Noise Level Compliance Report

for the

Lake Winds Energy Park – Spring 2016 Noise Level Measurements

Mason County, Michigan

August 2016

Prepared for:

Mason County Michigan
Scottville, Michigan

Prepared by:

Hankard Environmental, Inc.
Verona, Wisconsin

HANKARD ENVIRONMENTAL
ACOUSTICS AND VIBRATION CONSULTING

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Executive Summary

Hankard Environmental conducted noise level measurements at the Lake Winds Energy Park (LWEP) in Mason County Michigan in the Spring of 2016. The measurements were conducted at the request of Mason County, and followed the procedures laid out in the April 2015 *Mitigation Plan Sound Testing Protocol* and the December 2015 *Consent Judgement*. The purpose of the measurements was to determine if noise emissions from the LWEP are in compliance with Section 17.70.17.a of the Mason County Zoning Ordinance, which states that noise from a wind energy facility cannot exceed 45 dBA the property line of an unpooled parcel on which there is an occupied building or dwelling. Measurements were conducted at four locations; two from previous measurement campaigns (Locations 2 and 5), and two new locations (Locations 9 and 10). Noise levels were measured during three different four-day surveys; one each in the months of March, April, and May 2016.

The Mason County noise limit applies only to noise generated by the wind turbine generators (WTG). However, microphones placed outside measure all noise that is present in the environment, including that from the WTGs and that from non-WTG sources such as traffic, aircraft, the activities of the homeowners, dogs, birds/insects/amphibians, and wind blowing across the microphone and through nearby vegetation. The measured data was analyzed in accordance with the LWEP *Mitigation Plan Sound Testing Protocol*, applicable portions of ANSI S12.9 Part 3 and ANSI S12.18, as well using methods developed by Hankard Environmental. The results of the noise level measurements and data analysis for each location are described below.

Note that, per the *Consent Judgement*, testing at Location 2 was conducted with the two closest turbines in Noise Reduced Operation Mode 1. For the purposes of this 2016 analysis, turbines operating in normal mode (NRO 0) were considered to be at "full electrical power" when their power output was 90% or more of full rated power (1,815 kw). Turbines operating in NRO 1 were considered to be operating at "full electrical power" when their power output was 80% or more of full rated power.

Location 5

The noise level data collected during the early morning hours of May 23rd are representative of loudest wind turbine conditions. The nearest turbine was operating at full electrical power, other nearby turbines were operating at or near full electrical power, the measurement location was downwind of the nearest turbines, and the atmosphere was stable and conducive to sound propagation. The loudest WTG-only 10-minute L_{eq} was 44 dBA. Adding to the validity of this data, multiple 10-minute data points were obtained during these conditions. Representative data was also collected at Location 5 on the night and morning of March 29th – 30th. During one 10-minute period of maximum turbine operations the loudest WTG-only 10-minute L_{eq} was 43.4 dBA. Based on all of the data collected at Locations 5 in 2016, we conclude that noise levels due to LWEP wind turbine operations are in compliance with Mason County's 45 dBA noise level limit. No additional testing is recommended at Location 5.

Location 2

Noise levels were measured on two occasions at Location 2, but neither represent loudest WTG conditions. On March 29 – 30, the nearest WTG operated at full electrical power for one 10-minute period, but at that time the three other nearest turbines were operating at about 50% of capacity, and the measurement location was upwind of the nearest turbine. On March 31st the nearest turbine never achieved more than about 60% of capacity. The 2nd, 3rd and 4th closest turbines did achieve full electrical power, but only sporadically and not necessarily at the same time. The loudest WTG-only noise level measured at Location 2 on March 29 - 30 was 43.3 dBA. On March 31 a level of 44.7 dBA was determined using the strict procedures outlined in the *Mitigation Plan Sound Testing Protocol*, but our field observations and further review of the measured data show that the WTG-only noise level was, at most, 44 dBA.

While we did not find any WTG-only noise levels above about 44 dBA at this location, we do not feel that we captured loudest WTG noise conditions. Based on all of the data we collected at Location 2, we cannot provide definitive conclusions regarding compliance with the Mason County noise level limit. We recommend continued testing at Location 2 in 2017.

With regard to NRO operation, we recommend that WTG-6 and WTG-15 near Location 2 be left in NRO Mode 2 until the Spring 2017 testing. This is based on the measurement data collected on March 29, 2016. On this night atmospheric conditions were conducive to maximum sound propagation, but three out of the closest four turbines were not at full electrical power production. We measured a maximum WTG-only noise level of about 43.4 dBA on this night. My calculations regarding how much louder the measured noise level would have been if all four of the nearest turbines were at full electrical power indicate that the full-production noise level could have been as high as 45.1 dBA. Given this result, and the uncertainty of the calculation, there is the possibility of exceeding 45 dBA if WTG-6 and WTG-15 are not placed into NRO 2.

With regard to NRO operation during the Spring 2017 measurements, we recommend testing with WTG-6 and WTG-15 in either NRO Mode 1 or Mode 0. For the purposes of determining maximum noise levels, these modes are acoustically equivalent according to Vestas technical documentation. That is, when hub-height wind speeds are 7 m/s or greater, noise emissions are the same in Modes 0 and 1. When hub-height wind speeds are in the 4 to 7 m/s range, NRO Mode 1 noise levels are about 0.5 to 1.5 dBA lower than Mode 0 noise levels. These turbines can be left in NRO Mode 1 or Mode 0 indefinitely if sufficient valid data is obtained at Location 2 in 2017, and the turbine-only sound level is determined to be less than 45 dBA. If, however, insufficient or inconclusive data are obtained in 2017, these turbines should be returned to NRO Mode 2 either indefinitely, or until such time that additional testing at Location 2 demonstrates compliance with the 45 dBA standard while WTG-6 and WTG-15 are in NRO Mode 0 or 1.

Location 10

Noise levels were measured on two occasions at Location 10 when the nearest turbine was producing full electrical power. On April 28th the nearest WTG operated at full electric power for two 10-minute periods, and during those times the three other nearest turbines were operating between 60 and 80% of full capacity. On April 25th the nearest WTG operated at full electric power for one 10-minute period, and during that time the three other nearby turbines were operating at about 50% of full capacity. The loudest WTG-only noise level measured at Location 10 was 43 dBA.

While we did not find any WTG-only noise levels above about 43 dBA at this location, we do not feel that we necessarily captured loudest WTG noise conditions. Therefore, based on all of the data we collected at Location 10, we cannot provide definitive conclusions regarding compliance with the Mason County limit. We recommend continued testing at this location in 2017.

Similarly, there is not enough valid data at Location 10 from the Spring 2016 measurements to recommend a propagation plan at this time. The need for a propagation plan should be reviewed after the Spring 2017 measurements, and should be based on the totality of the data measured at all sites in both 2016 and 2017.

Location 9

Noise levels were measured on one occasion at Location 9 when the nearest turbine was producing full electrical power. On April 28th the nearest WTG operated at full electric power for three 10-minute periods, and during those times the three other nearby turbines were operating at about 80% or greater. The loudest WTG-only noise level measured at Location 9 was between 43 and 44 dBA.

While we did not find any WTG-only noise levels above about 44 dBA at this location, we do not feel that we necessarily captured loudest WTG noise conditions. Therefore, based on all of the data we collected at Location 9, we cannot provide definitive conclusions regarding compliance with the Mason County limit. We do not recommend additional measurements at Location 9. There is a relatively high amount of traffic here, some full power data has been acquired, and as described below we prefer to focus on fewer sites. We do recommend reviewing the data from Location 9 after the 2017 testing, applying anything that was learned from the 2017 measurements and data analysis, and re-assessing compliance at Location 9 at that time. For example, if testing at other location(s) with similar turbine geometry and similar predicted noise levels indicates compliance, it might be reasonable to conclude the same for Location 9.

Similarly, there is not enough valid data at this location from the Spring 2016 measurements to recommend a propagation plan at this time. The need for a propagation plan should be reviewed after the Spring 2017 measurements, and should be based on the totality of the data measured at all locations in both 2016 and 2017.

Spring 2017 Noise Level Testing Recommendations

For the Spring 2017 measurements, the *Consent Judgement* mandates testing at Locations 1 and 6. As described above, we are recommending continued measurements at Locations 2 and 10. The *Consent Judgement* also mandates the selection of two, additional, measurement locations for 2017. We do not feel that this is in the best interest of this case, and recommend the *Consent Judgement* be amended to eliminate this requirement. We feel that testing at two sites on any given night is sufficient, having four sites to choose from is adequate, and Locations 1, 2, 6, and 10 provide a good representation of the LWEP as a whole. In general, we recommend measuring more data at fewer sites, versus less data at more sites. We also recommend that the turbines not be turned off unless and until field staff are confident that the turbine-only noise level being measured is approaching or exceeding 45 dBA. This procedure was implemented by Hankard Environmental for the last two weeks of 2016 testing, and is designed to maximize the amount of turbine-on noise data collected.

1. Introduction

The Lake Winds Energy Park (LWEP) is 100 megawatt utility grade wind energy system consisting of 56 Vestas V100 1.8-megawatt wind turbine generators located in Riverton and Summit Townships of Mason County, Michigan. The general location of the facility is shown in Figure 1-1, and the layout of the facility is shown in Figure 1-2. The LWEP was constructed in 2011 and 2012, and began commercial operation in November 2012.

Noise emissions from the LWEP must meet the sound level limits of the Mason County Zoning Ordinance. Post-construction sound studies were completed by other acoustical consultants in 2013, 2014, 2015. Testing in 2015 confirmed the mitigation measures (Noise Reduced Operation (NRO) Mode 2) in place at four of the eight original testing locations were both necessary and sufficient to maintain compliance. Pursuant to the December 2015 *Consent Judgement*, turbines near one of the eight original locations (Location 7) will remain in NRO Mode 2 for the remainder of operations. After three rounds of testing at one of the locations (Location 5) there was still no viable data for the Planning Commission to form a conclusion. Appeals and court proceedings have arisen from the previous testing results.

Through the terms of the December 2015 *Consent Judgement* between Mason County and Consumers Energy, Hankard Environmental, Inc. was selected by the Mason County Planning Commission as a new third party acoustical consultant. Hankard Environmental is a Wisconsin-based acoustical consulting firm with significant wind energy facility noise level measurement and analysis experience. The Commission requested that Hankard Environmental conduct a new post-construction sound survey per the terms of *Consent Judgement* and the *Mitigation Plan Sound Testing Protocol* (Appendix 2 to April 18, 2014 memorandum from Consumers Energy to Mason County, Revised April 2015).

Hankard Environmental conducted testing at four locations near the LWEP in the Spring of 2016. Testing was conducted during three four-day surveys; one in each of the months of March, April, and May 2016. This report describes the results of the measurements, the results of the analysis of the data, and conclusions regarding what the measured data do and not show about LWEP compliance with the sound level limits of the Mason County Zoning Ordinance. Also described herein are the sound level limits themselves, measurement locations, equipment, and procedures, as well as the procedures used to analyze the data, turbine and atmospheric conditions during the measurements, the measurement results, and the quality of the data as it pertains to demonstrating compliance.

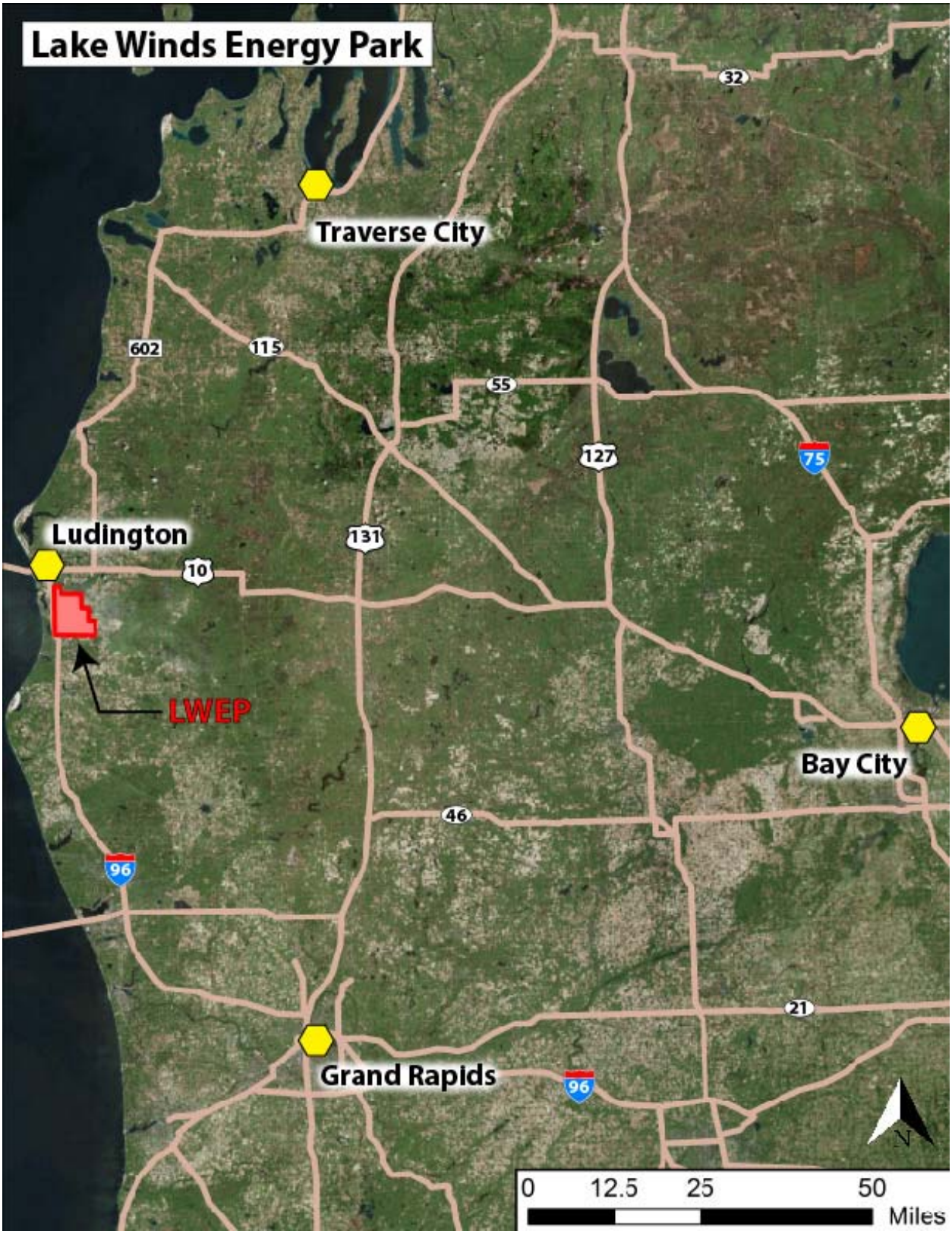

Figure 1-1: General Location of the LWEP

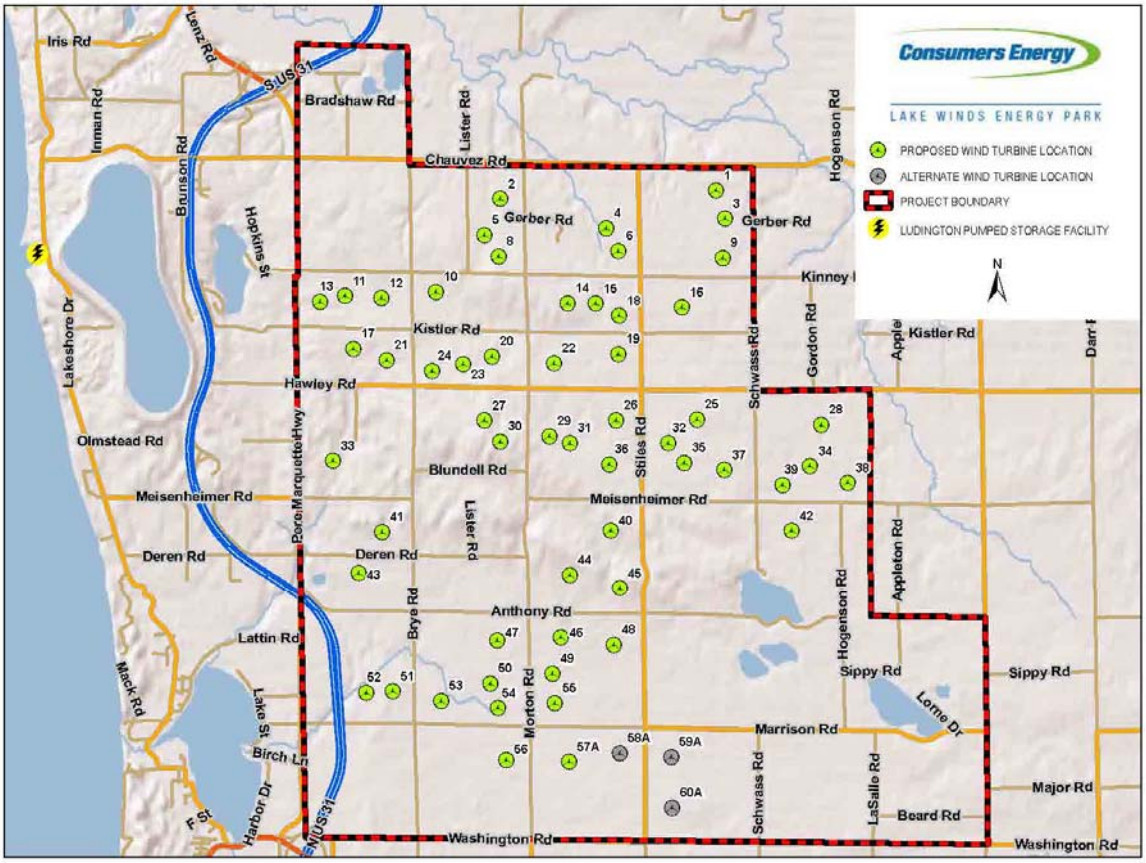

Figure 1-2: LWEP Layout

2. Applicable Noise Regulation

Noise emissions from the LWEP must adhere to the sound level limits contained within the Mason County Zoning Ordinance, Section 17.70, subsection 17.a. The pertinent portion of this ordinance is provided below.

17. Noise

a. Sound Level Limits.

1. The A-weighted equivalent sound level (LA_{eq}) measured at the property line of an unpooled (single) parcel (as defined in subsection 19 hereof) upon which there is an occupied building or dwelling shall not exceed 45 dBA. If the unpooled parcel does not have an occupied principal building or dwelling on it, then the 45 dBA sound limit may be exceeded at the property line; provided that when an occupied principal building or dwelling is built on such unpooled parcel after the special land use permit has been issued, the sound level shall not exceed 45 dBA measured at the nearest wall of the occupied building or dwelling located on the unpooled parcel and in compliance with the minimum required front, side and rear yard setbacks then in effect within the zoning district in which the occupied building or dwelling is located.

2. On a pooled parcel, the ten-minute LA_{eq} sound level measured at the wall of an occupied building nearest to the wind turbine or turbines shall not exceed 55 dBA.

3. These sound level limits are to be evaluated using the A-weighted equivalent sound level (LA_{eq}) descriptor. The LA_{eq} should be measured using a ten-minute time interval.

4. The sound level limits listed above apply to the contribution from the wind energy system only and do not include contributions from background ambient sounds.

3. Noise Measurement Equipment

All of the noise measurement equipment used on this project meet the Type 1 requirements of American National Standards Institute (ANSI) S1.4-1983 (R2006) *American National Standard Specification for Sound Level Meters*. Noise levels were measured using Bruel and Kjaer Type 2250 sound level meters and associated pre-amplifiers, and ½ inch diameter free-field precision microphones (Type 4951 outdoor microphone/pre-amplifier). All measurement and field calibration equipment was certified by a traceable laboratory within the past year (calibration certificates can be found in Appendix A). In addition, field calibrations were conducted before and after each measurement. The drift in the measured noise level was minimal (-0.1 to +0.1 over the entire measurement survey).

The microphones were mounted on tripods, and positioned approximately 1.5 meters above the ground (per ANSI S12.9). The microphones were covered with hydrophobically treated, seven-inch diameter, 80 pores per inch density windscreens (ACO Pacific Model WS7-80T). All electronic equipment was contained in weatherproof cases and was powered by batteries. Ground wind speed and direction were measured using Vaisala WINDCAP Ultrasonic Wind Sensor mounted on a tripod approximately 2 meters above the ground (per ANSI S12.18), and located within approximately 3 meters of the microphone. Figure 3-1 shows a picture of a typical noise/wind measurement configuration.

Sound level meters were time-synchronized to the LWEP control system to within approximately 2 seconds to allow for the integration of noise and ground wind data with WTG operations data. The sound level meters were configured to continuously measure and record 10-second averages of the following metrics: overall L_{eq}, L_{10}, L_{50}, and L_{90}, as well as one-third octave band L_{eq} levels (6.3 Hz to 10 kHz). The meters also logged ground wind speed and direction every 10 seconds.

Figure 3-1: Typical Noise/Wind Measurement Setup

4. Measurement Dates, Locations, and Procedures

4.1 Measurement Dates

Noise levels were measured during three different four-day surveys between March and May of 2016. After contracting was complete in mid-March, the weather forecast for the area was monitored on a daily basis. The first survey was scheduled as soon as sufficient nighttime wind speeds were forecast. Once on-site, measurements were conducted each night unless the wind turbines were not operating at sufficient capacity and not forecast to do so, or snow or rain was occurring. We generally stayed on-site for four to five nights, and only left when the forecast called for prolonged periods (days) of insufficient wind speeds or inclement weather. This process was repeated until three surveys had been completed. Table 4-1 lists the dates and times when measurements were conducted.

Table 4-1: Dates and Times of Noise Measurements – Spring 2016

Date (2016)	Start Time	End Time
March 29-30	10:00 pm	5:00 am
March 31	7:30 pm	12:00 am
April 24	9:10 pm	9:30 pm
April 25	4:40 pm	6:00 pm
April 26	3:00 pm	6:00 pm
April 28	1:00 am	4:40 am
May 23-24	11:00 pm	5:00 am
May 24	5:40 pm	7:00 pm

4.2 Measurement Locations

Noise levels were measured at four locations. Figures 4-1 through 4-4 show a map of each specific measurement location. As mandated by the *Mitigation Plan Sound Testing Protocol* and the *Consent Judgement*, measurements were conducted at Locations 2 and 5. As also mandated by these documents, measurements were conducted at two new locations selected by Hankard Environmental. These are denoted as Locations 9 and 10 herein. These two new locations were selected as follows:

1. The process started by reviewing the list of predicted noise levels contained in Appendix C (Table C-1) of the report entitled *Acoustic Study of the Lake Winds Energy Park* (prepared by Tech Environmental, Revised June 2011). We focused on the locations with the highest predicted noise levels (44.5 dBA or greater).

