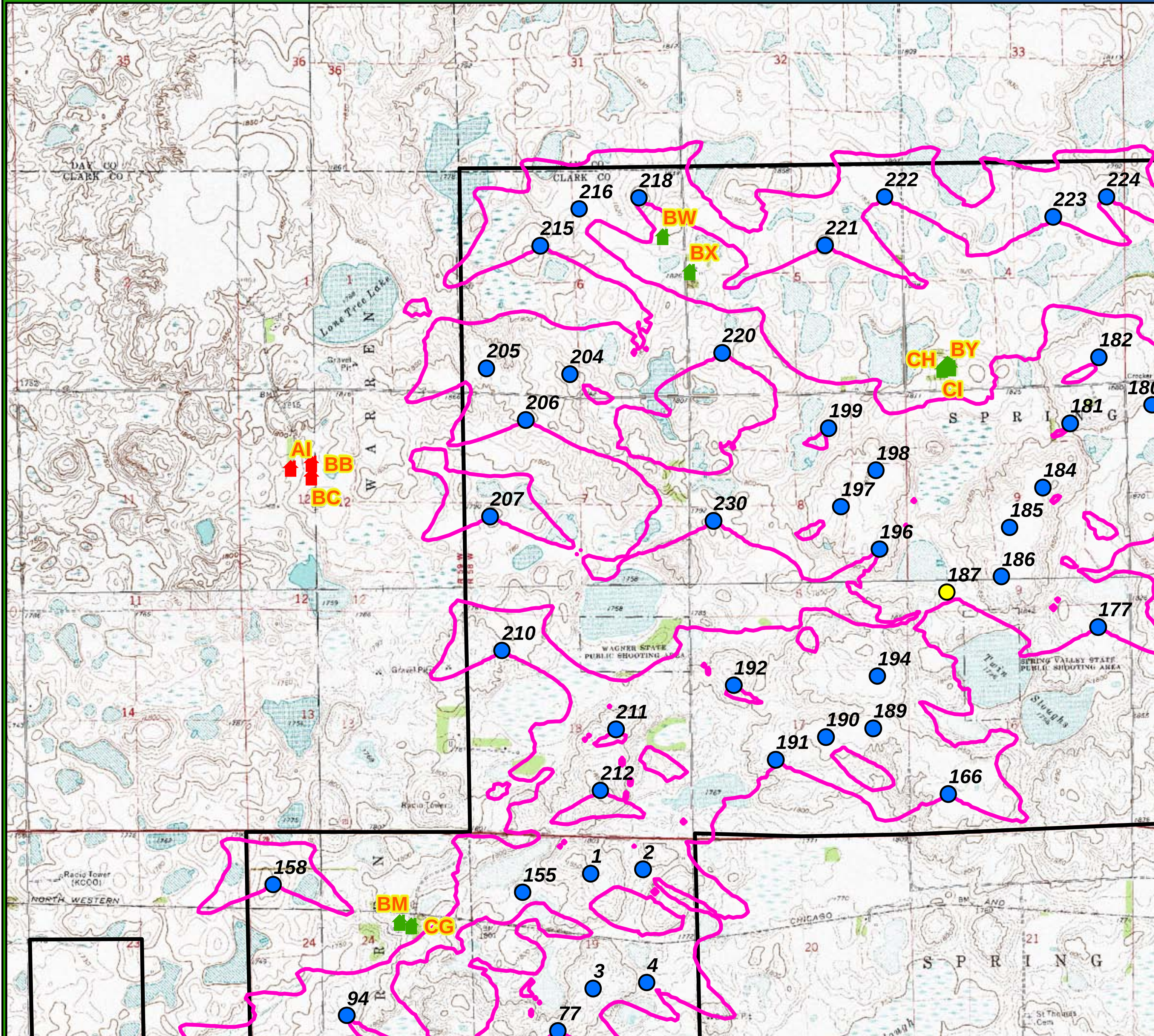
Receptor ID	X	Y	Status	Hours Per Year
A	590214	4984376	Non-Participating	0.0
B	592904	4982768	Non-Participating	0.0
C	593620	4982900	Non-Participating	0.0
D	594437	4982966	Non-Participating	0.0
E	594440	4982939	Non-Participating	0.0
F	594692	4983211	Non-Participating	0.0
G	594518	4983774	Non-Participating	0.0
H	596399	4982306	Non-Participating	0.0
I	592935	4984692	Non-Participating	0.0
J	591744	4987551	Non-Participating	0.0
K	591249	4987762	Non-Participating	0.0
L	591308	4985134	Non-Participating	0.0
M	591253	4985098	Non-Participating	0.0
N	590677	4989109	Non-Participating	0.0
O	591433	4990460	Non-Participating	0.0
P	586482	4986149	Non-Participating	0.0
Q	586122	4988415	Non-Participating	3.0
R	585758	4988140	Non-Participating	0.0
S	597127	4988614	Non-Participating	0.0
T	594514	4984684	Non-Participating	0.0
U	597663	4989857	Non-Participating	0.0
V	599365	4989264	Non-Participating	0.0
W	600501	4989800	Non-Participating	0.0
X	602317	4991734	Non-Participating	0.0
Y	602396	4994190	Non-Participating	0.0
Z	599751	4994157	Non-Participating	0.0
AA	595548	4994076	Non-Participating	0.0
AB	595404	4996511	Non-Participating	6.2
AC	595848	4999736	Non-Participating	0.0

