Falmouth Wind Turbine Noise Study

Falmouth, Massachusetts

HMMH Report No. 304390
September 2010

Prepared for:

Weston & Sampson Engineers, Inc.
5 Centennial Drive
Peabody, MA 01960

and

Town of Falmouth
59 Town Hall Square
Falmouth, MA 02540

hmmh HARRIS MILLER MILLER & HANSON INC.

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Prepared by:

Christopher Menge
J. Eric Cox
James Ferguson
Michael Carr

HARRIS MILLER MILLER & HANSON INC.

Harris Miller Miller & Hanson Inc.
77 South Bedford Street
Burlington, MA 01803
T 781.229.0707
F 781.229.7939

In association with:

Cross-Spectrum Labs
P.O. Box 90842
Springfield, MA 01139

Executive Summary

Harris Miller Miller & Hanson Inc. (HMMH) was retained by Weston & Sampson Engineers, Inc. under contract to the Town of Falmouth, MA to conduct a noise measurement and modeling study in connection with the Town's two new wind turbines at the Falmouth Wastewater Treatment Facility located off Blacksmith Shop Road. The first turbine, denoted Wind-1, became operational in March of this year. Wind-2 is under construction and expected to be commissioned in the Fall of 2010. Both turbines are Vestas V82 1.65 MW turbines. The study was prompted by concerns and complaints about noise from the Wind-1 turbine from a few nearby residents, mostly located along Blacksmith Shop Road, and by the Town's interest in understanding the noise implications of the Wind-2 turbine in the surrounding community prior to the erection of that turbine.

The purpose of this study was twofold. The first purpose was to conduct a noise measurement program at some of the closest community locations during times when the turbine was operating and when it was turned off for maintenance, to establish background noise levels. The noise levels measured during these different periods were to be compared to determine the significance of the increased noise, particularly in the context of the Massachusetts Department of Environmental Protection's (Mass DEP's) Noise Guidelines. The second purpose of the study was to model the noise levels in the surrounding community that would be expected from the operation of both the Wind-1 and Wind-2 turbines. This model would project where potential noise impact would occur with respect to the Mass DEP Noise Guidelines.

The noise study followed standard measurement and modeling protocols, and was closely coordinated with the Town and members of the surrounding community. The noise measurement program extended for ten days, from June 18 to 28, 2010. The noise measurement study concluded that background noise levels vary notably with wind speed and time of day, as expected. The average Mass DEP L90 background sound levels were measured to be 29 dBA in the early morning hours and 41 to 46 dBA during the day at the two long-term measurement locations. The average increases in background noise levels with the Wind-1 turbine operating were measured to be about 1 dBA during the day and 4 to 8 dBA at night; therefore, we conclude that Wind-1 is operating within Mass DEP requirements. Reference measurements conducted near the turbine confirmed that the noise levels from the turbine are consistent with the manufacturer's published specifications. The noise study also investigated the degree and effects of low frequency noise from the turbine. Under existing conditions, no violations of the Mass DEP noise guidelines occur at the homes nearest the Wind-1 turbine, although noise levels with the turbine operating approach the criterion of a 10-decibel increase in noise at the closest homes along Blacksmith Shop Road.

The evaluation of the effects of both Wind-1 and Wind-2 turbines operating simultaneously found that although no violations of the Mass DEP noise guidelines are expected at any of the noise measurement sites, the Mass DEP 10-decibel increase guideline may be exceeded at two homes at the end of Ambleside Drive with both turbines running during limited time frames. This possible exceedance would only occur during the early morning hours when the background sound levels are at their lowest, and when wind speeds at the wind turbine hub are in the range of 5 to 6 meters per second. At higher wind speeds, the background noise levels increase to a degree that the wind turbine noise does not increase sound levels by more than 10 decibels.

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1 Introduction

Harris Miller Miller & Hanson Inc. (HMMH) was retained by Weston & Sampson Engineers, Inc. under contract to the Town of Falmouth, MA to conduct a noise measurement and modeling study in connection with the Town's two new wind turbines at the Falmouth Wastewater Treatment Facility located off Blacksmith Shop Road. The first turbine, denoted Wind-1, became operational in March of this year. Wind-2 is under construction and expected to be commissioned in the Fall of 2010. Both turbines are 1.65 MW Vestas V82 turbines, with Mark II nacelles and Mark V towers. The study was prompted by 1) concerns and complaints about noise from the Wind-1 turbine from a few nearby residents, mostly located along Blacksmith Shop Road, and 2) by the Town's interest in understanding the noise implications of the Wind-2 turbine in the surrounding community prior to the erection of the turbine.

The purpose of this study was twofold. The first purpose was to conduct a noise measurement program at some of the closest community locations during times when the turbine was operating and when it was turned off for maintenance. The noise levels measured during these different periods were to be compared to determine background noise levels and the significance of the increased noise, particularly in the context of the Massachusetts Department of Environmental Protection's Noise Guidelines. The second purpose of the study was to model the noise levels in the surrounding community that would be expected from the operation of both the Wind-1 and Wind-2 turbines. This model would predict where potential noise impact would occur with respect to the Mass DEP Noise Guidelines.

Community involvement was an important part of this noise study. While details of that process are not presented in depth in this report, it is appropriate to mention that the Town of Falmouth maintained open communication about the study with nearby residents and interested parties throughout the study. An important element of the process was an initial meeting at the beginning of this study held on June 10th, where HMMH, Weston & Sampson and the Town presented the proposed noise study plans to interested and potentially affected residents. At that meeting, the study team also listened to the concerns of the citizens, and identified potential noise measurement locations. Also, the Town distributed noise survey forms to all residents in the vicinity of the wind turbine. Concurrent with the noise measurement program, residents were asked to document their impressions of audible sound from the turbine. The study team reviewed the forms that were returned as part of the overall study, and a summary of the results are to be provided separately.

In this report, we summarize the applicable noise standards and criteria, present the results of the noise and wind measurement program, describe the modeling used to project noise emissions from the wind turbines, and assess potential noise impacts from the project. Appendix A provides descriptions of the various noise metrics used in this report. Other appendices provide supporting information and data.

2 Noise Standards and Criteria

Applicable noise standards for the proposed wind turbine are the Massachusetts Department of Environmental Protection (DEP) noise guidelines, supplemented by the Falmouth Wind Turbine bylaw.

The Code of Massachusetts Regulations (Title 310, Section 7.10, amended September 1, 1972) empowers the Division of Air Quality Control (DAQC) of the Department of Environmental Protection (DEP) to enforce its noise standards. According to DAQC Policy 90-001 (February 1, 1990), a source of sound will be considered to be violating the Department's noise regulation if the source (1) increases the broadband sound level by more than 10 dBA above ambient, or (2) produces a "pure tone condition," when any octave-band center frequency sound pressure level exceeds the two adjacent frequency sound pressure levels by 3 decibels or more. (Appendix A provides descriptions of the noise metrics used in this report, and Appendix B provides background and the complete policy from Mass DEP.) Ambient is defined as the background A-weighted sound level that is exceeded 90 percent of the time (i.e. L90) measured during equipment operating hours. Wind turbines only operate when there is sufficient wind speed to run them (i.e. the "cut-in" speed), which is 3.5 meters per second (m/s) (8 mph) at the hub, in the case of the Vestas V82 turbines. Therefore, it is appropriate to determine the background L90 when winds are blowing at speeds sufficient to turn the turbines, for purposes of comparison to the turbine noise emissions.

Article XXXIV, "Windmills" in Chapter 240, Zoning, in the Town of Falmouth bylaws states "There shall be a rebuttable presumption that noise from the windmill in excess of 40 dBA, as measured at the property line, shall not be excessive."

3 Noise and Wind Measurement Program and Results

3.1 Introduction and Overview

Noise measurements of existing conditions in the project study area were conducted by HMMH from June 18 to 28, 2010. A total of six noise measurement sites in the residential community were chosen, two for long-term continuous monitoring for 10 days, and four sites where periodic short-term measurements of up to 30-minutes duration were obtained. Figure 1 shows the locations of each of the noise and wind measurement sites on an aerial photograph of the study area, with the Wind-1 and proposed Wind-2 turbine locations shown as well. In the figure, long-term sites are designated with an "LT" prefix, and short-terms sites with "ST." In addition, reference noise measurements near the turbine were conducted during two one-hour periods when the turbine was operating. In addition to noise, wind speed measurements were conducted in several locations, including at the Wind-1 turbine hub, at an anemometer set up near the turbine at a 10m (33 ft) height (designated as MET-1 in the figure), and near the two long-term noise monitors.

The 10-day measurement period was selected to coincide with and take advantage of a planned maintenance shut-down of the Wind-1 turbine, three months after it became fully operational. The maintenance period was scheduled for approximately three days during the middle of the measurement period, from June 22 to 24. Measured sound levels conducted while the turbine was running would be compared with the background sound levels present when the turbine was shut down. Since the turbine needed to be shut down for maintenance only during workday hours, it was also deliberately shut down for three nights, to enable measurements of nighttime background sound levels without the turbine in operation.

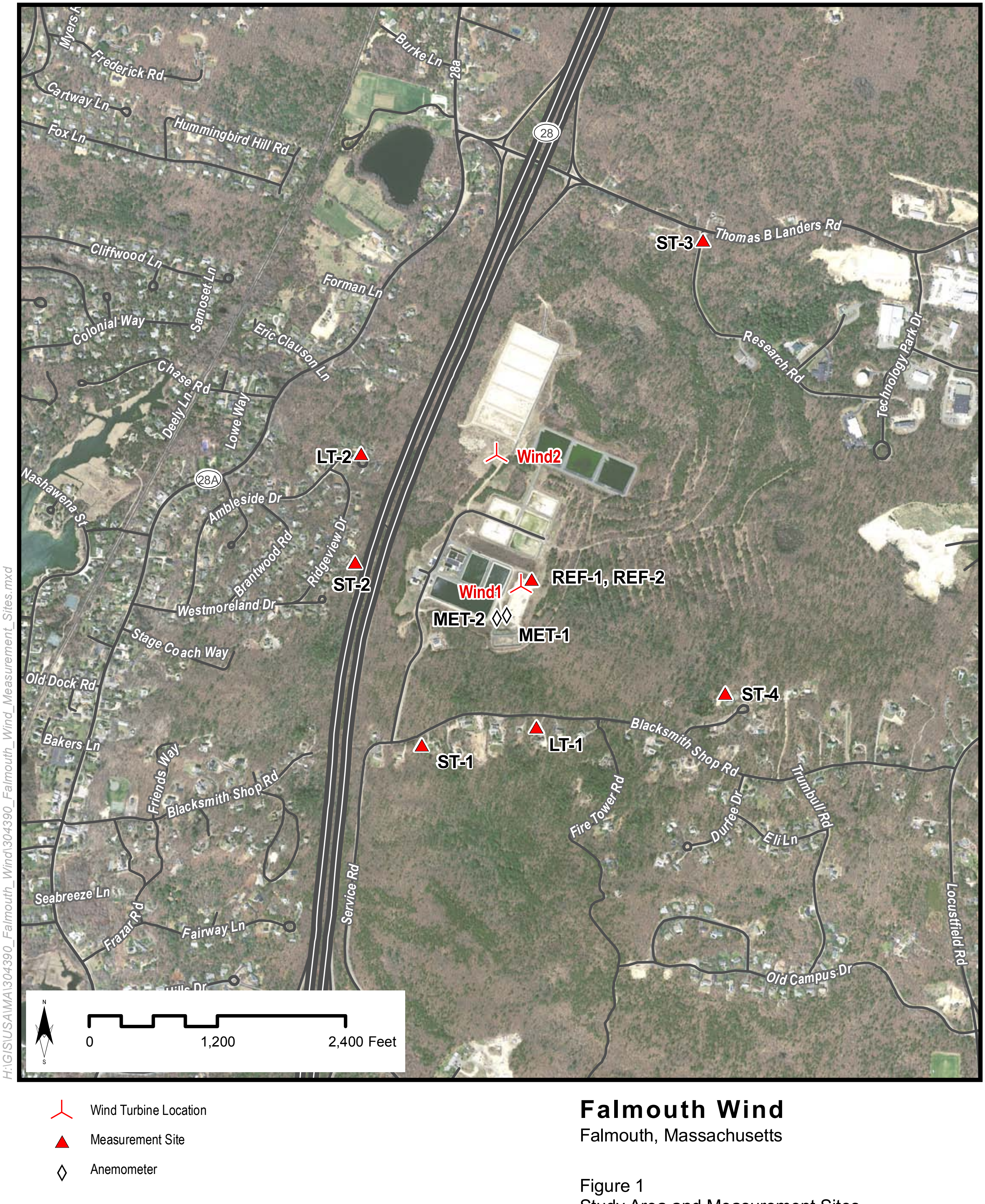
The measurement program was developed initially by HMMH in coordination with Weston & Sampson Engineers and the Town of Falmouth. The measurement program was later coordinated with acoustical consultants hired by several community members, Noise Control Engineering, Inc. (NCE), of Billerica, MA. Subsequent to a meeting with NCE and Weston & Sampson Engineers on June 14 to discuss the noise and wind measurement procedures, locations, instrument settings and durations, HMMH developed a detailed written protocol for the noise measurement program to provide guidance to the measurement personnel during the measurement period. An element of the protocol included logging of audible noise sources and events during each short-term measurement and at each of the long-term sites for a period of time during each study-area visit.

HMMH was assisted in conducting the measurements by Herb Singleton of Cross-Spectrum Labs (CSL). All data collection by CSL was directed by HMMH and obtained with HMMH-owned instrumentation.

3.2 Noise and Wind Measurement Instrumentation

Noise measurements were conducted with Brüel & Kjær 2250 sound level meters/noise analyzers owned by HMMH. These instruments were used to collect both A-weighted and 1/3-octave band data on a continuous basis. In addition, the instruments collect recordings in .WAV file format when thresholds are exceeded. These are very helpful for identification of the noise sources associated with loud events that appear in the sound level data record.

Regular field calibrations with acoustic calibrators were conducted for all of the measurements when the sites were visited. All instrumentation components, including microphones, preamplifiers and field calibrators have current laboratory certified calibrations traceable to the National Institute of Standards and Technology.



Falmouth Wind
Falmouth, Massachusetts

Figure 1
Study Area and Measurement Sites

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Wind speed and direction measurements were obtained near the long-term measurement sites throughout the long-term measurement periods. This data was collected and logged with Gill Instruments WindSonic ultrasonic anemometers mated to SpaceLogger-RS WindLogger data loggers by Richard Paul Russell Ltd. These anemometers were mounted 1.5m (5 ft) above the ground, the same height as the noise measurement microphones.

Wind speed and direction measurements were also logged during the measurement period at the Wind-1 turbine hub, at an 80-m (262-ft) height and at an anemometer supplied by Weston & Sampson Engineers, mounted 10m (33 ft) above the ground, approximately 91m (300 ft) southwest of the Wind-1 turbine, designated MET-1 in Figure 1.

3.3 Measurement Sites

Noise measurement sites focused on residential areas nearest the turbines and in different directions from them. One long-term site (LT-1) was chosen at 211 Blacksmith Shop Road, one of the homes closest to Wind-1 turbine (about 1320 ft south), and the home of residents who have expressed concerns about noise from the turbine. The Wind-2 turbine will be located approximately 2575 ft from this site. A second long-term site (LT-2) was chosen at one of the three homes closest to the future Wind-2 turbine, just west of Route 28, at 124 Ambleside Drive. This site is approximately 1265 ft west of Wind-2, and 1950 ft northwest of Wind-1. Microphones were located 5 ft above the ground, an average height for a person standing. As discussed above, local wind monitors were located near each of the long-term microphones, also at a height of 5 ft. Appendix C presents additional details about the noise measurements and sites, including photographs taken at the sites.

Four short-term sites were selected to supplement the measurements at the long-term sites. The measurements at these sites were conducted simultaneously with the data collection at the long-term sites, and the 10-minute intervals were synchronized. Site ST-1 was located at 161 Blacksmith Shop Rd., also at the home of residents who had expressed concern about noise from the turbine. This site, about 1755 ft from Wind-1, was chosen to characterize the western portion of Blacksmith Shop Rd., since noise concerns had been expressed by some of the residents in that area. Site ST-2 was located at 27 Ridgeview Drive, in the woods behind the home. This site represents the closest homes west of the Wind-1 turbine site. ST-2 is approximately 1575 ft from Wind-1 and 1665 ft from Wind-2. The measurement site is slightly closer than any of the closest homes in the area, which are all more than 1600 ft from Wind-1.

Two of the sites chosen for short-term measurements had been selected for noise measurements in the 2008 noise study for the then-proposed wind turbine for Notus Clean Energy.[1] The site names in that study, ST-3 and ST-4, have been retained in this study. The sites are in residential areas to the northeast and southeast of the Wind-1 and proposed Wind-2 turbines. Site ST-3 is located to the northeast of the turbine site near the intersection of Research Road and Thomas B. Landers Road, approximately 2780 ft from Wind-2, and 3650 ft from Wind-1. Site ST-4 was located at the Durham Rd. cul-de-sac near 30 Durham Rd., about 2350 ft southeast of Wind-1. One of the measurements in this area was conducted in the back yard of the home at 30 Durham Rd., approximately 200 ft closer to the turbine site, and was designated ST-4 #2.