2. From this list of approximately 20 locations we identified locations with the closest turbines situated to the west/southwest or east directions. This is because (a) historical wind data show these to be the primary wind directions in the spring in this area, and (b) to compliment the fact that the two mandatory locations have nearest turbines in the

north and south directions (thus giving field personnel options on any given night depending on wind direction).

3. We sought locations that had less vegetation located nearby (primarily large trees).

4. Finally, we required permission from the landowner.

Table 4-2 lists, for each measurement location, the distance and direction to the closest four WTGs (the direction listed is that which places the measurement location downwind of each turbine).

Table 4-2: Distance and Direction from Measurement Location to Nearest Turbines

Location	Nearest Distance (feet)	Nearest Direction (degrees)	2nd Distance (feet)	2nd Direction (degrees)	3rd Distance (feet)	3rd Direction (degrees)	4th Distance (feet)	4th Direction (degrees)
2	WTG-6		WTG-15		WTG-4		WTG-18	
	1,040	20	1,650	210	2,040	0	2,100	170
5	WTG-25		WTG-32		WTG-35		WTG-26	
	1,130	160	2,300	210	3,000	180	3,450	260
9	WTG-18		WTG-16		WTG-15		WTG-19	
	1,200	250	1,900	100	2,140	270	2,500	210
10	WTG-47		WTG-46		WTG-49		WTG-50	
	1,430	280	1,560	80	1,780	140	2,530	220

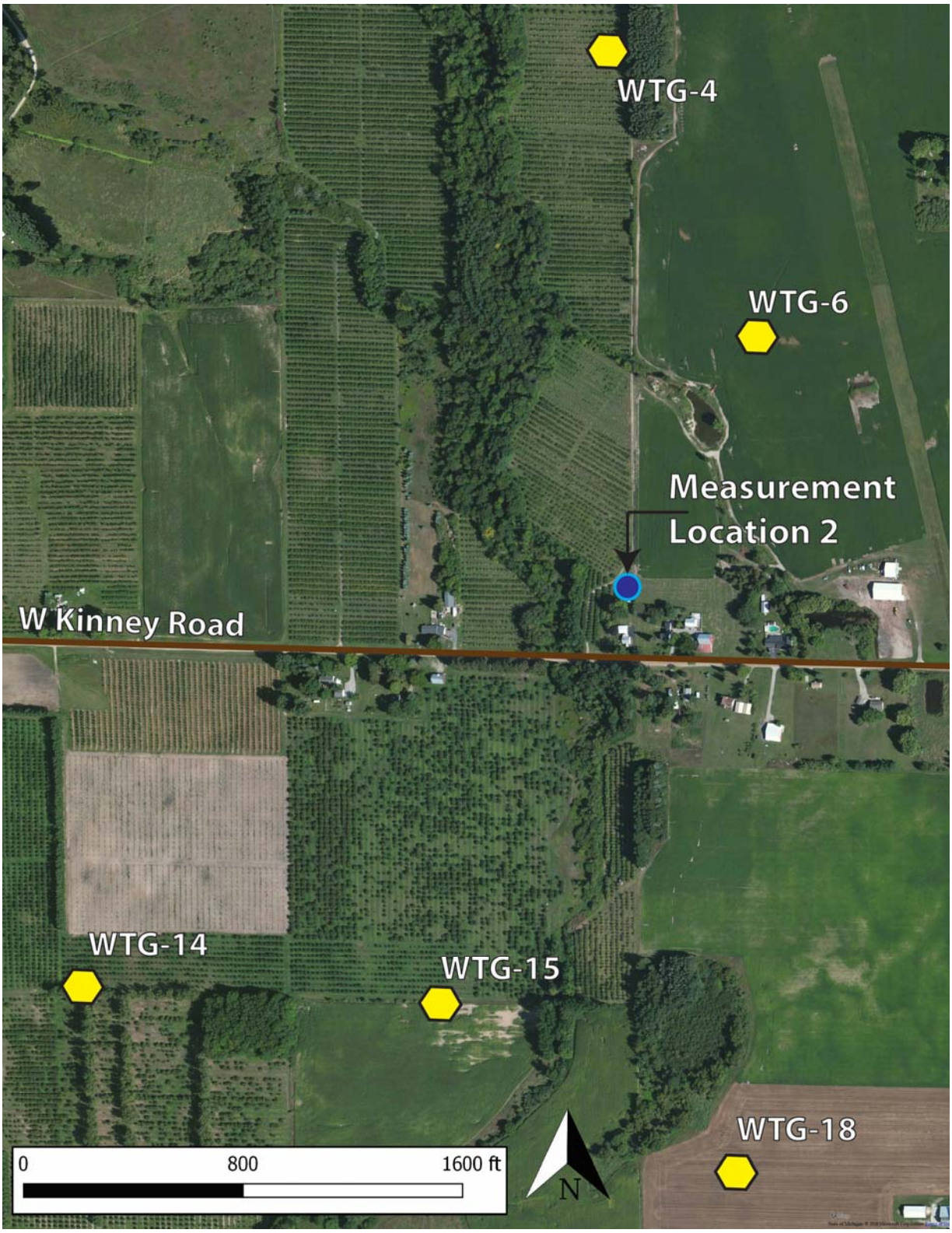

Figure 4-1: Map of Measurement Location 2

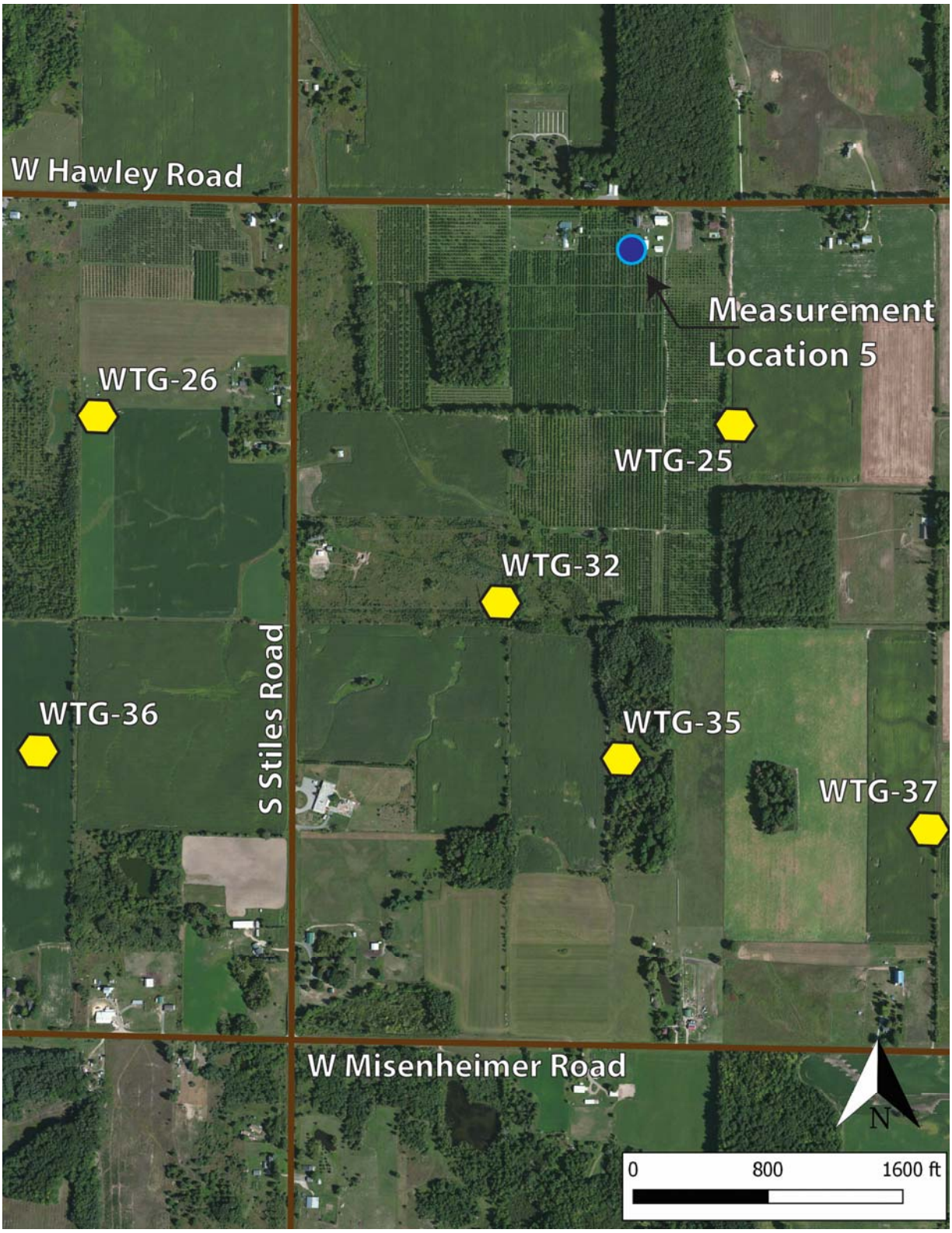

Figure 4-2: Map of Measurement Location 5

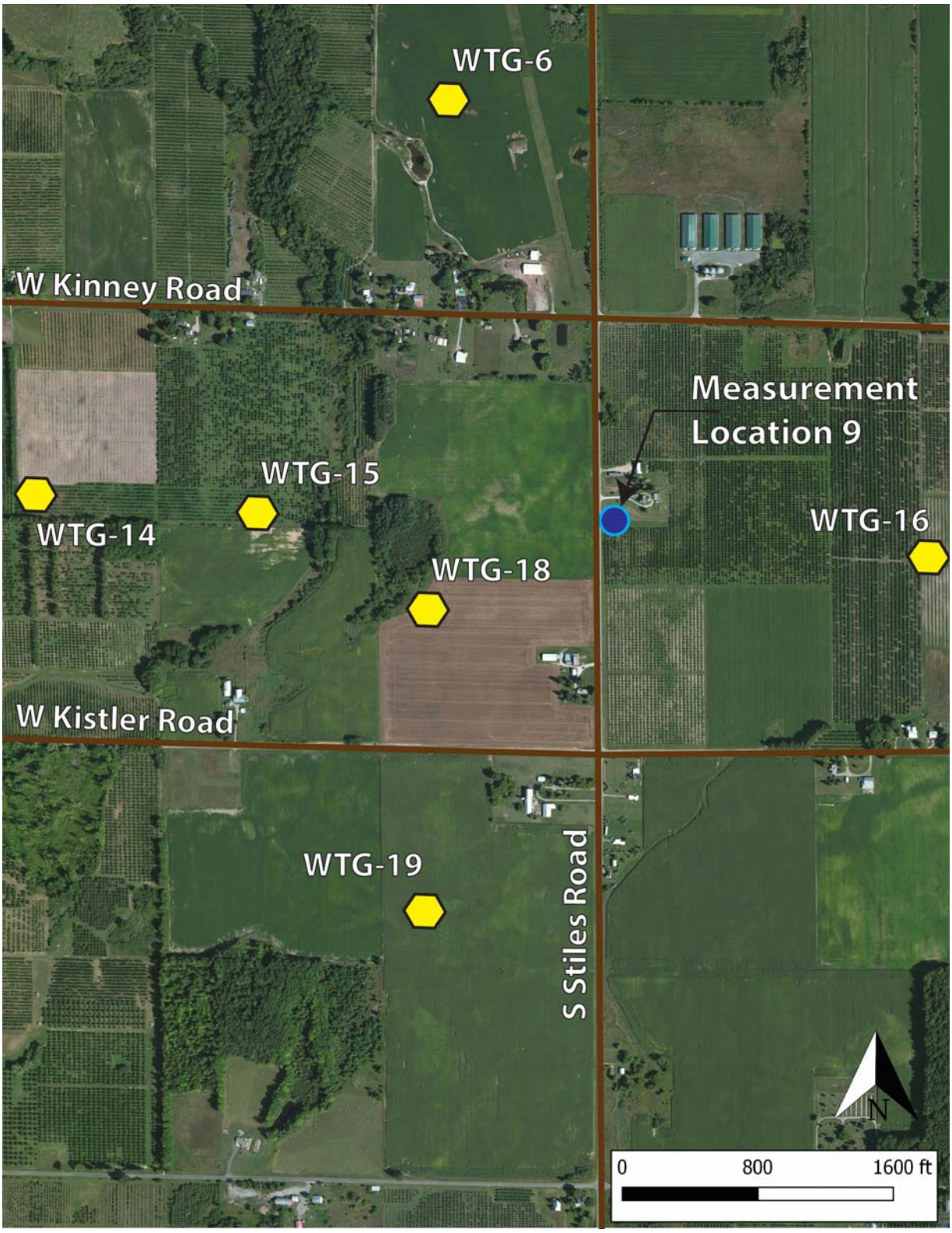

Figure 4-3: Map of Measurement Location 9

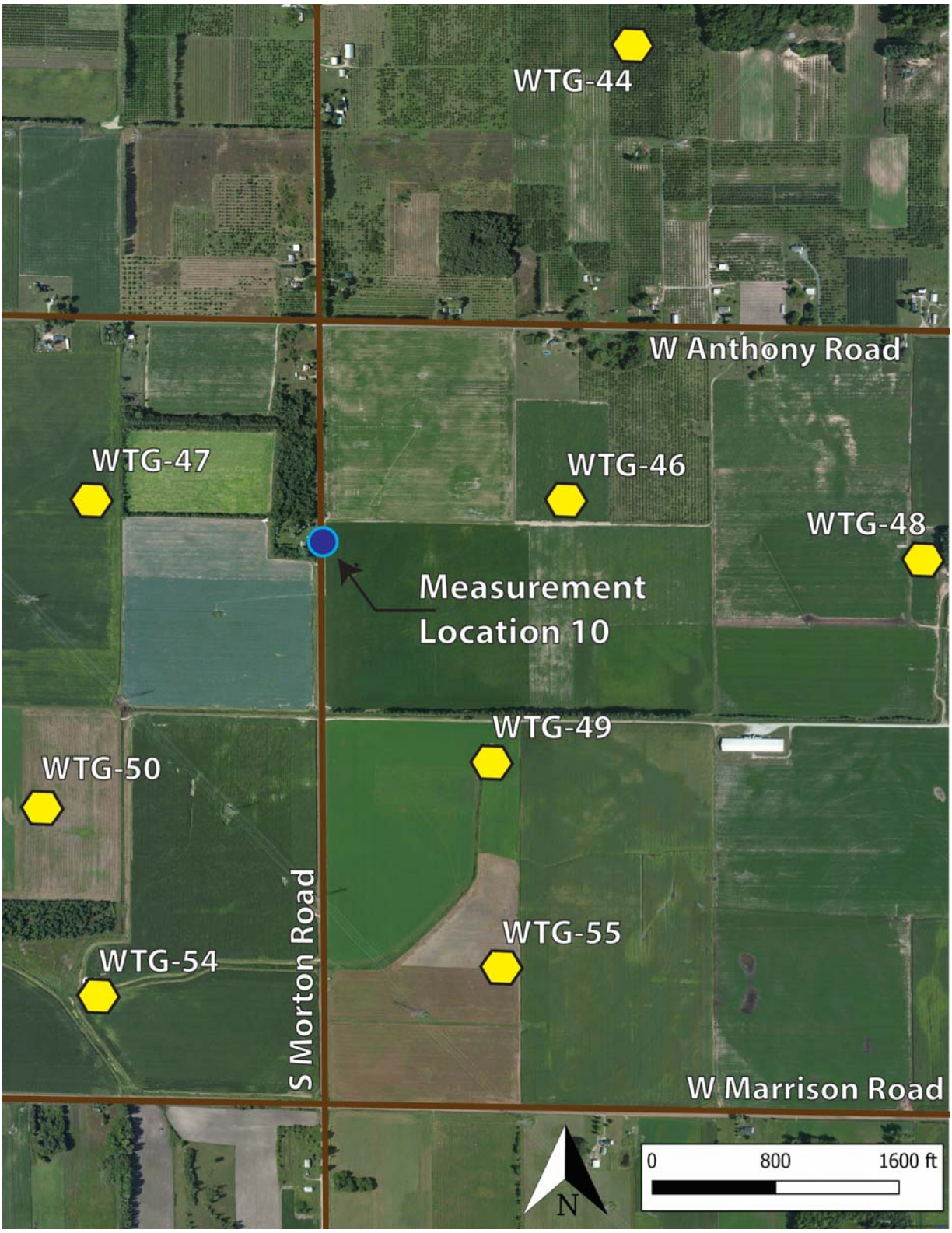

Figure 4-4: Map of Measurement Location 10

4.3 Measurement Procedures

Noise levels were measured at two locations on any given night, with one exception when on one night only one location had a chance of producing valid data due to forecasted turbine operations and wind direction. The selection of which locations to measure on any given night was made by Hankard Environmental on the day of the measurements and was based primarily on wind direction. In general, the loudest noise levels will be measured when the measurement location is situated downwind of the turbines. Once measurement locations for the day were established, wind conditions were monitored and field staff deployed to the locations as soon as turbine operations exceeded approximately 50% of capacity. The measurement equipment was set up first, which generally takes about 15 minutes, and left to run continuously as described above.

Next, field staff began noting the audibility of turbine noise, and the times when non-WTG noise sources were present, including but not limited to traffic, wind blowing through nearby vegetation, insects/birds/frogs, planes, dogs, etc. Based on our experience with previous wind turbine noise measurement projects, the type of notes that will prove most useful in the subsequent analysis of the data depends on conditions. On days/nights when ground winds are calm (less than about 1 to 2 m/s) and non-WTG noise sources are present infrequently, one only needs to note the approximate times when non-WTG noise was audible. After a review of the resulting noise level time history and frequency spectra to remove any residual non-WTG noise, one is left with a dataset consisting entirely of WTG-only noise. An example field measurement form from such a night is shown in Figure 4-5.

The more challenging situation is a night when ground wind speeds are moderate (about 2 to 5 m/s) on a continuous basis, and/or there is a consistent amount of non-WTG noise present (particularly traffic). In this case the objective of the field notes is to identify those minute(s) when WTG noise was most prominent. For example, minutes would be noted when there was a lull in ground wind, or the minutes when no traffic was audible. Minutes when wind or traffic was particularly audible were also noted. In the subsequent analysis of the data, frequency spectra from these various minutes are compared to determine what is and is not related to WTG operations. An example field form from such a night is shown in Figure 4-6.

The measurement and analysis procedures followed the applicable portions of ANSI S12.9 Part 3 (2013) *Quantities and Procedures for Description and Measurement of Environmental Sound: Short-Term Measurements With an Observer Present*, and ANSI S12.18-1994 (R2009) *Outdoor Measurement of Sound Pressure Level*.

Date	3/30/2016		**Location**	2
Personnel	Hankard		**Meter**	SN058
Start Time	12:00 AM Central		**End Time**	1:00 AM Central

W = Wind, T = Traffic, D = Dog, F = Frogs, B = Birds, P = Plane 5 = Dominant, 0 = Inaudible

Minute	Turbines Rating	Wind Rating	Traffic Rating	Frog Rating	Note Code	Time	Note Code	Time
0:00	4	0	0	1				
0:01	4	0	0	1				
0:02	4	0	0	1				
0:03	4	0	0	1				
0:04	4	0	0	1				
0:05	4	0	0	1				
0:06	4	0	0	1				
0:07	4	0	0	1				
0:08	4	0	0	1				
0:09	4	0	0	1				
0:10	4	0	0	1				
0:11	4	0	0	1				
0:12	4	0	0	1				
0:13	4	0	0	1				
0:14	4	0	0	1	P	11:14:50 car then helicopter		
0:15	4	0	0	1	P	helicopter		
0:16	4	0	0	1	P	helicopter		
0:17	4	0	0	1				
0:18	4	0	0	1				
0:19	4	0	0	1				
0:20	4	0	0	1				
0:21	4	0	0	1				
0:22	4	0	0	1				
0:23	4	0	0	1				
0:24	4	0	0	1				
0:25	4	0	0	1				
0:26	4	0	0	1		Turbines 43 dBA		
0:27	4	0	0	1				
0:28	4	0	0	1				
0:29	4	0	0	1				
0:30	4	0	0	1				
0:31	4	0	0	1				
0:32	4	0	0	1				
0:33	4	0	0	1				
0:34	4	0	0	1				
0:35	4	0	0	1				
0:36	4	0	0	1				
0:37	4	0	0	1				
0:38	4	0	0	1				
0:39	4	0	0	1				
0:40	4	0	0	1				
0:41	4	0	0	1				
0:42	4	0	0	1				
0:43	4	0	0	1				
0:44	4	0	0	1				
0:45	4	0	0	1				
0:46	4	0	0	1				
0:47	4	0	0	1				
0:48	4	0	0	1				
0:49	4	0	0	1				
0:50	4	0	0	1				
0:51	4	0	0	1				
0:52	4	0	0	1				
0:53	4	0	0	1				
0:54	4	0	0	1				
0:55	4	0	0	1				
0:56	4	0	0	1		Turbines 43 dBA		
0:57	4	0	0	1				
0:58	4	0	0	1				
0:59	4	0	0	1				

Figure 4-5: Field Form from a Night When WTG Noise was Dominant

Date	4/28/2016	Location	9
Personnel	Hankard	Meter	18
Start Time	4:00 am Central	End Time	5:00 am Central

W = Wind, T = Traffic, D = Dog, F = Frogs, B = Birds

5 = Dominant, 0 = Inaudible

Minute	Turbines Rating	Wind Rating	Traffic Rating	Other Rating	Note Code	Time	Note Code	Time
0:00	3	2	0	0	Windy			
0:01	3	2	3	0	Wind and car		Turbine Level	
0:02	3	2	0	0	Wind and turbines		43	
0:03	3	2	0	0	Wind and turbines		43	
0:04	4	2	0	0	More turbines than wind GOOD		43 to 44	
0:05	4	2	0	0	Wind and turbines			
0:06	4	1	0	0	Clean turbines GOOD		43	
0:07	4	2	0	0	Wind and turbines			
0:08	4	2	0	0	Wind and turbines			
0:09	4	2	0	0	Wind and turbines			
0:10	4	2	0	0	Wind and turbines		41	
0:11	4	2	3	0	Car			
0:12	4	2	2	0	Windy and car			
0:13	4	2	0	0	Wind and turbines		43	
0:14	4	2	3	0	Windy and car			
0:15	4	2	0	0	Windy			
0:16	4	2	0	0	Wind and turbines		43	
0:17	4	2	3	0	Windy and car			
0:18	4	2	3	0	Windy and car			
0:19	4	2	2	0	Windy and car		43	
0:20	4	2	0	0				
0:21	4	2	0	0	Wind and turbines		43	
0:22	4	2	0	0	Wind and turbines		42	
0:23	4	2	3	0	Car			
0:24	4	2	0	0	Wind and turbines		41	
0:25	4	2	0	0	Wind and turbines		41	
0:26	4	2	2	0	Car			
0:27	4	2	3	0	Car			
0:28	4	2	3	0	Car			
0:29	4	2	3	0	Car			
0:30	4	2	2	0	Wind and turbines		41	
0:31	4	2	0	0				
0:32	4	2	3	0	Car		40	
0:33	4	2	0	0				
0:34	3	1	0	0	Clean turbine GOOD		39	
0:35	3	1	0	0	Clean turbine GOOD		39	
0:36	3		0	0				
0:37	3		0	0				
0:38	3		0	0				
0:39	3	1	0	0	Clean turbine GOOD		39	
0:40	3		0	0				
0:41	3		3	0	Car			
0:42	3	1	0	0	Clean turbine GOOD		40	
0:43	3		0	0				
0:44	3		0	0				
0:45	3		0	0				
0:46	3		0	0				
0:47	3		0	0				
0:48	3		0	0				
0:49	3		0	0				
0:50	3		0	0				
0:51	3		0	0				
0:52	3		0	0				
0:53	3		0	0				
0:54	3		0	0				
0:55	3		0	0				
0:56	3		0	0				
0:57	3		0	0				
0:58	3		0	0				
0:59	3		0	0				

Figure 4-6: Field Form from a Night When Ground Wind Noise was Dominant

5. Turbine and Atmospheric Conditions

The goal of this study is to determine if noise levels from the WTGs are in compliance with the Mason County Zoning Ordinance, which states that noise levels "shall not exceed 45 dBA" at an unpooled parcel. If a relatively small number of noise samples are going to be used to demonstrate compliance for all time, the measurements must be conducted during conditions that produce the loudest WTG noise levels at residences. Loudest conditions are present when (a) nearby WTG operations are at or near capacity, and (b) the atmosphere is stable, and (c) the measurement location is downwind of nearby turbines. The following sections describe the extent to which each of these conditions was present during the measurements. Section 5.4 summarizes the conditions, and present the author's determination of which measurements conducted as part of this Spring 2016 survey represent loudest conditions, and which provide useful information about turbine noise at a given location albeit not loudest conditions.

