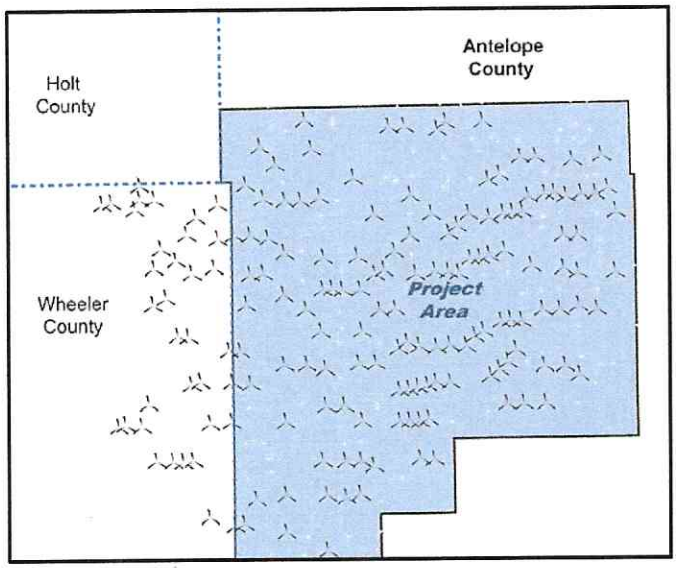
Wind Turbine Noise Analysis

for the proposed

Thunderhead Wind Energy Project

Antelope County, Nebraska

October 8, 2018



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HANKARD ENVIRONMENTAL
ACOUSTICS AND VIBRATION CONSULTING

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1. Introduction

The proposed Thunderhead Wind Energy Project (Project) is on private and state land in Antelope, Wheeler, and Holt Counties, Nebraska as shown in Figure 1. The Project intends to permit 171 wind turbines, with 137 located in Antelope County and 34 in Wheeler County, which will have a total load capacity up to 300 MW. The Project is proposing to use either the General Electric (GE) 2.52-127 or the GE 3.83-130 turbines. A new electrical substation is proposed to be in Antelope County and electrical transmission lines in Holt County.

Noise from the proposed wind turbines and substation must comply with applicable sections of Antelope County, Nebraska zoning regulations. Compliance with the numerical standards contained in this regulation is demonstrated herein by the results of an accurate, detailed, and conservative mathematical model of noise from the Project at all occupied non-participating residences in the area. This report provides a description of the applicable noise regulations, the Project site, the noise modeling methodology and input data used in the analysis, and the predicted noise levels and demonstration of regulatory compliance.

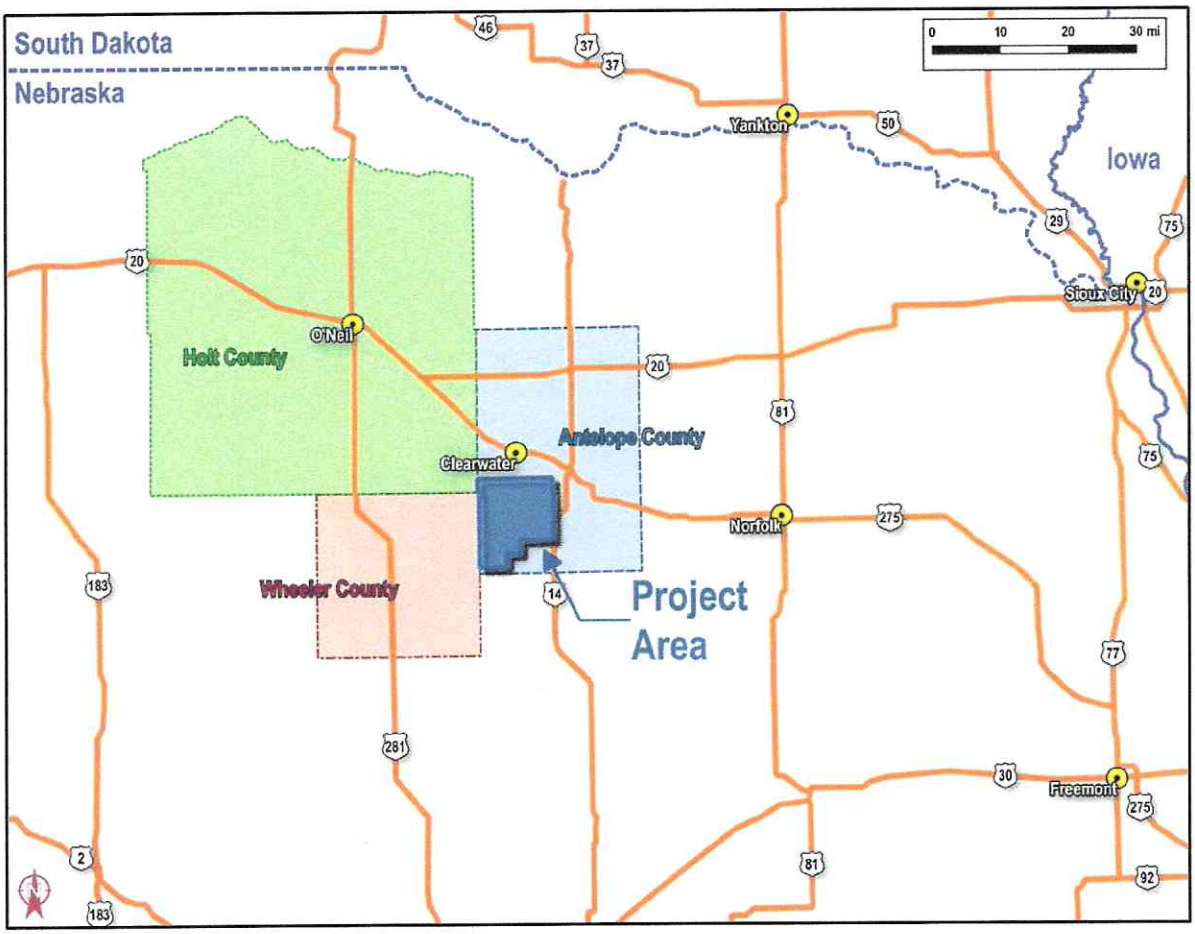


Figure 1: General Location of the Thunderhead Wind Energy Project

2. Applicable Noise Standard

Antelope County has specific regulations concerning noise emissions from utility scale wind turbine farms as defined by *Zoning Resolution (2017) – Article 8: Supplemental regulations – Section 8.08 Commercial / Utility Grade Wind Energy Systems – Subsection 8.08.06 Special Safety and Design Standards and Additional Requirements – 12. Noise,* which states:

> 1. Noise: A noise/sound limit of 50-decibels shall be hereby set and shall not be exceeded by any individual wind turbine facility or close group of wind turbine facilities and upon any adjoining, non-participating landowner's occupied dwelling; based upon ANSI testing requirements.
>
> Exception: A Commercial/Utility WECS may exceed 50 dBA during periods of severe weather as defined by the US Weather Service or during shut down or restart for normal maintenance.
>
> 2. All noise standards shall be based upon ANSI S12.18 standards, or successor standards and shall be per the Leq_{10} (10-minute) standards.
>
> 3. The Zoning Administrator shall be notified by any person, of a violation of said noise/sound limit. Said notification and complaint shall be made to the Zoning Administrator and must be accompanied by written substantiating evidence including an independent physical and scientific sound/acoustical study documenting the suspected violation. The Zoning Administrator will review the study and its findings, report the findings to the Board of Commissioners and address any violation found accordingly.

3. Project Site

In general, the land in and around the Project area is primarily used for cultivated agriculture and livestock grazing. A general site plan of the proposed Thunderhead Wind Energy Project (Layout L030) is shown in Figure 2 and more detailed site plan figures are provided in Appendix A. The Project is proposing to permit a total of 171 wind turbines overall with 137 of those wind turbines and an electrical substation located in Antelope County. The remaining 34 proposed wind turbines are planned to be permitted in Wheeler County. Noise levels were predicted at each of the 133 non-participating residences located within the Project area in Antelope County. Noise levels at more distant residences will be well below those described herein, and well below the applicable limits. The Universal Transverse Mercator (UTM) coordinates of each residence, turbine, and transformer are provided in Appendix B, C, and D, respectively. If the Project Applicant changes the layout or turbine type this noise analysis should be updated accordingly and compliance again demonstrated.

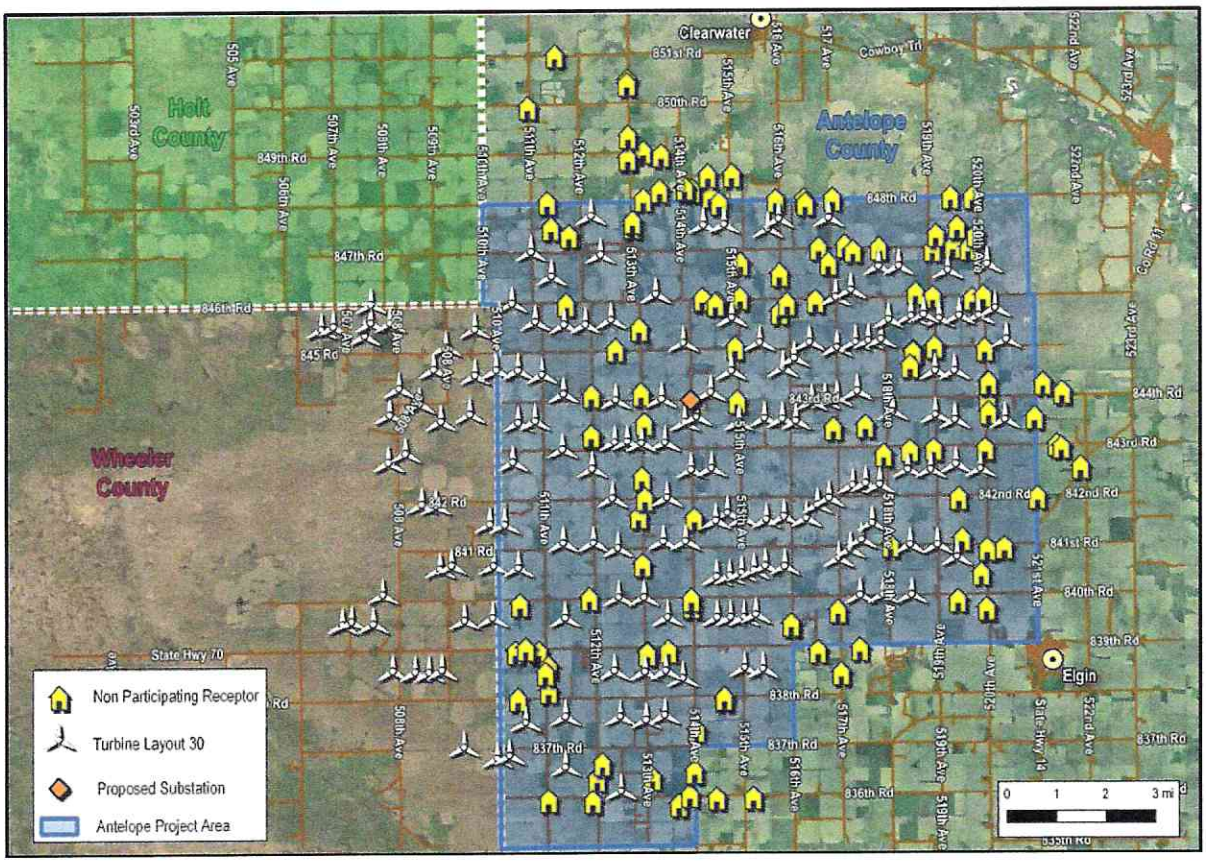


Figure 2: General Site Plan (Layout L030) of the Thunderhead Wind Energy Project

4. Noise Modeling Methodology

Noise levels from the proposed Thunderhead Wind Energy Project were predicted using the International Organization for Standardization (ISO) method 9613-2 (1996), *Attenuation of Sound During Propagation Outdoors*. The method was implemented using the SoundPLAN v7.4 acoustical modeling software program. A sample view of the resulting acoustical model is provided in Figure 3.