[1] "Sound Level Impact Assessment – Notus Clean Energy, LLC, Falmouth, MA Wind Turbine Generator," prepared for Boreal Renewable Energy Development, prepared by Epsilon Associates Inc., March 4, 2008.

3.4 Community Noise Measurement Results

This section of the report covers all of the noise measurement results and the conclusions drawn about noise levels in the community based on the measurements. Much data were collected during the measurement program, so only data pertinent to an understanding of the primary issues are presented in this section. Appendix C provides more detailed information, including more detailed data than are presented in the body of the report. However, it is not practical to supply all of the noise measurement data that may be of interest to some, even in an appendix to a report, partly because today's noise measurement instruments collect a very large amount of information. Therefore, the Town of Falmouth has released the noise and wind data spreadsheets to members of the public, and that information has been posted on the Town's website: http://www.falmouthmass.us/.

For reference, Figure 2 presents a graphic showing the sound levels associated with common outdoor and indoor sound sources and environments. Appendix A provides detailed descriptions of the noise metrics discussed in this report.

3.4.1 Overall results at the long-term measurement sites

All of the noise measurements were conducted with the instruments' interval duration set to 10 minutes. This approach is used by HMMH for wind noise studies, since anemometer data is typically reported in 10-minute intervals, and it is important to be able to correlate wind speed and noise levels. This correlation is important is because wind turbines do not operate or make noise when winds are calm, and calm-wind conditions most commonly result in the lowest ambient background noise environments. Therefore, to accurately assess the potential impact that noise from a wind turbine has on a community in Massachusetts according to the Mass DEP noise guidelines, we choose ambient noise levels that are characteristic of conditions when a wind turbine would be operating. Therefore, we must determine wind speeds during our measurements of the background noise levels. As described above, several anemometers were used in the Falmouth wind noise measurement program. In addition to the 10-minute interval data, the noise monitors also collected and stored continuous one-second overall levels and 1/3-octave band levels.

The anemometer at the Wind-1 turbine hub more accurately represents the wind that drives the turbine than any other anemometer. Therefore, the wind speed data from the hub anemometer was used for most of the comparisons with noise data. The Vestas V82 1.65 MW turbine operating at Wind-1 will begin to operate at hub wind speeds at 3.5 m/s and above, called the turbine's "cut-in" speed. During the measurement period, winds were high enough for the turbine to operate most of the time.

Since the operative metric of the existing noise level to which noise from the turbine operations must be compared is the L90, the analysis of the measured noise levels focuses on the L90 metric. However, in Appendix C, we provide graphs of the detailed noise data showing several of the 10-minute interval noise metrics (Lmax, L1, Leq, L33, L90) throughout the 10-day measurement period along with the local wind speed measured near the microphones. Figure 17 and Figure 18 in Appendix C provide these data for Sites LT-1 and LT-2, respectively.

Figure 3 and Figure 4 below are graphs of the 10-minute L90 values measured at the LT-1 and LT-2 sites, respectively, plotted with the hub wind speed. Also shown (with the orange line) are periods when the Wind-1 turbine was deliberately shut down for maintenance or for purposes of measuring the background noise levels. When the orange line is at the top of the graph, the turbine was set to run; when the line is at the bottom, it was shut down. The start of each day (midnight) is marked with a vertical black line. The noise monitor at site LT-2 inadvertently reset itself shortly before noon on June 23, and was not re-started until the next site visit at 11:40AM on June 25. As a result, no noise data were collected at that site during that interval, which was when the turbine had been shut down

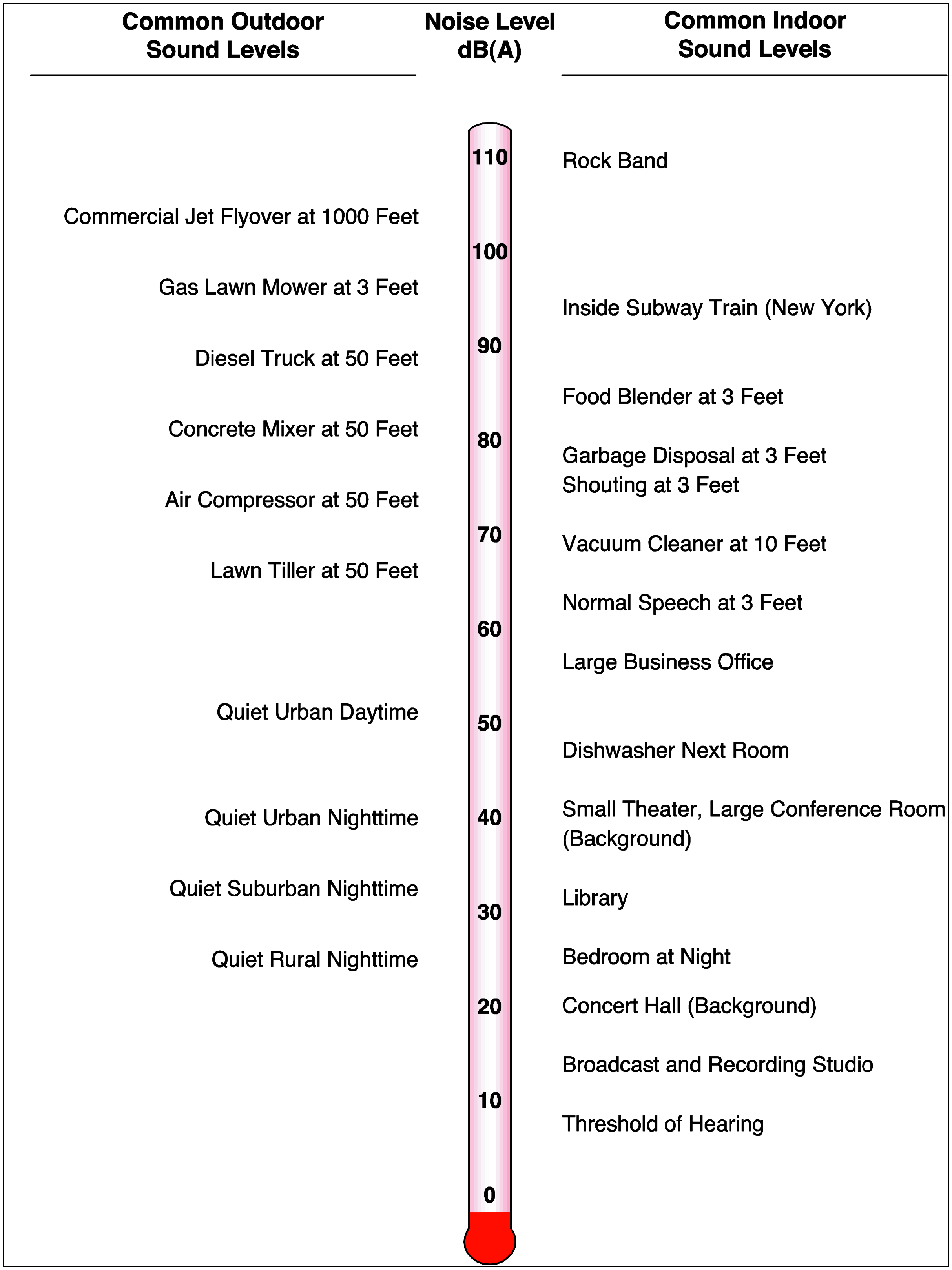

Figure 2 Common Outdoor and Indoor Sound Levels

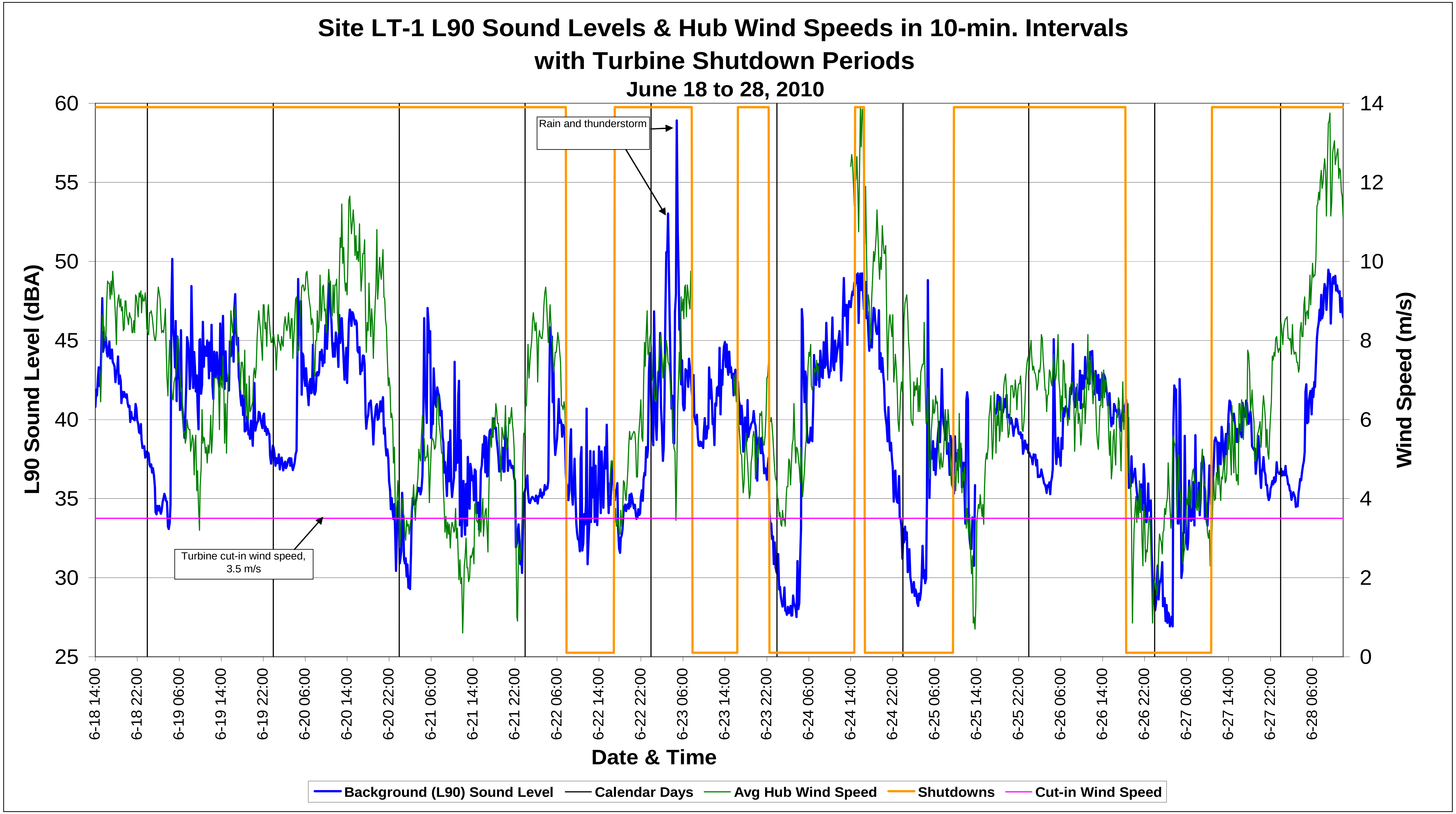

Figure 3 Graph of L90 Sound Level and Hub Wind Speed at Site LT-1, 211 Blacksmith Shop Rd.

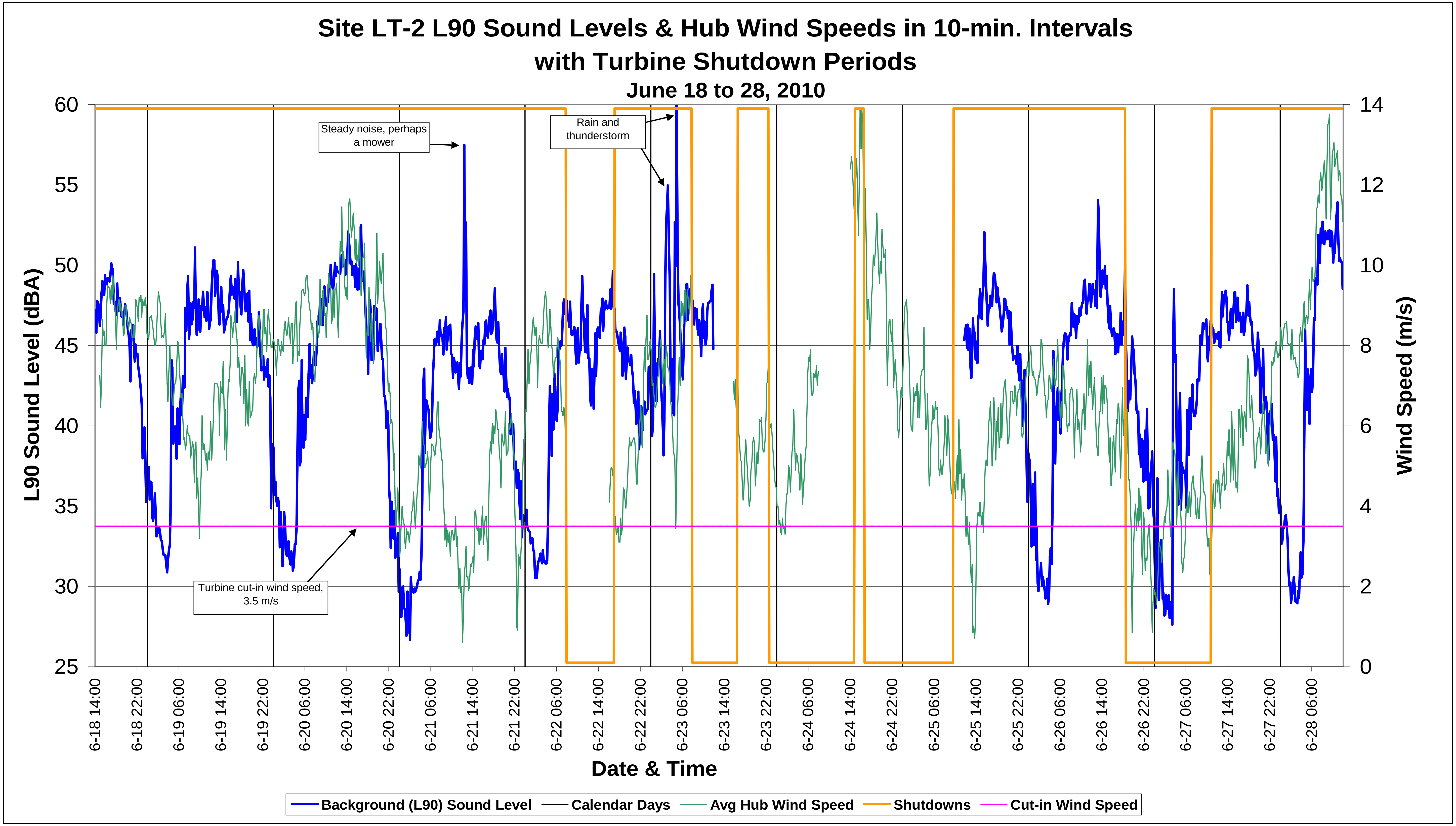

Figure 4 Graph of L90 Sound Level and Hub Wind Speed at Site LT-2, 124 Ambleside Dr.

both nights for background data collection. Partly because of this unfortunate incident, the turbine was also shut down during the night of June 26-27, so that more nighttime background noise data could be collected. As a result of the instrument failure, more background noise data were collected at Site LT-1, and more of those data were used in the analysis as a result.

The graph of the hub wind speed (green line) shows that during the early morning hours of June 21, the wind speed was light, varying above and below the cut-in speed of 3.5 m/s. Power production data from that night show that the turbine was either not running at all (see Figure 26 in Appendix D), or running very slowly for much of the time between midnight and 3:00AM. Therefore, the noise data collected that night have not been used in our analysis, since the state of the turbine operation is not consistent. However, the turbine was operating and generating power all other nights (between midnight and 3:00 AM) that the turbine was set for operation.

A close examination of the patterns of the L90 sound levels at site LT-1 in Figure 3 reveals clear differences in the values during the early morning hours of the nights that the turbine was shut down as compared to the nights it was operating. L90's averaged in the high 20's dBA on nights when the turbine was off, and in the mid 30's when it was operating. However, such patterns are not clear during the daytime hours. Upon review of the data, the patterns of noise levels at site LT-2 are less clear, largely because the background noise was higher there, due to the proximity of Route 28 about 350 ft away, and partly because there is less data available for comparison.

To establish the measured L90 noise levels associated with the background, for comparison with the turbine-operation noise levels, we separated daytime and nighttime periods. Nighttime periods were chosen as the period between midnight and 3:00 AM primarily because it is clear from the patterns of noise levels measured at both LT-1 and LT-2, that this is the quietest period of the night. During other periods, noise sources such as traffic on Rt. 28 raise the background noise levels significantly. We believe that traffic volumes on Rt. 28 fall off significantly during the early morning hours, such that for 10 percent of the time or more, no traffic on the road is contributing to the background noise level. Therefore the L90 in these nighttime hours represents the background without any significant traffic noise. HMMH chose the period between 7:00 AM and 6:00 PM as the daytime period for the purposes of comparing the noise levels with and without the turbine operating because it represents the period of the day when both winds and human activity are relatively high. Seven AM was chosen as the beginning of the day period partly because that was the time the turbine was shut down on the days it underwent maintenance.