5.1 Turbine Operations During Measurements

The Vestas V100-1.8 turbines reach their maximum acoustical output when hub-height wind speeds reach approximately 10 meters per second (m/s). Winds speeds in excess of this create more electrical power, but do not create additional acoustic output because the turbine has reached its maximum rotational speed. For the purposes of this analysis, maximum turbine operation is defined by the *Mitigation Plan Sound Testing Protocol*, which states: "Full electrical power shall be defined as the nearest mitigated turbine(s) to a test location producing at least 80% of rated electric power in the applicable Mode 2, or 90% for the nearest turbine operating in NRO Mode 0 (test site 5 only). If testing under full electrical power, and suitable weather/ambient-sound conditions, is not achieved in six nights, the testing shall be extended".

Table 5-1 lists, for each measurement day and for each location, the number of 10-minute intervals during which there was full electrical power production at the nearest turbine according to the above definition. Also listed are the exact time intervals when this occurred. Plots of power production for the four turbines closest to each measurement location are provided in Appendix B.

After the first week of testing in March 2016 we realized that shutting down the turbines every other hour, as outlined in the *Mitigation Plan Sound Testing Protocol*, is only necessary if during any given measurement it is the opinion of field personnel that the WTG-only noise level is approaching or greater than the 45 dBA limit. This determination comes from our intent watching of the instantaneous noise level (L_{eq}, Fast, dBA) and listening to the acoustic environment. Until the WTG-only noise level regularly exceeds about 44 dBA it is better to keep the turbines running. This maximizes the amount of time spent measuring "turbine on" conditions, which maximizes the chance that we are capturing loudest turbine conditions.

Table 5-1: Turbine Operations During Measurements

Date	Location	Number of 10-minute Intervals of Full Electric Power at Nearest Turbine	Times of Full Electric Power for Nearest Turbine
March 29-30	2	1	02:50
	5	3	00:20, 00:30, 00:50
March 31	2	0	---
April 24	9	0	---
	10	0	---
April 25	5	0	---
	10	1	17:00
April 26	9	0	---
	10	0	---
April 28	9	3	1:20, 4:00, 4:10
	10	2	4:30, 4:40
May 23-24	5	11	23:50 - 01:30
	10	0	---
May 24	5	0	---
	10	0	---

5.2 Atmospheric Stability During Measurements

In general, during the daytime the atmosphere is unstable as the sun heats the air, heated masses of air rise and shift, and there is subsequently a lot of atmospheric mixing. These conditions are not favorable for sound propagation and therefore measurements taken under such conditions should not be considered representative of loudest conditions. Mixing generally decreases at night after sunset and there is a greater chance for both wind gradients and temperature inversions to set up. A wind gradient is where ground wind speeds are low (<~3 m/s) while wind speeds at hub-height are relatively high (>~8 m/s). Under these conditions, sound waves traveling away from and downwind of a source are bent toward the ground and noise levels are greater than in the upwind direction. Temperature inversions, the condition where temperature increases with height up to a point, bend sound waves back toward the ground in all directions from the source. Noise levels during a temperature inversion are, as a result, louder than what they would be otherwise.

Atmospheric stability was not measured, per se, as part of this study. Table 5-2 lists the stability of the atmosphere during each day surveyed based on field observations. For example, on two nights, turbine operations were at or near maximum (high hub-height wind speeds) and ground winds were very low, indicating the presence of a wind gradient. On days when conditions forced us to measure in the late afternoon, hub-heights winds were low to moderate, as were ground winds, thus indicating no wind gradient.

Table 5-2: Observed Atmospheric Stability During Measurements

Date (2016)	Stability	Notes
March 29-30	Stable	Moderate hub-height wind speeds, very low ground wind speeds
March 31	Unstable	Moderate hub-height wind speeds, moderate ground wind speeds
April 24	Unstable	Moderate hub-height wind speeds, moderate ground wind speeds
April 25	Unstable	Windy (storm moving in), late afternoon
April 26	Unstable	Sun still strong, late afternoon
April 28	Unstable	Moderate hub-height wind speeds, moderate ground wind speeds
May 23-24	Stable	Full turbine operations, very low ground wind speeds
May 24	Unstable	Windy, sun still strong, late afternoon

5.3 Wind Direction During Measurements

In general, noise levels are louder downwind of a source versus upwind or at some intermediate angle. This is not straightforward in the case of wind turbine farms due to the fact that the noise source (turbines) is distributed and located in many different directions from any given measurement location. Wind direction is less important for those turbines located within approximately 2,000 feet, because WTG noise emissions are nearly identical upwind and downwind of the turbine (somewhat lower to the sides). Wind direction becomes more important for more middle-distance turbines (2,000 to 5,000 feet), as atmospheric conditions now play a greater role in how much of the emitted sound energy reaches more distant locations. Turbines located more than 5,000 feet of residences where the closest turbines are in the 1,500 foot-range do not significantly affect the total measured level, as their contribution is more than 10 dB less than that from the closest turbines. Table 5-3 lists the dates on which measurements were conducted at each location, the prevailing wind direction during each measurement, and which locations were downwind of which turbines.

5.4 Representation of Loudest Conditions

Table 5-4 summarizes, for each measurement day and each location, the occurrence of full operations for at least one 10-minute interval, the observed presence of a stable atmosphere, and if the wind direction was such that the measurement location was downwind of the nearest turbine(s). Also shown is the author's opinion as to whether or not the measured noise levels are representative of the loudest condition that might occur at each location. The data most representative of loudest conditions is that obtained on May 23, 2016 at Location 5. Representative data was also obtained at Location 5 on March 29, 2016. Thus, as described in Section 8, below, definitive conclusions can be reached about WTG noise levels at Location 5. At Location 2 there was only one 10-minute period of maximum operations at the nearest turbine, but at the time the atmosphere was not stable and other nearby turbines were operating at low power. At Locations 9 and 10, turbine power production was maximum on one night. However, on this night the nearest turbines were located at a crosswind direction, and the atmosphere was not stable.

Table 5-3: Location of Measurement with Respect to Wind Direction and Turbines

Date	Location	Wind Direction (compass)	Nearest Orientation (relative)	2nd Orientation (relative)	3rd Orientation (relative)	4th Orientation (relative)
March 29-30	2	S	Upwind	Downwind	Upwind	Crosswind
March 29-30	5	S	Downwind	Downwind	Downwind	Crosswind
March 31	2	N	Downwind	Upwind	Downwind	Crosswind
April 24	9	ESE	Downwind	Upwind	Upwind	Crosswind
April 24	10	E	Upwind	Downwind	Crosswind	Crosswind
April 25	5	S	Downwind	Downwind	Downwind	Crosswind
April 25	10	S	Crosswind	Crosswind	Downwind	Crosswind
April 26	9	NNE	Upwind	Crosswind	Upwind	Upwind
April 26	10	NE	Crosswind	Downwind	Crosswind	Upwind
April 28	9	S	Crosswind	Crosswind	Crosswind	Downwind
April 28	10	S	Crosswind	Crosswind	Downwind	Crosswind
May 23-24	5	S	Downwind	Downwind	Downwind	Crosswind
May 23-24	10	S	Crosswind	Crosswind	Downwind	Crosswind
May 24	5	SSW	Downwind	Downwind	Downwind	Crosswind
May 24	10	S	Crosswind	Crosswind	Downwind	Crosswind

Table 5-4: Summary of Measurements' Representation of Loudest Conditions

Date	Location	Wind Direction (from)	Full Turbine Operation	Stable Atmosphere	Loudest Wind Direction	Representative of Loudest Condition?
March 29-30	2	S	YES	YES	No	YES - limited
March 29-30	5	S	YES	YES	YES	YES
March 31	2	N	No	No	YES	No
April 24	9	ESE	No	No	No	No
April 24	10	E	No	No	YES	No
April 25	5	S	YES	No	YES	No
April 25	10	S	YES	No	No	No
April 26	9	NNE	No	No	No	No
April 26	10	NE	No	No	No	No
April 28	9	S	YES	No	No	No
April 28	10	S	YES	No	No	No
May 23-24	5	S	YES	YES	YES	YES
May 23-24	10	S	No	YES	No	No
May 24	5	SSW	No	No	YES	No
May 24	10	S	No	No	No	No

6. Noise Level Analysis Procedures

As described in Section 2, the noise level limit at the property line of an un-pooled parcel upon which there is an occupied building or dwelling is 45 dBA. However, this applies to WTG noise only, and the microphones placed at the measurement locations measure noise from the WTGs, as well as that from traffic, planes, birds/insects/amphibians, the activities of residents, and wind blowing across the microphone and through vegetation. The measurement data needs to be analyzed in order to separate WTG noise from non-WTG noise. The data analysis process employed is that outlined in the LWEP *Mitigation Plan Sound Testing Protocol*, follows applicable portions of ANSI S12.9 Part 3, and includes techniques developed by Hankard Environmental based on our in-depth experience with other wind turbine noise projects.

1. First, a couple of remarks regarding how Hankard Environmental believes a wind turbine noise compliance analysis should be conducted:

    a. We believe in analyzing all of the data we measure, regardless of turbine operations, wind direction, ground wind speed, time of day, etc. We can learn something from any and all measurements, and can make a better determination of each 10-minute sample's validity to the LWEP compliance process after reviewing all of the data.

    b. During the first week of measurements in March 2016 we implemented the turbine-on / turbine-off measurement procedure that had become the norm on LWEP studies. As such, the data from these measurements was analyzed in accordance with the *Mitigation Plan Sound Testing Protocol*.

    c. Starting with the April measurements and continuing through the May measurements, the turbines were not turned off unless Hankard Environmental field staff felt that WTG-only noise levels were consistently above 44 dBA. This maximizes the amount of turbine-on data we collect. Turbine-off noise levels are used to determine background noise levels, primarily from wind, and are only needed if the total level exceeds 45 dBA.

    d. Thus, after analyzing all of the data according to the *Mitigation Plan*, the resulting 10-minute L_{eq} levels contain some background noise for the April and May 2016 data. At this point, if background noise from wind or traffic was consistent, the data likely still includes some non-WTG noise. To minimize this, Hankard Environmental applies additional data analysis and reduction. The result is an L_{eq} noise level attributed primarily to wind turbine operations, and absolutely does not exceed 45 dBA (or we would have shut down the turbines to determine background levels).

    e. Based on our experience, which consists of hundreds of hours spent in rural environments listening to wind turbine noise and background noise, as well as thousands of hours spent analyzing turbine-noise-wind datasets, we believe that the key to most closely determining WTG-only noise level lies in the review of the

one-third octave band frequency spectra of both 10-second and 10-minute L_{eq} samples. When wind turbines are operating at their maximum acoustic output the noise level, on a 10-minute L_{eq} basis, is relativley consistent, and has a very distinct spectral shape in the absence of background noise. We seek out this WTG-only spectral shape in the data and eliminate those 10-second samples that exhibit clear signs of being significantly influenced by non-WTG sources.

f. On this project, this primarily applies to separating noise from wind blowing across the microphone and through vegetation. As described in Section 4.3, above, we find that the analysis required is different for measurements conducted when the ground winds are very low (less than 2 m/s), versus when they are moderate 2 to 5 m/s). The low-wind analysis requires primarily the elimination of non-WTG noise through the review of field notes and noise level versus time plots (overall, A-weighted L_{eq}).

g. We separate WTG and wind noise using both a primary method and a secondary method. The primary method generally follows the *Mitigation Plan Sound Testing Protocol* and ANSI S12.9, as it relies on field technicians' observations and notes.

   i. The primary method is to plot the one-third octave band frequency spectra of those one-minute periods when field staff identified turbines as the primary source of audible noise. If the resulting spectra have no clear signs of significant wind influence (explained below), the resulting overall level is reported as the WTG noise level.

   ii. The secondary method consists of sorting the measured turbine-on 10-second L_{eq} samples according to their 25 Hz one-third octave band level (dBA). The 25 Hz level correlates with the amount of "pseudo noise" that is being generated by wind passing over the microphone (despite the 7" diameter windscreen). After sorting, the samples are grouped into 5 dB bins (25 Hz band level of 50 to 55 dB, 55 to 60 dB, etc.) and the energy-average one-third octave band spectrum for each bin is plotted. The spectra with lower overall levels will exhibit a WTG-only spectral shape (unless ground winds are consistently too strong), and the higher level spectra will exhibit a wind influenced spectral shape.

2. The first step in the *Mitigation Plan* and ANSI S12.9 data analysis method is to create and review "noise level versus time plots" for each measurement survey at each location. Noise levels are measured in 10-second L_{eq} samples, but ultimately calculate a 10-minute L_{eq}. 10-second samples during which non-WTG noise was noted by field technicians is removed. This mainly applies to noise from traffic, planes, dogs, etc. ANSI S12.9 allows for the elimination of up to ½ of the data points in any given interval (10 minutes in this case).

3. In addition to eliminating specific times when field technicians noted the presence of non-WTG noise, Hankard Environmental reviews the frequency spectrum of each 10-second sample remaining in the dataset. We further eliminate 10-second samples that have an

erratic spectral shape, often due to sources that the technicians may not have noticed. WTG-only noise level has a distinct spectral shape, and no 10-second samples with any sign of WTG noise are eliminated in this manner.

4. Per ANSI S12.9, environmental noise level measurements should not be taken when ground wind speeds exceed 5 m/s, and thus data acquired under these conditions was discarded.

5. High-frequency bird/insect/amphibian noise, when present, was eliminated from all turbine-on and turbine-off 10-minute L_{eq} samples. Per ANSI S12.9, the overall A-weighted L_{eq} was re-calculated using only the 31.5 through 1,000 Hz octave band noise levels.

6. For the March 2016 measurements only, during which the turbines were turned off every other one hour to allow for the measurement of background noise levels, the turbine-on 10-minute L_{eq} is calculated for each of the six 10-minute period in the hour. For turbine-off measurements, the 10-minute L_{eq} is not calculated for the first 40 to 50 minutes of the hour, because the cooling fans on the turbines do not turn off and control the background noise level accept for the last one or two 10-minute samples in the hour. The lowest of these measured 10-minute samples was then carried forth in the analysis. The WTG-only noise level results from this analysis.

7. For the April and May 2016 measurements, for which field staff determined that WTG-only noise levels were less than 45 dBA, the above-described additional analyses were conducted instead of Item 6.

7. Measurement and Analysis Results

The following sub-sections describe the results of the noise level measurements and data analysis for each location. Conclusions from the results are provided in Section 8.0, along with statements of data validity and compliance with Mason County standards. The descriptions in this section reference plots of nearby WTG operations during the measurements, and these can be found in Appendix B. Also, the data are described for Location 5 first, as this is the location where the most representative data was acquired. Similarly, for each location, the most representative measurement data are described first, followed by data from measurements when turbine operations were low or atmospheric conditions were not ideal for sound propagation.

7.1 Analysis of Noise Levels Measured at Location 5

March 29th – 30th, 2016 – Location 5

Measurements were conducted between 10:00 pm on March 29th through 5:00 am on the 30th. From the power production data it can be seen that the closest turbine (WTG-25) was operating at or very near full electrical power during the 10-minute periods of from 0:20 to 0:50. The next three closest turbines were operating at approximately 75% to 80% of capacity. The wind direction during this time period was out of the north, placing the residence upwind of all the nearest turbines. Ground wind speeds were very light during the measurement (1 to 3 m/s).

Figure 7-1 shows the noise level versus time for the entire measurement period. Shown is the 10-second L_{eq} (dBA), the 10-minute L_{eq} (dBA), the 10-second average ground wind speed (meters per second, m/s), and the two-minute average ground wind speed (m/s). The presence of noise from passing vehicles is obvious. Figure 7-2 shows the same information, with the noise levels during non-WTG events removed based on field notes, the noise level versus time signature, and a review of the spectral content of the signal at different times.

Table 7-1 lists the loudest WTG-on 10-minute noise level for each of the four turbine-on hours, as well as the lowest 10-minute turbine-off noise levels measured before and after each turbine-on hour, and the average of before and after turbine-off levels. Also shown is the 1.5 dB uncertainty level from ANSI S12.9 Part 3, and the resulting WTG-only noise level. The highest WTG-only noise level is 43.4 dBA. This level agrees with field observations.

Figure 7-3 shows the one-third octave band frequency spectra for the 10-minute periods of turbine-on and turbine-off data from Table 7-1. The turbine-on spectra show the characteristic shape of WTG-only noise levels. Specifically, low frequency levels below about 60 dB, a peak in the mid-band levels (in this case 315 Hz), and a steady drop off in levels at frequencies higher than the mid-band peak.