AD	597375	4999190	Non-Participating	0.0
AE	596303	4998806	Non-Participating	1.9
AF	597640	4985323	Non-Participating	0.0
AG	594453	4984844	Non-Participating	0.0
AH	596005	4997305	Non-Participating	0.5
AI	588255	4998326	Non-Participating	1.2
AJ	597824	4985846	Non-Participating	0.0
AK	597941	4986803	Non-Participating	0.0
AL	595632	4996006	Non-Participating	0.0
AM	595760	4995351	Non-Participating	0.0
AN	595603	4995405	Non-Participating	0.0
AO	595521	4995356	Non-Participating	0.0
AP	595551	4995280	Non-Participating	0.0
AQ	595498	4995279	Non-Participating	0.0
AR	595447	4995369	Non-Participating	0.0
AS	595449	4995337	Non-Participating	0.0
AT	595704	4995308	Non-Participating	0.0
AU	595709	4995351	Non-Participating	0.0
AV	595767	4995197	Non-Participating	0.0
AW	595400	4995287	Non-Participating	0.0
AX	595386	4995334	Non-Participating	0.0
AY	595614	4995299	Non-Participating	0.0
AZ	595826	4995087	Non-Participating	0.0
BA	595777	4995057	Non-Participating	0.0
BB	588407	4998361	Non-Participating	7.5
BC	588407	4998261	Non-Participating	1.6
BD	597825	4985337	Non-Participating	0.0
BE	595191	4987671	Participating	0.0
BF	595234	4987683	Participating	0.0
BG	592571	4987592	Participating	0.0
BH	588306	4990357	Participating	8.4
BI	588362	4990440	Participating	10.1
BJ	589764	4989175	Participating	0.0
BK	592787	4990119	Participating	0.0
BL	595289	4990578	Participating	0.0
BM	589052	4995012	Participating	16.2

BN	586436	4993857	Participating	9.0
BO	596670	4988022	Participating	0.0
BP	597789	4987895	Participating	0.0
BQ	597594	4984416	Participating	0.0
BR	597744	4984181	Participating	0.0
BS	600067	4991330	Participating	0.0
BT	600783	4994038	Participating	0.0
BU	599531	4993078	Participating	0.0
BV	597588	4993203	Participating	0.0
BW	590972	5000014	Participating	2.5
BX	591168	4999758	Participating	10.3
BY	593070	4999056	Participating	12.6
BZ	595172	4999096	Participating	16.9
CA	595105	4999100	Participating	14.9
CB	588527	4990461	Participating	8.4
CC	596204	4981998	Participating	0.0
CD	586274	4988056	Participating	6.3
CE	594425	4990983	Participating	3.2
CF	586112	4992711	Participating	12.9
CG	589138	4994988	Participating	18.9
CH	593049	4999085	Participating	11.4
CI	593007	4999048	Participating	11.1
CJ	600048	4991352	Participating	0.0

APPENDIX C – SHADOW FLICKER RESULTS MAPS

EXHIBIT D



Turbine Status

- Alternate
- Primary

Shadow Receptor Status

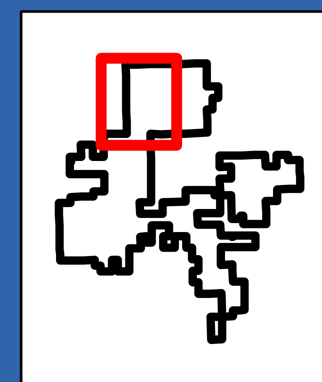
- Non-Participating
- Participating

Shadow Hours Per Year

- 30

Project Boundary

Crocker Wind Farm Shadow Flicker



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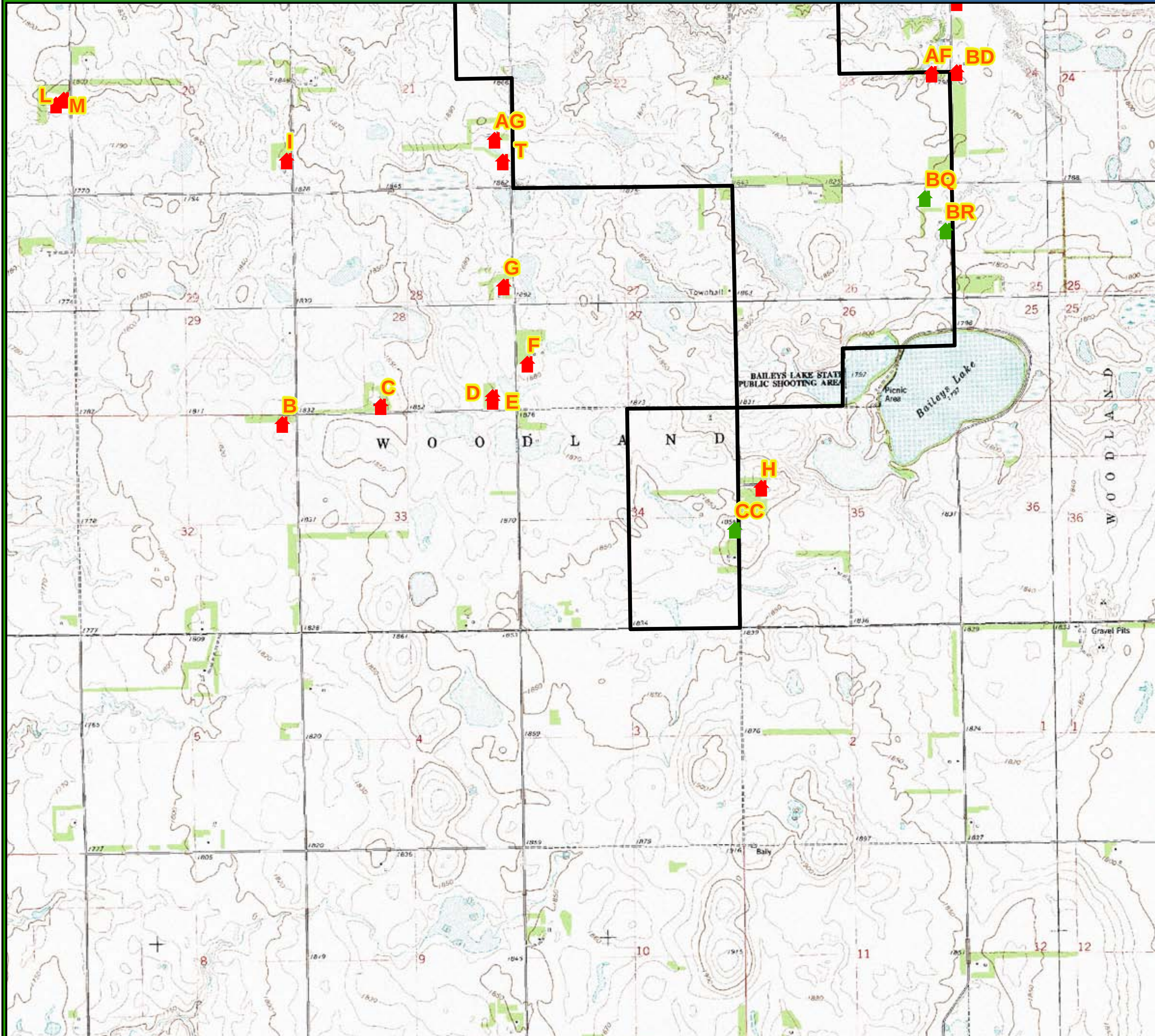
CROCKER WIND FARM Clark County, SD