Table 1 presents the median 10-minute L90 values for each day of the measurement program at the long-term measurement sites. Daytime and nighttime periods are separated as described above, and the predominant turbine operating condition is given along with the median hub wind speed. The median L90 and wind speed values are computed based only on the 10-minute periods when the turbine was set as shown in the table – either to operate (on) or shut down (off). Periods during days when the turbine was set in the opposite condition are excluded from the computation of the median values. On June 21, the turbine was set to operate, although it switched on and off due to the low-wind condition that day.

3.4.2 Measured sound levels with and without the Wind-1 turbine operating

To more precisely define the measured background sound levels with and without the turbine operating, particularly for the daytime periods when the turbine was intermittently turned off and on during maintenance, HMMH developed a database query to evaluate the statistics of the measurement periods only during times when the turbine was operating and when it was not. As above, these were separated into the daytime and nighttime periods. In this composite analysis, all days were combined to determine overall median values for L90 and wind speeds.

Table 1 Median L90 Values Measured at the Long-term Sites and Turbine Conditions

Date	Median L90 Values (dBA) Turbine Condition and Median Hub Wind (m/s)							
	Daytime: 7AM to 6PM				Nighttime: 12Mid to 3AM			
	LT-1	LT-2	Turb.	Speed	LT-1	LT-2	Turb.	Speed
18-Jun-2010	43.9	48.5	On	9.0	NA	NA	On	NA
19-Jun-2010	43.5	47.4	On	5.9	35.3	34.2	On	8.5
20-Jun-2010	44.4	48.9	On	9.4	37.3	34.2	On	8.1
21-Jun-2010	36.9	45.4	On/Off	3.3	31.2	29.4	On/Off	3.5
22-Jun-2010	35.5	46.1	Off	4.9	35.1	32.5	On	8.0
23-Jun-2010	41.4	47.0	Off	6.7	41.0	42.1	On	7.2
24-Jun-2010	44.6	NA	Off	9.0	28.2	NA	Off	4.0
25-Jun-2010	37.3	46.8	On	4.4	29.9	NA	Off	7.0
26-Jun-2010	41.6	47.2	On	6.3	37.1	32.1	On	7.3
27-Jun-2010	39.1	46.6	On	4.9	28.5	29.5	Off	3.1
28-Jun-2010	48.0	51.6	On	12.3	35.9	31.8	On	8.1

The L90 metric was used to characterize the levels of noise when the turbine was operating as well as for the periods when it was not operating. The primary reason for this approach was because there were many other noise sources in the study area that increased the noise levels for a relatively high percentage of the time. These sources were predominantly traffic noise on local and distant roads, wind in the trees and community sources such as lawn mowers. When the turbine is operating, it produces nearly constant sound, so the L90 represents a good metric to represent how the turbine sound may increase the background. At LT-2 (and other homes in the area), the L90 noise level, as well as most of the other noise metrics, is by dominated by traffic noise for most of the day. Therefore, the increased noise level associated with the turbine is less than would be seen farther from Rt. 28 but at the same distance from the turbine.

Table 2 presents the composite L90 noise descriptors for daytime and nighttime periods when the turbine was running and when it was shut down. As described above in Section 3.4.1, data from all of June 21 and the daytime on June 25 have been excluded from this composite analysis, because the turbine was switching on and off due to low wind speeds. The number of 10-minute periods included in the set from which the median is derived are given in parentheses after the L90 values. Median hub wind speeds are also given. The last row gives the differences between the turbine running and shut down conditions. During the day, the differences are only 1 to 2 dBA. This is because there are many

Table 2 Median L90 Values at Long-Term Sites with Turbine Running and Shut Down

Condition	Median L90 Values (in dBA) and Median Hub Wind (m/s)					
	Daytime: 7AM to 6PM			Nighttime: 12Mid to 3AM		
	LT-1 L90 (no. per.)	LT-2 L90 (no. per.)	Wind Speed	LT-1 L90 (no. per.)	LT-2 L90 (no. per.)	Wind Speed
Turbine Running	42.8 (295)	47.8 (295)	7.0	36.8 (108)	33.6 (108)	8.0
Turbine Shut Down	41.4 (160)	46.4 (78)	7.3	28.8 (54)	29.5 (18)	4.2
Difference	1.4	1.4	-0.3	8.0	4.2	3.8

other sources of noise that control the existing background, as mentioned above. During the early morning hours, however, without the background traffic noise, the background noise level drops to around 29 dBA, and the increased noise with the turbine operating averaged 8 dBA at LT-1 and 4 dBA at LT-2. However, note that at night, the median wind speeds with the turbine running were 8 m/s, whereas during the periods when it was not operating they were lower, about 4 m/s at the hub. The higher wind speeds increase the ambient background noise from wind in the trees, so a portion of the measured increase in noise levels at night is likely due to natural background sources.

Since the increases in noise levels at LT-1 and LT-2 due to the turbine operation is less than the Mass DEP criterion of 10 dBA, we conclude that the Wind-1 turbine is operating within the DEP requirements, with regard to increases in existing noise.

With respect to the noise level reference of 40 dBA for wind turbines stated in Town of Falmouth's bylaws, the measured data do not show that the Wind-1 turbine produces noise levels exceeding 40 dBA. The highest measured noise level attributable to the turbine shown in Table 2 is 36.8 dBA at site LT-1 during the night. The measured daytime sound levels higher than 40 dBA are attributable to sources of noise other than the wind turbine.

3.4.3 Measurements at the short-term sites

Table 3 provides a summary of the measured noise levels at the short-term sites. Several standard descriptors of the time-varying A-weighted noise level are shown in the table. These descriptors

Table 3 Noise Measurement Results at Short-term Sites

Site Name	Address	Turbine Condition	Start Date/Time	Dur. (min.)	A-weighted sound level metrics (dBA)			
					Leq	Lmax	L33	L90
ST-1	161 Blacksmith Shop Road	Operating	06/18/2010 20:30:00	30	48	57	43	41
		Operating*	06/21/2010 15:00:00	30	49	62	40	35
		Operating	06/25/2010 15:10:00	30	51	63	43	37
		Shut down	06/23/2010 09:50:00	30	51	66	44	39
ST-2	27 Ridgeview Street	Operating	06/18/2010 17:20:00	30	68	71	64	57
		Operating*	06/21/2010 11:20:00	30	67	73	62	53
		Operating	06/25/2010 09:50:00	30	69	73	64	57
		Shut down	06/23/2010 14:20:00	30	67	73	63	55
ST-3	Research Rd & Thomas B Landers Rd.	Operating	06/18/2010 18:30:00	30	58	73	51	45
		Operating	06/21/2010 16:40:00	30	62	78	55	43
		Operating	06/25/2010 10:40:00	30	60	71	54	41
		Shut down	06/23/2010 15:10:00	30	61	74	55	47
ST-4	Durham Road cul-de-sac	Operating	06/18/2010 19:30:00	30	50	58	44	42
		Operating	06/25/2010 14:40:00	10	44	57	41	36
		Operating	06/25/2010 16:10:00	20	45	57	41	35
		Not operating	06/21/2010 13:00:00	30	51	65	40	32
ST-4 #2	30 Durham Rd., back yard	Operating	06/25/2010 16:40:00	20	43	48	40	37

* Note: The observer noted the turbine was operating, but wind speeds were near cut-in, and power data show little or no power generated until 16:40.

include the Leq, which is the average sound level with equivalent sound energy as a continuous sound at that level and the Lmax, which is the maximum sound level that occurred during the measurement period. Common statistical descriptors are included as well, including the L33, the sound level exceeded 1/3 of the time, and the L90. The measured noise levels in the table show that the two sites closer to roadways with moderate to high traffic volumes, ST-2 and ST-3, have higher average and background L90 noise levels during the daytime hours than do sites ST-1 and ST-4, which are farther from such roads. As with the long-term sites, little difference between the condition with the turbine operating and shut down was heard or can be observed from the data measured at the short-term sites during the daytime hours.

Since the turbine operation only slightly increases daytime noise levels in the study area, it is the early morning hours when the turbine sound is most audible and has the highest potential of approaching the Mass DEP noise criterion.

3.4.4 Characterization of the nighttime background noise throughout the study area

The only nighttime background noise data collected in the study area were at sites LT-1 and LT-2. The median L90s at those sites was measured to be 28.8 dBA at LT-1 and 29.5 dBA at LT-2, as shown in Table 2, above. Significantly more data were acquired at site LT-1 than at LT-2, as a result of the LT-2 instrument malfunction on two of the turbine shut-down nights. The similarity of the L90 values at the two sites, which are quite far apart and exposed to different nearby noise sources, suggests that such a noise level is characteristic of the entire study area during the early morning hours, the quietest time of day. Therefore, we have assumed that the noise levels measured at LT-1 during the nighttime period are representative of the entire study area.

It is well known that background noise levels increase with increasing ambient wind speeds. The particular relationship between wind speed and noise level depends upon local characteristics, such as terrain and proximity to trees, but the Falmouth study area is quite homogeneous in this regard. To examine the potential relationship of wind speed and background noise level in the Falmouth study area, a scatter plot of the LT-1 nighttime L90 values vs. hub wind speed was developed, and is shown in Figure 5. This plot includes both periods when the turbine was running as well as periods when it was shut down, but those are grouped separately. Only light to moderate winds were experienced during the nighttime measurement periods, with the highest 10-min average hub wind speeds reaching approximately 9.5 m/s. Further, no moderately low wind speeds were experienced when the turbine was running. The data from the June 21 are excluded from this set, because the winds were fluctuating above and below the cut-in speed, and the turbine was turning on and off repeatedly throughout the day. Therefore, many 10-minute intervals had both turbine-on and -off conditions, and were unusable.

An examination of the background noise levels (with the turbine shut down) shows fairly constant background noise levels from the lowest speeds up to about 6 m/s, and then a slight upward trend in the noise levels between wind speeds of approximately 6 m/s and 9 m/s. This trend is commonly seen. Wind speeds near the ground are much lower than at the hub, but sufficient to slightly increase the background noise level.

As mentioned above, wind speeds during nighttime hours only reached moderate levels. While typically it is the low to moderate, not high wind speeds where wind turbines are the most audible above the ambient background noise, an understanding of background levels at higher wind speed is useful, since the potential for noise impact also occurs at these higher wind speeds. To supplement the data collected for this study, HMMH reviewed other sound data collected in the project area.

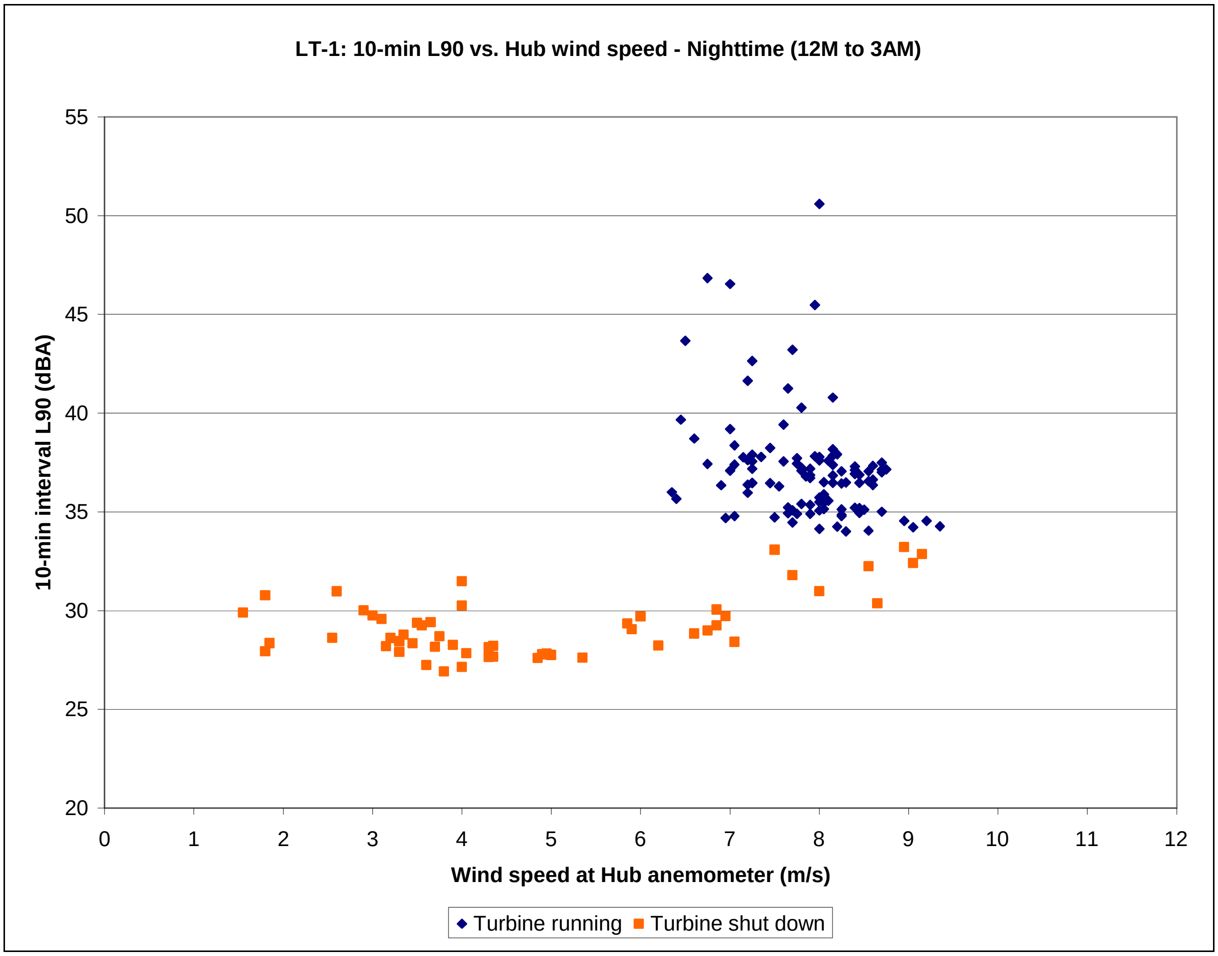

Figure 5 Nighttime L90 Noise Levels vs. Hub Wind Speed

The March 2008 Notus Clean Energy wind turbine noise study[2] included a long-term noise measurement site "CM-1" in the study area, located at 412 Blacksmith Shop Road. During one of the nights in January 2008, when the noise measurement were conducted, wind speeds increased to relatively high values in the early morning hours. Prior to that increase, at midnight and 1:00 AM, the background L90 noise levels were 30 dBA, very comparable to the measurements at LT-1 and LT-2 with similarly low wind speeds. Due to the increased wind speeds, there was an increase in ambient L90 noise levels. These data are shown in Figure 2 of the referenced report. The winds were measured at the Otis Air Base anemometer, located at 10 meters above the ground. At an hourly average wind speed of 9.5 m/s at 2:00 AM, the measured L90 increased to 42 dBA, and at a wind speed of 10.5 m/s at 3:00 AM, the L90 was 45 dBA. These wind speeds translate to 80-m hub-height speeds of 12.8 m/s and 14.7 m/s, respectively.

To better identify the trend in the noise level with wind speed in the L90s measured at LT-1, we grouped the L90 values into four groups with similar wind speeds. We chose only hub wind speeds greater than the cut-in wind speed of 3.5 m.s, since the turbine will not run at lower speeds. The groups and averages are shown in Table 4.

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[2] "Sound Level Impact Assessment – Notus Clean Energy, LLC, Falmouth, MA Wind Turbine Generator," prepared for Boreal Renewable Energy Development, prepared by Epsilon Associates Inc., March 4, 2008. (website: www.notuscleanenergy.com)

Table 4 Nighttime Background L90 at LT-1 as a Function of Hub Wind Speed

Range of Hub Wind Speeds (meters/second)	Average Hub Wind Speed (m/s)	Average LT-1 Nighttime L90 Sound Level, (dBA)
3.5 to 4	3.8	28.7
5.3 to 6.6	6.0	28.8
6.8 to 8	7.2	30.3
8.5 to 9.2	8.9	32.4

Combining the nighttime L90 data measured at LT-1 with the data measured for the higher wind speeds in 2008 for the Notus Clean Energy turbine project, a representative curve of existing nighttime background noise level as a function of hub wind speed for the study area was developed and is shown in Figure 6. We believe that using the ambient noise data from January 2008 is reasonable and appropriate even though it was at a different location during a different season, because the location is in the current project's study area, and because the measured background noise levels are very similar to the June 2010 levels for the low-wind conditions, as mentioned above. Under the higher wind conditions, it is possible that background noise levels would be somewhat higher in the summer due to leaves on the trees, but a higher background would result in a less conservative assessment of noise impact.