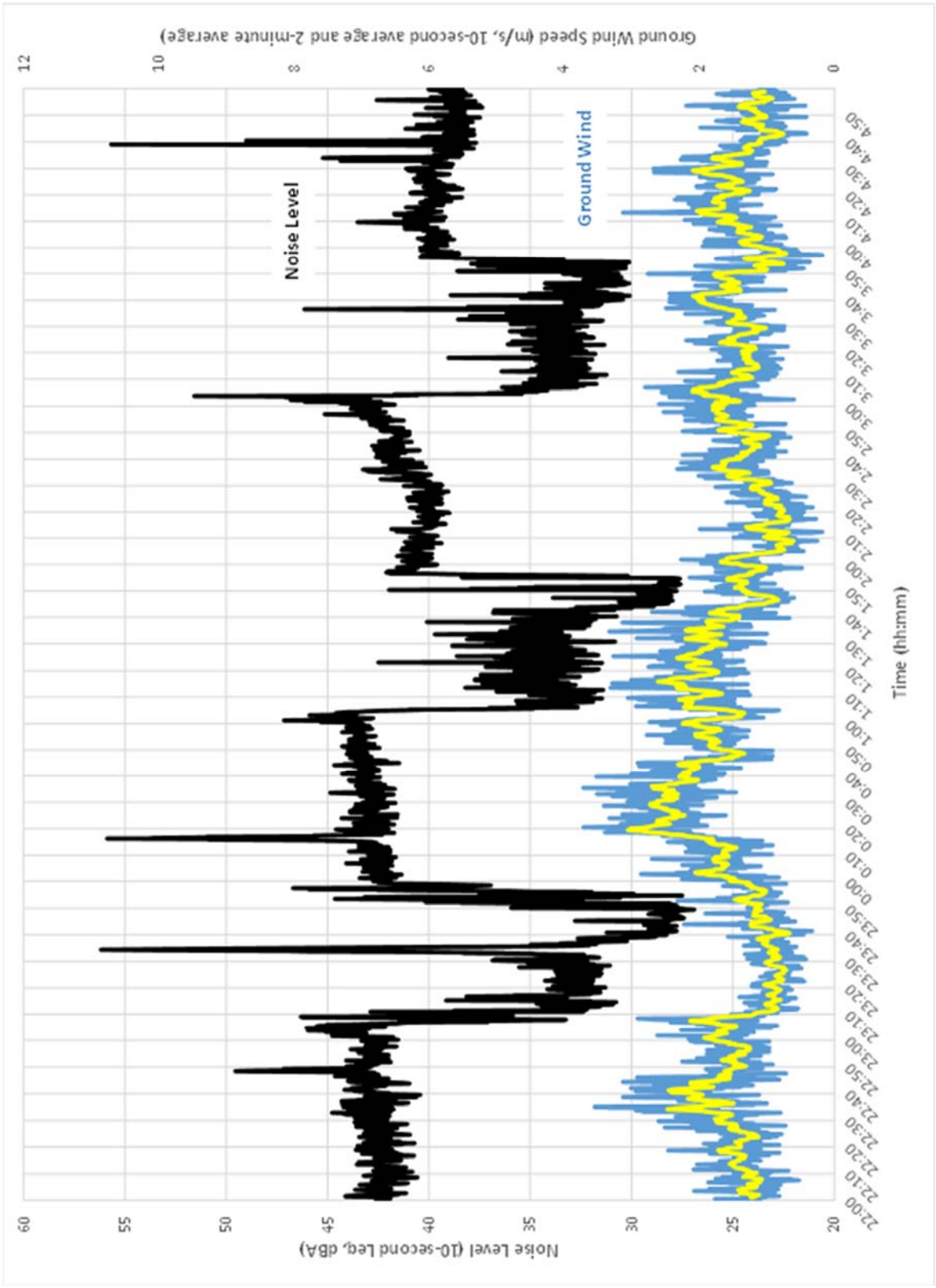

Figure 7-1: Location 5 Noise Level Versus Time, March 29-30, 2016

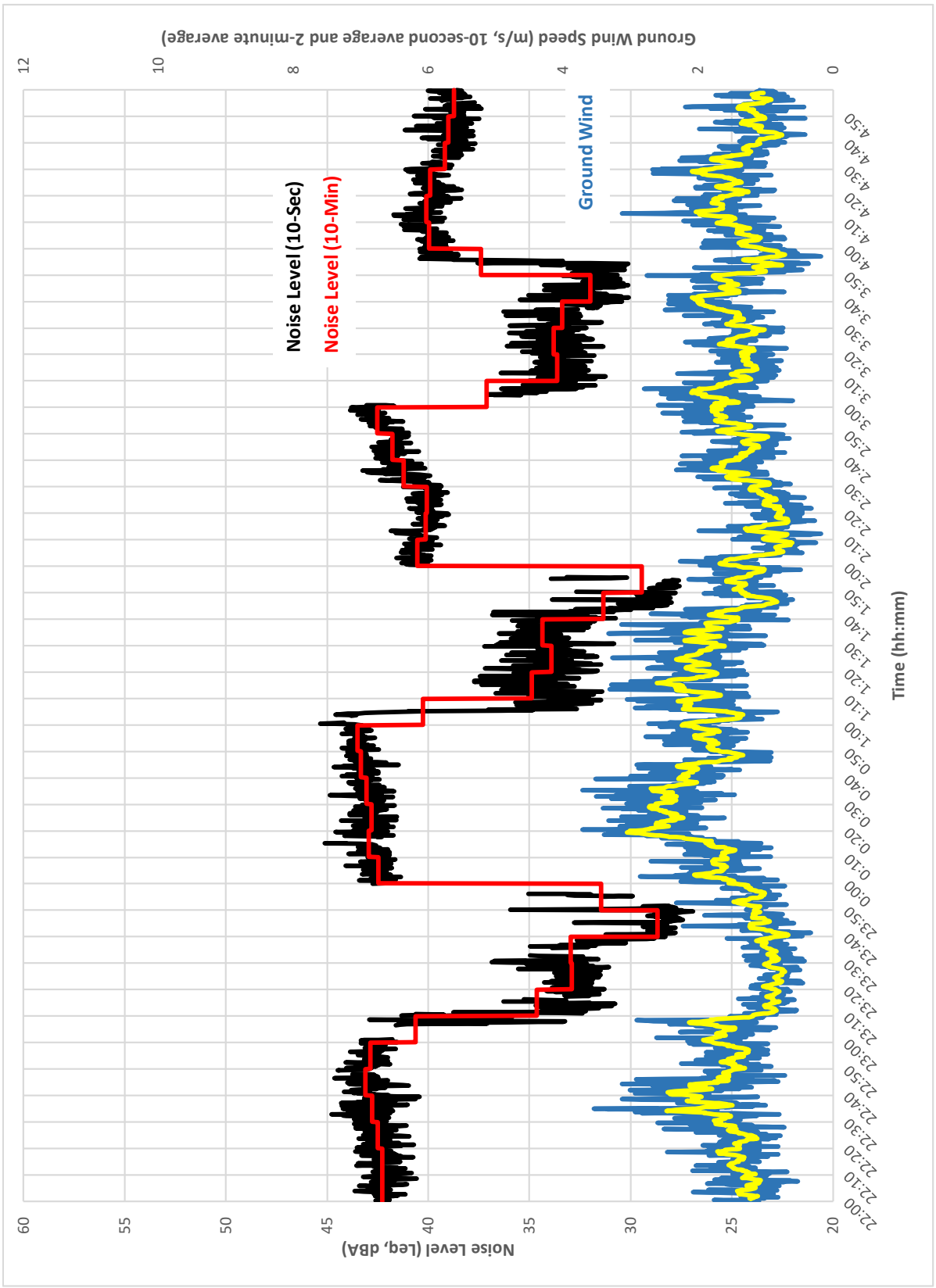

Figure 7-2: Location 5 Noise Levels Without non-WTG Events March 29-30, 2016

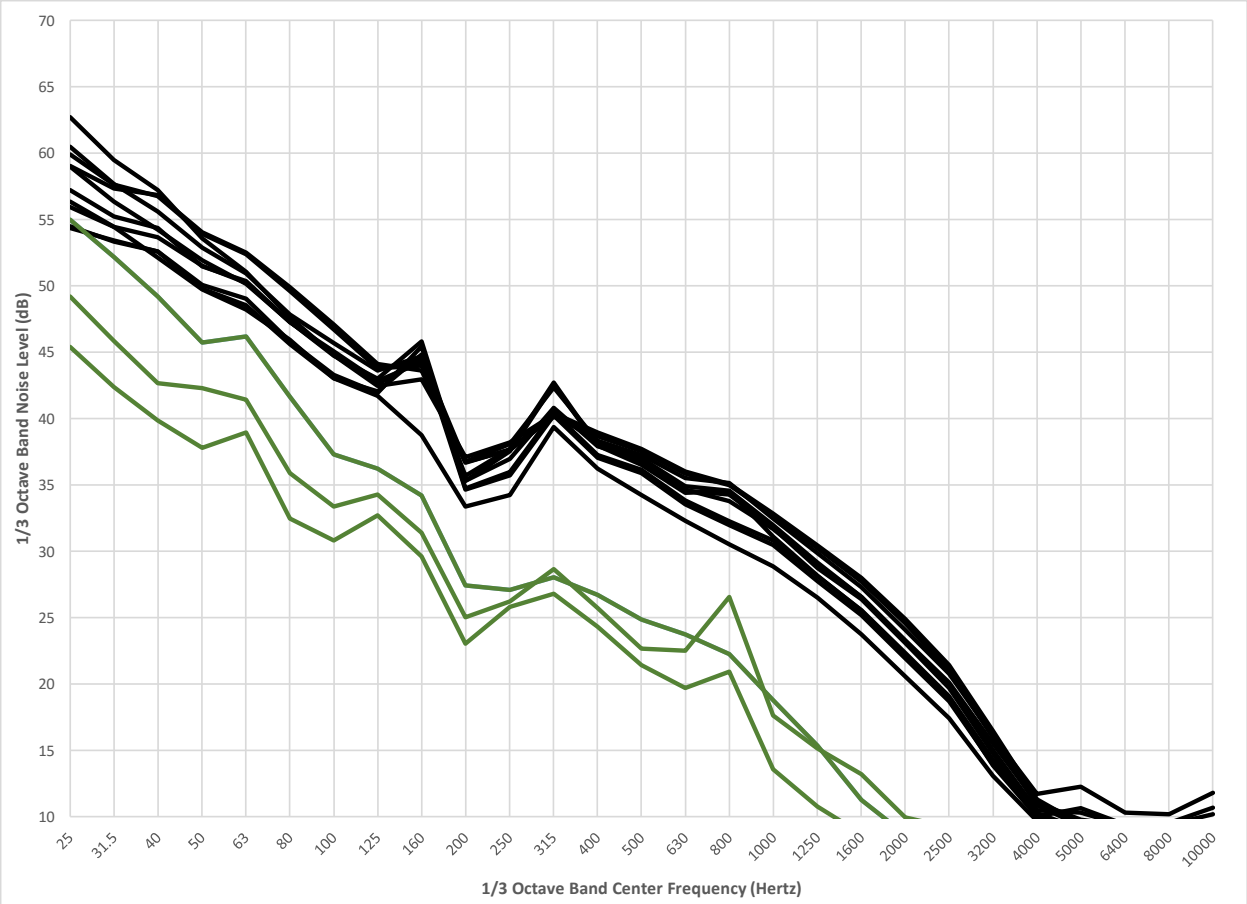

Figure 7-3: Location 5 One-Third Octave Band Spectra March 29-30, 2016

Table 7-1: Location 5 WTG Noise Levels March 29-30, 2016 (10-min L_{eq}, dBA)

Time	Measured All	Measured Before	Measured After	Average Before After	Uncertainty	Background	WTG Only Noise Level
22:00	43.1		28.7	28.7	1.5	27.2	43.0
0:00	43.5	28.7	29.5	29.1	1.5	27.6	43.4
2:00	42.5	29.5	32.0	30.8	1.5	29.3	42.3
4:00	40.1	32.0		32.0	1.5	30.5	39.6

May 23rd, 2016 – Location 5

Measurements were conducted between 11:00 pm on May 23rd and 5:00 am on the 24th. From the power production data it can be seen that the closest turbine (WTG-25) was operating at or very near full electrical power during the 10-minute periods of from 11:50 pm to 1:30 am. The next two closest turbines were operating at approximately 80% of capacity. The 4th closet turbine was operating between 30 and 90%. The wind direction during this time period was out of the south,

placing the residence downwind of all the nearest turbines. Ground wind speeds were very light during the measurement (about 1 m/s).

Figure 7-4 shows the noise level versus time for the entire measurement period with the noise levels during non-WTG events removed. Also shown is the running 10-minute L_{eq} with the 2,000 – 8,000 octave bands removed to minimize the impact of bird noise. The 10-minute L_{eq} gets as high as 44.6 dBA between 0:10 and 0:20, when turbine operations are at their greatest. Somewhat following turbine operations, the 10-minute L_{eq} drops slightly between about 2:00 and 4:30 am (the noise level hovers between 42 and 44 dBA during this time), and then increases again around 4:30 when the noise level goes to 44.2 dBA for about 20 minutes.

Figure 7-5 shows two sets of 10-minute one-third octave band frequency spectra. The top set shows the spectra for the 11:10 pm to 1:50 am time frame when turbine operations were maximum. Notice that the acoustic energy is centered at 315 Hz, and the 315 Hz band level is about 45 dB. The bottom set of spectra shown the levels between 2:00 and 4:50 am, when turbine operations at the nearest turbine dropped to below 50%. Notice how the 315 Hz level is about 2 dB lower, as expected with lower turbine operations. Notice also that the levels from 500 to 2,000 Hz are at times higher due to non-WTG sources, and the influence of birds can be seen from 2,000 to 10,000 Hz.

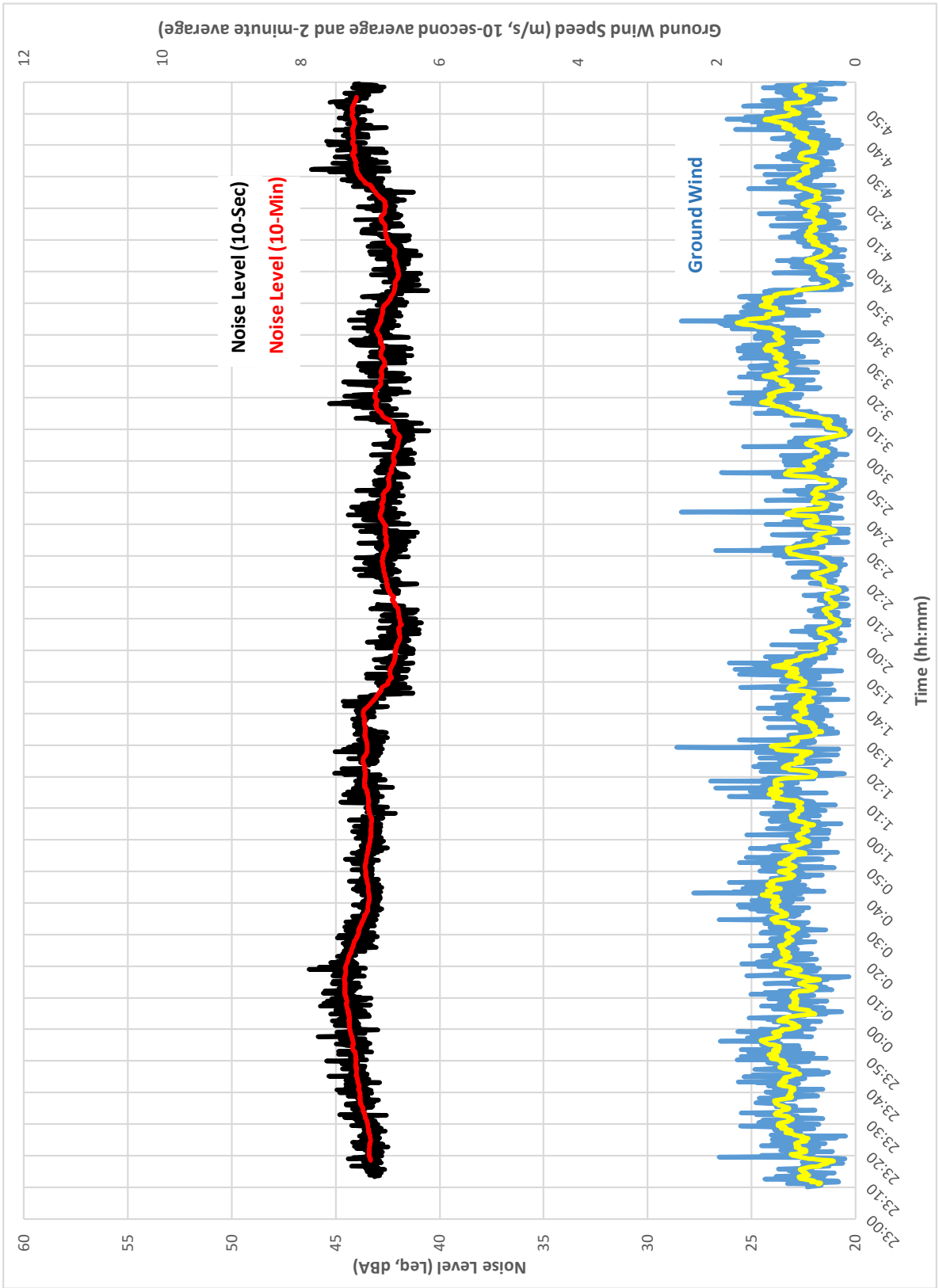

Figure 7-4: Location 5 Noise Levels Without non-WTG, May 23rd, 2016

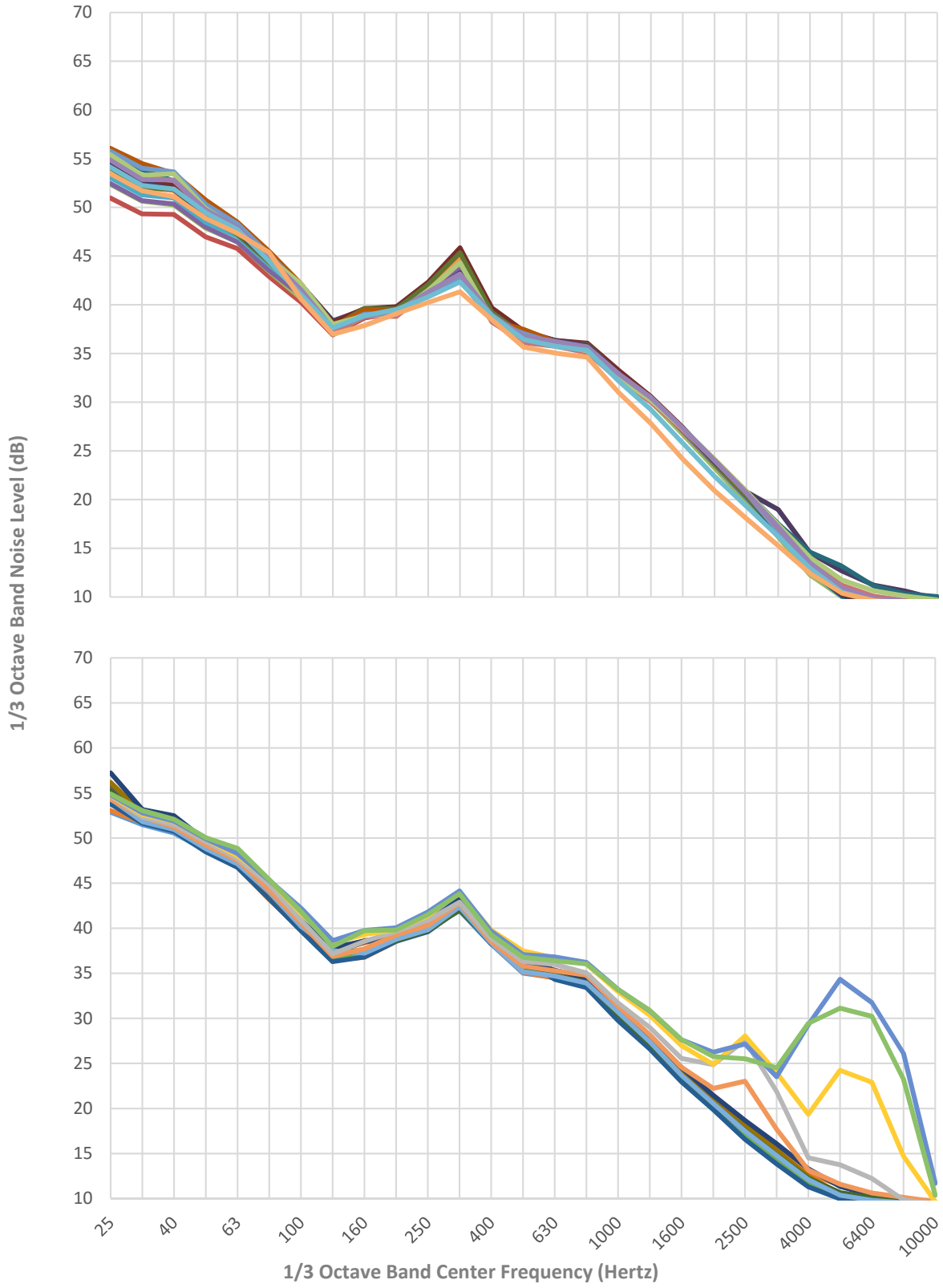

Figure 7-5: Location 5 One-Third Octave Band Spectra, May 23, 2016

April 25th, 2016 – Location 5

Measurements were conducted between 5:00 and 6:00 pm on April 25th. A strong rain storm moved in at 6:00 pm. Ground wind speeds were moderate (2 to 4 m/s), background noise was present, and turbine operations were low (<50%). We analyzed this hour of data by looking at the 10 one-minute periods during which field staff noted "good turbine minute". A plot of the frequency spectrum of each of these one-minute samples is shown in Figure 7-6. Only one spectrum has a clear WTG-only shape, and it has an overall level of 40 dBA.

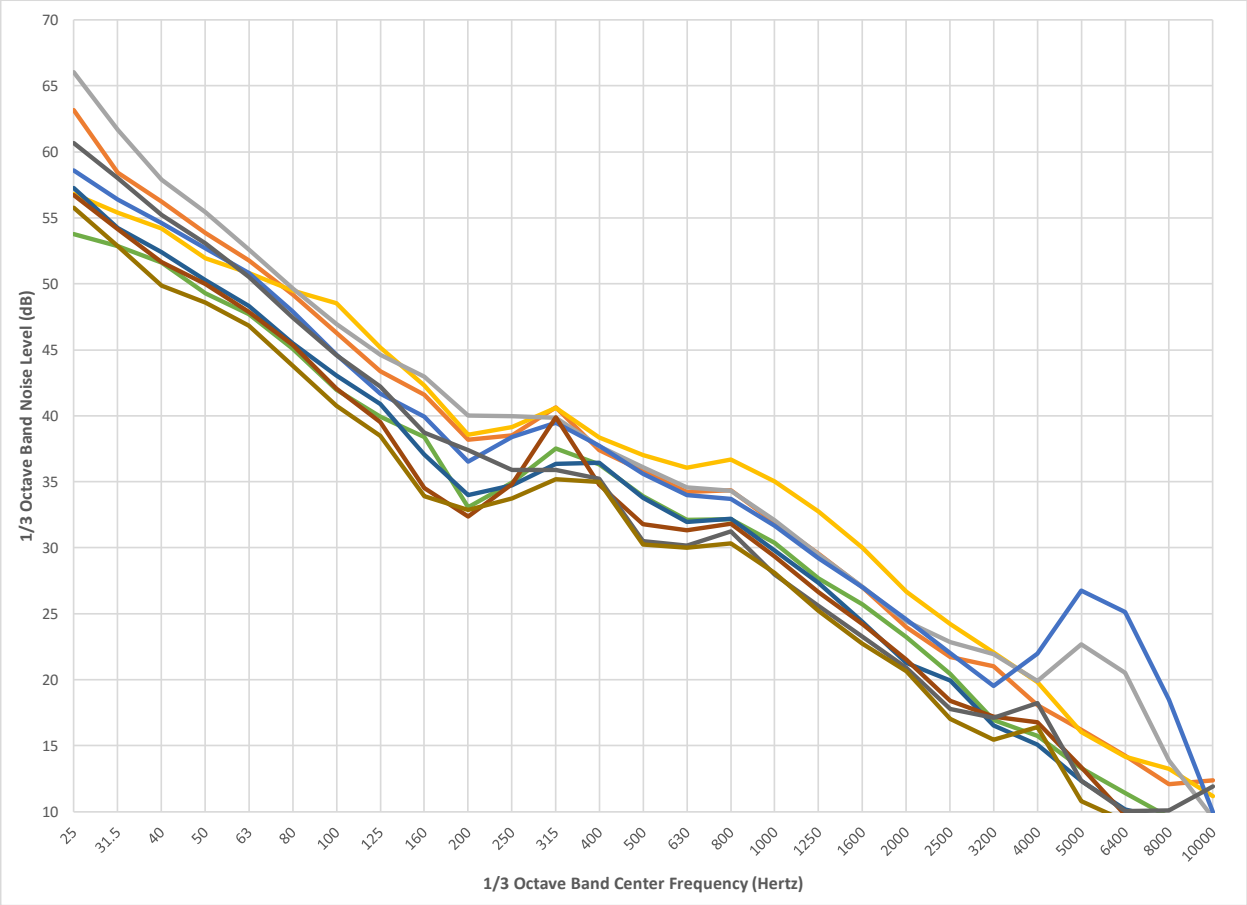

Figure 7-6: Location 5 One-Third Octave Band Spectra, April 25th, 2016

May 24th, 2016 – Location 5

Measurements were conducted between 5:40 and 6:50 pm on May 24th. Ground wind speeds were light to moderate (1 to 3 m/s), background noise was present (traffic, distant lawn mowing), and turbine operations were low (less than 30%). We first analyzed this hour of data by looking at the spectra of the five one-minute periods during which field staff noted "good turbine minute". The spectra revealed that only two were dominated by turbine noise, and these are shown in Figure 7-7. The overall level of the louder of the two is 41 dBA. The data were also analyzed by first sorting on the overall level, then reviewing the one-third octave band spectra of the resulting levels, and determining the loudest level that exhibits a WTG-only spectral shape. The results of that analysis are also shown in Figure 7-7. The shape is remarkably similar to that noted by field technicians, and the overall level is the same (41 dBA).