EXHIBIT D



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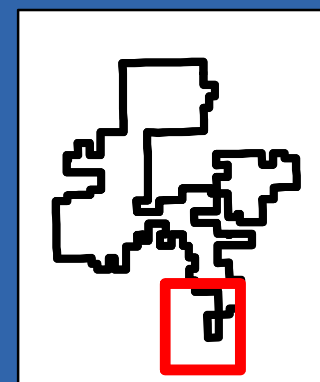

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CROCKER WIND FARM

Clark County, SD

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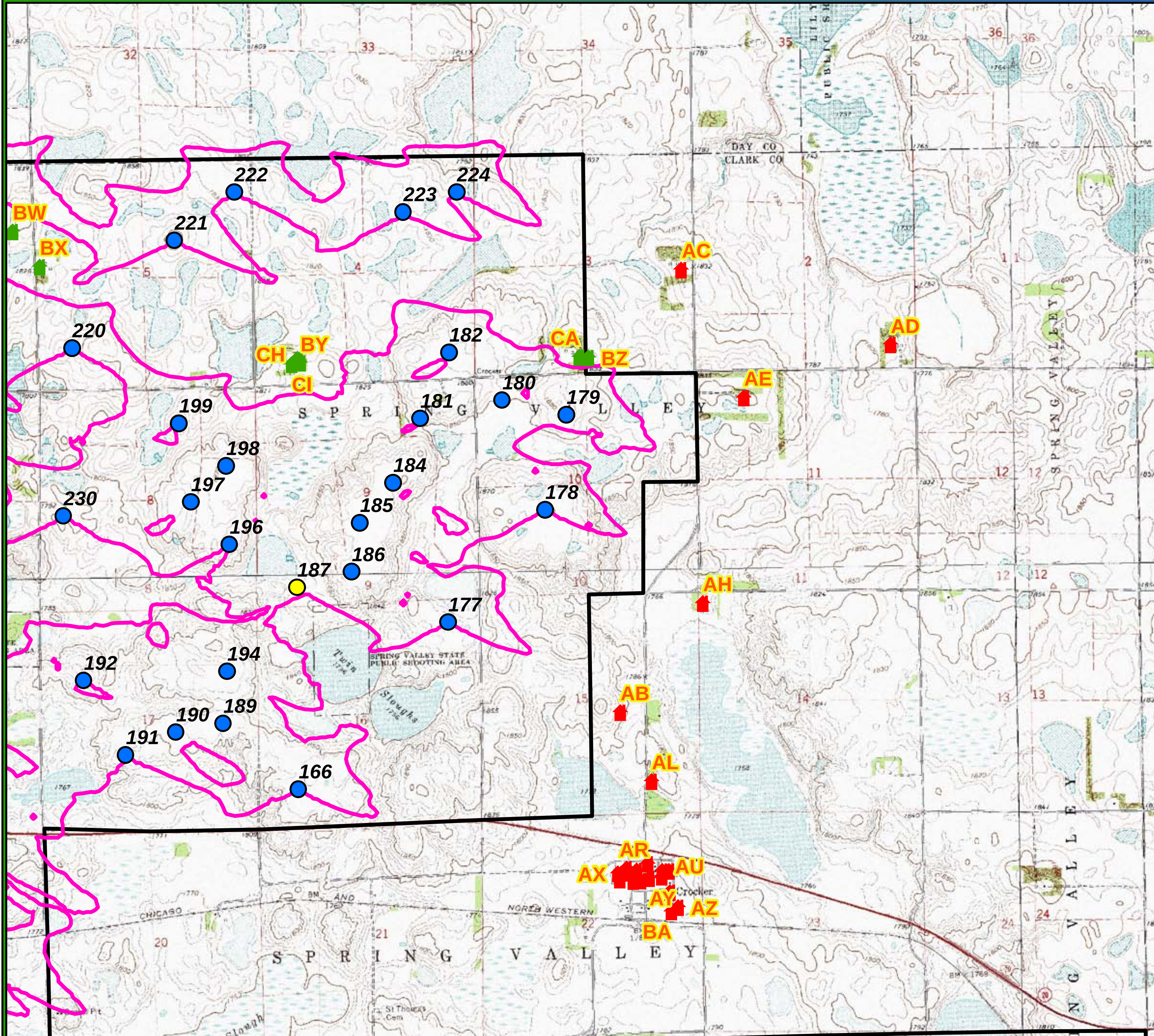

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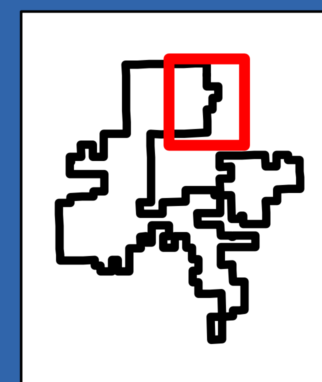