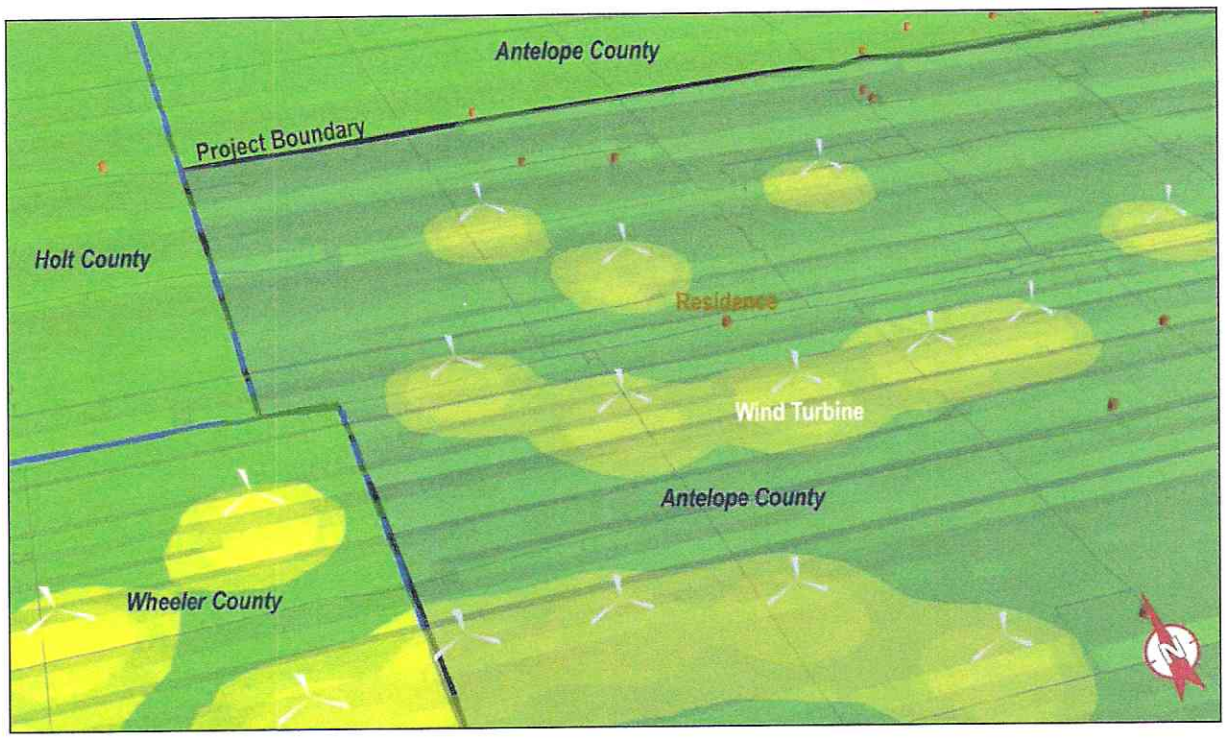


Figure 3: Three-Dimensional View of the Thunderhead SoundPLAN Noise Model

Terrain

The ground elevation contours in the project area, taken from the USGS National Elevation Dataset, were imported into the model. The acoustical effect of the ground was modeled using the ISO 9613-2 "general method". This requires the selection of ground factors for the ground near the source, near the receiver, and between the two. Ground factors range from 0.0 to 1.0 and effect how much sound is absorbed or reflected such that 0.0 represents completely reflective terrain such as pavement, and 1.0 represents absorptive terrain such as thick grass or crops. For this project a ground factor of 0.0 (completely reflective) was used to be conservative. Actual ground conditions could, at rare times, be 0.0 when the ground is completely frozen, but would generally be closer to 0.5 when the ground is covered with new snow, crops, or the ground is bare and unfrozen. In addition, the model was constrained to not calculate any noise reduction due to terrain barriers, which also helps provide more conservative noise level predictions.

Atmospheric Conditions

The air temperature, relative humidity, and atmospheric pressure were set to standard day conditions of 10°C, 70%, and 1 atmosphere, respectively.

Noise Receivers

In the SoundPLAN model receivers (prediction points) were located at each of the 133 non-participating residences located within the Project area in Antelope County. The location of each residences was provided by Thunderhead Wind Energy, LLC. The coordinates of each residence are provided in Appendix B. In accordance with ISO 9613-2, the height above the ground for each receiver was set to 5 feet (1.5 meters).

Noise Sources

The location of each of the 171 proposed wind turbines and the substation were provided by Thunderhead Wind Energy, LLC (Layout L030, September 28, 2018). The Project proposes to utilize either the General Electric (GE) 2.52-127 or GE 3.83-130 model wind turbine with the substation being comprised of two GSU transformers rated at approximately 185 Mega Volt Amps (MVA). All noise sources were represented as an acoustical point source with each turbine located at its hub-height above the ground (88.6 meters for GE 2.52-127 and 81.5 meters for the GE 3.83-130) and each transformer located 3 meters above the ground. No directivity was applied to the noise sources, thus assuming maximum sound emission in all directions.

Table 1 shows the sound power levels used in this analysis. The wind turbine sound power level data are provided by General Electric and were determined according to *International Electrotechnical Commission (IEC) Standard 61400-11*. In general, wind turbine noise emissions increase with increasing wind speeds up to approximately 10 meters per second as measured at a height of 10 meters. The maximum noise emission values were used in the analysis (10 m/s).

The transformer sound power levels shown in Table 1 were obtained from published sources that utilized measurements of existing similar facilities together with predicted levels based on *National Electrical Manufacturers Association (NEMA) TR 1 Transformers, Regulators, and Reactors.* The transformer sound power levels in Table 1 represent the maximum expected transformer noise emission levels.

Table 1: Sound Power Levels (dBA)

Center Frequency (Hz)	16	31.5	63	125	250	500	1,000	2,000	4,000	8,000	Overall
GE 2.52-127 Turbine	69.9	83.9	93.8	99.3	102.4	104.9	104.4	100.5	93.3	76.5	110.0
GE 3.83-130 Turbine	61.9	76.1	88.0	96.7	100.1	101.1	101.2	98.7	90.2	69.8	107.0
Transformer	---	69.6	79.8	87.9	92.4	96.8	94.9	87.2	80.0	71.9	101.4

Validation of Noise Prediction Method

The noise level prediction method employed on this Project has been validated by a number of acoustical consultants, including Hankard Environmental. This involves the comparison of predicted noise levels to those measured at operating wind farms. The results of these validation comparisons consistently show that the acoustical model used in this analysis over-predicts maximum wind turbine-only noise levels by approximately 1 dBA.