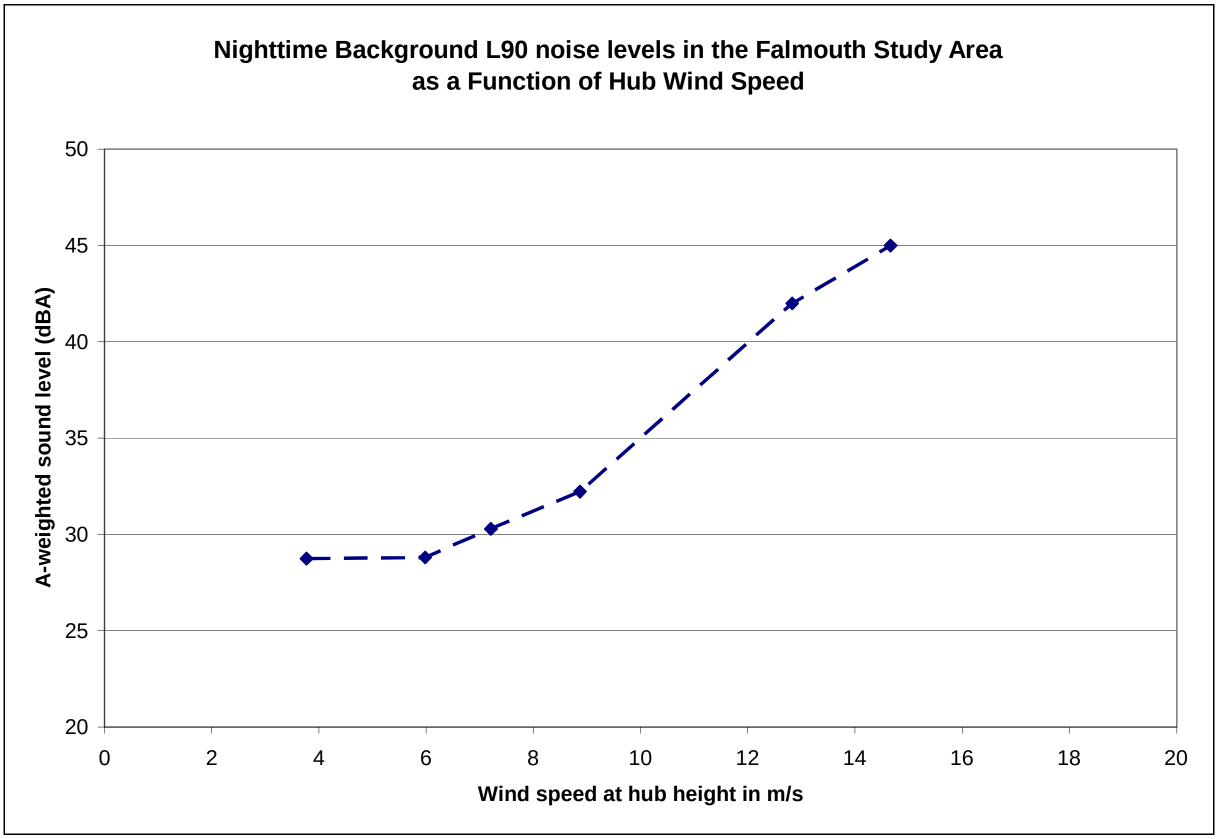


Figure 6 Nighttime Background L90 Noise Levels in Falmouth Study Area as a Function of Hub Wind Speed

3.4.5 Frequency characteristics of turbine sound and pure tone evaluation

HMMH examined the measured frequency content in the community during the turbine operation to determine compliance with the Mass DEP pure tone guideline. A sound is said to have a “pure tone component” if one octave band in the frequency spectrum is 3 dB or more higher than both adjacent octave bands. The noise analyzers used to collect the noise data collected 1/3-octave band frequency data along with the A-weighted sound level. To evaluate the spectral characteristics of the turbine sound with respect to the Mass DEP pure tone guideline, we combined the measured 10-minute interval 1/3-octave band L90 values into octave bands, and then averaged all 18 values between midnight and 3:00 AM on several nights, to obtain average nighttime spectra. We examined nights with the turbine shut down as well, for comparison.

Figures 7 and 8 present graphs of the nighttime octave band L90 noise levels at LT-1 on four different nights, two with the turbine running, and two with it shut down. It is clear from the shape of the two average spectra with the turbine running, that no pure tone conditions exist, according to the Mass DEP definition.

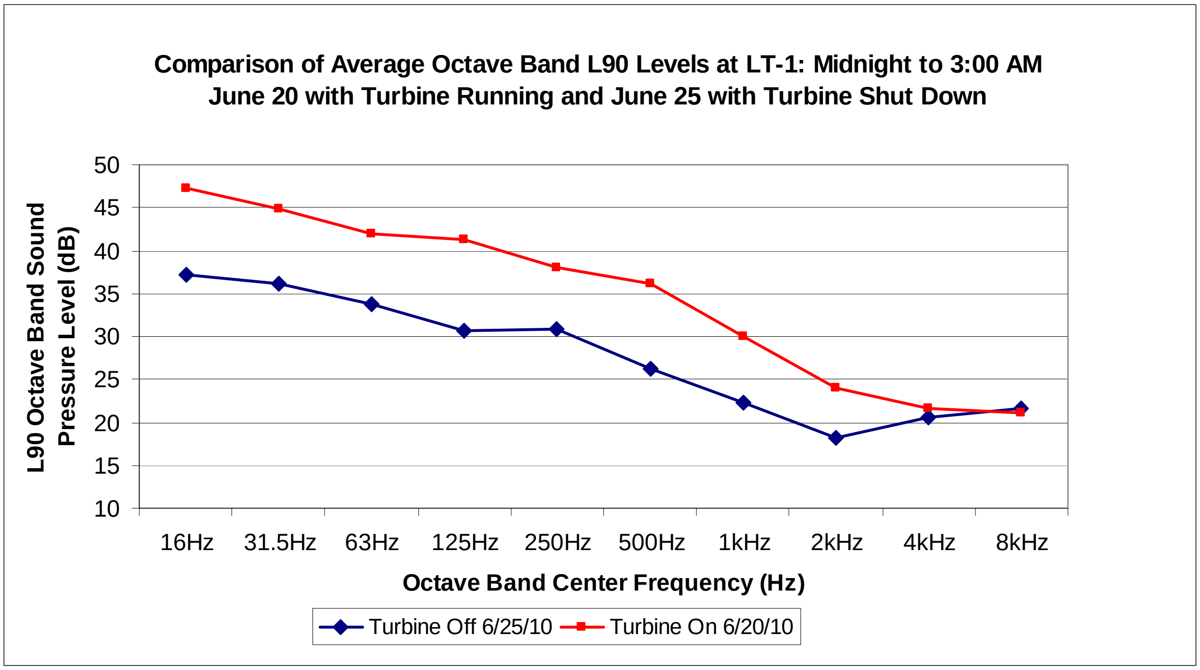


Figure 7 Average Octave band L90 values at LT-1 during nighttime on June 20 (Turbine running) and June 25 (Turbine shut down)

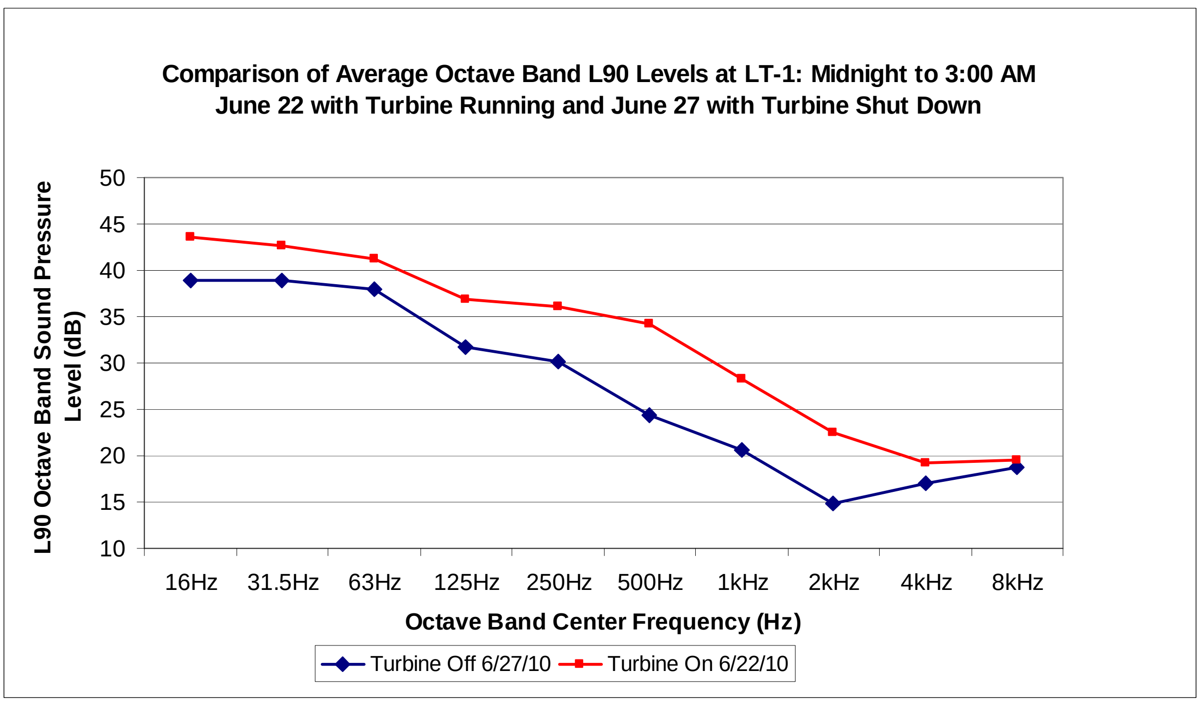


Figure 8 Average Octave band L90 values at LT-1 during nighttime on June 22 (Turbine running) and June 27 (Turbine shut down)

3.4.6 Investigation of low-frequency characteristics of turbine sound

Early wind turbines with the blades downwind of the tower produced low-frequency thump sounds as the blades passed the wind wake produced by the tower. However, modern upwind turbines do not produce this sound, and do not generally produce enough low frequency sound to be an issue in surrounding communities[3,4]. However, some Falmouth residents have described the noise from the Wind-1 turbine as having low-frequency characteristics, sometimes a "thunderous" sound. An examination of the spectra shown above in Figures 7 and 8 shows that while the sound from the Wind-1 turbine does have low-frequency content (as represented by the levels in the 16 Hz, 31.5 Hz and 63 Hz octave bands)[5], the relative increases in average sound level in the low frequency bands is not greater than that in the middle frequencies.

The resident at 211 Blacksmith Shop Road (Site LT-1) described the turbine sound at 4:30 pm on June 24th as "powerful, thunderous pulses." Members of the study team were in the area for the testing at that time, and shut down the turbine at 4:30 PM. Winds were relatively strong at that time, averaging about 13 m/s at the hub for the 30 minutes before the shut-down, and about 11 m/s for the 30 minutes after the shut-down.

Figure 9 presents plots of the 10-minute L90 octave band spectra for the three periods before the shut-down and for the three periods after the shut-down. It is notable that the low frequencies with the turbine running appear more pronounced compared to background than they do in the nighttime periods. However, the relative levels of the low-frequency sound compared to the mid-frequency sound with the turbines running is very similar between the nighttime period and the daytime period. It is the background noise spectrum that is different, with significantly more mid-frequency content during the daytime – such that it is not increased by the sound from the turbine. This is consistent with the A-weighted sound level results discussed earlier, which are much closer with turbine on and off during the day than at night. Our conclusion is that the wind in the trees and traffic noise during the day increase the middle frequency sound more than the low frequencies.

Figure 10 shows plots of the 30-minute averages of the L90s and the Leqs (energy average sound levels) for each of the three 10-minute periods before and after the turbine was shut down. These are shown with a finer, 1/3-octave band resolution, and only in the low frequency bands from 12.5 Hz to 80 Hz. Two additional curves plotted on the graph are the average threshold of audibility and the threshold of audibility minus 5 dB, which capture hearing sensitivity for 84% of the population.[6] Note that turbine noise levels are low enough such that people with sensitive hearing should not be able to hear the sound directly at frequencies of 31.5 Hz and below outdoors, because the noise is below the threshold. Also plotted on the same graph are dashed lines representing criteria for low-frequency sound pressure levels sufficient to cause perceptible vibrations of building floors, walls and windows in residential structures.[7] These results suggest that the noise levels measured from the Wind-1 turbine on June 24th are sufficient to possibly cause perceptible window vibration at the very lowest frequency

[3] Leventhall, Geoff, "How the 'mythology' of infrasound and low frequency noise related to wind turbines might have developed," First International Meeting on Wind Turbine Noise, Berlin, Germany, 2005.
[4] O'Neal, Robert D., et. al., "Low frequency sound and infrasound from wind turbines – A status update," Proceedings of Noise-con 2010, Baltimore, MD, April , 2010.
[5] ANSI/ASA S12.9-2005/Part 4, Annex D, "Quantities and Procedures for Description and Measurement of Environmental Sound – Part 4: Noise Assessment and Prediction of Long-term Community Response," American National Standards Institute, Acoustical Society of America, 2005.
[6] From Moeller and Pedersen (2004) as presented in footnote (4) by O'Neal.
[7] Hubbard, H.H., "Noise Induced House Vibrations and Human Perception," Noise Control Engineering Journal, Vol. 19, No. 2, September – October 1982.

of 12.5 Hz. However, the existing ambient noise with the same amount of wind in the community are only about 6 or 7 decibels below the criteria.

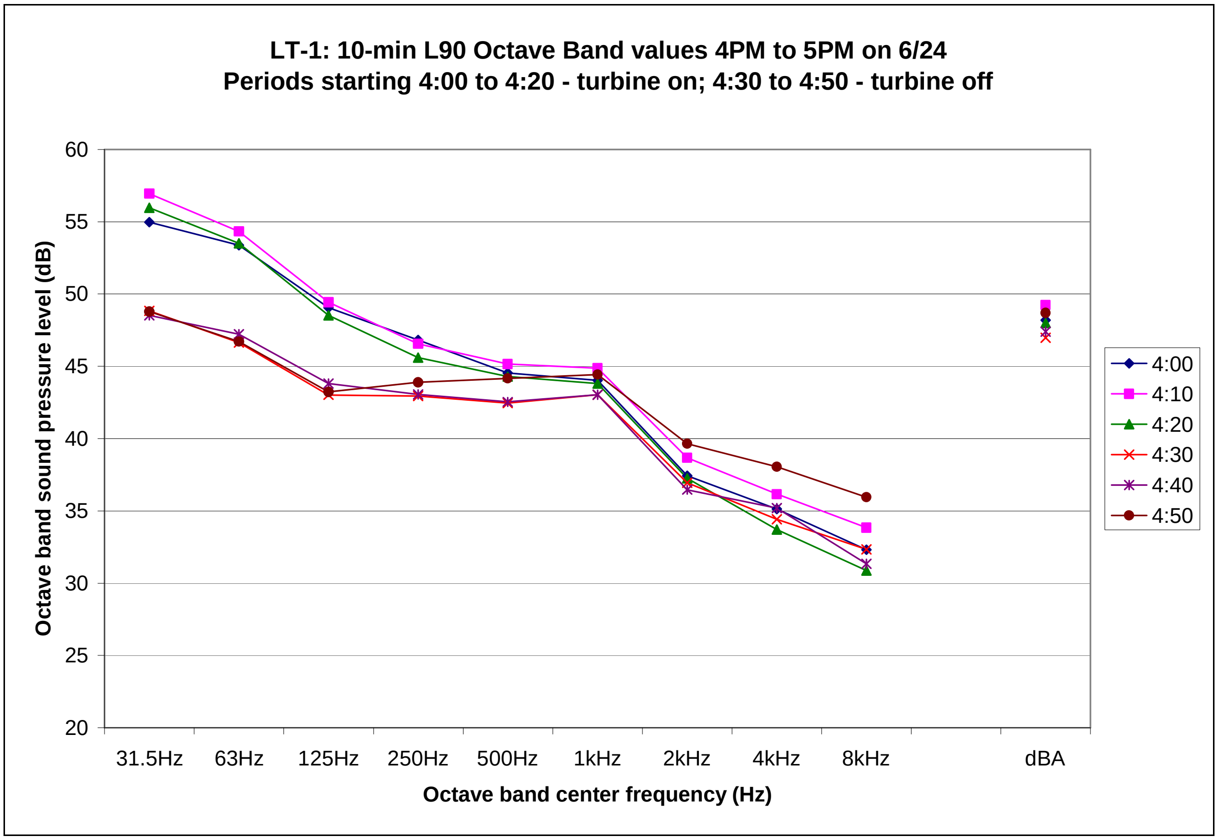


Figure 9 L90 Spectra at LT-1 Before and After the Turbine Shut-down on June 24

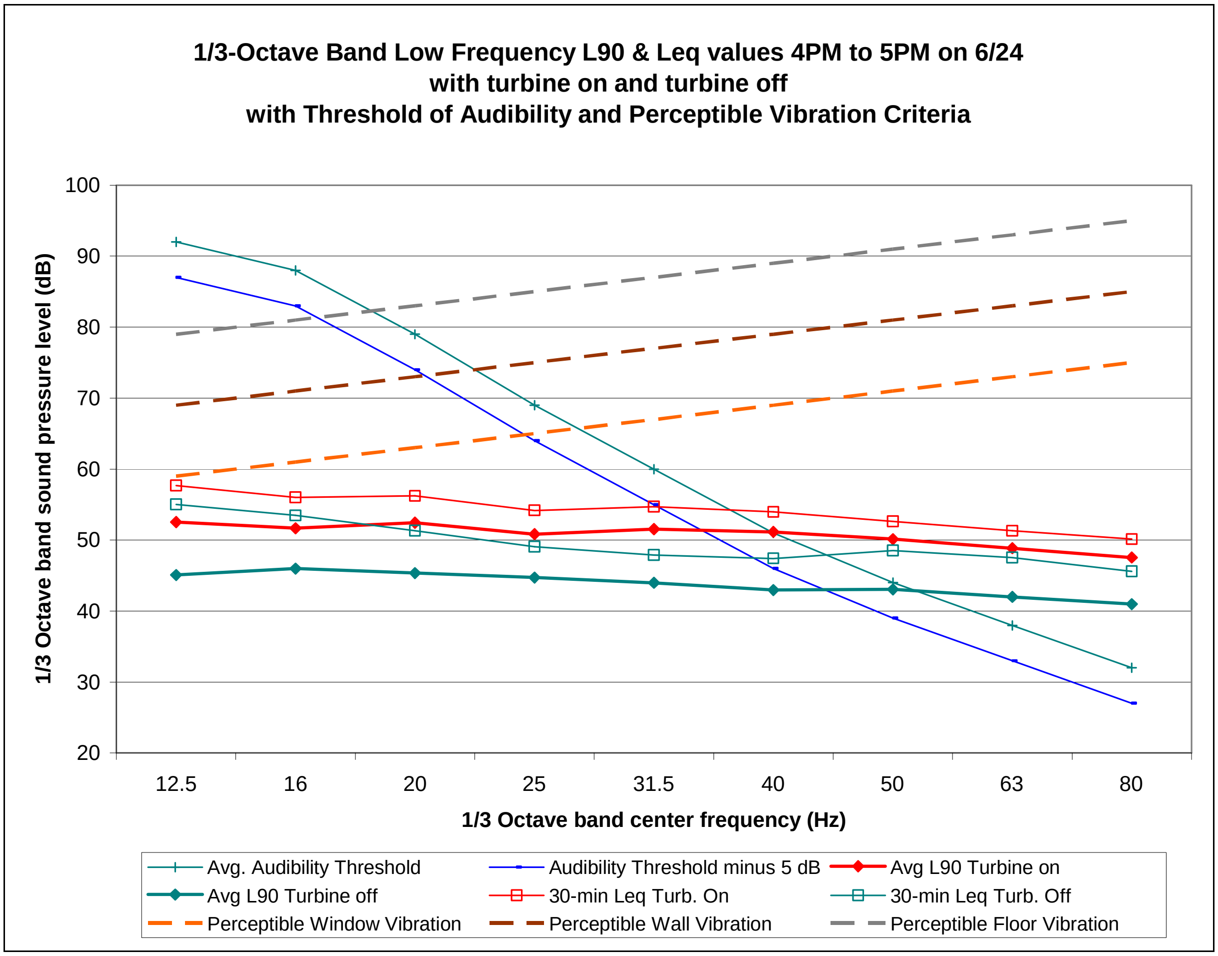


Figure 10 Low-frequency Sound Levels before and after June 24 Shutdown with Audibility Threshold and Perceptible Vibration Criteria