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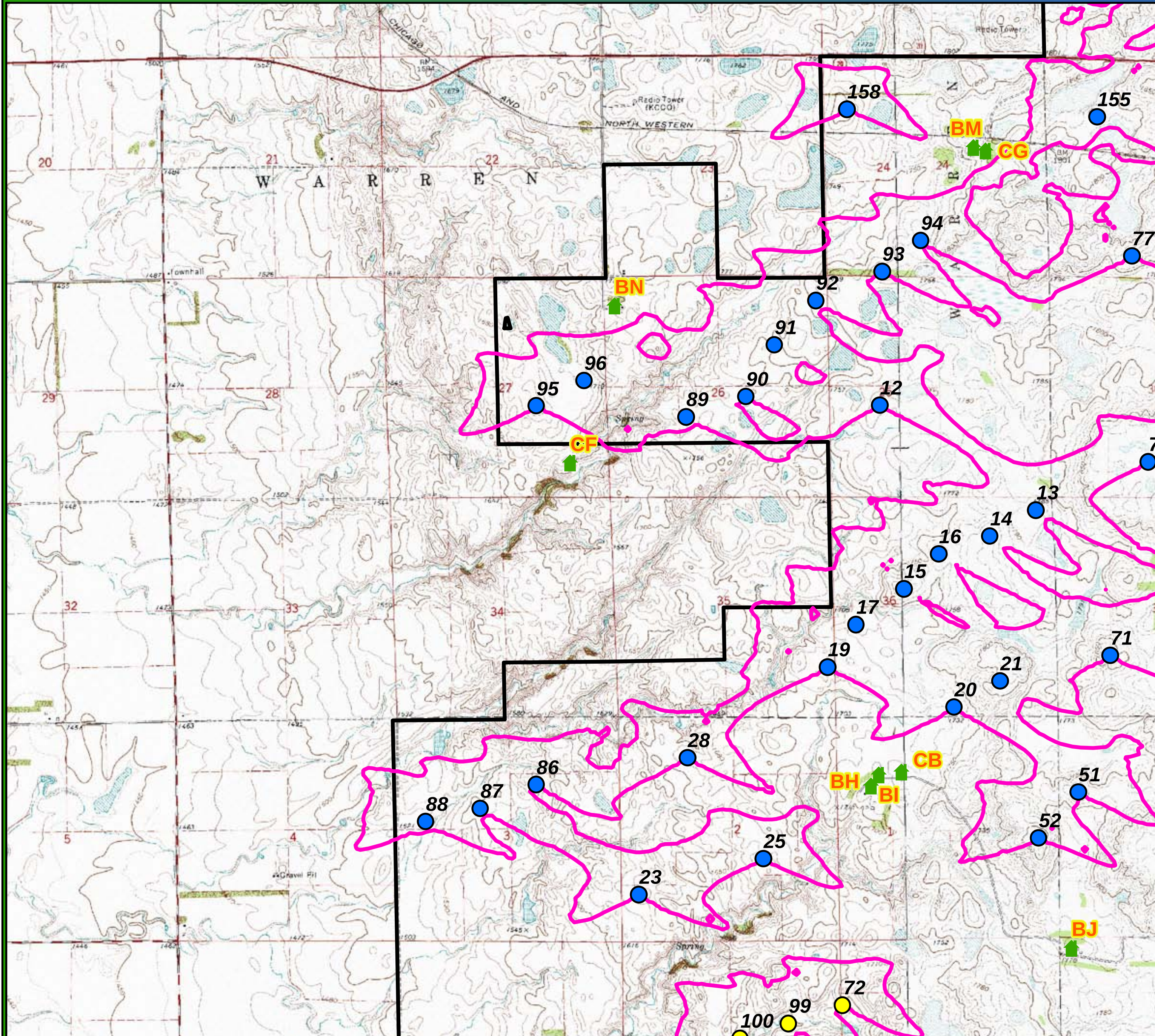

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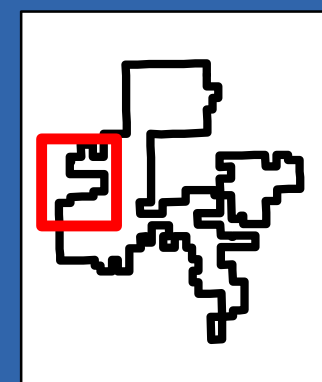

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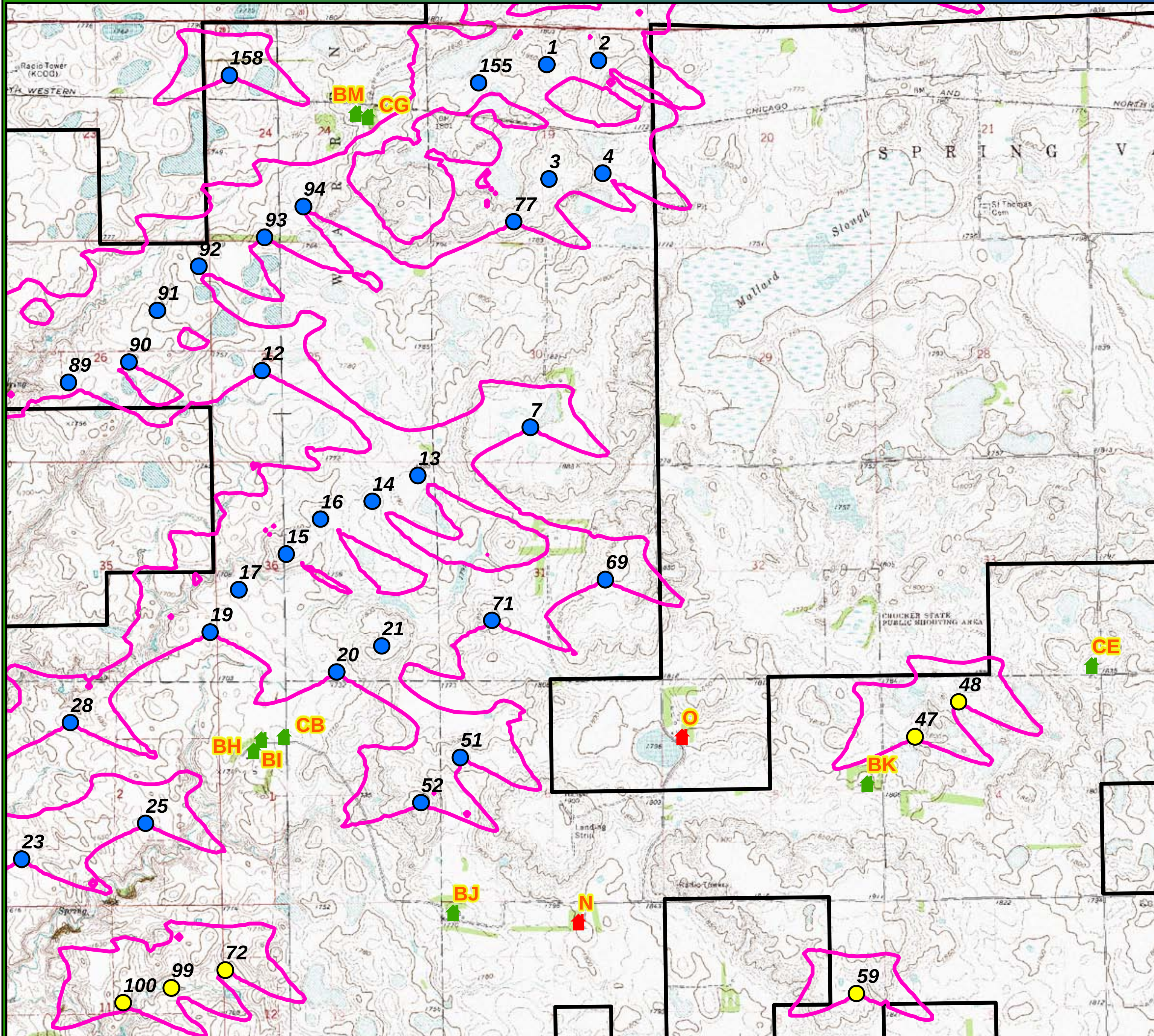