The validation assessments compared predicted noise levels to the highest measured turbine-only noise levels. A majority of the time, the operating turbine noise levels will be less than the model predictions due to either less than full turbine operation in moderate and low wind conditions, or atmospheric conditions not being as ideal for propagation as represented in the model.

In summary, the noise levels predicted from the operation of the Thunderhead Wind Energy Project described herein are expected to be higher than those experienced once the Project becomes operational.

5. Predicted Noise Levels

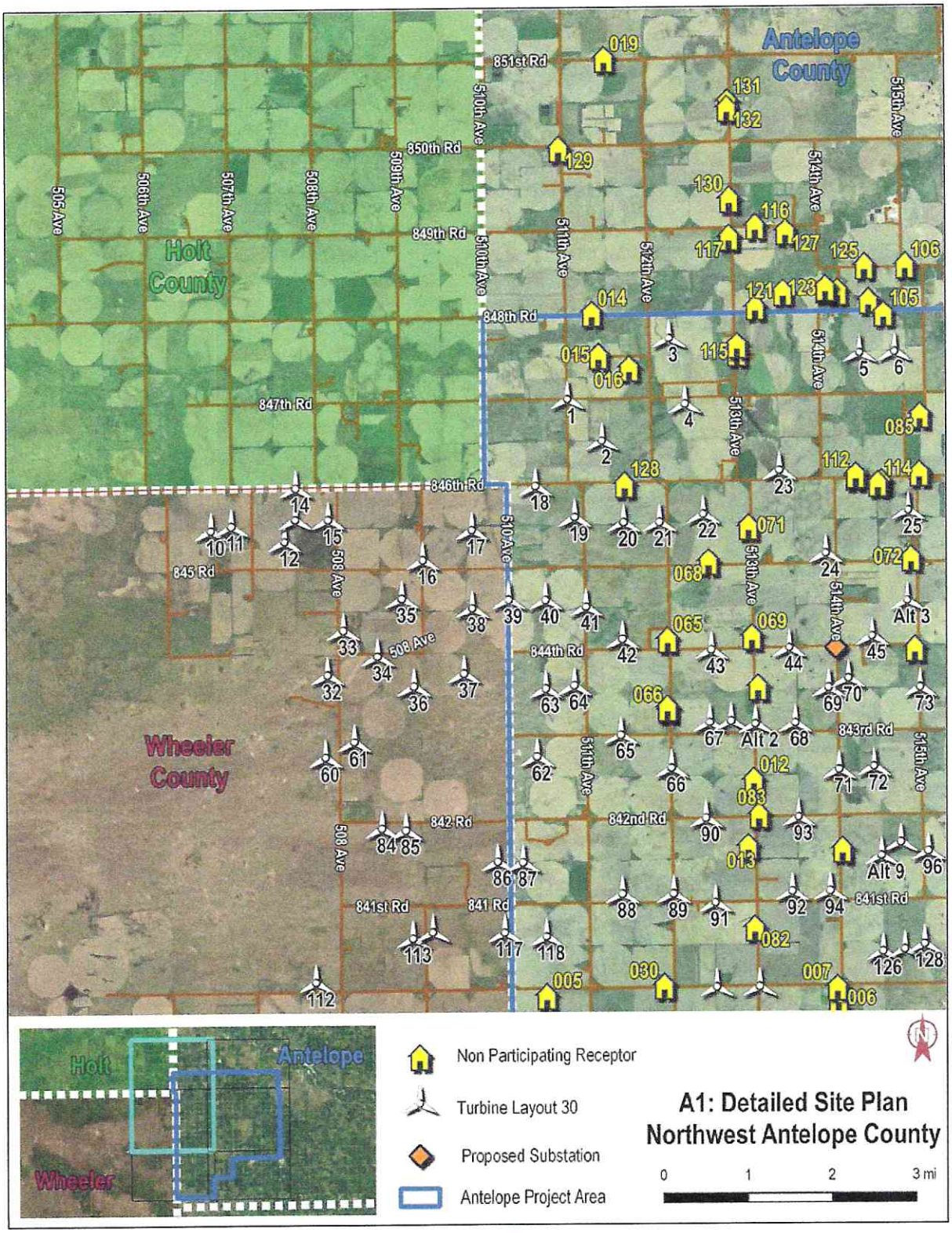
Noise levels from the full and continuous operation of the Thunderhead Wind Energy Project (Layout L030), which includes 137 wind turbines and a substation in Antelope County and 34 wind turbines in Wheeler County, were predicted at each of the closest 133 non-participating residences located within the study area inside Antelope County. Noise levels were predicted using either the GE 2.52-127 or the GE 3.83-130 wind turbine model.