3.5 Reference Sound Power Level Measurement Results

HMMH conducted limited reference sound level measurements near the Wind-1 turbine during two one-hour periods when the turbine was operating. These were conducted with a so-called "ground-plane microphone," where the microphone is placed on a hard reflecting board placed on the ground (See Figure 11). The purpose of locating the microphone on the ground is to minimize wind-induced noise at the microphone and to get predictable reflected sound from the ground. The measurements were conducted in as much compliance as possible with the IEC 61400-11 standard[8] for wind turbine reference noise measurements, as a check on the noise emissions of the particular Vestas V82 1.65 MW turbine installed at the Falmouth Wind-1 site. Due to constraints at the site, the microphone location was closer to the turbine than is called for in the standard, but HMMH corrected for this through an appropriate distance adjustment to the sound levels.

Figure 11 Photo of Reference Ground-plane Microphone and Wind-1 Turbine

Using the equations in the IEC standard, HMMH computed the Sound Power Level of the turbine for periods during the measurement. The hub anemometers recorded 10-minute average wind speeds, and HMMH's 1.5-m high anemometer located near the site recorded one-second wind speed data. In the analysis, HMMH examined the one-second wind speed and noise level for relatively steady patterns

[8] IEC 61400-11, "Wind turbine generator systems – Part 11: Acoustic noise measurement techniques," International Standard, International Electrotechnical Commission, 2002-12.

for analysis. We adjusted the one-second 1.5-m wind speeds to hub height based on the average difference in the 10-minute averages. We also used the 10-minute period averages that the hub anemometer and the noise monitor collected.

Figure 12 shows the Vestas V82 1.65 MW turbine published reference sound power levels for hub wind speeds from 4 m/s to 11 m/s. The data points are HMMH's ground-plane measurements converted to sound power levels via the equations in the IEC standard. The red dots are based on the averages of 30- to 60-second samples of noise and wind speed with relatively steady wind speeds over a range of speeds for data measured on June 18. The yellow dots and blue squares represent the data for the 10-minute averages on June 18 and 28, respectively, where wind speeds were considerably higher on June 28.

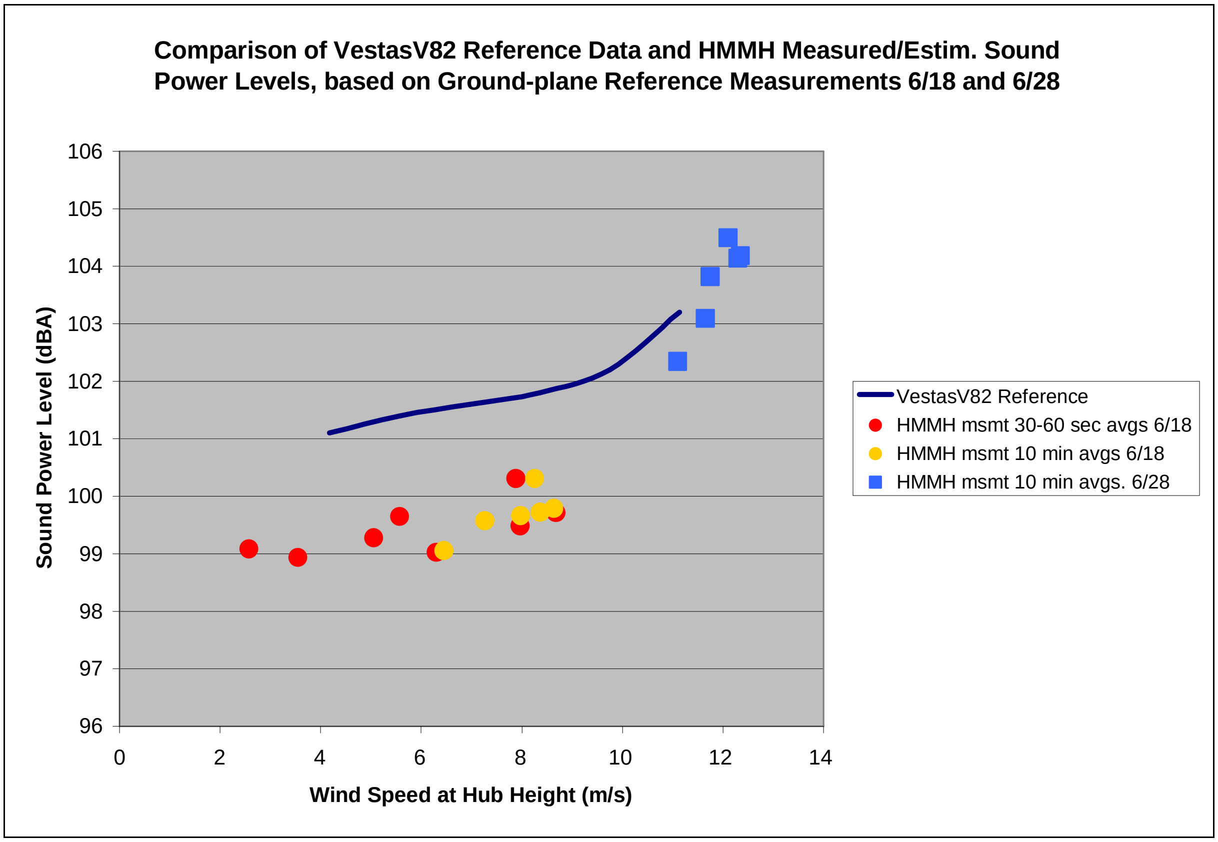


Figure 12 Comparison of Vestas Reference data and HMMH Measurements of Wind-1 Noise Emissions

The measurements suggest that Falmouth Wind-1 turbine is operating at or below the reference noise emissions published by Vestas. At the hub wind speeds between 2 m/s and 9 m/s, our data show the Wind-1 turbine averages approximately 2 decibels less than the reference noise curve. At hub wind speeds around 12 m/s, HMMH's measurements are approximately equal to the reference curve published by Vestas.

4 Predicted Wind Turbine Noise Levels and Impact

HMMH predicted the wind turbine noise levels in the Falmouth study area using 1) reference noise emissions information for the Vestas V82 1.65 MW turbine provided by the manufacturer, Vestas, 2) aerial photography and digital terrain information from MassGIS, and 3) the SoundPLAN® noise prediction model.

4.1 Pure tone evaluation

HMMH evaluated the expected frequency spectrum of sound from the Vestas V82 1.65 wind turbines to add further validation that a pure tone condition will not exist due to noise from the turbines. Figure 13 shows a frequency plot of the un-weighted octave band sound power level[9] spectrum of a Vestas V82 wind turbine operating at the reference wind speed of 8 m/s measured at a 10-m height; this data is taken from Vestas' specifications for this turbine and a wind shear factor of 0.15. The resulting comparable wind speed at hub height in this case is 11 m/s.

It is clear from the graph that no octave bands are higher than both adjacent bands by 3 dB or more, therefore, no pure tone condition will exist, according to the Mass DEP guidelines.

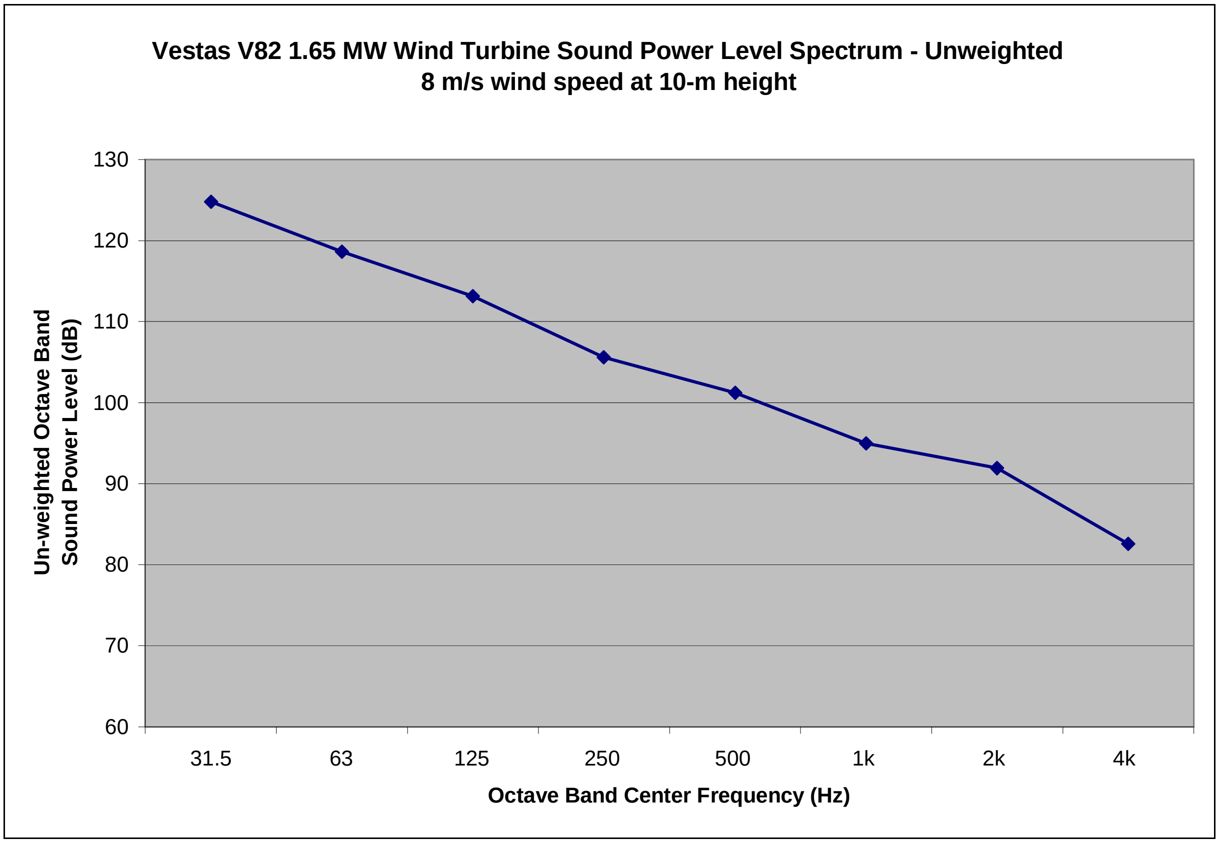


Figure 13 Sound Power Level Spectrum of Vestas V82 1.65 MW Wind Turbine

[9] The Sound *Power* Level represents the total sound energy produced by the wind turbine under the specified operating conditions. Sound Power Levels cannot be measured directly; instead they are computed from reference sound *pressure* level measurements, conducted by the manufacturer.

4.2 Noise Prediction Model and Noise Source Characteristics

The SoundPLAN® computer noise model was used for computing sound levels from the proposed wind turbine throughout the surrounding community. An industry standard, SoundPLAN was developed by Braunstein + Berndt GmbH to provide estimates of sound levels at distances from specific noise sources taking into account the effects of terrain features including relative elevations of noise sources, receivers, and intervening objects (buildings, hills, trees), and ground effects due to areas of hard ground (pavement, water) and soft ground (grass, field, forest). In addition to computing sound levels at specific receiver positions, SoundPLAN can compute noise contours showing areas of equal and similar sound level.

As input, SoundPLAN incorporated a *geometric model* of the study area and reference *noise source* levels for the turbines. SoundPLAN uses a *sound propagation model* to project noise levels from the turbines into the surrounding community.

The three-dimensional geometric model of the study area was developed from aerial photography and digital terrain information (with 1-m contour intervals) provided through the MassGIS Executive Office of Energy and Environmental Affairs.

The reference noise source levels were provided by Vestas Wind Systems, in the form of octave-band A-weighted Sound Power Levels (LwA) for the reference wind speed of 8 m/s measured at a height of 10 m. These levels are shown in Table 5 as included in the SoundPLAN noise prediction model. The reference wind speed of 8 m/s was chosen for the modeling for two reasons. First, it was the highest speed and loudest overall noise emission at which Vestas published spectral data, needed for the model. Second, 8 m/s is a common wind speed to use for community noise impact studies, since the speed is high enough to usually produce near-maximum noise emissions from the wind turbine, yet low enough such that ambient background noise levels in the community are relatively low, commonly resulting in a worst-case noise evaluation.

Table 5 Reference Sound Power Level Spectrum for Vestas V82 Wind Turbine at 8 m/s wind speed at 10-m height

Octave-band Center Frequency (Hz)	LwA ref (A-weighted)
31.5	85.4
63	92.4
125	97.0
250	97.0
500	98.0
1000	95.0
2000	93.1
4000	83.6
A-weighted, total	103.8

Source: Vestas Wind Systems A/S

It is appropriate to point out that the reference sound power levels provided by Vestas have been developed based on the turbine noise emissions in the downwind direction. That is the reference direction called for in the IEC 61400-11 standard, which all manufacturers must follow, where noise levels from wind turbines are the highest. Therefore, the modeling of the noise from the turbines reflects the loudest orientation of the turbine, and projects that in all directions.

The sound propagation model within SoundPLAN that was used for this study was ISO 9613-2.[10] This international standard propagation model is used nearly universally in the U.S. for wind turbine noise studies, due to its conservative propagation equations. ISO 9613-2 uses "worst-case" downwind propagation conditions in all directions, and accounts for variations in terrain and the effects of ground type.

In the ISO standard, ground type is usually specified as "soft" for fields, forests and lawns, or "hard" for areas of asphalt, concrete and water. The default ground factors in the standard are 1 for soft ground, and 0 for hard ground. However other factors between 0 and 1 are commonly used to either make more conservative estimates of projected sound levels or to make the model's predictions match measurements better. Commonly, values between 0.7 and 0.8 are used for "conservatively soft" ground. However, in this study, we were able to choose a ground factor to match our measurements best, since HMMH had reliable long-term measurements of the existing noise levels in the community when the Wind-1 turbine dominated the overall noise levels (during the nighttime hours). We found that for the Falmouth site, a ground factor of 0.5 resulted in a close match between the measured values at both sites, so that factor was used for all soft ground in the modeling. Areas of asphalt and water were designated as "hard," with a factor of 0.