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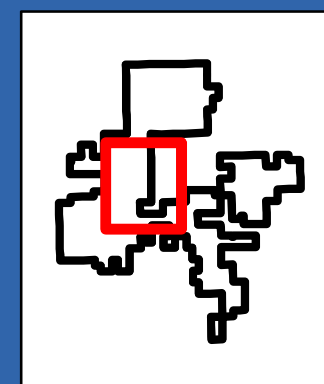

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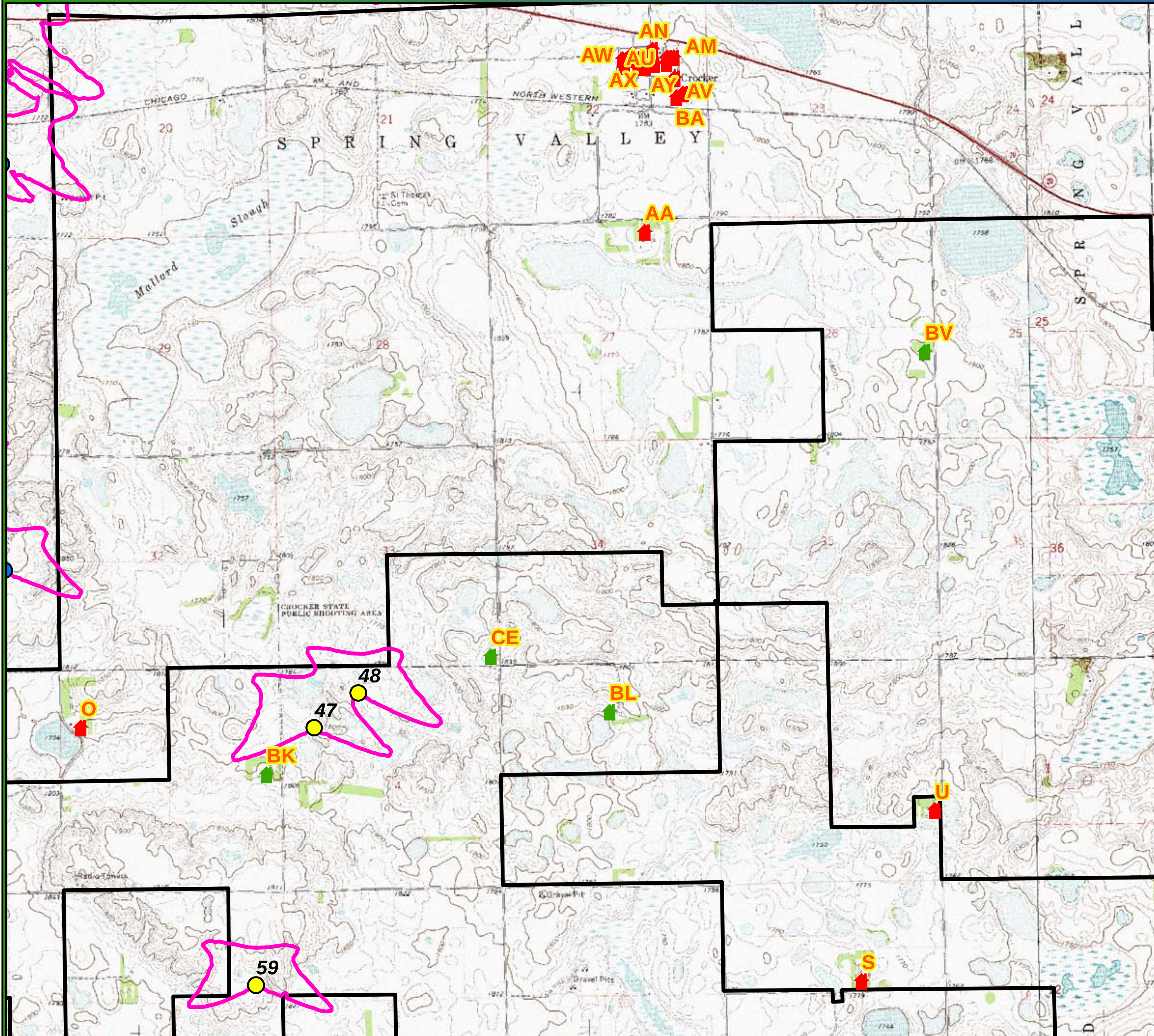
CROCKER WIND FARM Clark County, SD