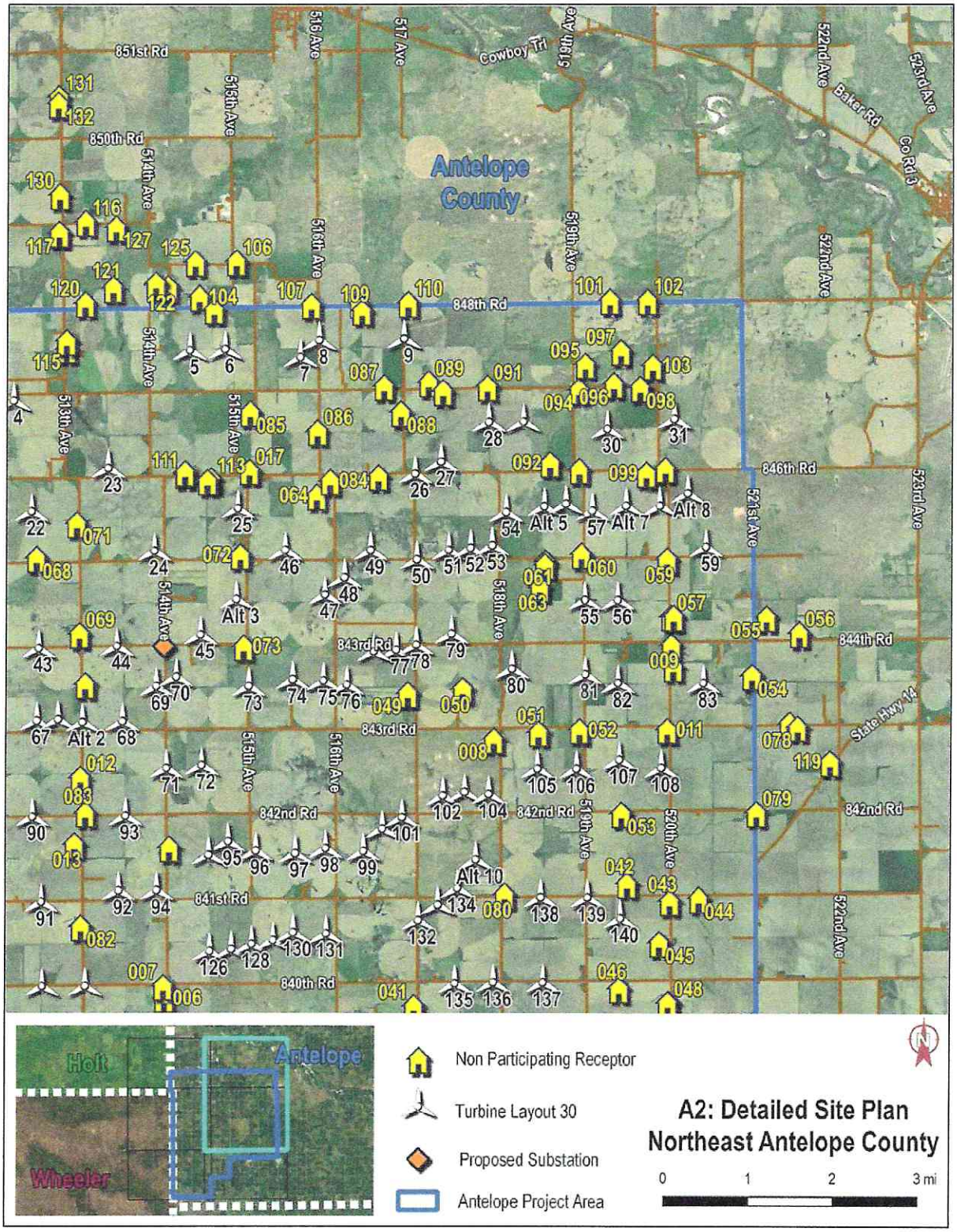
The predicted wind turbine noise levels range from 31.7 to 49.3 dBA for the GE 2.52-127 model and 28.4 to 46.3 dBA for the GE 3.83-130 model. The predicted levels at each residence are listed in Appendix E. None of the predicted noise levels exceed the 50 dBA Antelope County limit.

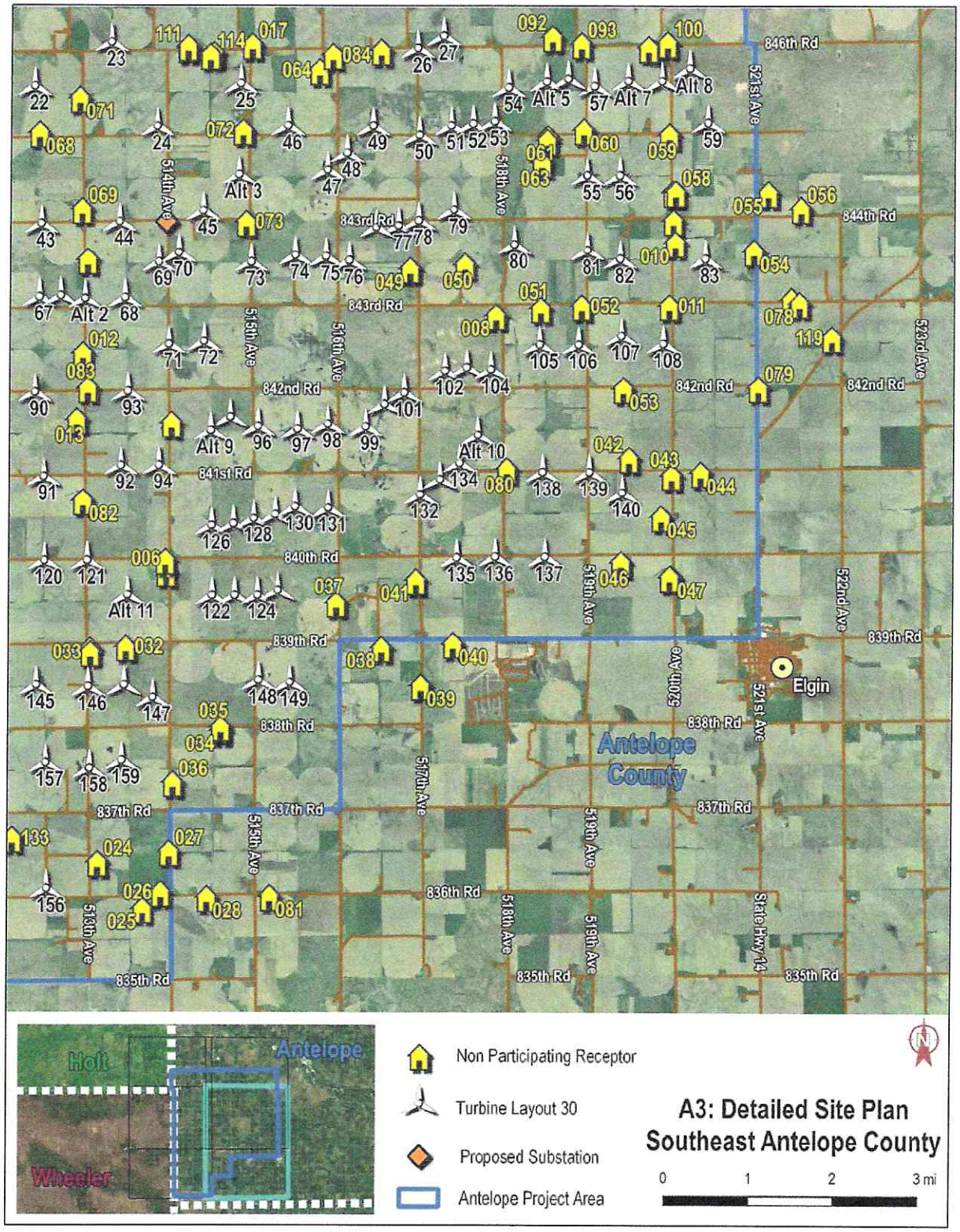
In summary, the noise levels experienced once the Thunderhead Wind Energy project becomes operations are expected to be lower than what is predicted by this analysis.