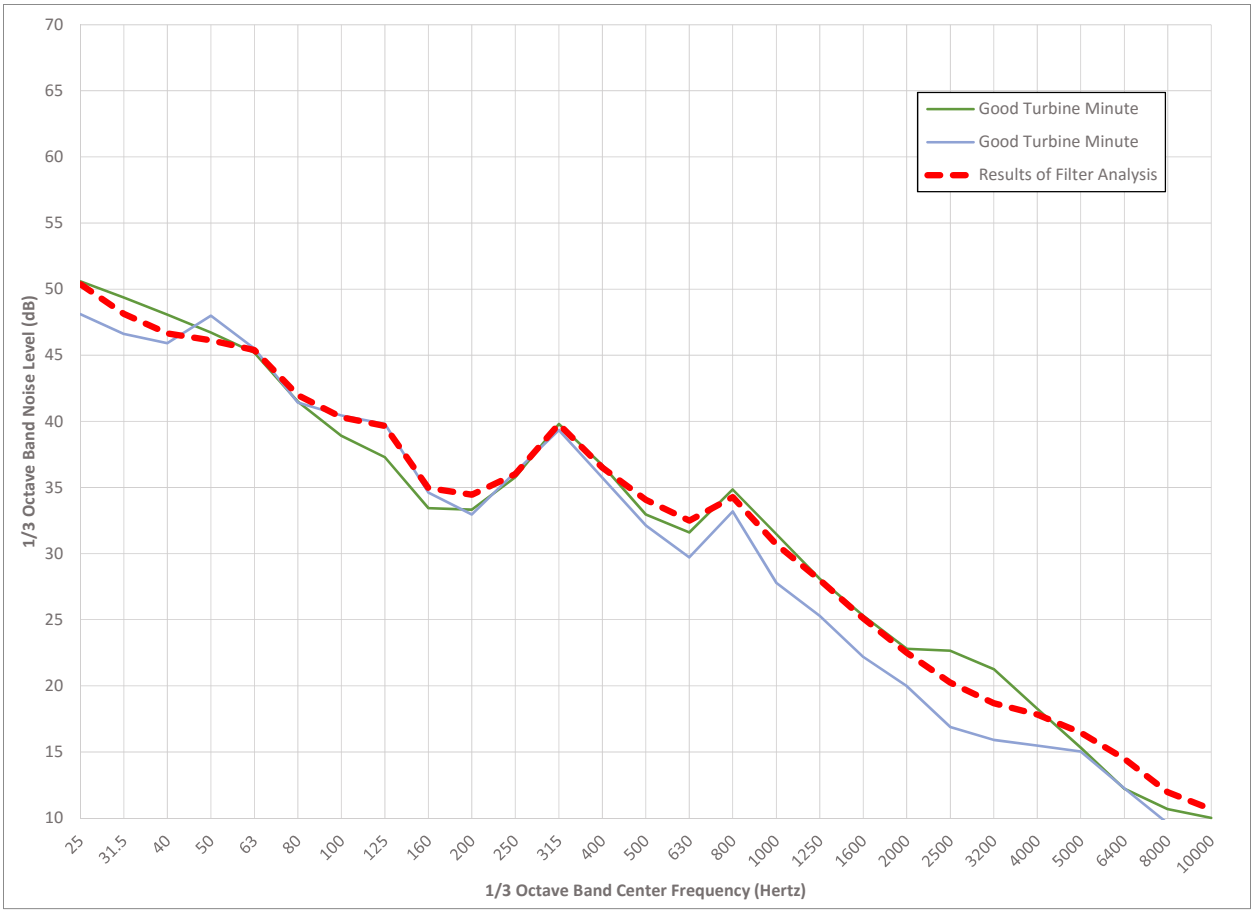

Figure 7-7: Location 5 One-Third Octave Band Spectra, May 24th, 2016

7.7 Analysis of Noise Levels Measured at Location 2

March 29th – 30th, 2016

Measurements were conducted between 10:00 pm on March 29th and 5:00 am on the 30th. From the power production data it can be seen that the closest turbine (WTG-6) was operating at or very near full electrical power during the one 10-minute period from 2:50 to 3:00 am (note that, for this location, full electric power is defined as 80% or greater). The next three closest turbines were operating at approximately 30% to 50% of capacity. The wind direction during this time period was out of the south, placing the residence upwind of the nearest turbine, and downwind of the 2nd closest turbine. Ground wind speeds were very light during the measurement (about 1 m/s).

Figure 7-8 shows the noise level versus time for the entire measurement period. Shown is the 10-second L_{eq} (dBA), the 10-minute L_{eq} (dBA), the 10-second average ground wind speed (meters per second, m/s), and the two-minute average ground wind speed (m/s). The presence of noise from a few passing vehicles is obvious. Figure 7-9 shows the same information, yet with the noise

levels due to non-WTG sources removed based on field notes, the noise level versus time signature, and a review of the spectral content of the signal at different times.

Table 7-2 lists the loudest WTG-on 10-minute noise level for each of the four turbine-on hours, as well as the lowest 10-minute turbine-off noise levels measured before and after each turbine-on level, and the average of before and after off levels. Also shown is the 1.5 dB uncertainty level from ANSI S12.9 Part 3, and the resulting WTG-only noise level. The highest level, 43.4 dBA, occurred at 2:50, as expected based on turbine operations. Figure 7-10 shows the one-third octave band frequency spectra for select 10-minute periods of both turbine-on and turbine-off conditions. The turbine-on spectra show a somewhat characteristic WTG-only shape, although the strength (level) of the WTG-only signal is low. Specifically, during full operations WTG-only 25 Hz levels are usually in the 50 to 60 dB range, and 315 Hz levels are usually in the 40 to 45 dB range.

Table 7-2: Location 2 WTG Noise Levels March 29-30, 2016 (10-min L_{eq}, dBA)

Time	Measured All	Measured Before	Measured After	Average Before After	Uncertainty	Background	WTG Only Noise Level
22:00	42.2		31.1	31.1	1.5	29.6	42.0
0:00	43.1	31.1	32.4	31.8	1.5	30.3	42.9
2:00	43.7	32.4	35.4	33.9	1.5	32.4	43.4
4:00	42.1	32.0		32.0	1.5	30.5	41.8

As described in Section 5., above, loudest turbine noise levels are measured when there is a stable atmosphere and turbine operations are at or near maximum. On this night the atmosphere was very stable, but turbine operations were less than full. A calculation was performed to estimate how loud the turbine-only sound level could have been on this night had turbine operations been full. Using the 10-minute period starting at 2:50, when the nearest turbine was operating near full electrical output, the hub-height wind speed for each of the six closest turbines was identified from operations data. As shown in Table C-1 (see Appendix C), these ranged from 7.6 to 9.2 m/s. From Vestas technical data, the sound power level of each turbine was determined for these wind speeds. Using these sound power levels, we calculated the sound level at Location 2 due to the operation of each of the closest six turbines, as well as the total sound level due to all six turbines. As shown in the Table C-2, this calculation only took into account hemispherical divergence (6 dB per doubling of distance), and did not account for atmospheric absorption, etc. The total noise level was then adjusted to match the measured noise level of 43.4 dBA. This was accomplished by subtracting an adjustment factor from the power level of each turbine (same factor applied to each turbine). Finally, the calculation was repeated using the maximum sound power level (105 dBA) for each turbine. The resulting predicted maximum possible noise level is 45.1 dBA.

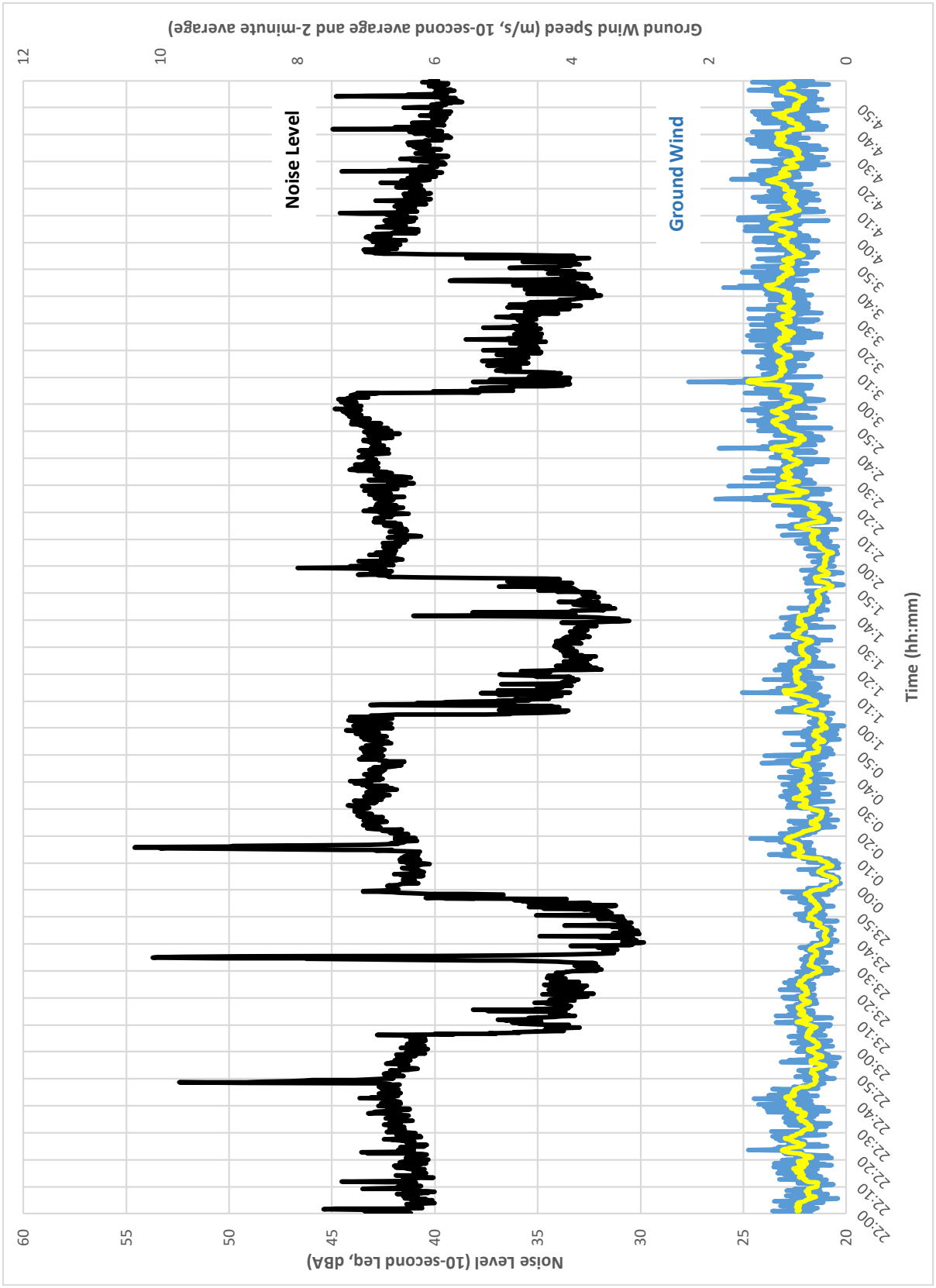

Figure 7-8: Location 2 Noise Levels Versus Time, March 29-30, 2016

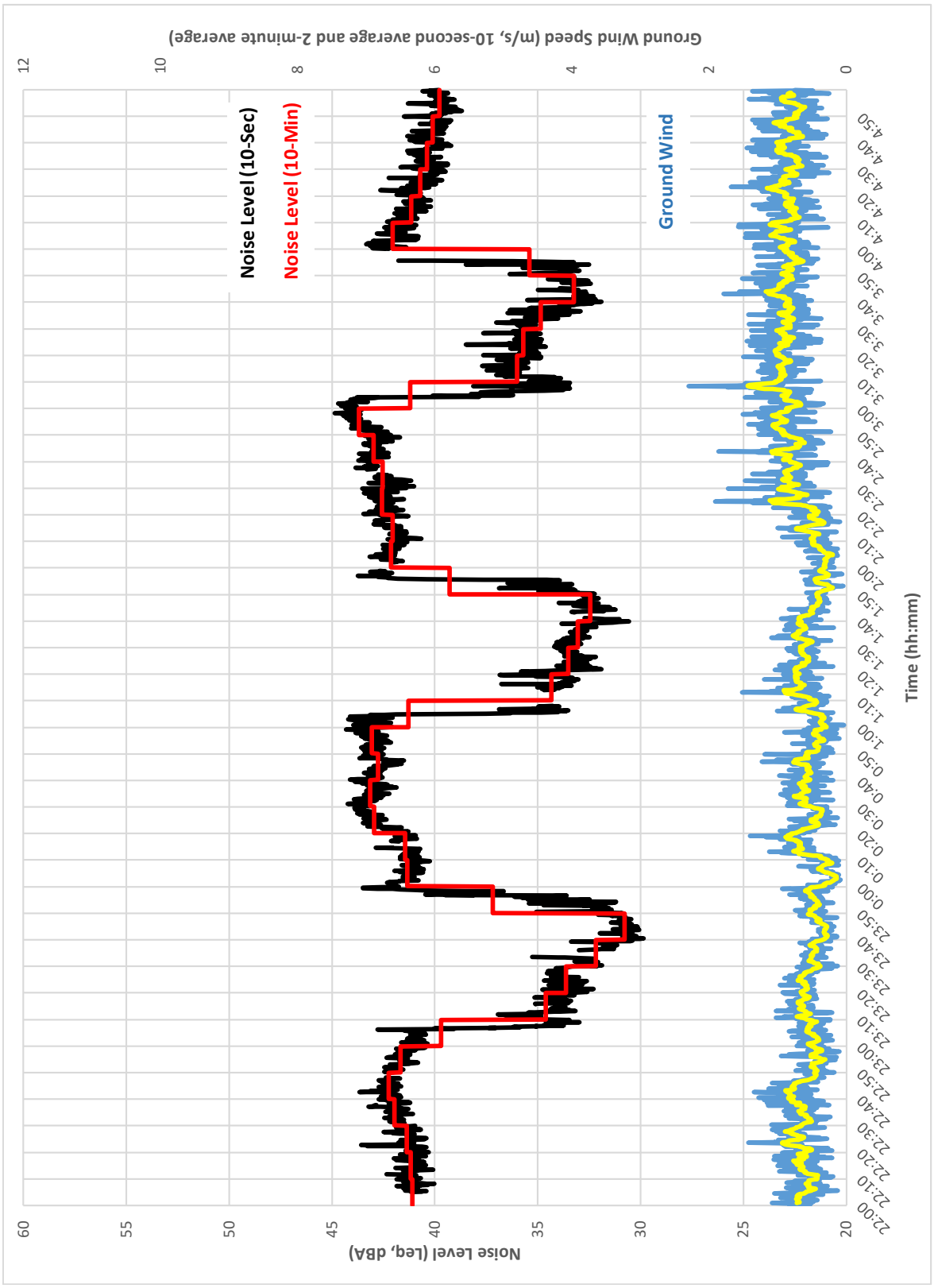

Figure 7-9: Location 2 Noise Levels Without Non-WTG Sources, March 29-30, 2016

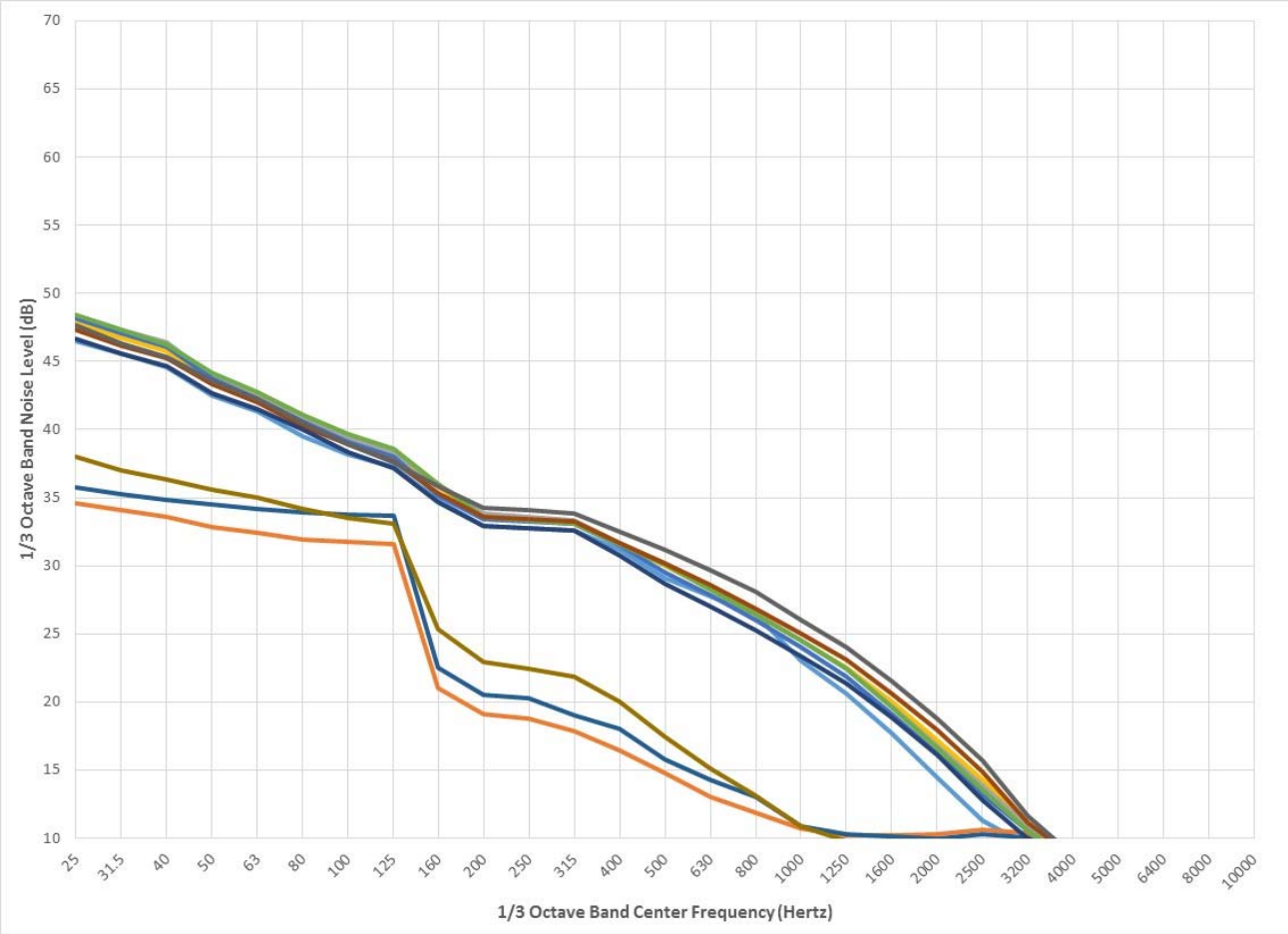

Figure 7-10: Location 2 One-Third Octave Band Spectra, March 29-30, 2016

March 31st, 2016

Measurements were conducted between 7:30 pm to midnight on March 30th. From the power production data it can be seen that full power was not reached by the nearest turbine. Full electric power production was achieved by the 2nd and 4th closest turbines for a few 10-minute periods. The wind direction during this time period was out of the north, placing the residence downwind of the nearest turbine, and upwind of the 2nd closest turbine. Ground wind speeds were moderate to strong during the measurement (2 to 5 m/s).

Figure 7-11 shows the noise level versus time for the entire measurement period. The plot displays a "jittery" character due to the moderate ground winds (2 to 5 m/s). The presence of noise from the loudest passing vehicles is obvious, but the effect of more distant traffic is lost in the jitter. Figure 7-12 shows the same information, yet with the noise levels due to non-WTG sources removed to the degree possible based on field notes and a review of the spectral content of 10-second samples.

Table 7-3 lists the loudest WTG-on 10-minute noise level for each of the three turbine-on hours, as well as the lowest 10-minute turbine-off noise levels measured before and after each turbine-on level, and the average of before and after off levels. Also shown is the 1.5 dB uncertainty level

from ANSI S12.9 Part 3, and the resulting WTG-only noise level. The highest level, 44.7 dBA, occurred at 7:30 pm, as expected based on turbine operations.

However, field staff noted the WTG-only level as being closer to 43 dBA. A review of the spectral shape of the 10-minute averages in Table 7-3 indicated that wind noise is present. Figure 7-13 shows the frequency spectra for three one-minute periods when field technicians noted "good turbine minute", and one one-minute period that was noted as "windy". The lower "good minute" shows evidence of WTG noise and the overall level is 41.4 dBA. The higher two show evidence of containing wind noise and the overall levels range from 44 to 45 dBA.

A 25 Hz filter analysis was conducted, and the results of that are shown in Figure 7-14. The lower two traces show some signs of turbine spectral shape, and have overall levels of 42 to 43 dBA which more closely matches field observations. The higher level spectra show signs of being influenced by wind.