4.3 Predicted Turbine Noise Levels in the Community

Table 6 presents the predicted Leq noise levels from the proposed Vestas V82 wind turbine at the noise measurement sites. For the turbine noise predictions in this report, the noise levels are based on the standard reference wind speed of 8 m/s (18 mph) as measured at a height of 10 m, which equates to 11 m/s at hub height. Figures 12 and 13 present the predicted turbine noise levels in the form of

Table 6 Computed Noise Levels in the Study Area from the Existing and Planned Wind Turbines operating at a speed of 8 m/s at 10-m height (11 m/s at hub height)

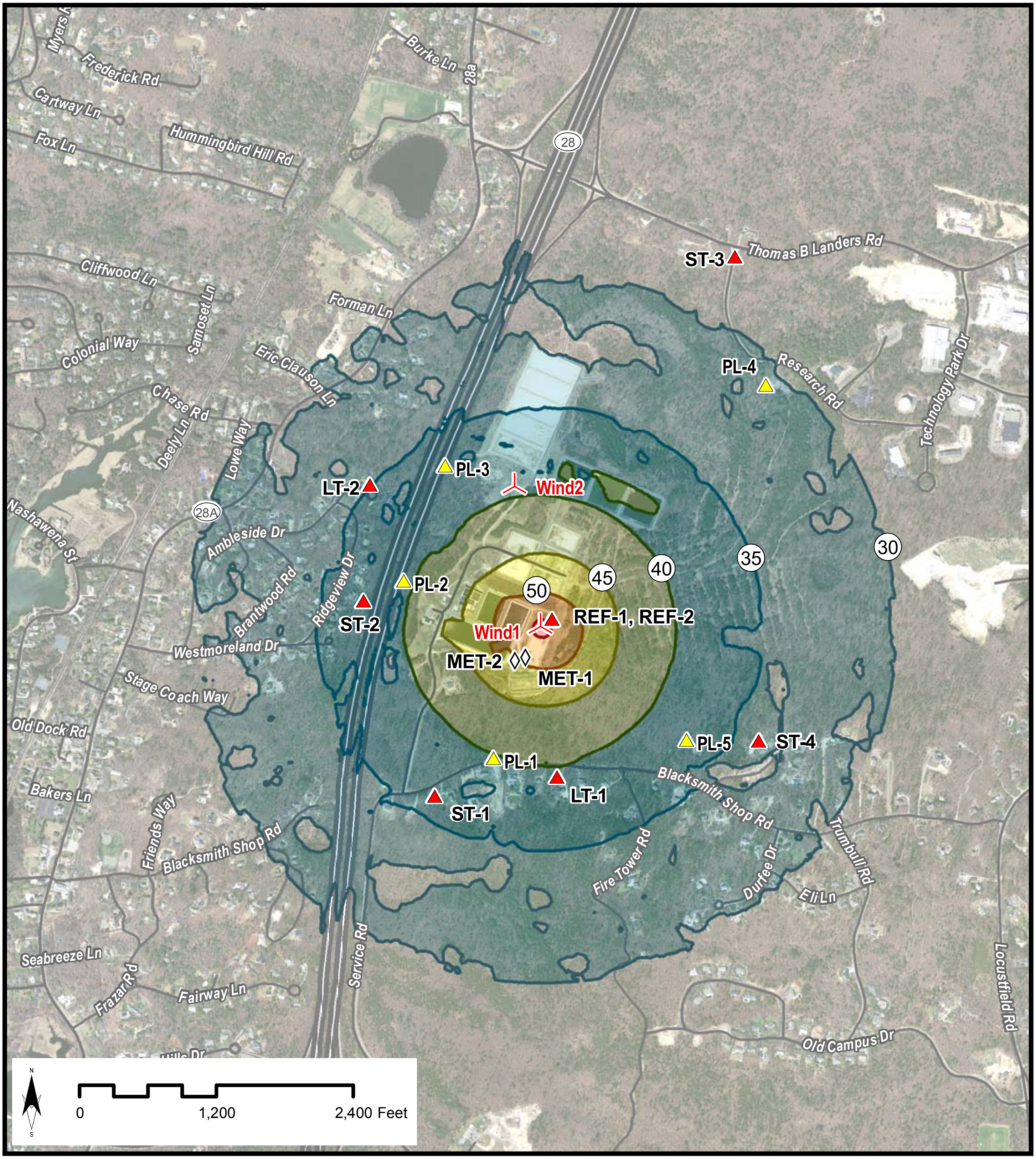
Site ID	Address	Computed Turbine Leq (dBA)	
		Wind-1 alone	Wind-1 & Wind-2
LT-1	211 Blacksmith Shop Rd.	39.1	39.8
LT-2	124 Ambleside Drive	35.0	40.6
ST-1	161 Blacksmith Shop Rd.	36.0	37.4
ST-2	27 Ridgeview Street	37.7	40.2
ST-3	Research Rd. & Thomas B. Landers Rd.	28.2	33.0
ST-4	30 Durham Rd.	33.7	35.1
PL-1	Facility property line – south, near Blacksmith Shop Road	39.5	40.3
PL-2	Facility property line west of Wind-1	38.9	42.0
PL-3	Facility property line west of Wind-2	36.7	46.0
PL-4	Northeast facility property line	30.8	35.0
PL-5	Southeast facility property line	36.8	37.8

[10] International Organization for Standardization (ISO), International Standard ISO 9613-2, "Acoustics – Attenuation of Sound during Propagation Outdoors", Part 2: General Method of Calculation, 1996-12-15.

noise contours on an aerial photograph of the study area. The figures also show the locations of all of the noise prediction sites shown in Table 6. Figure 14 presents the noise contours for the Wind-1 turbine alone. Figure 15 provides noise contours for both the Wind-1 and Wind-2 turbines running together.

Wastewater Treatment Facility Property-line locations have been included in the modeling because the Mass DEP noise guidelines suggest that noise levels be evaluated there as well as at the noise-sensitive locations. However, the Mass DEP recognizes that actions are necessary only if the noise guidelines are exceeded in inhabited noise-sensitive areas. The LT-1 and LT-2 sites are exposed to the highest noise levels from the turbine operations, except for the property-line locations PL-2 and PL-3 to the west of the two turbines and east of Route 28, and PL-1 to the south, north of Blacksmith Shop Road, where projected turbine noise levels are slightly higher.

Table 6 shows that the Wind-1 turbine alone will not produce noise levels greater than 40 dBA at the nearest residential property line, therefore the noise level reference for wind turbines in the Town of Falmouth’s bylaws would not be exceeded by Wind-1. With Wind-1 and Wind-2 turbines operating together at a wind speed of 8 m/s at 10m (11 m/s hub, turbine noise levels at a few residential locations would be slightly greater than the Town’s 40 dBA reference for wind turbines.



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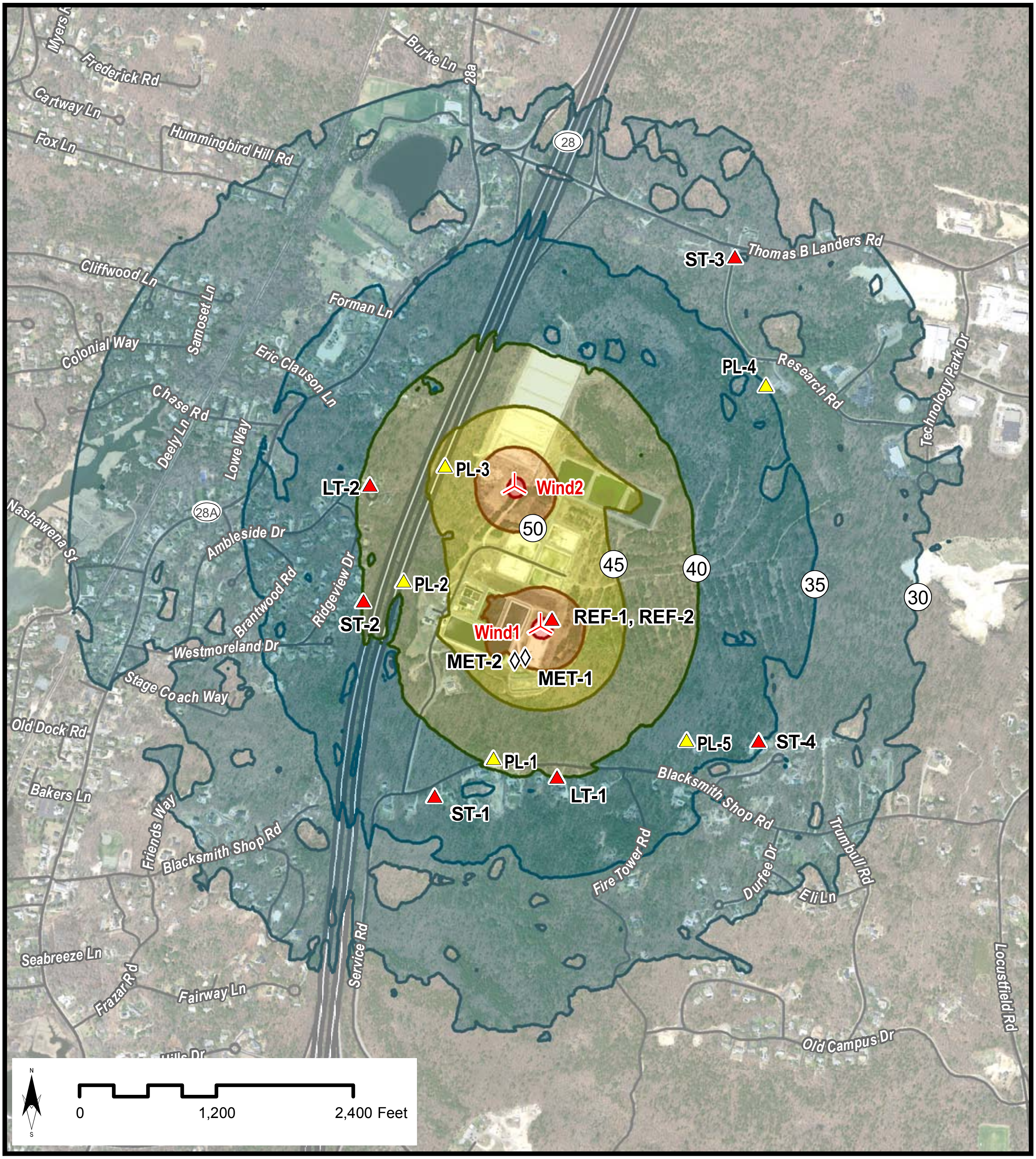
Wind Turbine Location
Measurement Site
Anemometer
Prediction Site

dBA
< 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
> 55

Falmouth Wind
Falmouth, Massachusetts

Figure 14
Falmouth Wind1 Turbine Noise Contours
(wind 8 m/s @ 10m)

HARRIS MILLER MILLER & HANSON INC.



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Wind Turbine Location

Measurement Site

Anemometer

Prediction Site

dBA
< 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
> 55

Falmouth Wind

Falmouth, Massachusetts

Figure 15
Falmouth Wind1 and Wind2 Turbine Noise Contours (wind 8 m/s @ 10m)

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4.4 Comparison of Turbine Noise with L90 Background Sound Levels

As discussed above in Section 2, the Mass DEP noise guidelines state that a noise source should not increase the broadband sound level by more than 10 dBA above ambient. Ambient is defined as the background L90 measured during equipment operating hours.

4.4.1 Reference conditions with 8 m/s wind speed at 10-m height

The Vestas V82 turbine only operates when hub wind speeds exceed 3.5 m/s, as mentioned earlier. Figure 6 in Section 3.4.4 shows the measured background noise levels as a function of hub wind speed that are considered representative of the nighttime early morning hours in the Falmouth study area. That section of the report also describes why the entire study area is characterized with the same background noise levels. At the wind speed of 8 m/s at 10 m and 11 m/s at the hub, the speed at which the turbine noise was modeled in this analysis, the average background L90 was approximately 37.5 dBA. Therefore, to evaluate the noise level increase associated with the turbine operation (shown in Table 6) with respect to the Mass DEP guidelines, we must first add the turbine noise to the background levels.

Table 7 shows the following noise levels: background L90, turbine operation (Leq), turbine plus background, and increase above background caused by the turbine. The values for both the Wind-1 turbine alone and the Wind-1 plus Wind-2 turbines together are shown in separate columns under each heading.

Table 7 Background and Computed Turbine Noise Levels at Measurement and Property-line Sites, with Wind Speed 8 m/s at 10m, 11 m/s at Hub

Site ID	Address	Nighttime Bkgrnd L90 (dBA)	Computed Turbine Leq (dBA)		Turbine Leq plus Bkgrnd (dBA)		Increase above Bkgrnd (dB)	
			Wind-1 alone	Wind-1 & Wind-2	Wind-1 alone	Wind-1 & Wind-2	Wind-1 alone	Wind-1 & Wind-2
LT-1	211 Blacksmith Shop Rd.	37.5	39.1	39.8	41.4	41.8	3.9	4.3
LT-2	124 Ambleside Drive	37.5	35.0	40.6	39.4	42.3	1.9	4.8
ST-1	161 Blacksmith Shop Rd.	37.5	36.0	37.4	39.8	40.5	2.3	3.0
ST-2	27 Ridgeview Street	37.5	37.7	40.2	40.6	42.1	3.1	4.6
ST-3	Research Rd & Thomas B Landers Rd.	37.5	28.2	33.0	38.0	38.8	0.5	1.3
ST-4	30 Durham Rd.	37.5	33.7	35.1	39.0	39.5	1.5	2.0
PL-1	South property line	37.5	39.5	40.3	41.6	42.1	4.1	4.6
PL-2	Prop. line west of Wind-1	37.5	38.9	42.0	41.3	43.3	3.8	5.8
PL-3	Prop. line west of Wind-2	37.5	36.7	46.0	40.1	46.6	2.6	9.1
PL-4	Northeast property line	37.5	30.8	35.0	38.3	39.4	0.8	1.9
PL-5	Southeast property line	37.5	36.8	37.8	40.2	40.7	2.7	3.2

It is clear from the table that under the conditions of moderately high wind speeds, the sound levels from either the Wind-1 turbine operation alone or the combined operation of the Wind-1 and Wind-2 turbines will not increase the background sound level by more than 10 dBA. The greatest increase for

Wind-1 alone, approximately 4 decibels, is computed to occur south of the turbine, at the south property line and Site LT-1. For the combined turbines, the greatest increases, 6 and 9 decibels, are projected at the property line locations west of the two turbines, adjacent to Route 28. In the residential areas, the greatest projected increase is about 5 dB, at Site LT-2. Most of the closest homes would experience increases in the range of 4 to 5 decibels.

4.4.2 Wind speeds other than reference conditions

Figure 6 in Section 3.4.4 and the results of the noise measurement program showed that the wind turbine will still operate in lower-wind conditions when the background noise levels in the community are lower than those at the reference wind speed of 8 m/s at 10m and 11 m/s at hub height. In Figure 6, the lowest average L90 background sound levels were approximately 29 dBA, which occur with hub wind speeds between 4 and 6 m/s.

Vestas has provided the study team with information about the reference noise emissions of the V82 wind turbine at a wide range of wind speeds. Table 8 presents the reference sound power levels at the integer 10m wind speeds between 3 m/s and 14 m/s. Also included for reference are the corresponding wind speeds at the 80-m hub height.

Table 8 Vestas V82 Turbine Reference Sound Power Levels as a Function of Wind Speed

Wind Speed in meters/second at height		Sound Power Level (LwA, A-weighted, dBA))
10 meters	Hub height (80m)	
3	4.1	101.1
4	5.5	101.4
5	6.8	101.6
6	8.2	101.9
7	9.6	102.5
8	10.9	103.8
9	12.3	106.1
10	13.7	108.4
11	15.0	109.5
12	16.4	109.5
13	17.8	108.4
14	19.1	107.4

Source: Vestas Wind Systems A/S

To determine the greatest potential for noise impact in the community with respect to increases in the ambient background noise level, HMMH computed the Wind-1 turbine noise levels at LT-1 at the different wind speeds shown in Table 8. These calculations were based on the 8 m/s 10m wind speed turbine noise SoundPLAN computations at LT-1 as a starting point, and applying the differences in A-weighted sound power levels at the different speeds to the computed level at LT-1. This is a reasonably accurate approach, since the spectrum shape of the turbine noise emissions does not change very much with wind speed.

Figure 16 shows graphs of the LT-1 background L90 and the computed Wind-1 turbine Leq sound levels at the different wind speeds, based on Vestas' information and the SoundPLAN computation at the reference 8 m/s 10m wind speed. This plot makes it easy to see that the speed with the greatest

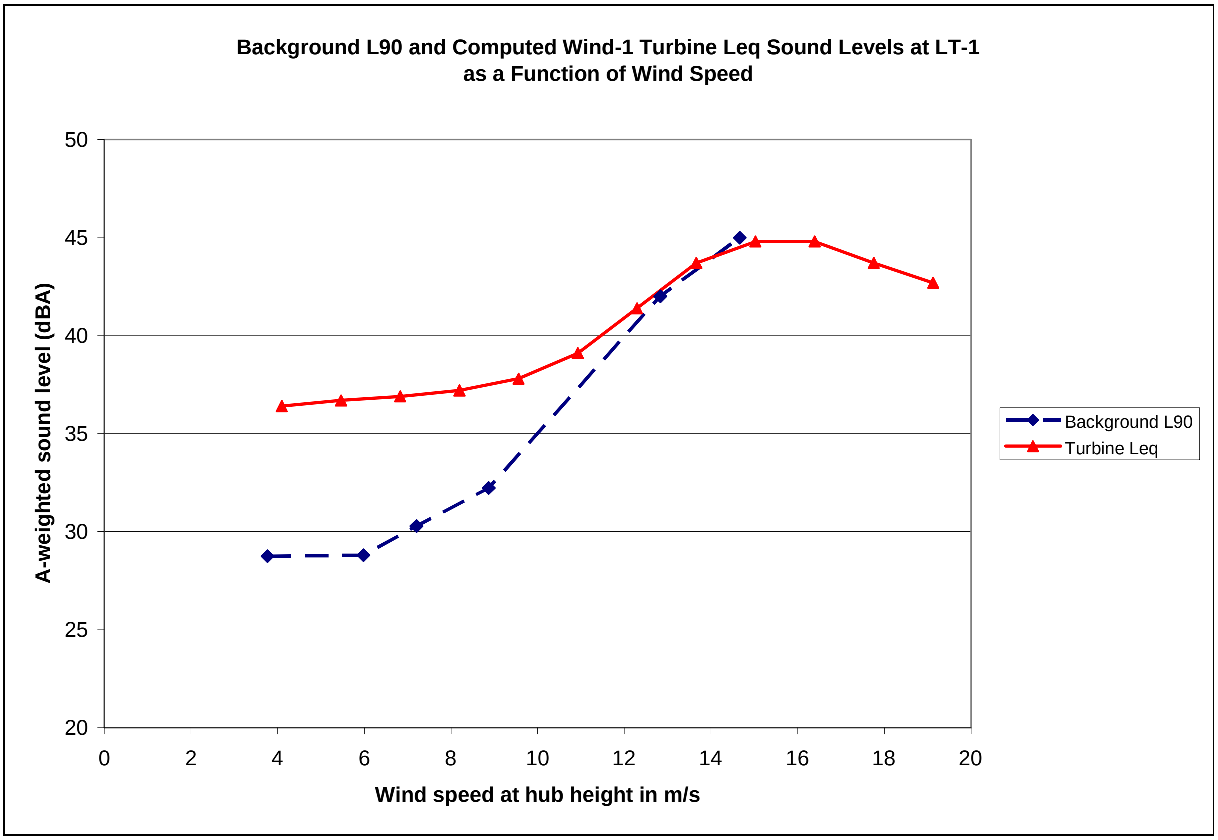


Figure 16 Background L90 and Wind-1 Turbine Noise Levels at LT-1 with Varying Wind Speed

difference between turbine noise level and background is the hub height wind speed of 6 m/s, when background sound levels are lowest. This condition comes about because the background noise levels rise faster with wind speed than the turbine emissions do.