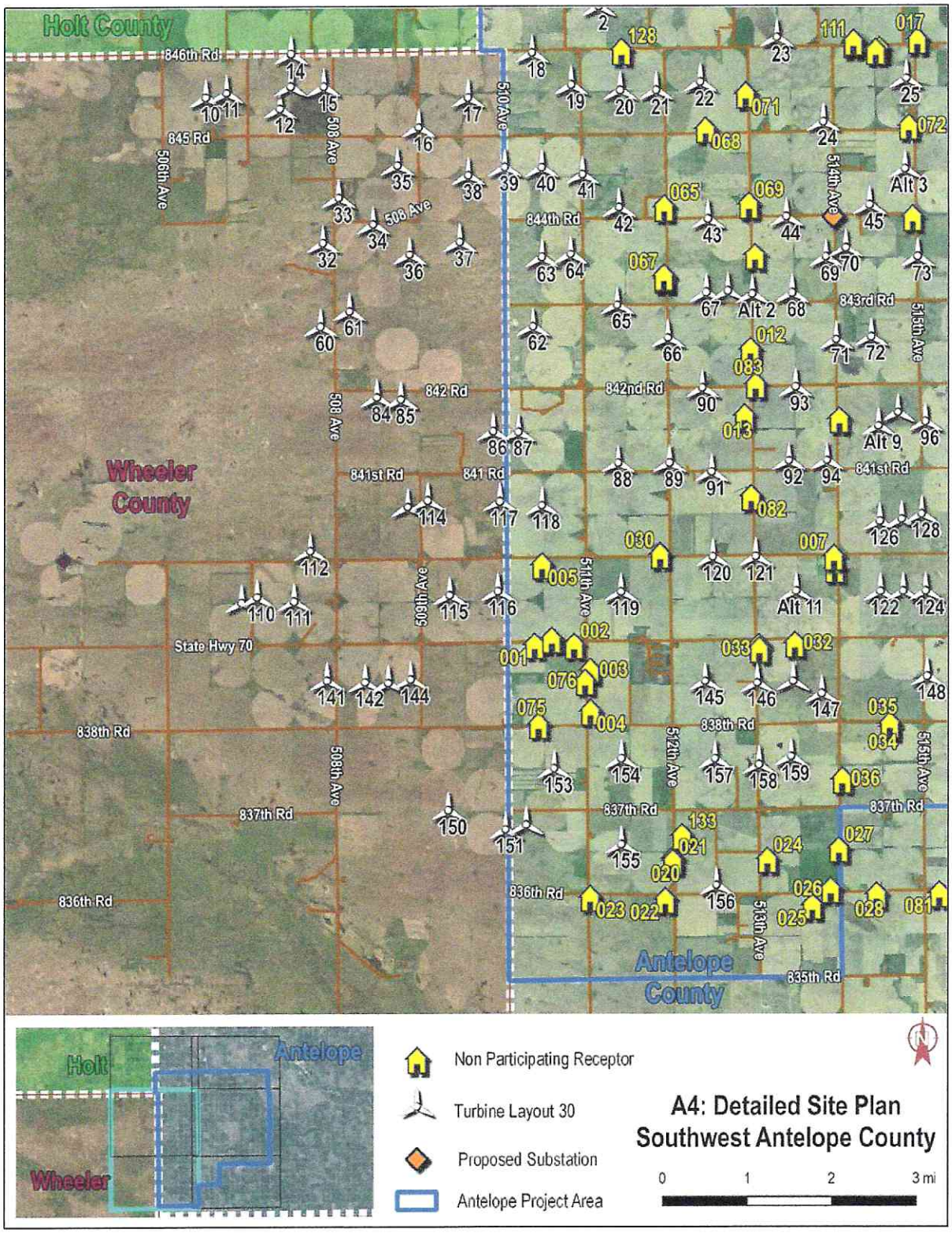
APPENDIX A

Detailed Site Plan Figures


Antelope County
Holt County
Wheeler County
851st Rd
850th Rd
849th Rd
848th Rd
847th Rd
846th Rd
845 Rd
844th Rd
843rd Rd
842 Rd
842nd Rd
841st Rd
841 Rd
505 Ave
506th Ave
507th Ave
508th Ave
509th Ave
510th Ave
511th Ave
512th Ave
513th Ave
514th Ave
515th Ave
508 Ave
Alt 2
Alt 3
Alt 9
Non Participating Receptor
Turbine Layout 30
Proposed Substation
Antelope Project Area
A1: Detailed Site Plan
Northwest Antelope County
0 1 2 3 mi


Antelope County
851st Rd
850th Rd
848th Rd
846th Rd
843rd Rd
842nd Rd
841st Rd
840th Rd
844th Rd
Cowboy Trl
Baker Rd
Co Rd 3
State Hwy 14
513th Ave
514th Ave
515th Ave
516th Ave
517 Ave
518 Ave
519th Ave
520th Ave
521st Ave
522nd Ave
523rd Ave
Alt 2
Alt 3
Alt 5
Alt 7
Alt 8
Alt 10
Holt
Antelope
Wheeler
Non Participating Receptor
Turbine Layout 30
Proposed Substation
Antelope Project Area
A2: Detailed Site Plan
Northeast Antelope County
0 1 2 3 mi


Antelope County
Elgin
Holt
Antelope
Wheeler
Non Participating Receptor
Turbine Layout 30
Proposed Substation
Antelope Project Area
A3: Detailed Site Plan
Southeast Antelope County
0 1 2 3 mi


Holt County
Wheeler County
Antelope County
846th Rd
845 Rd
844th Rd
843rd Rd
842 Rd
842nd Rd
841st Rd
841 Rd
838th Rd
837th Rd
836th Rd
835th Rd
State Hwy 70
506th Ave
508 Ave
508th Ave
509th Ave
510 Ave
511th Ave
512th Ave
513th Ave
514th Ave
515th Ave
Alt 2
Alt 3
Alt 9
Alt 11
Non Participating Receptor
Turbine Layout 30
Proposed Substation
Antelope Project Area
A4: Detailed Site Plan
Southwest Antelope County
0
1
2
3 mi
Holt
Antelope
Wheeler