Table 7-3: Location 2 WTG Noise Levels March 31, 2016 (10-min L_{eq}, dBA)

Time	Measured All	Measured Before	Measured After	Average Before After	Uncertainty	Background	WTG Only Noise Level
19:00	45.1		35.8	35.8	1.5	34.3	44.7
21:00	44.6	32.4	35.4	33.9	1.5	32.4	44.3
23:00	42.3	32.0		32.0	1.5	30.5	42.0

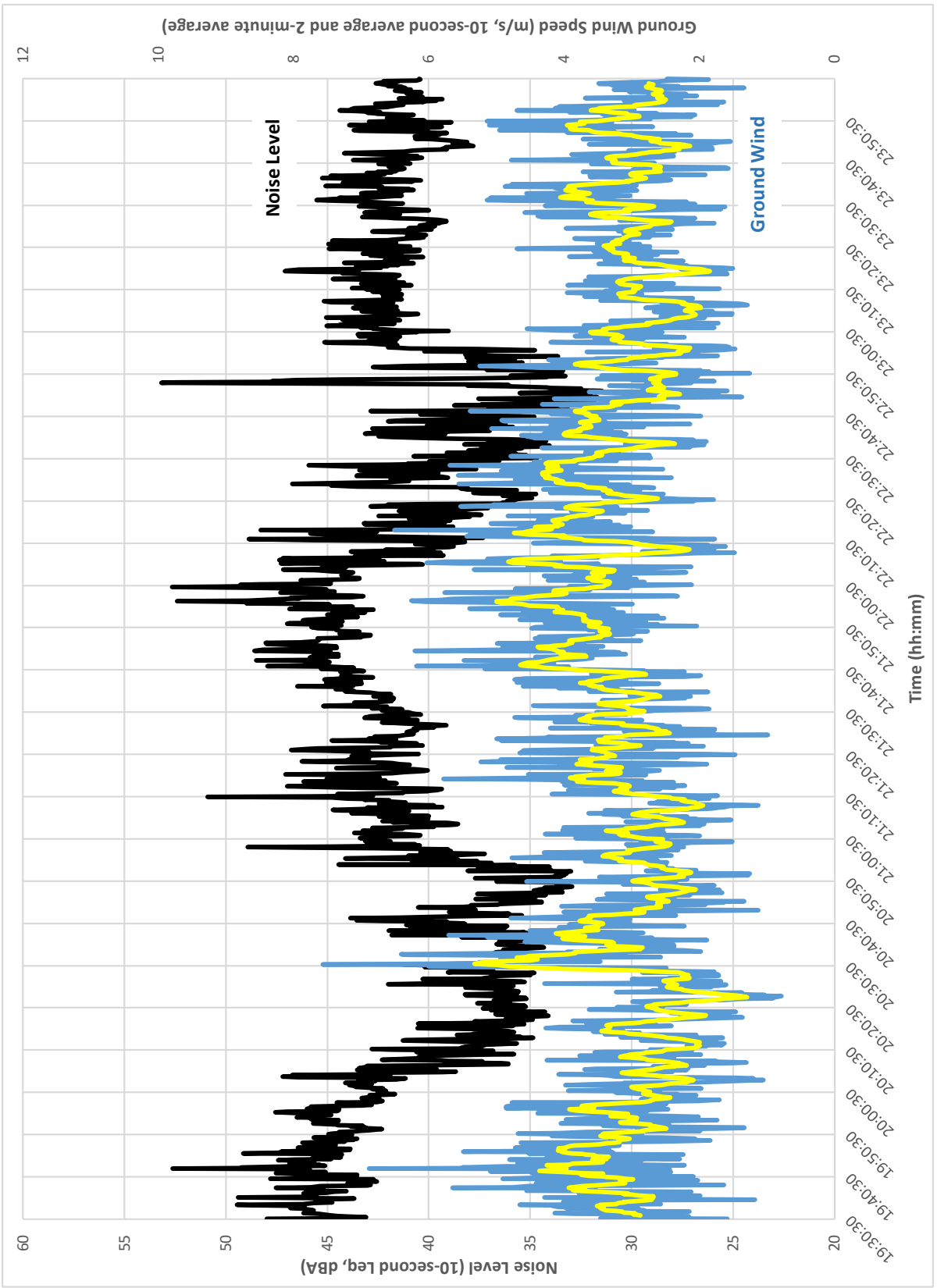

Figure 7-11: Location 2 Noise Levels Versus Time, March 31, 2016

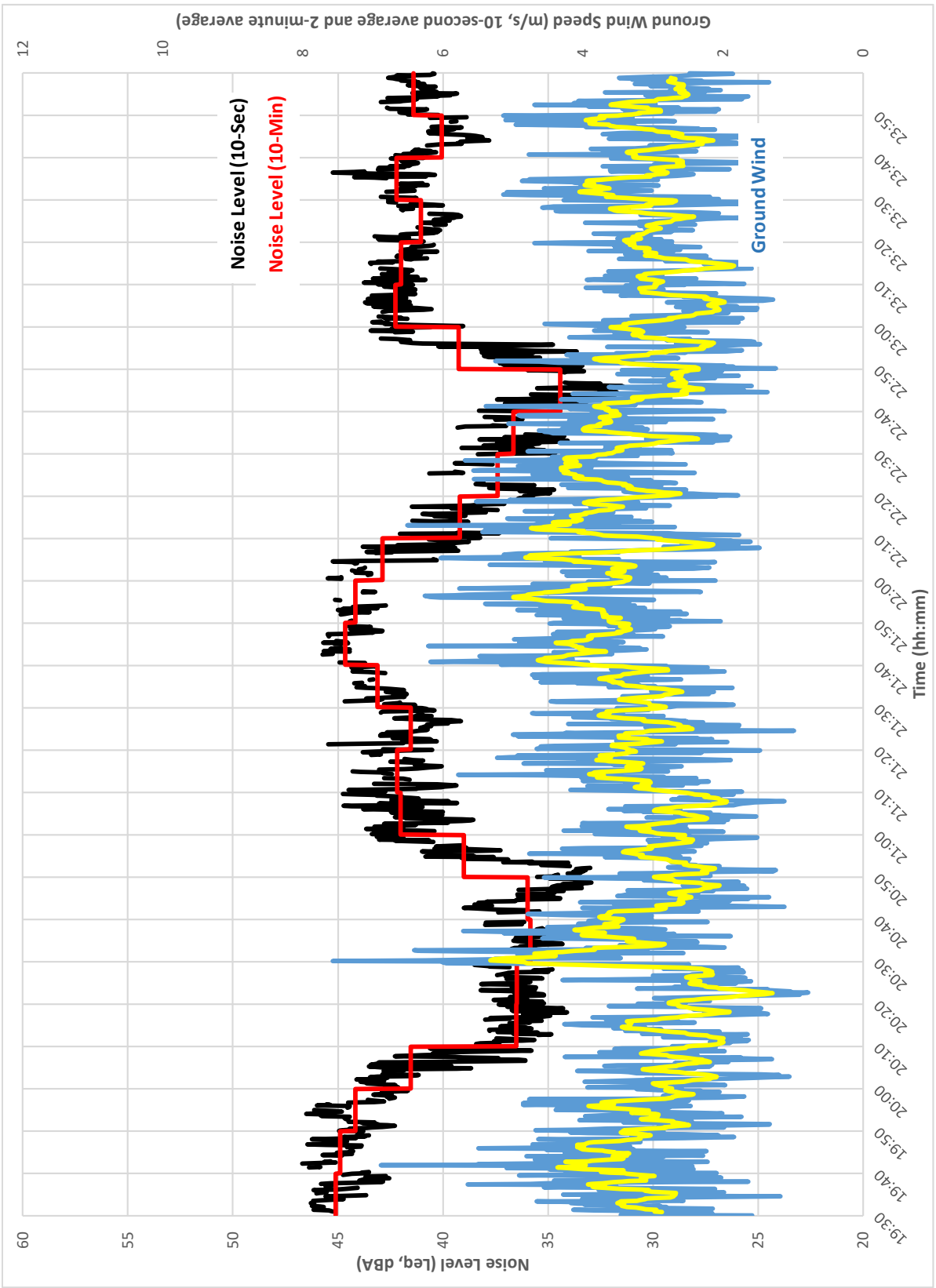

Figure 7-12: Location 2 Noise Levels Without Non-WTG Sources, March 31, 2016

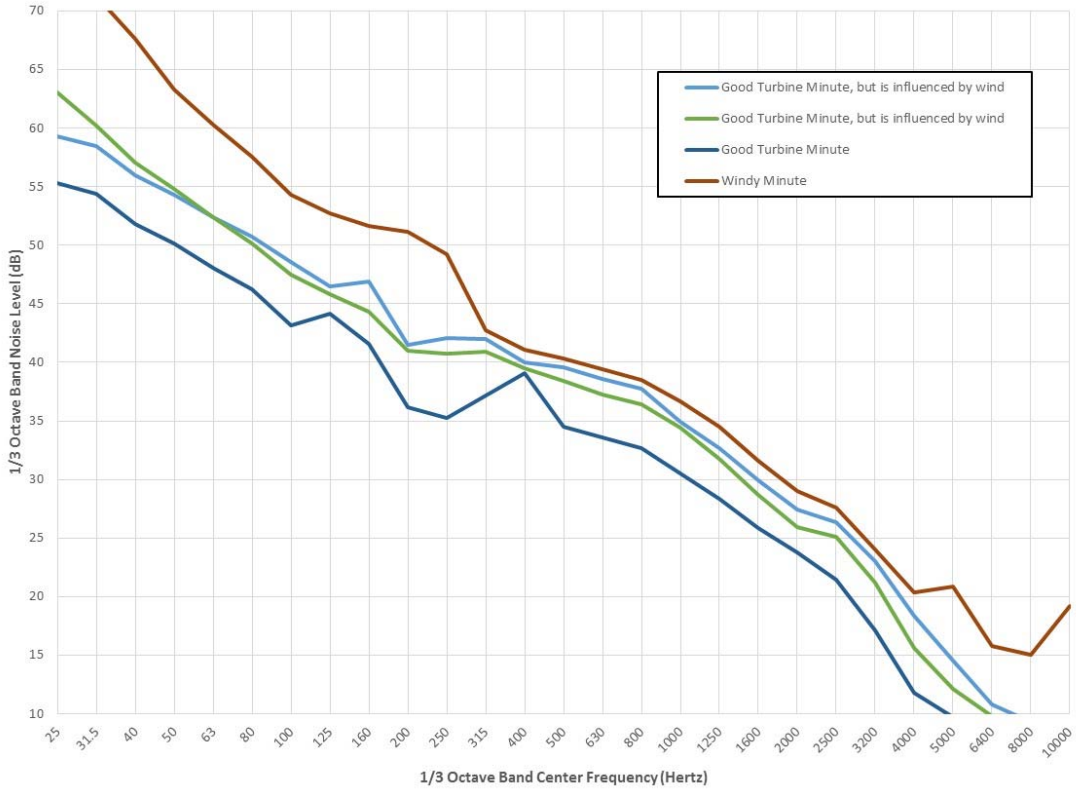

Figure 7-13: Location 2 One-Third Octave Band Spectra, March 31, 2016

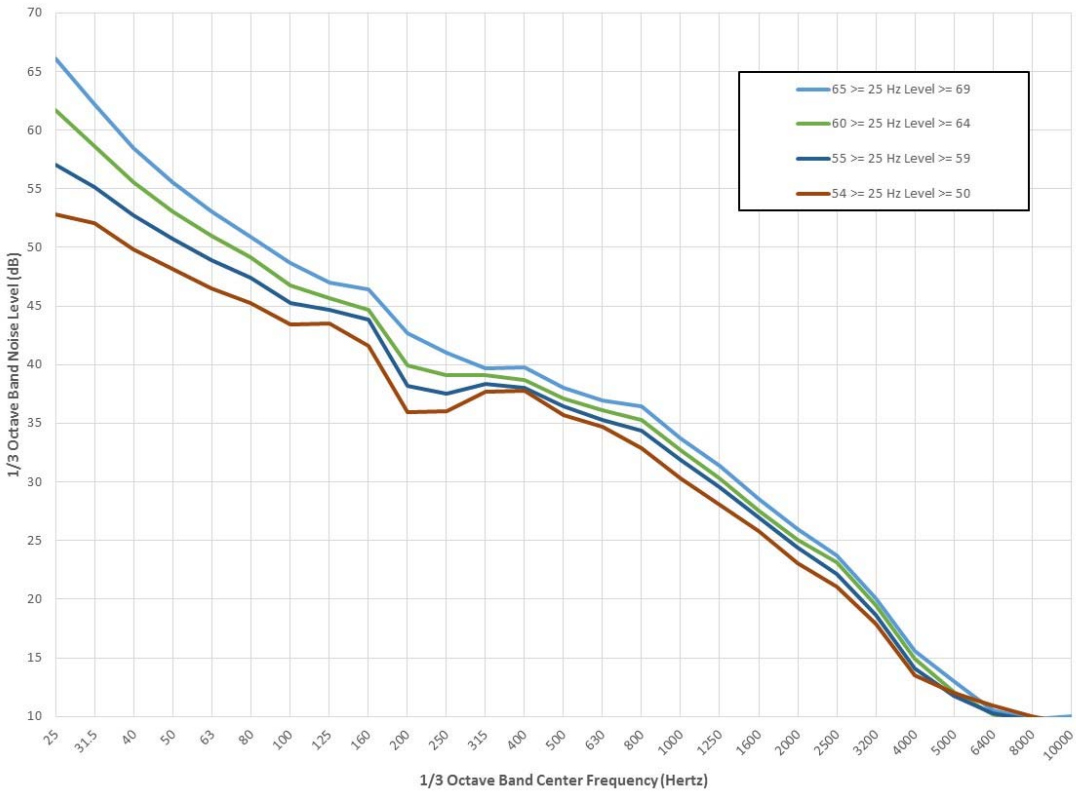

Figure 7-14: Location 2 Results of 25 Hz Filter Analysis, March 31, 2016

7.3 Analysis of Noise Levels Measured at Location 10

April 28th, 2016

Measurements were conducted between 1:00 am and 5:00 am on April 28th. From the power production data it can be seen that full power was reached by the nearest two turbines for two 10-minute periods. At this time power production from the 3rd and 4th closest turbines ranged from about 60 to 80%. The wind direction during this time period was out of the south, placing the residence in a crosswind position with respect to the nearest two turbines. Ground wind speeds were moderate to strong during the measurement (3 to 6 m/s).

Figure 7-15 shows the noise level versus time for the entire measurement period. The plot displays a "jittery" character due to ground winds. Field technicians noted the WTG-only level as being, at most, 43 to 44 dBA. Figure 7-16 shows the frequency spectra of those one-minute intervals where staff noted that turbines were the primary audible source, and where a subsequent review of the spectra substantiated that observation. The overall level of these spectra is about 43 dBA.

A 25 Hz filter analysis was conducted, and the results of that are shown in Figure 7-17. The lower three traces show signs of turbine spectral shape. The louder of the three has an overall level of about 43 dBA, and a shape that almost exactly matches that of the times when field staff noted turbines as the dominant source.

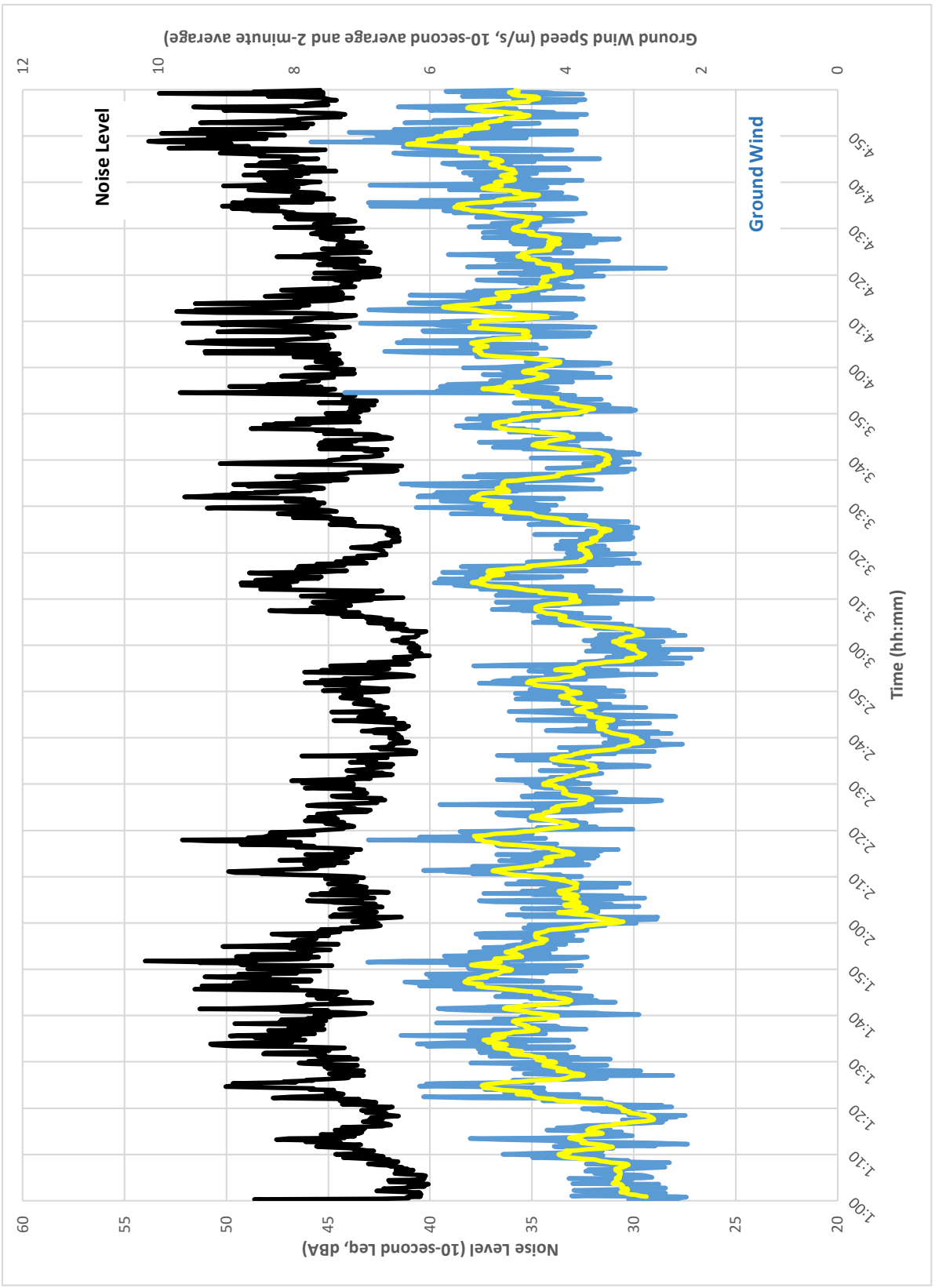

Figure 7-15: Location 10 Noise Levels Versus Time, April 28, 2016

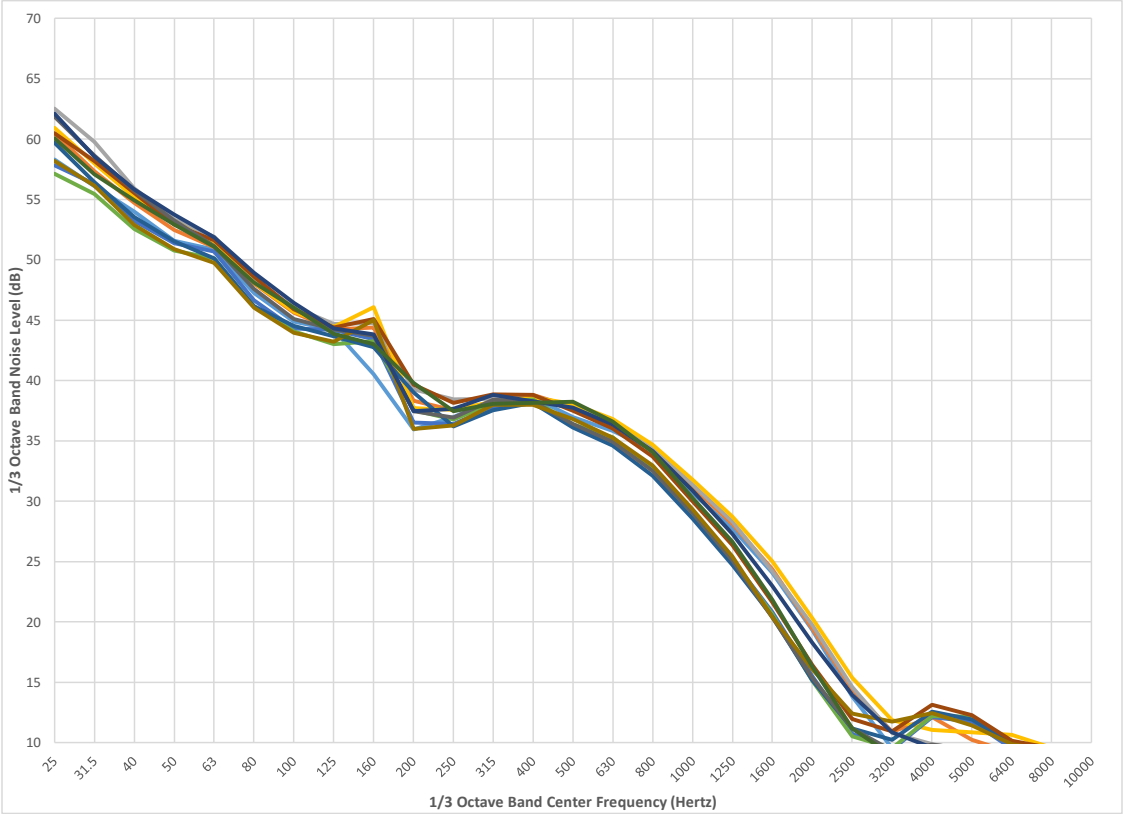

Figure 7-16: Location 10 One-Third Octave Band Spectra, April 28, 2016

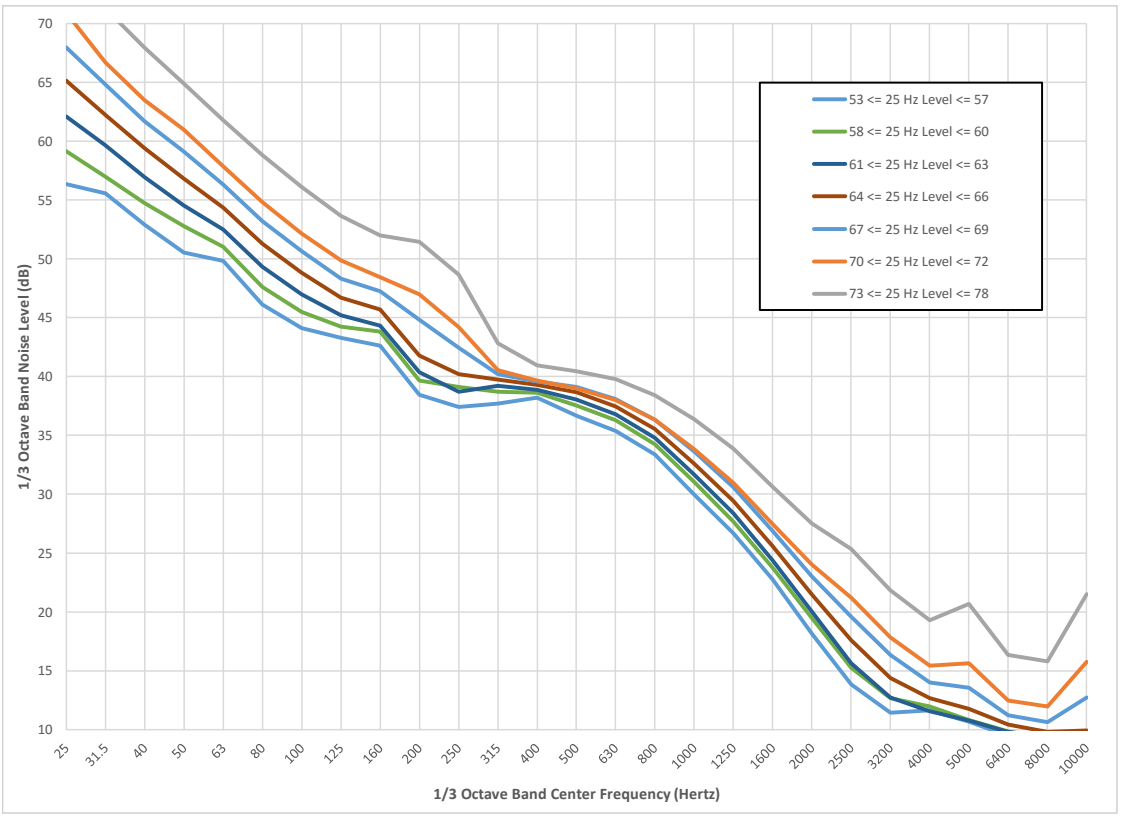

Figure 7-17: Location 10 Results of 25 Hz Filter Analysis, April 28, 2016

April 25th, 2016

Measurements were conducted between 4:40 pm and 6:00 pm on April 25th. From the power production data it can be seen that full power was reached by the nearest turbine for one 10-minute period. At this time power production from the next three closest turbines was about 50%. The wind direction during this time period was out of the south, placing the residence in a crosswind position with respect to the nearest two turbines. Ground wind speeds were moderate during the measurement (2 to 5 m/s).