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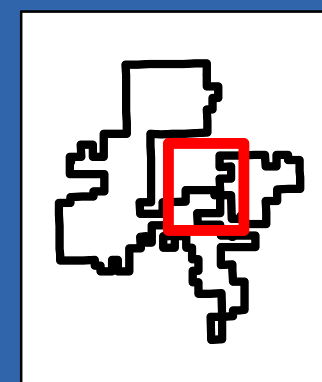

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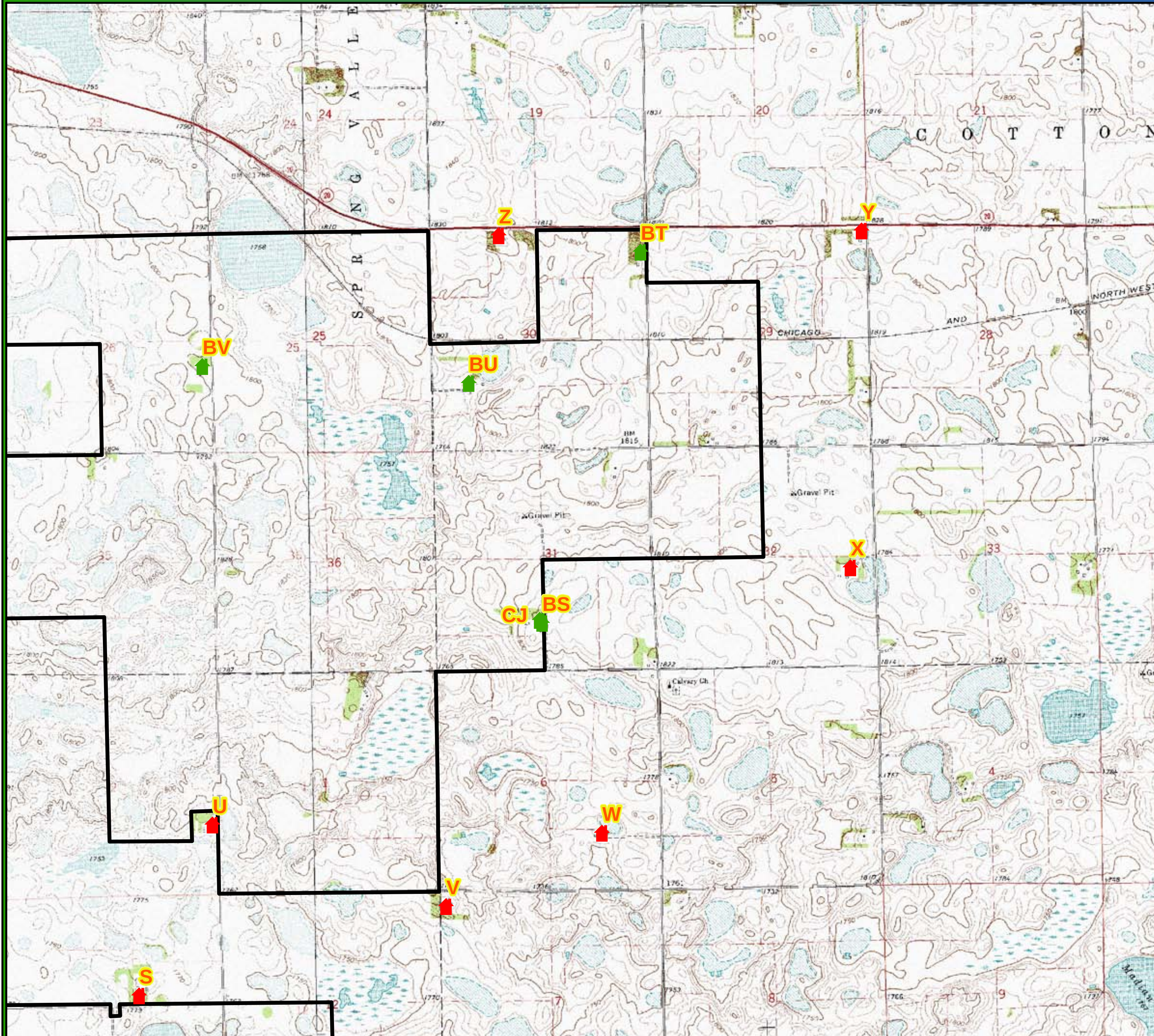

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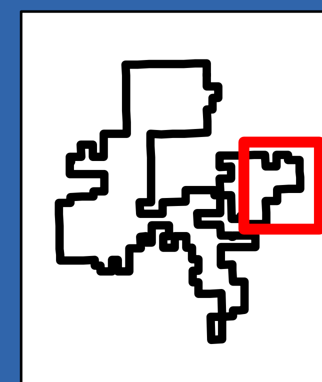