APPENDIX B

Non-Participating Residence Locations

Receptor ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
1	558858	4648587	617
2	559608	4648579	626
3	559919	4648101	622
4	559924	4647321	627
5	559000	4650115	622
6	564567	4650036	625
7	564548	4650267	578
8	570798	4654960	613
9	574156	4656761	581
10	574195	4656336	600
11	574086	4655152	609
12	562957	4654226	606
13	562847	4652957	576
14	559897	4663187	596
15	560023	4662364	559
16	560605	4662128	606
17	566138	4660079	573
18	568592	4659971	606
19	560151	4667998	600
20	561489	4644511	608
21	561490	4644457	615
22	561349	4643733	616
23	559921	4643772	626
24	563286	4644493	613
25	564145	4643617	618
26	564494	4643925	614
27	564647	4644696	627
28	565366	4643830	620
29	559183	4648695	611
30	561243	4650304	619
31	563120	4648570	624
32	563803	4648609	617
33	563128	4648506	627
34	565617	4647015	627
35	565613	4647078	600
36	564711	4646020	614
37	567793	4649453	629
38	568659	4648596	614
39	569406	4647873	626
40	570013	4648669	615
41	569304	4649886	626
42	573339	4652219	625
43	574147	4651888	617
44	574701	4651941	606
45	573953	4651098	579
46	573198	4650224	602
47	574148	4649953	582
48	574121	4649952	583
49	569162	4655836	608
50	570200	4655915	590
51	571644	4655098	616
52	572419	4655145	601
53	573225	4653554	620
54	575689	4656180	575
55	575959	4657294	601
56	576581	4656994	598
57	574146	4657302	603
58	574198	4657303	603
59	574070	4658391	579
60	572441	4658482	576
61	571758	4658345	578
62	571750	4658283	577
63	571654	4657858	562
64	567420	4659600	573
65	561318	4656920	606
66	561331	4655577	600
67	561313	4655617	601
68	562107	4658411	595
69	562928	4656967	586
70	563041	4656004	589
71	562870	4659071	586
72	565972	4658463	592
73	566043	4656728	604
74	564649	4652895	620
75	558935	4647064	621
76	559821	4647891	622

Receptor ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
77	576403	4655273	601
78	576559	4655199	599
79	575784	4653577	594
80	571017	4652008	617
81	566562	4643850	593
82	562972	4651402	594
83	563054	4653555	606
84	567672	4659887	592
85	566150	4661198	619
86	567428	4660838	564
87	568692	4661695	568
88	569009	4661200	623
89	569535	4661767	607
90	569806	4661599	593
91	570648	4661685	590
92	571840	4660227	589
93	572393	4660098	549
94	572381	4661623	612
95	572502	4662108	618
96	573049	4661734	623
97	573179	4662365	606
98	573545	4661667	614
99	573669	4660031	546
100	574030	4660117	565
101	572966	4663342	588
102	573678	4663337	599
103	573783	4662089	584
104	565178	4663399	570
105	565462	4663156	602
106	565877	4664068	586
107	567304	4663254	589
108	568212	4663269	599
109	568264	4663137	566
110	569141	4663289	553
111	564911	4660008	573
112	564921	4660048	592
113	565412	4659910	607
114	565345	4659880	554

Receptor ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
115	562664	4662406	612
116	563015	4664828	589
117	562518	4664605	566
118	562515	4664622	564
119	577180	4654540	596
120	563015	4663289	575
121	563543	4663570	593
122	564584	4663579	597
123	564351	4663620	594
124	564354	4663649	549
125	565101	4664055	594
126	562665	4662558	612
127	563593	4664723	574
128	560511	4659891	595
129	559270	4666302	600
130	562523	4665335	600
131	562499	4667176	600
132	562489	4667054	600
133	561663	4644949	608

APPENDIX C

Turbine Locations

Turbine ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
1	559503	4661427	607
2	560161	4660629	599
3	561445	4662589	575
4	561742	4661327	606
5	565084	4662288	600
6	565750	4662309	609
7	567181	4662157	567
8	567536	4662481	583
9	569147	4662510	593
10	552697	4658933	585
11	553087	4659017	550
12	554103	4658719	570
13	554307	4659137	579
14	554315	4659742	580
15	554934	4659135	587
16	556738	4658354	596
17	557674	4658920	597
18	558890	4659759	598
19	559634	4659159	585
20	560570	4659056	561
21	561253	4659057	566
22	562090	4659209	598
23	563543	4660036	553
24	564427	4658454	578
25	566005	4659264	580
26	569366	4659928	599
27	569857	4660161	561
28	570760	4660924	618
29	571414	4660931	610
30	573006	4660793	589
31	574277	4660986	612
32	554914	4656156	609
33	555215	4657009	614
34	555873	4656510	587
35	556337	4657620	602
36	556563	4655933	592
37	557514	4656172	605
38	557679	4657427	604
39	558373	4657589	611
40	559074	4657579	611
41	559848	4657446	600
42	560543	4656822	604
43	562234	4656607	608
44	563718	4656645	605
45	565306	4656861	585
46	566906	4658468	604
47	567663	4657628	574
48	568031	4657953	597
49	568527	4658468	590
50	569406	4658295	604
51	570008	4658472	598
52	570420	4658511	563
53	570833	4658557	565
54	571094	4659195	592
55	572596	4657529	562
56	573219	4657529	562
57	572727	4659222	585
58	574009	4659317	597
59	574889	4658535	566
60	554872	4654581	605
61	555423	4654875	597
62	558907	4654578	595
63	559076	4655879	605
64	559618	4655938	596
65	560509	4654993	609
66	561471	4654354	617
67	562203	4655226	606
68	563830	4655214	609
69	564473	4655880	600
70	564849	4656058	607
71	564672	4654317	605
72	565337	4654373	583
73	566222	4655881	599
74	567061	4656009	587
75	567640	4655984	604
76	568083	4655911	589