Figure 7-18 shows the noise level versus time for the entire measurement period. The plot displays a "jittery" character due to ground winds. Field technicians noted the WTG-only level as being, at most, 43 dBA. Figure 7-19 shows those the frequency spectra of those one-minute intervals where staff noted that turbines were the primary audible source, and where a subsequent review of the spectra substantiated that observation. The overall level of these spectra is about 43 dBA.

A 25 Hz filter analysis was conducted, and the results of that are shown in Figure 7-20. The lower two traces show signs of turbine spectral shape. The louder of these two lower spectra has an overall level of about 43 dBA, and a shape that almost exactly matches that of the times when field staff noted turbines as the dominant source.

April 26th, 2016

Measurements were conducted from 3:00 to 6:00 pm. Figure 7-21 shows the noise level versus time for the entire measurement period. The erratic nature of the noise level is due to nearby farm machinery. Turbine operations were very low (less than 30%) and turbine noise barely audible. Figure 7-22 shows those the frequency spectra of those one-minute intervals where staff noted that turbines were the primary audible source, and where a subsequent review of the spectra substantiated that observation. The overall level of these spectra is about 40 dBA.

April 24th, 2016

We arrived on site at approximately 9pm. We measured for 2 minutes at Location 10 (9:25 pm to 9:26 pm). At 9:27 pm the entire LWEP shut down, reportedly due to an animal causing a short at the substation. During the measurements the turbines were operating at relatively low power (about 30%). The measured WTG-only noise level was ~40 dBA.

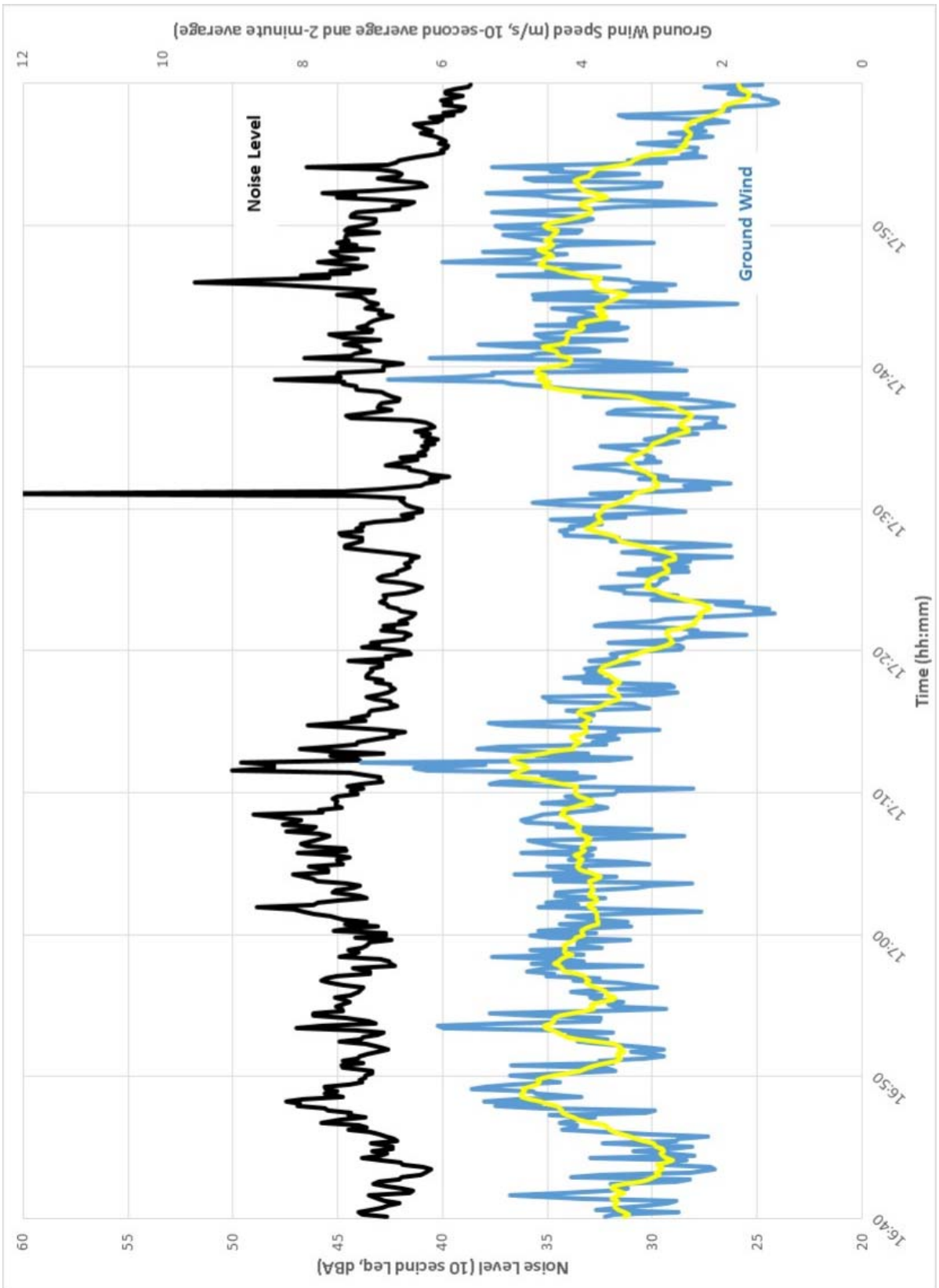

Figure 7-18: Location 10 Noise Levels Versus Time, April 25, 2016

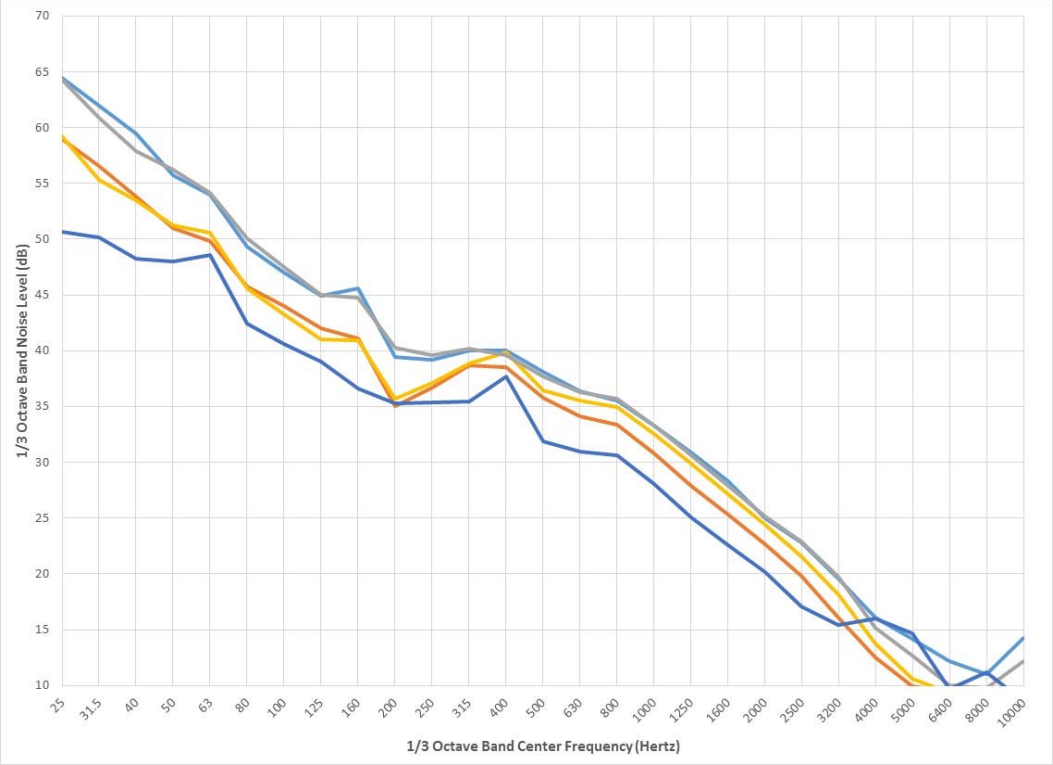

Figure 7-19: Location 10 One-Third Octave Band Spectra, April 25, 2016

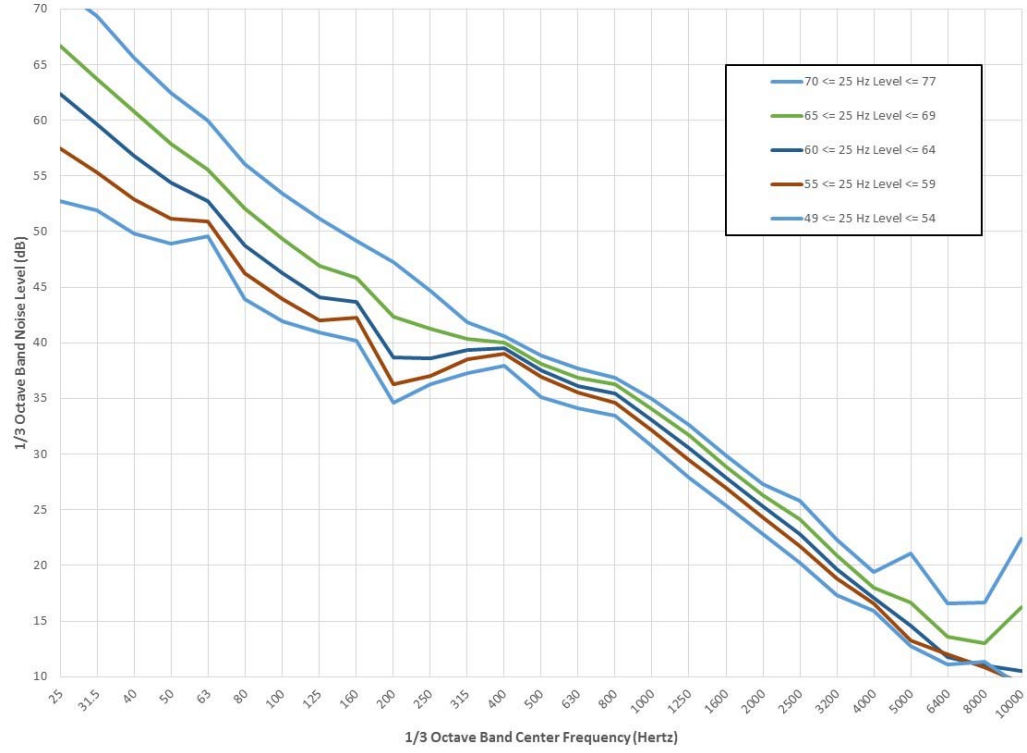

Figure 7-20: Location 10 Results of 25 Hz Filter Analysis, April 25, 2016

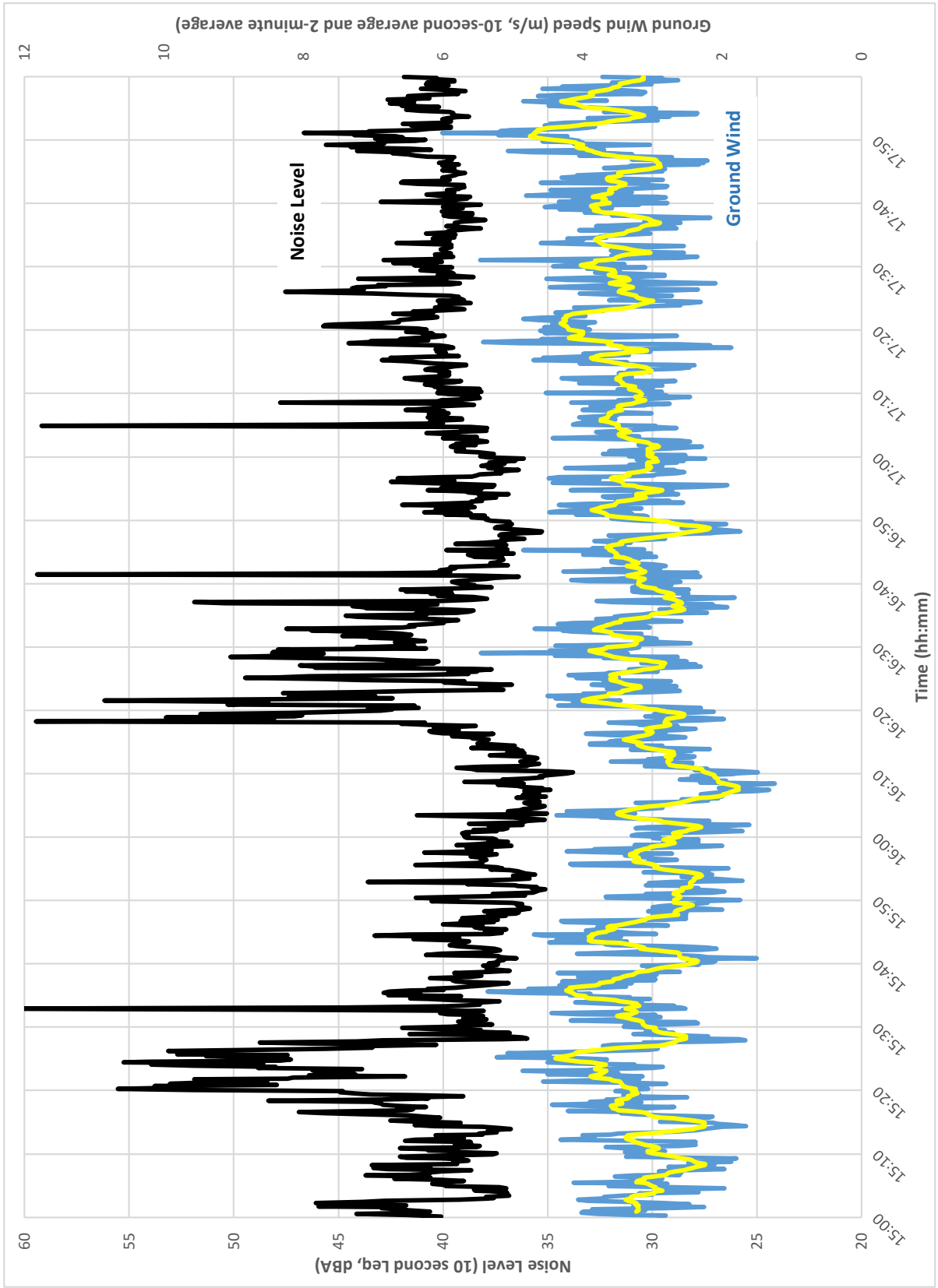

Figure 7-21: Location 10 Noise Levels Versus Time, April 26, 2016

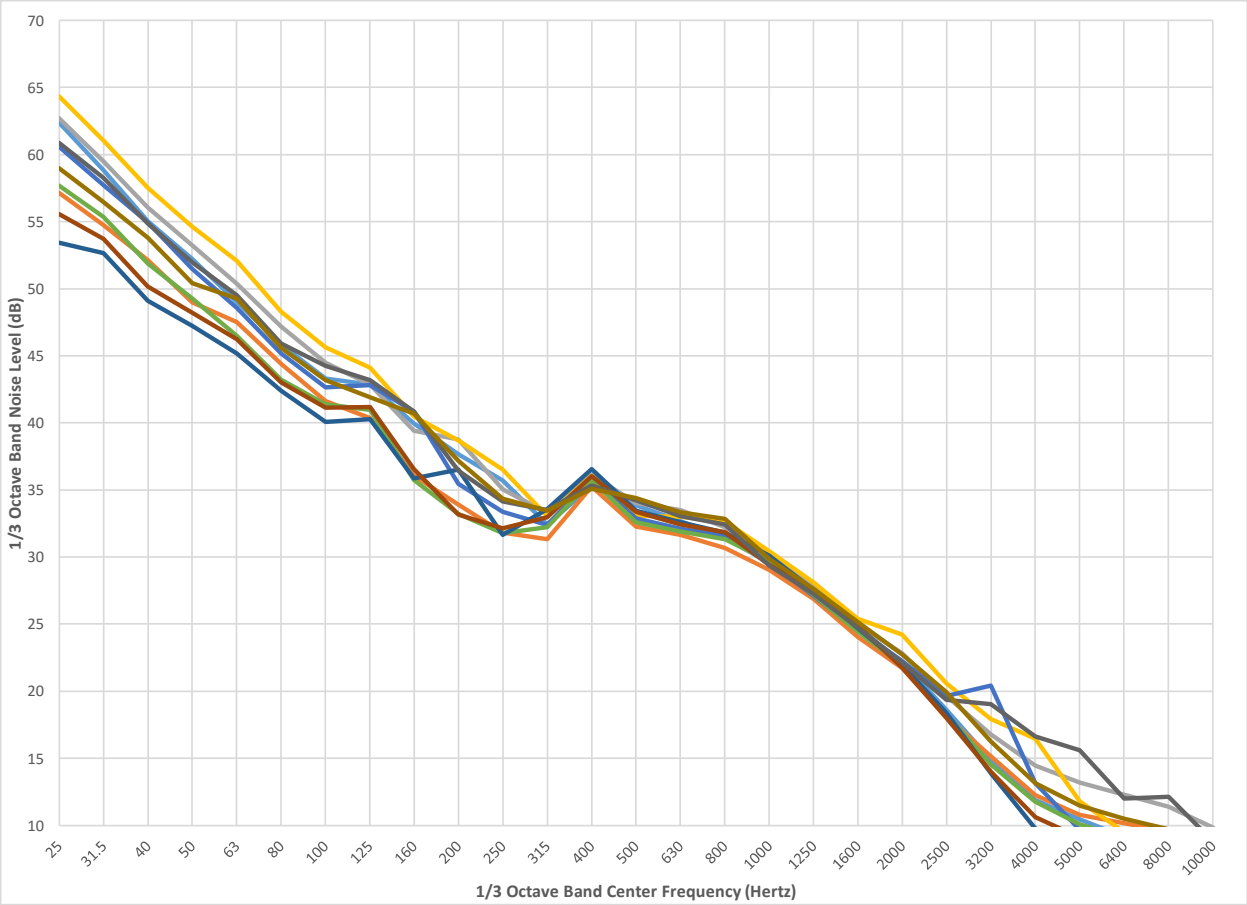

Figure 7-22: Location 10 One-Third Octave Band Spectra, April 26, 2016

7.4 Analysis of Noise Levels Measured at Location 9

April 28th, 2016

Noise levels were measured from 1:00 to 5:00 am. From the power production data it can be seen that full power was reached by the nearest turbine for three 10-minute periods. During these times power production from the next closest three turbines was generally 80% or more. The wind direction during this time period was out of the south, placing the residence in a crosswind position with respect to the nearest three turbines. Ground wind speeds were moderate during the measurement (2 to 5 m/s).

Figure 7-23 shows the frequency spectra of the one-minute intervals where staff noted that WTGs were the primary audible source, and where a subsequent review of the spectra substantiated that observation. The overall level of these spectra ranges from 42 to 44 dBA, which matches field observations. Figure 7-24 shows the frequency spectra of the one-minute intervals where field staff noted that turbines were audible, but wind blowing through the trees was as well. Note how the level at the turbine-dominated portion of the spectrum at 315 Hz does not increase (mostly), but there is longer a dip below 315 Hz and the low frequency levels increase significantly. The overall level of these spectra ranges from 42 to 46 dBA (not WTG-only). Figure 7-25 shows the frequency spectra of the one-minute intervals where field staff noted that wind was the dominant noise source. Note that now the turbine-only spectral shape gone, low frequency levels are very high. The overall levels range from 46 to 50 dBA (not WTG-only).