As a result of this analysis, HMMH evaluated the potential for noise impact at all of the receiver positions at the 6 m/s hub wind speed (4.4 m/s at 10m). This evaluation was performed in the same manner as the turbine Leq values were determined at different speeds at LT-1, based on the differences in turbine sound power levels compared with the reference 8 m/s wind speed emissions, and the SoundPLAN computations at those receivers under the reference conditions. A sound power level of 101.5 dBA at a 10m wind speed of 4.4 m/s was used for the V82 turbine. This noise emission level is 2.3 decibels lower than the 8 m/s sound power level of 103.8 dBA. Therefore, we subtracted 2.3 dBA from the predicted turbine noise levels at all of the receivers to closely approximate the 6m/s hub wind (4.4 m/s at 10m) condition. The measured background noise level at this wind speed was 28.8 dBA, and that value is considered applicable throughout the study area.

Table 9 presents the results of this computation in the same format as Table 7. Shown are background L90, turbine operation (Leq), turbine plus background, and increase above background caused by the turbine. The predicted values for both the Wind-1 turbine alone and the Wind-1 plus Wind-2 turbines together are shown.

Table 9 Background and Computed Turbine Noise Levels at Measurement and Property-line Sites, with Wind Speed 4.4 m/s at 10m, 6 m/s at Hub

Site ID	Address	Nighttime Bkgrnd L90 (dBA)	Computed Turbine Leq (dBA)		Turbine Leq plus Bkgrnd (dBA)		Increase above Bkgrnd (dB)	
			Wind-1 alone	Wind-1 & Wind-2	Wind-1 alone	Wind-1 & Wind-2	Wind-1 alone	Wind-1 & Wind-2
LT-1	211 Blacksmith Shop Rd.	28.8	36.8	37.5	37.4	38.0	8.6	9.2
LT-2	124 Ambleside Drive	28.8	32.7	38.3	34.2	38.8	5.4	9.96
ST-1	161 Blacksmith Shop Rd.	28.8	33.7	35.1	34.9	36.0	6.1	7.2
ST-2	27 Ridgeview Street	28.8	35.4	37.9	36.3	38.4	7.5	9.6
ST-3	Research Rd & Thomas B Landers Rd.	28.8	25.9	30.7	30.6	32.9	1.8	4.1
ST-4	30 Durham Rd.	28.8	31.4	32.8	33.3	34.3	4.5	5.5
PL-1	South property line	28.8	37.2	38.0	37.8	38.5	9.0	9.7
PL-2	Prop. line west of Wind-1	28.8	36.6	39.7	37.3	40.0	8.5	11.2
PL-3	Prop. line west of Wind-2	28.8	34.4	43.7	35.5	43.8	6.7	15.0
PL-4	Northeast property line	28.8	28.5	32.7	31.7	34.2	2.9	5.4
PL-5	Southeast property line	28.8	34.5	35.5	35.5	36.3	6.7	7.5

Shown in the last two columns, the increases in sound level above background are notably higher at the lower wind speeds. The model predicts the increases in background noise will approach 10 dBA at sites LT-2 and ST-2, but not exceed 10. An increase above 10 dBA is expected at the two property-line positions west of the turbines and adjacent to Route 28, but not at any noise-sensitive areas. No violations of the Mass DEP criteria are expected at any of the residential noise measurement sites.

It is appropriate to point out that two homes are located slightly closer to Wind-2 than the LT-2 site; both homes are near LT-2. Therefore, the turbine sound levels at those two homes could be high enough such that with both Wind-1 and Wind-2 operating at low wind (6 m/s), the ambient background L90 sound level is expected to increase by 11 decibels in the early morning hours. It is also appropriate to point out that as the hub wind speed increases to 7 m/s, the background noise levels increase sufficiently to reduce the increase at the nearest home to 9.8 decibels, such that a violation of the Mass DEP criteria would no longer occur. With either of the turbines running by itself, the Mass DEP increase in ambient criteria will not be exceeded under any conditions.

4.5 Conclusions

In conclusion, noise from the operation of the wind turbines will be audible at the closest residences, particularly when the background noise levels drop at night, and there is sufficient wind aloft to drive the turbines. The Massachusetts DEP noise guidelines require that noise sources should not increase existing background noise levels by more than 10 dBA. The Falmouth Wind-1 and Wind-2 turbines will not cause such exceedances in the surrounding community, except when both turbines are running with hub wind speeds of 6 m/s at night between about midnight and 3:00 or 4:00 AM, at the two homes closest to the Wind-2 turbine. Under all other conditions, the noise from the turbines will be in compliance with the Mass DEP noise guidelines.

Appendix A Description of Noise Metrics

This Appendix describes the noise metrics used in this report.

A.1 A-weighted Sound Level, dBA

Loudness is a subjective quantity that enables a listener to order the magnitude of different sounds on a scale from soft to loud. Although the perceived loudness of a sound is based somewhat on its frequency and duration, chiefly it depends upon the sound pressure level. Sound pressure level is a measure of the sound pressure at a point relative to a standard reference value; sound pressure level is always expressed in decibels (dB), a logarithmic quantity.

Another important characteristic of sound is its frequency, or “pitch.” This is the rate of repetition of sound pressure oscillations as they reach our ears. Frequency is expressed in units known as Hertz (abbreviated “Hz” and equivalent to one cycle per second). Sounds heard in the environment usually consist of a range of frequencies. The distribution of sound energy as a function of frequency is termed the “frequency spectrum.” The frequency spectrum of sound is often represented as the sum of the sound energy in frequency bands that are one octave or 1/3-octave wide. An octave represents a doubling of frequency.

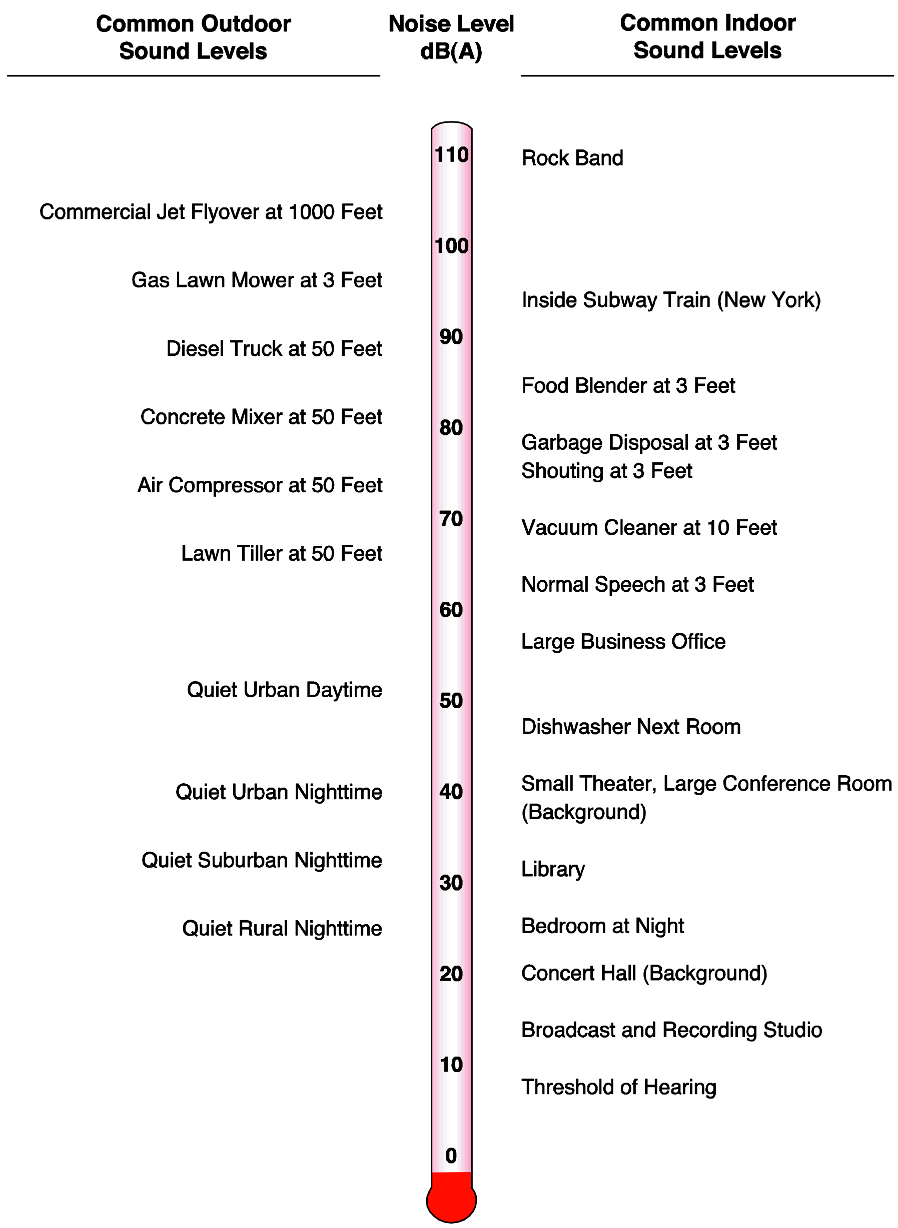
The human ear does not respond equally to identical noise levels at different frequencies. Although the normal frequency range of hearing for most people extends from a low of about 20 Hz to a high of 10,000 Hz to 20,000 Hz, people are most sensitive to sounds in the voice range, between about 500 Hz to 2,000 Hz. Therefore, to correlate the amplitude of a sound with its level as perceived by people, the sound energy spectrum is adjusted, or “weighted.”

The weighting system most commonly used to correlate with people's response to noise is “A-weighting” (or the “A-filter”) and the resultant noise level is called the “A-weighted noise level” (dBA). A-weighting significantly de-emphasizes those parts of the frequency spectrum from a noise source that occurs both at lower frequencies (those below about 500 Hz) and at very high frequencies (above 10,000 Hz) where we do not hear as well. The filter has very little effect, or is nearly “flat,” in the middle range of frequencies between 500 and 10,000 Hz. A-weighted sound levels have been found to correlate better than other weighting networks with human perception of “noisiness.” One of the primary reasons for this is that the A-weighting network emphasizes the frequency range where human speech occurs, and noise in this range interferes with speech communication. The figure below shows common indoor and outdoor A-weighted sound levels and the environments or sources that produce them.

A.2 Equivalent Sound Level, Leq

The Equivalent Sound Level, abbreviated L_{eq}, is a measure of the total exposure resulting from the accumulation of A-weighted sound levels over a particular period of interest -- for example, an hour, an 8-hour school day, nighttime, or a full 24-hour day. However, because the length of the period can be different depending on the time frame of interest, the applicable period should always be identified or clearly understood when discussing the metric. Such durations are often identified through a subscript, for example L_{eq1h}, or $L_{eq(24)}$.

L_{eq} may be thought of as a constant sound level over the period of interest that contains as much sound energy as (is “equivalent” to) the actual time-varying sound level with its normal peaks and valleys. It is important to recognize, however, that the two signals (the constant one and the time-varying one) would sound very different from each other. Also, the “average” sound level suggested by L_{eq} is not an



arithmetic value, but a logarithmic, or "energy-averaged" sound level. Thus, the loudest events may dominate the noise environment described by the metric, depending on the relative loudness of the events.

A.3 Statistical Sound Level Descriptors

Statistical descriptors of the time-varying sound level are often used instead of, or in addition to L_{eq} to provide more information about how the sound level varied during the time period of interest. The descriptor includes a subscript that indicates the percentage of time the sound level is exceeded during the period. The L_{50} is an example, which represents the sound level exceeded 50 percent of the time, and equals the median sound level. Another commonly used descriptor is the L_{10}, which represents the sound level exceeded 10 percent of the measurement period and describes the sound level during the louder portions of the period. The L_{90} is often used to describe the quieter background sound levels that occurred, since it represents the level exceeded 90 percent of the period.

Appendix B Mass DEP Noise Policy and Background

Massachusetts Department of ENVIRONMENTAL PROTECTION

f a c t   s h e e t

Noise

Background

Noise is a type of air pollution that results from sounds that cause a nuisance, are or could injure public health, or unreasonably interfere with the comfortable enjoyment of life, property, or the conduct of business. Types of sounds that may cause noise include:

- "Loud" continuous sounds from industrial or commercial activity, demolition, or highly amplified music;
- Sounds in narrow frequency ranges such as "squealing" fans or other rotary equipment; and
- Intermittent or "impact" sounds such as those from pile drivers, jackhammers, slamming truck tailgates, public address systems, etc.

Policy

A noise source will be considered to be violating the Department's noise regulation (310 CMR 7.10) if the source:

1. Increases the broadband sound level by more than 10 dB(A) above ambient, or
2. Produce a "pure tone" condition – when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 decibels or more.

These criteria are measured both at the property line and at the nearest inhabited residence. "Ambient" is defined as the background A-weighted sound level that is exceeded 90% of the time, measured during equipment operating hours. "Ambient" may also be established by other means with consent of the Department.

For more information:
For complaints about specific noise sources, call the Board of Health for the municipality in which the noise source is located.

To learn more about responding to noise, odor and dust complaints or to request state assistance or support, please contact the service center in the nearest DEP regional office.

- Central Region, Worcester: (508) 792-7683
- Northeast Region, Wilmington: (978) 661-7677
- Southeast Region, Lakeville: (508) 946-2714
- Western Region, Springfield: (413) 755-2214

This Policy was originally adopted by the MA Department of Public Health in the early 1970's. It was reaffirmed by DEP's Division of Air Quality Control on February 1, 1990, and has remained in effect.

Massachusetts Department of
Environmental Protection
One Winter Street
Boston, MA 02108-4746

Commonwealth of
Massachusetts
Mitt Romney, Governor

Executive Office of
Environmental Affairs
Ellen Roy Herzfelder, Secretary

Department of
Environmental Protection
Edward P. Kunce,
Acting Commissioner

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February 2003.
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This information is available in alternate format by calling our ADA Coordinator at (617) 574-6872.

Appendix C Noise Measurement Details

This appendix provides further details about the noise measurements, including a table showing the noise measurement instrumentation (Table 10), graphs of the noise level metrics throughout the noise measurement period at sites LT-1 and LT-2 (Figure 17 and Figure 18), and photographs taken at the noise measurement sites (Figure 19 through Figure 25).