Turbine ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
77	569018	4656575	576
78	569401	4656672	576
79	570066	4656880	612
80	571218	4656211	611
81	572607	4656106	614
82	573231	4655943	610
83	574850	4655945	601
84	555948	4653221	612
85	556401	4653183	610
86	558152	4652571	584
87	558633	4652557	596
88	560529	4651951	619
89	561503	4651952	614
90	562128	4653394	627
91	562303	4651778	610
92	563769	4651992	575
93	563895	4653412	607
94	564495	4651998	578
95	565845	4652923	599
96	566370	4652749	589
97	567120	4652697	612
98	567694	4652793	609
99	568414	4652743	578
100	568772	4653170	608
101	569148	4653388	604
102	569917	4653802	595
103	570328	4653867	613
104	570789	4653827	605
105	571709	4654310	603
106	572448	4654310	606
107	573263	4654480	611
108	574058	4654331	617
109	553377	4649305	620
110	553668	4649410	598
111	554372	4649330	582
112	554680	4650284	592
113	556533	4651117	616
114	556910	4651237	579
115	557329	4649441	622
116	558247	4649516	582
117	558281	4651219	601
118	559077	4651145	569
119	560585	4649507	591
120	562327	4650172	589
121	563142	4650176	578
122	565513	4649510	627
123	565945	4649516	620
124	566378	4649518	620
125	566765	4649608	622
126	565501	4650841	575
127	565916	4650880	617
128	566299	4650978	612
129	566709	4651053	622
130	567086	4651202	588
131	567712	4651179	613
132	569458	4651432	619
133	569830	4651725	614
134	570199	4652039	616
135	570156	4650228	618
136	570886	4650247	578
137	571829	4650246	582
138	571778	4651865	585
139	572667	4651864	595
140	573294	4651470	596
141	554999	4647811	627
142	555723	4647779	601
143	556167	4647763	616
144	556587	4647833	622
145	562184	4647795	626
146	563171	4647765	595
147	564398	4647561	602
148	566408	4647887	621
149	567002	4647847	600
150	557306	4645336	610
151	558396	4644973	626
152	558785	4645064	628

Turbine ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
153	559314	4646133	610
154	560596	4646317	614
155	560596	4644686	627
156	562402	4643909	642
157	562373	4646314	613
158	563207	4646205	645
159	563816	4646358	623
Alt 1	562611	4655252	575
Alt 2	563073	4655197	611
Alt 3	565981	4657541	565
Alt 4	568597	4656544	602
Alt 5	571815	4659306	577
Alt 6	572224	4659356	571
Alt 7	573370	4659317	593
Alt 8	574537	4659555	587
Alt 9	565475	4652666	591
Alt 10	570545	4652578	610
Alt 11	563908	4649520	622
Alt 12	563852	4647795	623

APPENDIX D

Substation GSU Transformer Locations

Source ID	UTM Zone 14		Ground Elevation (m)
	Easting (m)	Northing (m)	
Substation - Transformer 1 of 2	564524	4656726	605
Substation - Transformer 2 of 2	564544	4656726	605

APPENDIX E

Predicted Noise Levels

Receptor ID	Predicted Noise Level (dBA)	
	GE 2.52-127	GE 3.83-130
1	43.9	40.9
2	43.4	40.4
3	43.1	40.1
4	43.8	40.8
5	46.2	43.1
6	47.9	44.8
7	47.6	44.5
8	47.2	44.2
9	45.7	42.7
10	46.7	43.6
11	47	43.9
12	48.1	45.0
13	47.5	44.4
14	40.3	37.2
15	43.3	40.2
16	44.6	41.5
17	45.3	42.3
18	46.7	43.7
19	31.7	28.4
20	44.6	41.5
21	44.6	41.5
22	43	40.0
23	42.3	39.2
24	43	39.9
25	39.1	36.1
26	39	36.0
27	40.4	37.4
28	37.8	34.8
29	43.7	40.7
30	45.9	42.8
31	47.5	44.4
32	47.9	44.8
33	47.8	44.7
34	44.5	41.5
35	44.7	41.7
36	44.5	41.4
37	45.9	42.8

Receptor ID	Predicted Noise Level (dBA)	
	GE 2.52-127	GE 3.83-130
38	42.6	39.6
39	40.6	37.6
40	42.1	39.1
41	45.5	42.5
42	47.1	44.1
43	43.7	40.7
44	41.1	38.1
45	44.7	41.7
46	43.1	40
47	39.9	36.8
48	39.9	36.9
49	49.1	46.1
50	47.6	44.5
51	47.8	44.7
52	48.2	45.1
53	46.4	43.3
54	43.5	40.5
55	41.3	38.3
56	39.5	36.4
57	45.8	42.7
58	45.6	42.6
59	47.7	44.7
60	49.1	46
61	48.7	45.6
62	48.5	45.4
63	47.7	44.6
64	45.3	42.2
65	47.4	44.3
66	47.7	44.7
67	47.6	44.6
68	46.7	43.6
69	47.7	44.8
70	49.3	46.3
71	46.3	43.3
72	47.9	44.9
73	49.3	46.3
74	48.9	45.9

Receptor ID	Predicted Noise Level (dBA)	
	GE 2.52-127	GE 3.83-130
75	44	41
76	43	40
77	39.7	36.6
78	39.1	36.1
79	39.7	36.7
80	49.2	46.1
81	36.8	33.7
82	47.9	44.8
83	47.7	44.7
84	44.6	41.6
85	44.3	41.2
86	43.9	40.8
87	45	42
88	44.9	41.8
89	45.4	42.3
90	45.1	42.1
91	46.2	43.1
92	48.6	45.5
93	48.9	45.8
94	44.7	41.6
95	42.6	39.6
96	44.3	41.3
97	41.4	38.4
98	44.6	41.6
99	48.8	45.7
100	48.6	45.5
101	38.7	35.7
102	38.2	35.2
103	42.4	39.4
104	42.9	39.8
105	44.8	41.8
106	40.1	37
107	45	42
108	43.8	40.7
109	44.4	41.3
110	44.2	41.1
111	44.2	41.2
112	44.1	41.1
113	45.1	42.1
114	45	42
115	42.6	39.5
116	37	33.9
117	37.5	34.4
118	37.5	34.4
119	37.2	34.2
120	40.1	37.1
121	39.5	36.4
122	41	37.9
123	40.4	37.3
124	40.3	37.2
125	39.8	36.7
126	42.3	39.3
127	37.3	34.2
128	47.9	44.8
129	33.7	30.5
130	36.1	33
131	33.3	30.1
132	33.5	30.2
133	44.2	41.2