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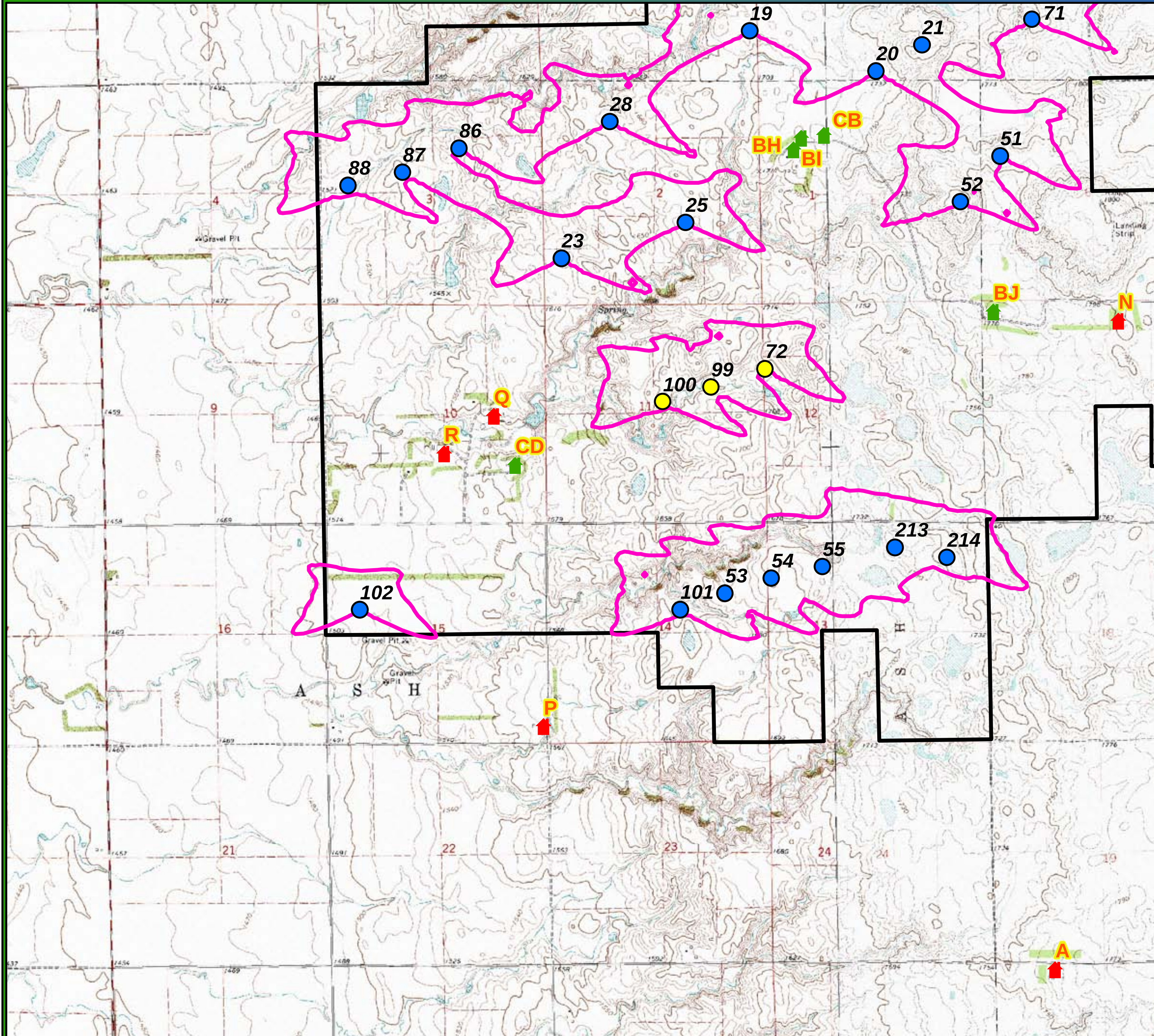

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Crocker Wind Farm Shadow Flicker

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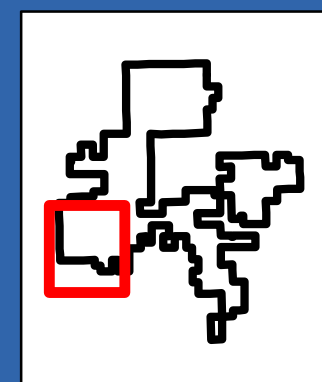

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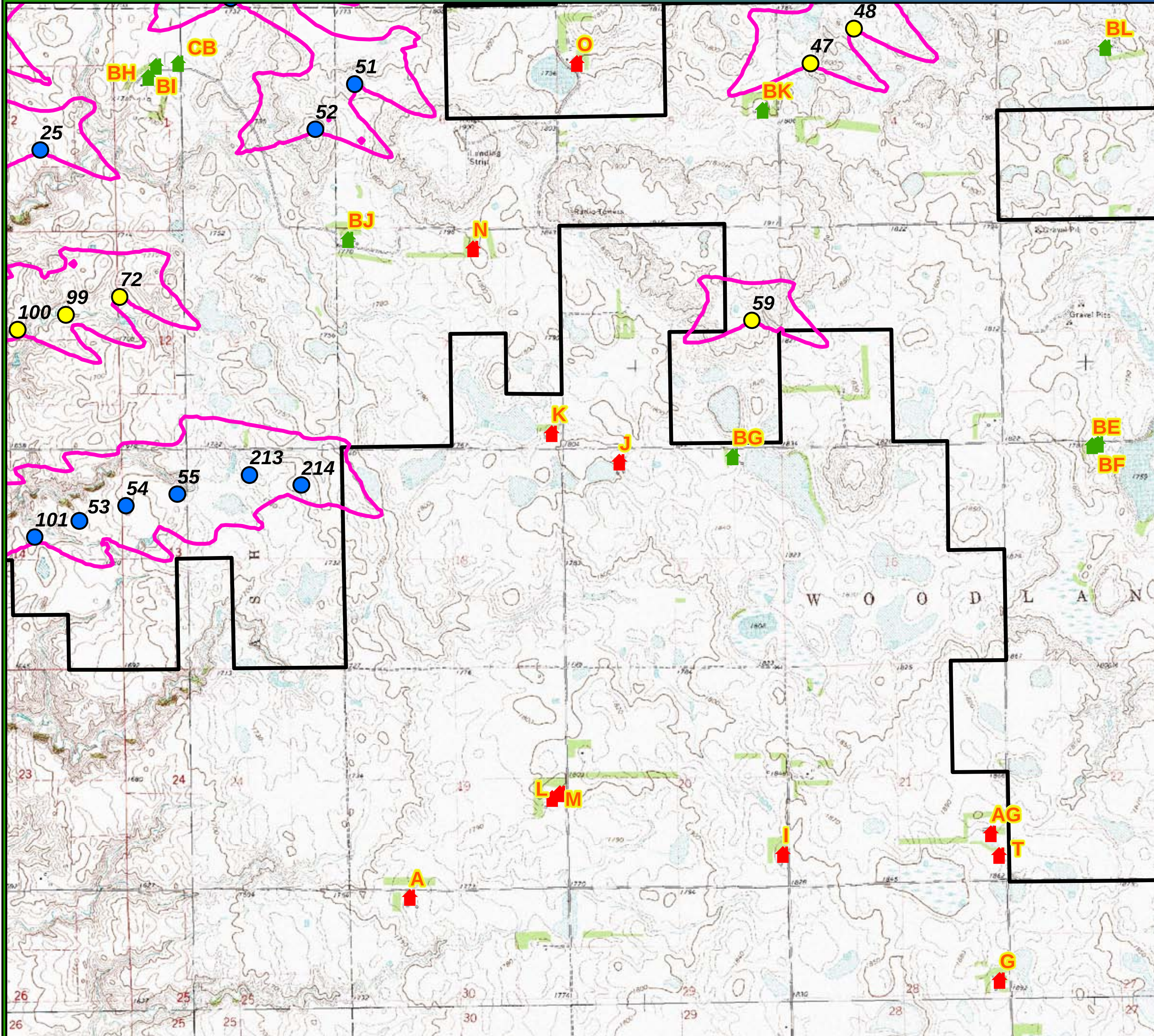