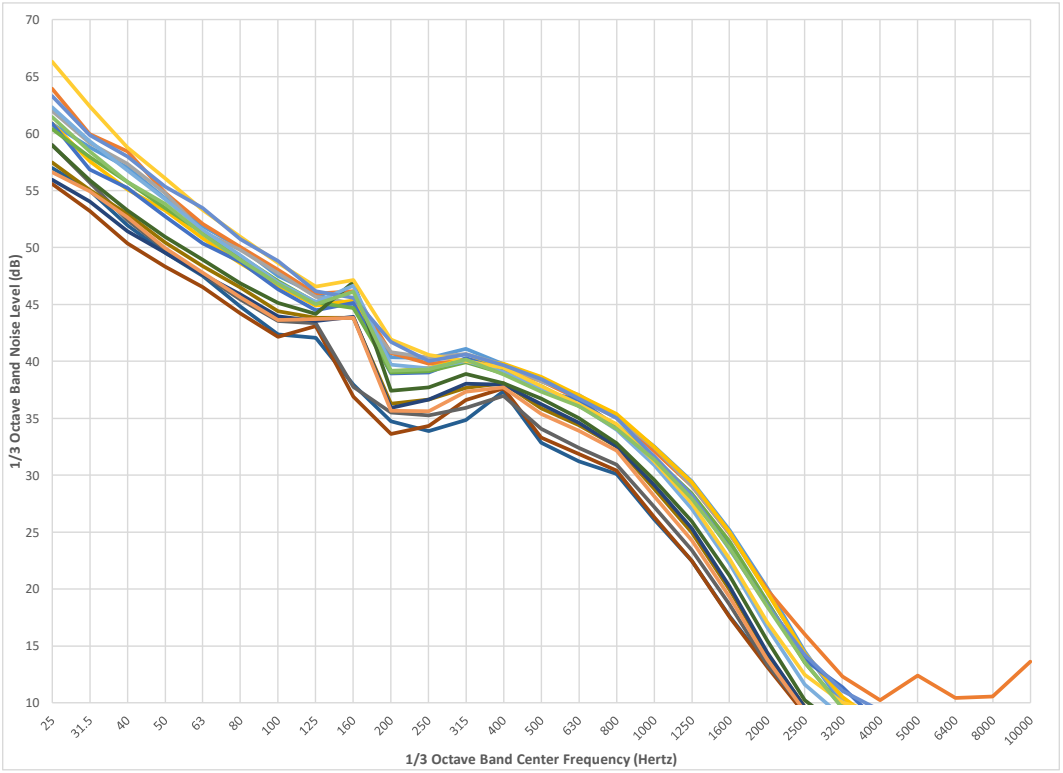

Figure 7-23: Location 9 Mainly WTG Frequency Spectra, April 28, 2016

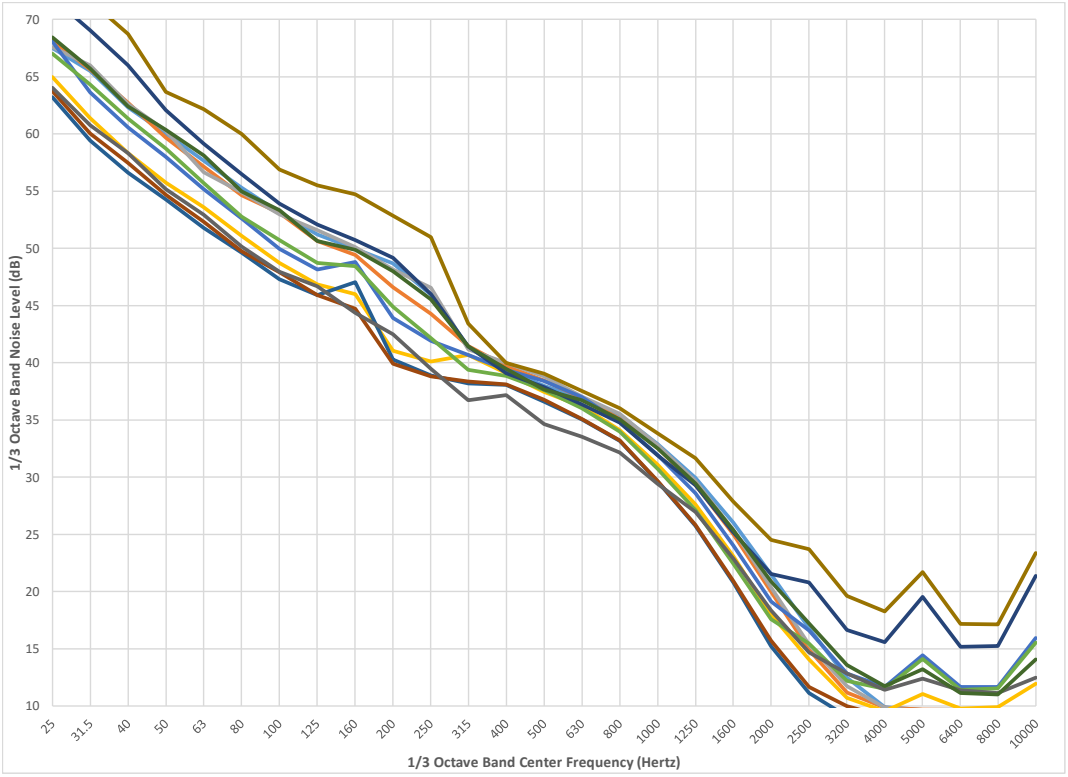

Figure 7-24: Location 9 WTG and Wind Frequency Spectra, April 28, 2016

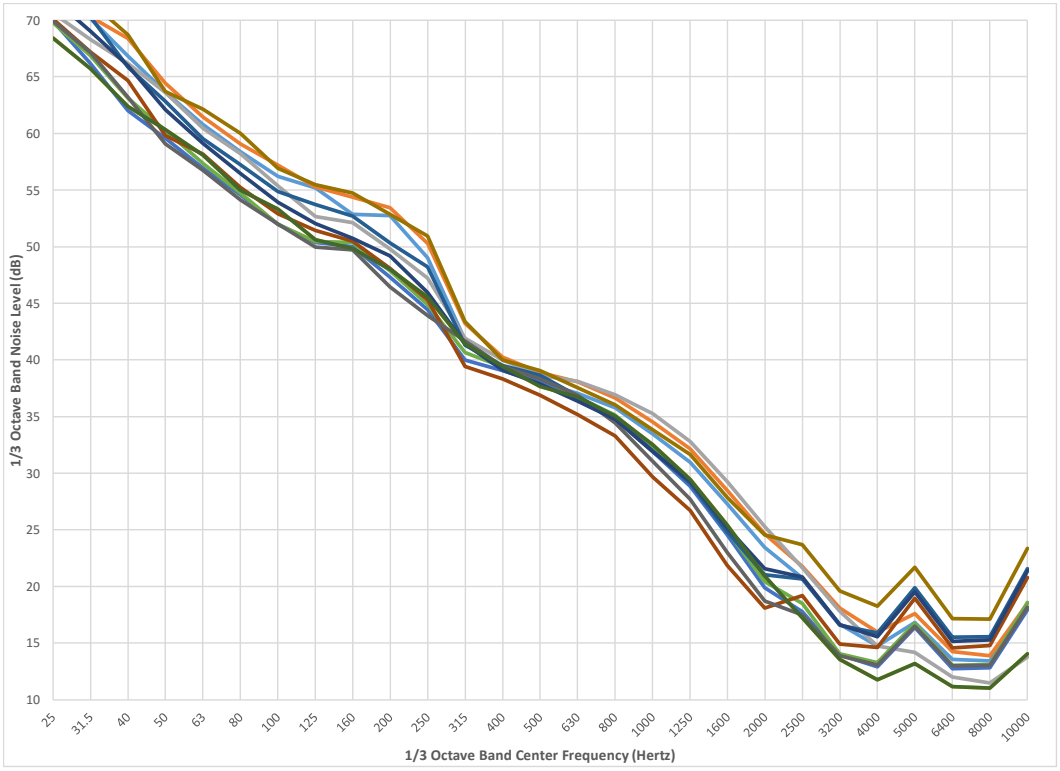

Figure 7-25: Location 9 Wind Dominated Frequency Spectra, April 28, 2016

April 26th, 2016

Measurements were conducted from 3:00 to 6:00 pm. Figure 7-26 shows the noise level versus time for the entire measurement period. The levels are almost completely dominated by traffic. Turbine operations were very low (less than 30%) and turbine noise barely audible. Figure 7-27 shows the frequency spectra of those one-minute intervals where staff noted that turbines were the primary audible source, and where a subsequent review of the spectra substantiated that observation. The overall level of these spectra is about 39 dBA.

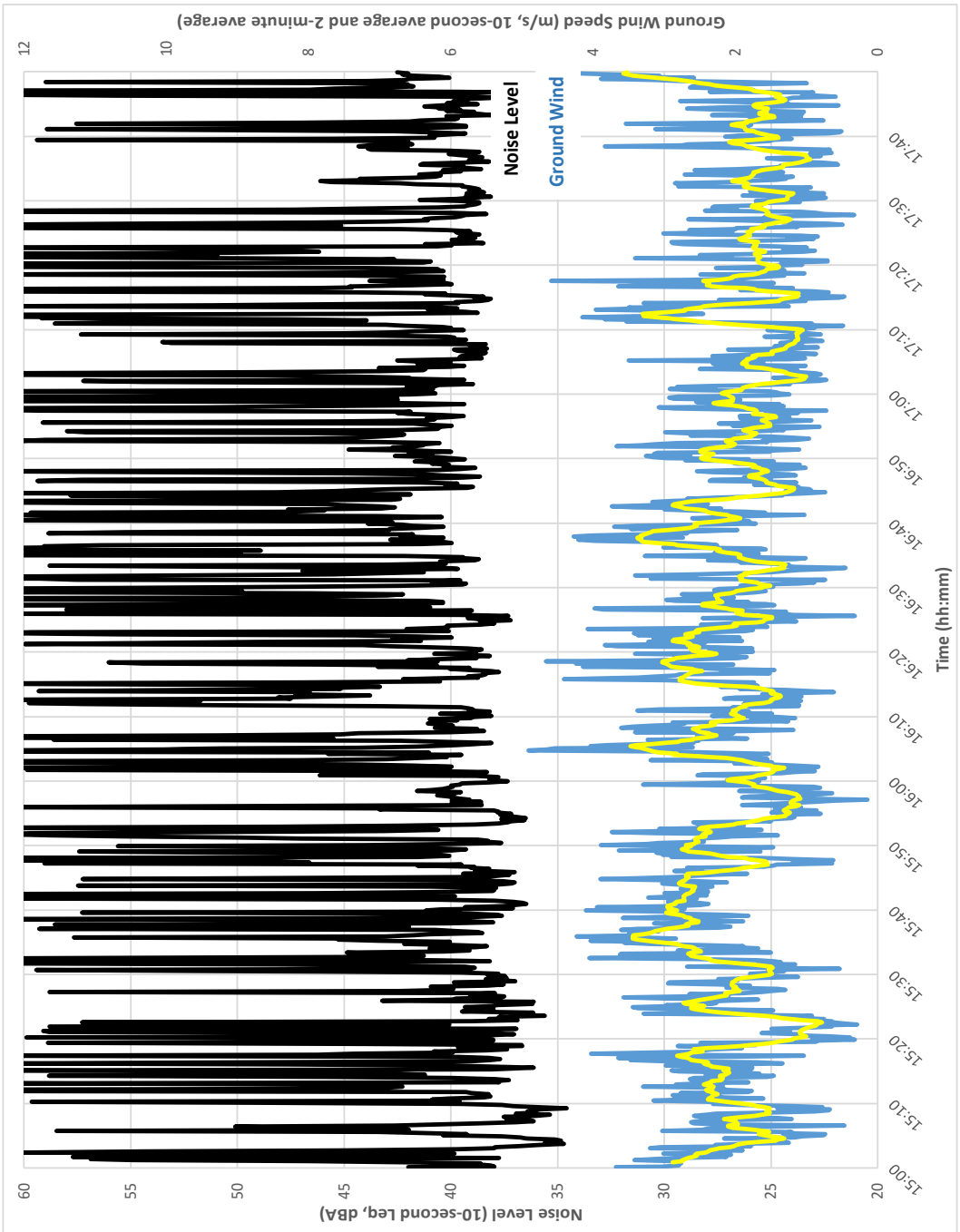

Figure 7-26: Location 9 Noise Levels Versus Time, April 26, 2016

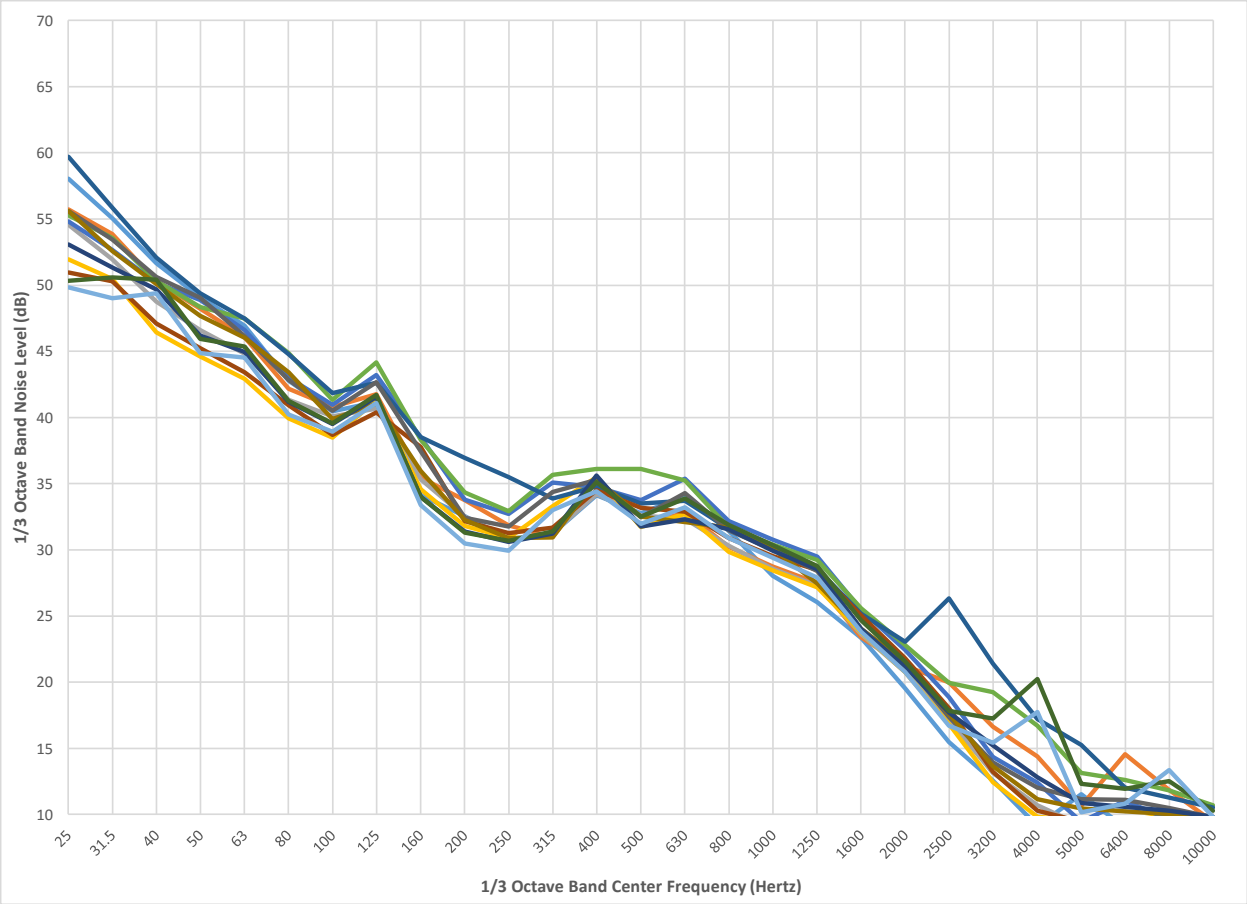

Figure 7-27: Location 9 One-Third Octave Band Spectra, April 26, 2016

April 24th, 2016

We measured noise levels from 9:18 pm to 9:27 pm. At 9:27 pm the entire LWEP shut down, reportedly due to an animal causing a short at the substation. During the measurements the turbines were operating at relatively low power (about 30%). The measured WTG-only noise level was ~40 dBA.

8. Conclusions

Location 5

The noise level data collected during the early morning hours of May 23rd are representative of loudest wind turbine conditions. The nearest turbine was operating at full electrical power, other nearby turbines were operating at or near full electrical power, the measurement location was downwind of the nearest turbines, and the atmosphere was stable and conducive to sound propagation. The loudest WTG-only 10-minute L_{eq} was 44 dBA. Adding to the validity of this data, multiple 10-minute data points were obtained during these conditions. Representative data was also collected at Location 5 on the night and morning of March 29th – 30th. During one 10-minute period of maximum turbine operations the loudest WTG-only 10-minute L_{eq} was 43.4 dBA. Based on all of the data collected at Locations 5 in 2016, we conclude that noise levels due to LWEP wind turbine operations are in compliance with Mason County's 45 dBA noise level limit. No additional testing is recommended at Location 5.

Location 2

Noise levels were measured on two occasions at Location 2, but neither represent loudest WTG conditions. On March 29 – 30, the nearest WTG operated at full electrical power for one 10-minute period, but at that time the three other nearest turbines were operating at about 50% of capacity, and the measurement location was upwind of the nearest turbine. On March 31st the nearest turbine never achieved more than about 60% of capacity. The 2nd, 3rd and 4th closest turbines did achieve full electrical power, but only sporadically and not necessarily at the same time. The loudest WTG-only noise level measured at Location 2 on March 29 - 30 was 43.3 dBA. On March 31 a level of 44.7 dBA was determined using the strict procedures outlined in the *Mitigation Plan Sound Testing Protocol*, but our field observations and further review of the measured data show that the WTG-only noise level was, at most, 44 dBA.

While we did not find any WTG-only noise levels above about 44 dBA at this location, we do not feel that we captured loudest WTG noise conditions. Based on all of the data we collected at Location 2, we cannot provide definitive conclusions regarding compliance with the Mason County noise level limit. We recommend continued testing at Location 2 in 2017.

With regard to NRO operation, we recommend that WTG-6 and WTG-15 near Location 2 be left in NRO Mode 2 until the Spring 2017 testing. This is based on the measurement data collected on March 29, 2016. On this night atmospheric conditions were conducive to maximum sound propagation, but three out of the closest four turbines were not at full electrical power production. We measured a maximum WTG-only noise level of about 43.4 dBA on this night. My calculations regarding how much louder the measured noise level would have been if all four of the nearest turbines were at full electrical power indicate that the full-production noise level could have been as high as 45.1 dBA. Given this result, and the uncertainty of the calculation, there is the possibility of exceeding 45 dBA if WTG-6 and WTG-15 are not placed into NRO 2.

With regard to NRO operation during the Spring 2017 measurements, we recommend testing with WTG-6 and WTG-15 in either NRO Mode 1 or Mode 0. For the purposes of determining maximum noise levels, these modes are acoustically equivalent according to Vestas technical

documentation. That is, when hub-height wind speeds are 7 m/s or greater, noise emissions are the same in Modes 0 and 1. When hub-height wind speeds are in the 4 to 7 m/s range, NRO Mode 1 noise levels are about 0.5 to 1.5 dBA lower than Mode 0 noise levels. These turbines can be left in NRO Mode 1 or Mode 0 indefinitely if sufficient valid data is obtained at Location 2 in 2017, and the turbine-only sound level is determined to be less than 45 dBA. If, however, insufficient or inconclusive data are obtained in 2017, these turbines should be returned to NRO Mode 2 either indefinitely, or until such time that additional testing at Location 2 demonstrates compliance with the 45 dBA standard while WTG-6 and WTG-15 are in NRO Mode 0 or 1.

Location 10

Noise levels were measured on two occasions at Location 10 when the nearest turbine was producing full electrical power. On April 28th the nearest WTG operated at full electric power for two 10-minute periods, and during those times the three other nearest turbines were operating between 60 and 80% of full capacity. On April 25th the nearest WTG operated at full electric power for one 10-minute period, and during that time the three other nearby turbines were operating at about 50% of full capacity. The loudest WTG-only noise level measured at Location 10 was 43 dBA.

While we did not find any WTG-only noise levels above about 43 dBA at this location, we do not feel that we necessarily captured loudest WTG noise conditions. Therefore, based on all of the data we collected at Location 10, we cannot provide definitive conclusions regarding compliance with the Mason County limit. We recommend continued testing at this location in 2017.

Similarly, there is not enough valid data at Location 10 from the Spring 2016 measurements to recommend a propagation plan at this time. The need for a propagation plan should be reviewed after the Spring 2017 measurements, and should be based on the totality of the data measured at all sites in both 2016 and 2017.

Location 9

Noise levels were measured on one occasion at Location 9 when the nearest turbine was producing full electrical power. On April 28th the nearest WTG operated at full electric power for three 10-minute periods, and during those times the three other nearby turbines were operating at about 80% or greater. The loudest WTG-only noise level measured at Location 9 was between 43 and 44 dBA.

While we did not find any WTG-only noise levels above about 44 dBA at this location, we do not feel that we necessarily captured loudest WTG noise conditions. Therefore, based on all of the data we collected at Location 9, we cannot provide definitive conclusions regarding compliance with the Mason County limit. We do not recommend additional measurements at Location 9. There is a relatively high amount of traffic here, some full power data has been acquired, and as described below we prefer to focus on fewer sites. We do recommend reviewing the data from Location 9 after the 2017 testing, applying anything that was learned from the 2017 measurements and data analysis, and re-assessing compliance at Location 9 at that time. For example, if testing at other location(s) with similar turbine geometry and similar predicted noise levels indicates compliance, it might be reasonable to conclude the same for Location 9.

Similarly, there is not enough valid data at this location from the Spring 2016 measurements to recommend a propagation plan at this time. The need for a propagation plan should be reviewed after the Spring 2017 measurements, and should be based on the totality of the data measured at all locations in both 2016 and 2017.

Spring 2017 Noise Level Testing Recommendations

For the Spring 2017 measurements, the *Consent Judgement* mandates testing at Locations 1 and 6. As described above, we are recommending continued measurements at Locations 2 and 10. The *Consent Judgement* also mandates the selection of two, additional, measurement locations for 2017. We do not feel that this is in the best interest of this case, and recommend the *Consent Judgement* be amended to eliminate this requirement. We feel that testing at two sites on any given night is sufficient, having four sites to choose from is adequate, and Locations 1, 2, 6, and 10 provide a good representation of the LWEP as a whole. In general, we recommend measuring more data at fewer sites, versus less data at more sites. We also recommend that the turbines not be turned off unless and until field staff are confident that the turbine-only noise level being measured is approaching or exceeding 45 dBA. This procedure was implemented by Hankard Environmental for the last two weeks of 2016 testing, and is designed to maximize the amount of turbine-on noise data collected.