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Non-Participating

Participating

Shadow Hours Per Year

30

Project Boundary

Crocker Wind Farm Shadow Flicker

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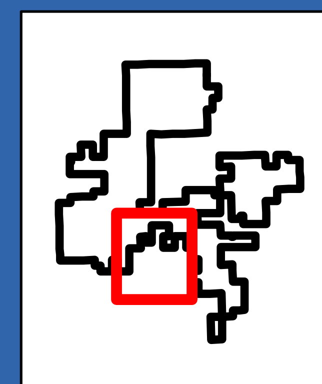

3,900 1,950 0 Feet

CROCKER WIND FARM

Clark County, SD

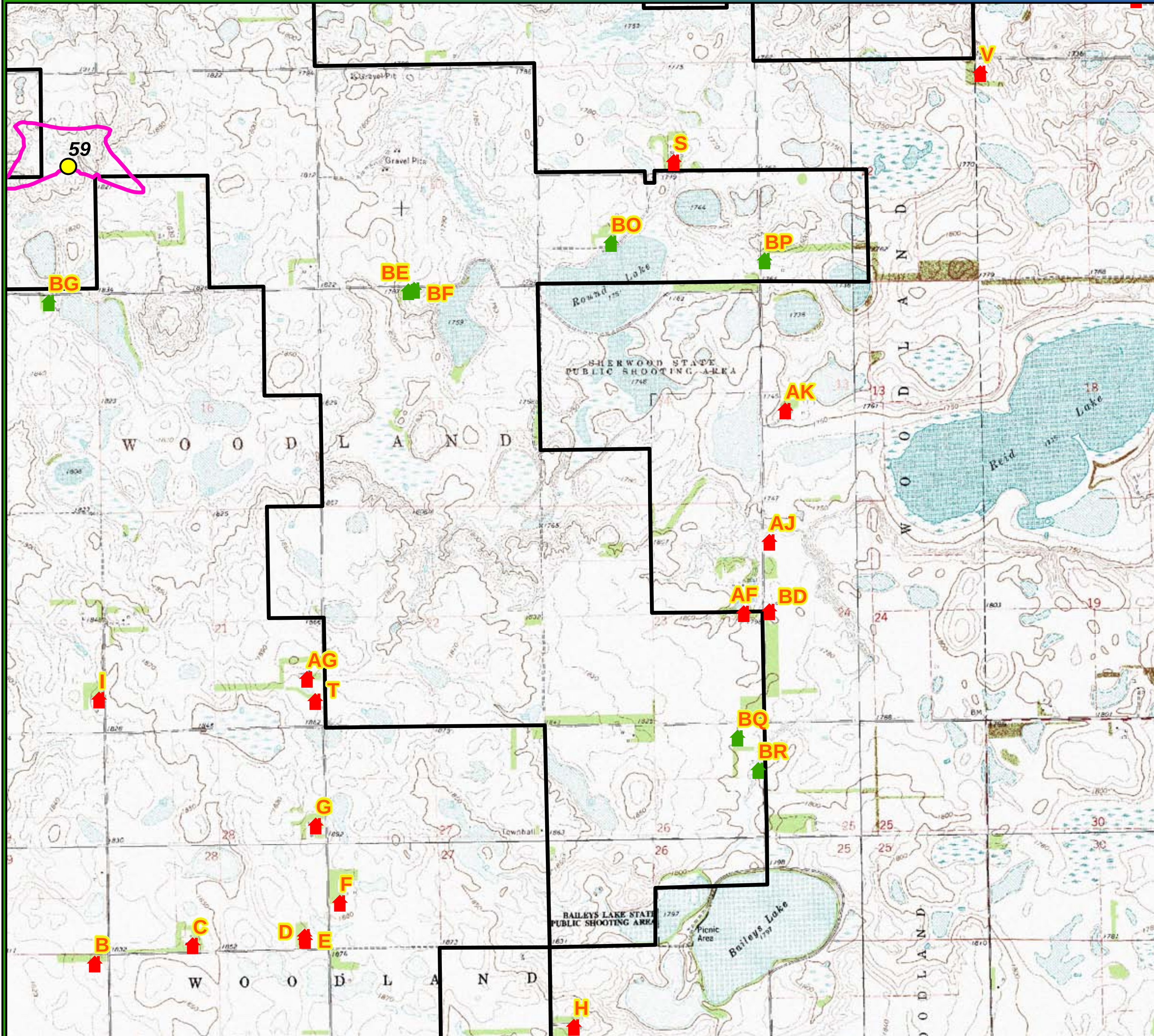

EXHIBIT D

Turbine Status

- Alternate
- Primary

Shadow Receptor Status

- Non-Participating
- Participating

Shadow Hours Per Year

- 30

Project Boundary

Crocker Wind Farm Shadow Flicker

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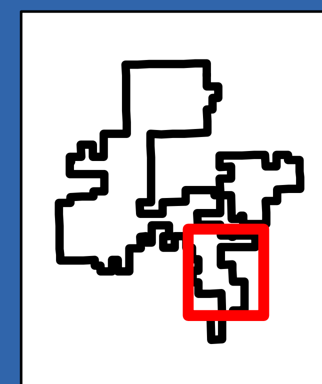

3,900 1,950 0 Feet

CROCKER WIND FARM
Clark County, SD