Table 10 Noise Measurement Instrumentation

Used for:	SLM Kit	Instrument Model and Serial Number			
		Analyzer	Pre-amplifier	Microphone	Calibrator
Long-Term 1	BK2250 #2	B&K 2250 2579775	B&K ZC0032 6175	B&K 4189 2578994	B&K 4231 2579293
Long-Term 2	BK2250 #3	B&K 2250 2619790	B&K ZC0032 7758	B&K 4189 2616506	B&K 4231 2579291
Short-Term and Ground-Plane Sites	BK2250 #4	B&K 2250 2579777	B&K ZC0032 6182	B&K 4189 2578555	B&K 4231 2579295

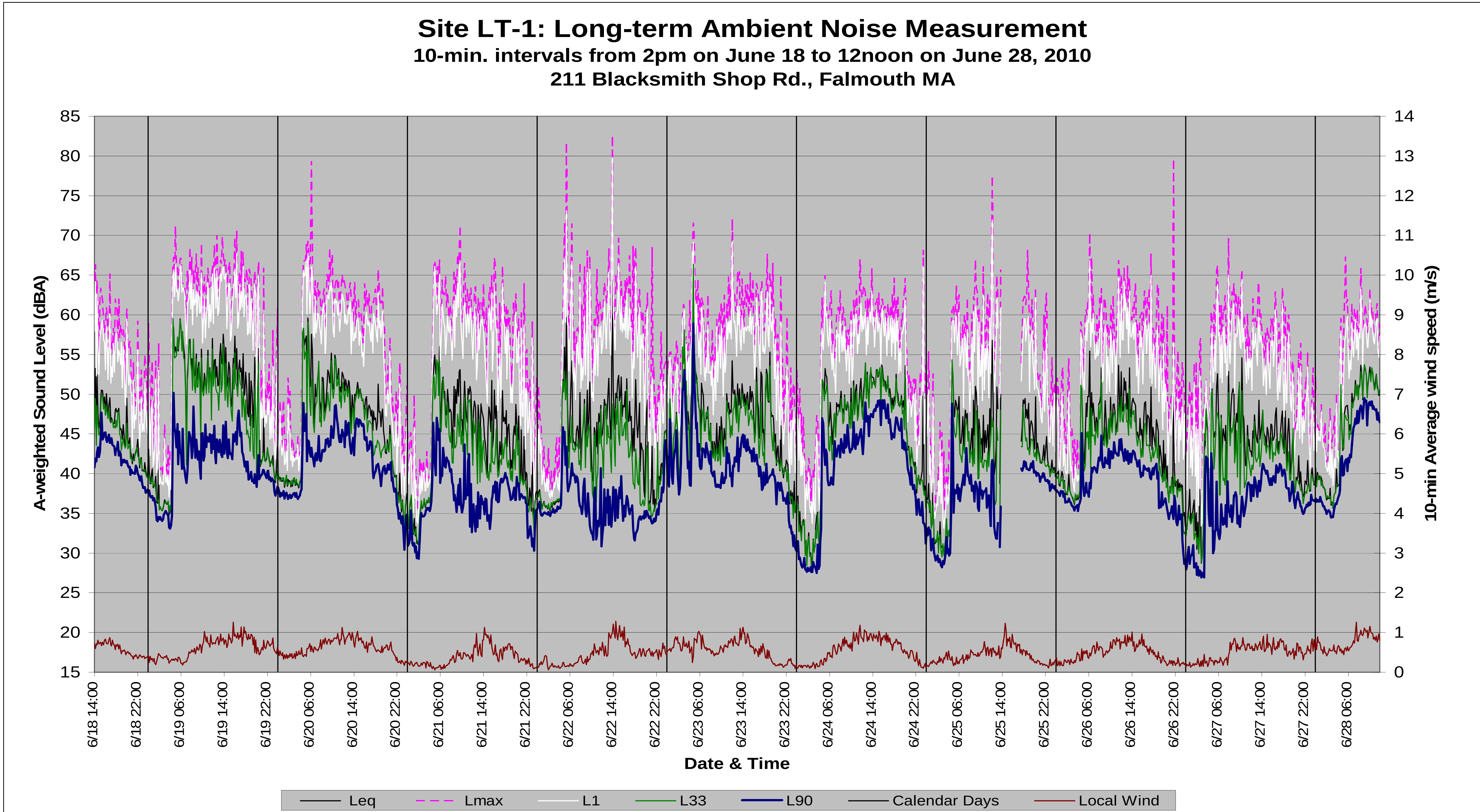

Figure 17 Graph of Noise Level Metrics at Site LT-1, 211 Blacksmith Shop Road

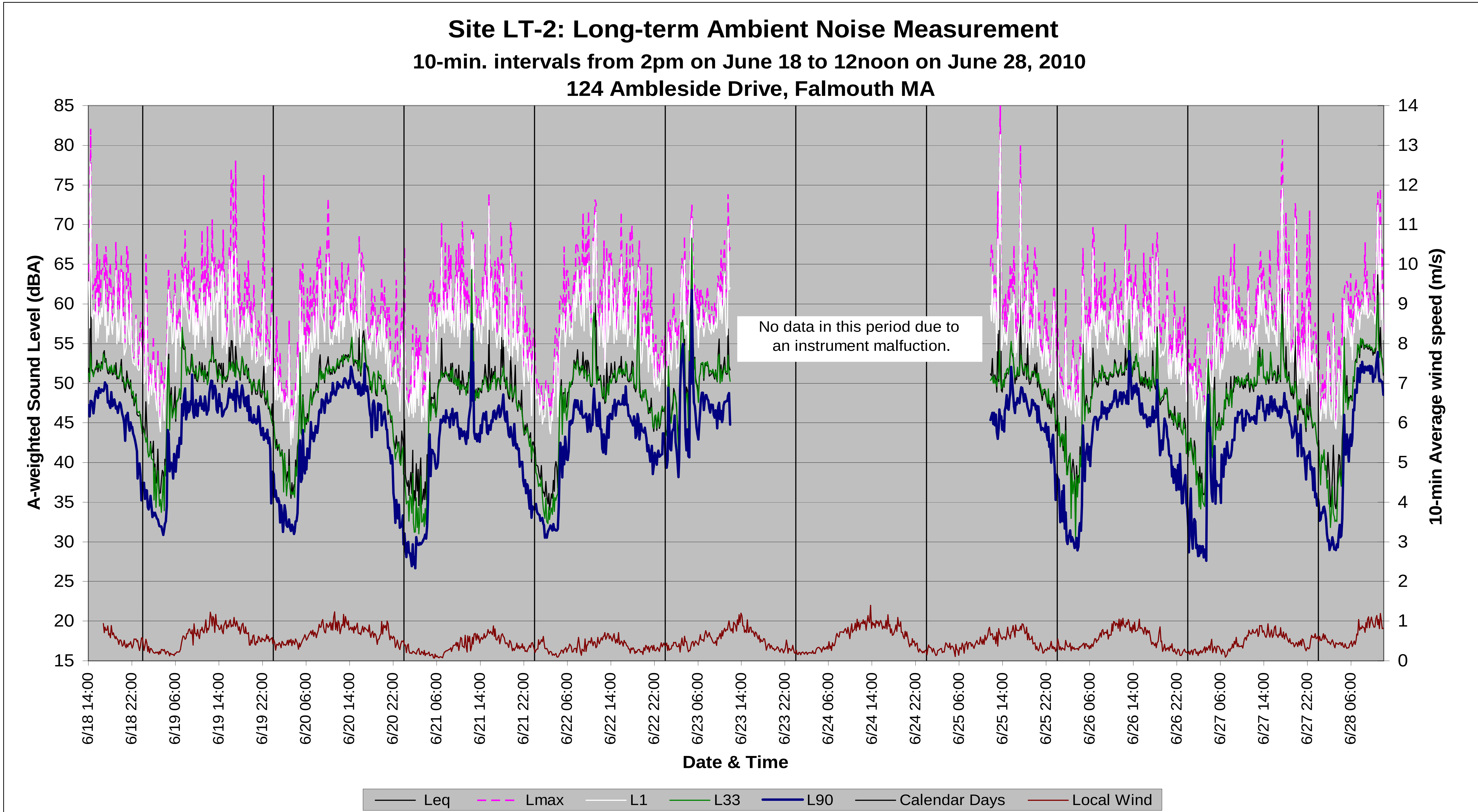

Figure 18 Graph of Noise Level Metrics at Site LT-2, 124 Ambleside Drive

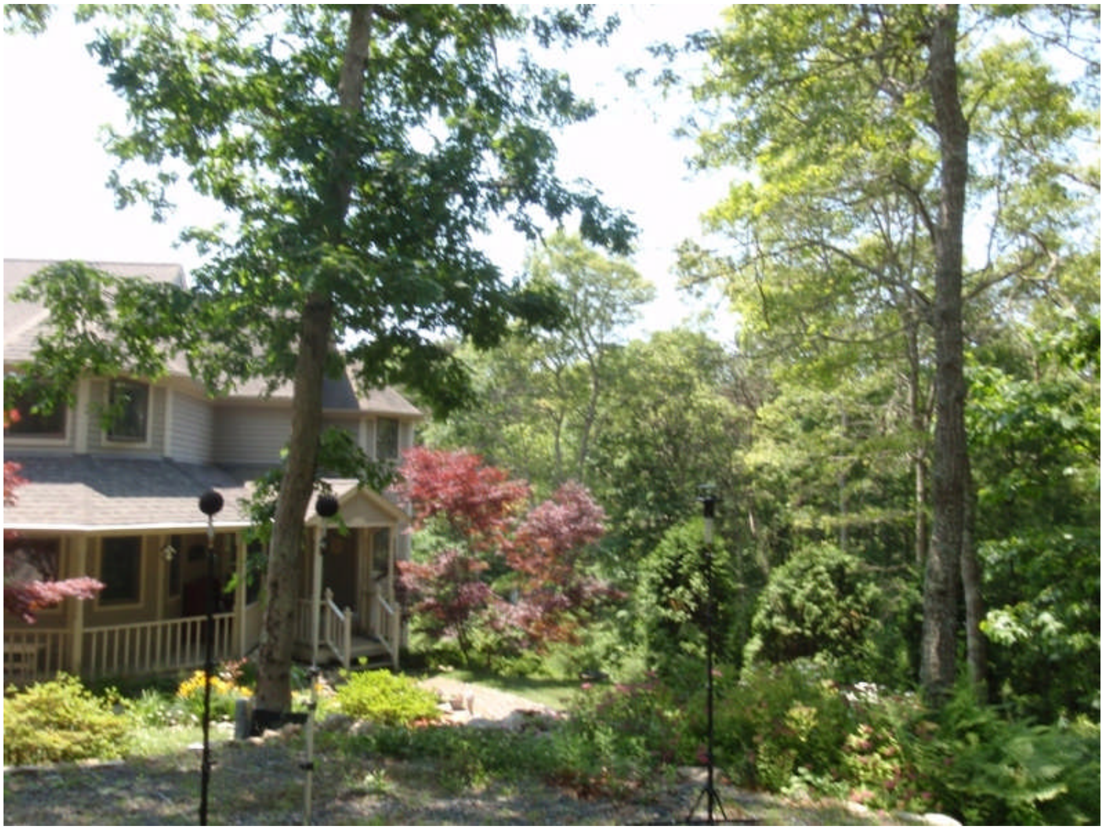

Figure 19 Photo of Site LT-1, 211 Blacksmith Shop Road

Figure 20 Photo of Site LT-2, 124 Ambleside Drive

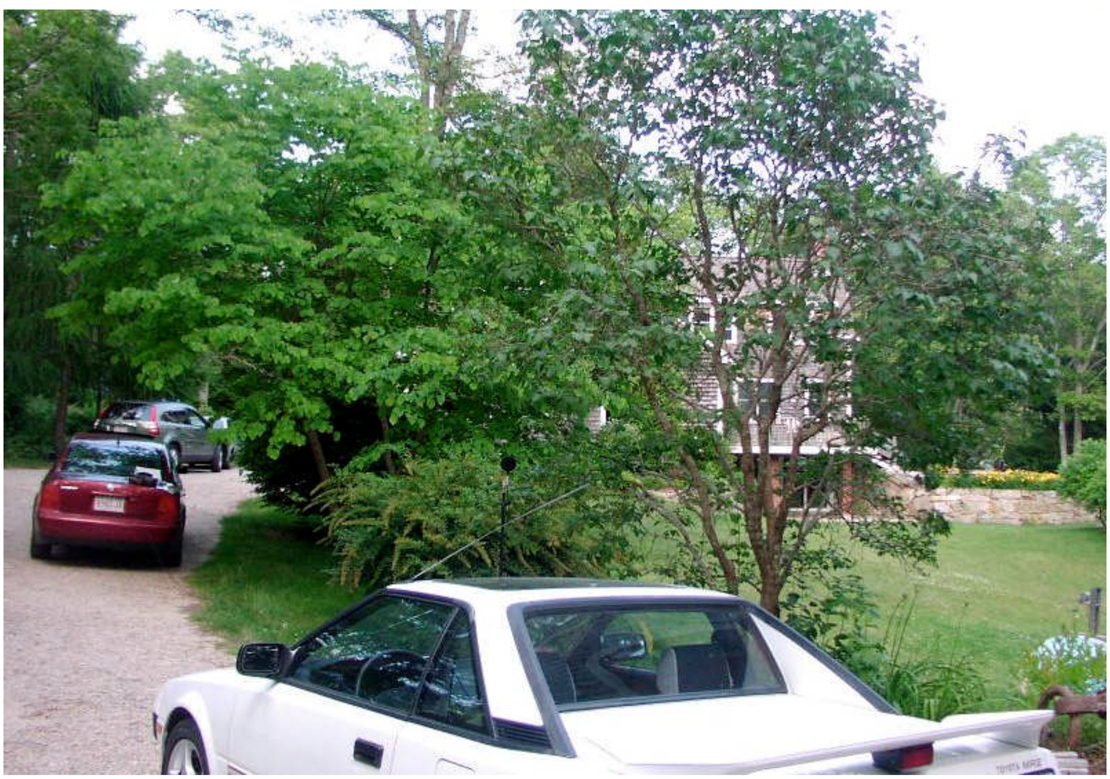

Figure 21 Photo of Site ST-1, 161 Blacksmith Shop Road

Figure 22 Photo of Site ST-2, 27 Ridgeview Street

Figure 23 Photo of Site ST-3, Research Road and Thomas B. Landers Road

Figure 24 Photo of Site ST-4, Durham Road Cul-de-sac

Figure 25 Photo of Site ST-4 Position 2, 30 Durham Rd

Appendix D Powerdash Data from Wind-1, June 18 to 28, 2010

This appendix presents a graph of the Wind-1 turbine's power output throughout the noise measurement period. The data were available and are plotted in 15-minute intervals.

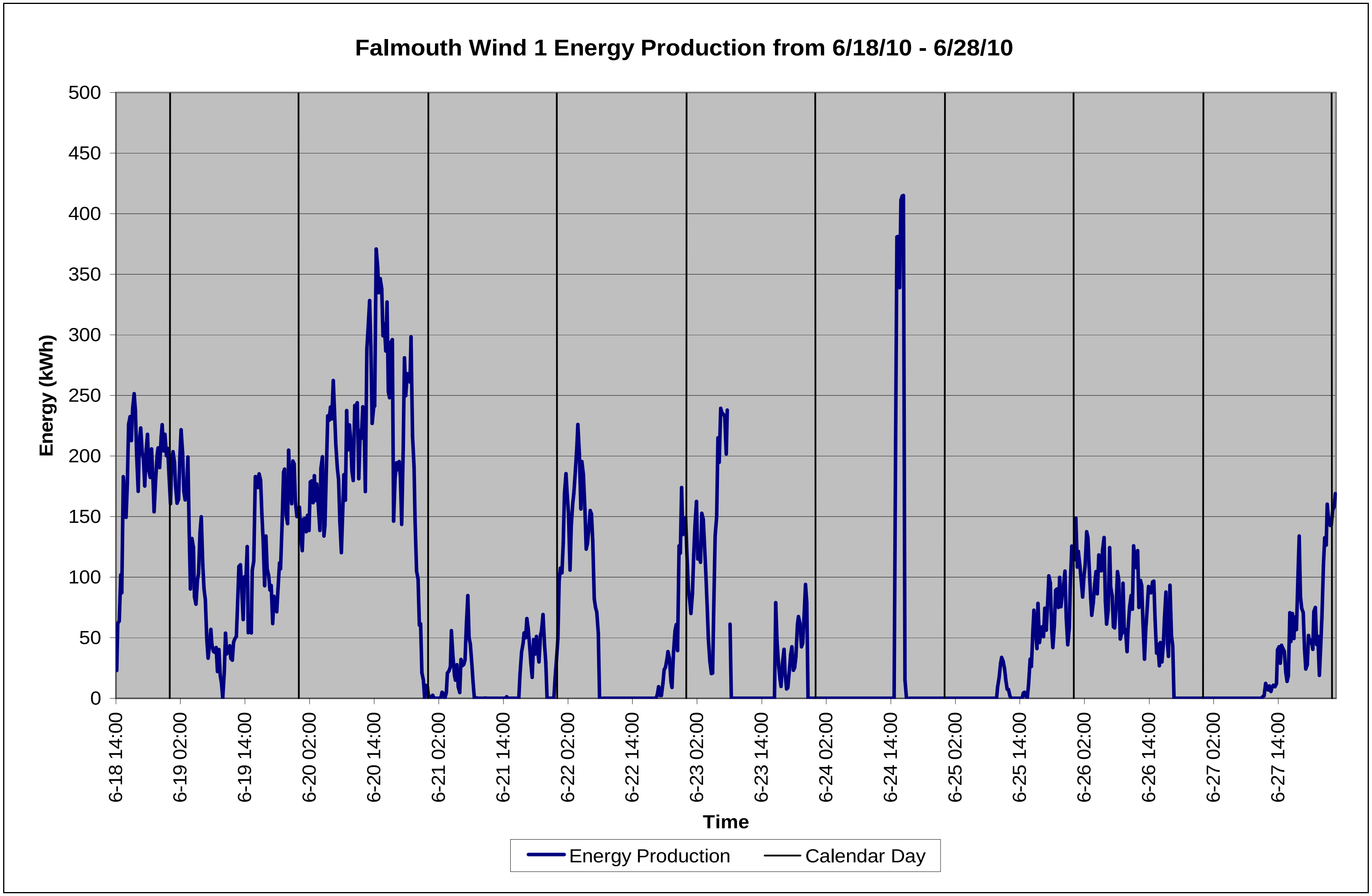

Figure 26 Powerdash Data Showing Wind-1 Power Output during Noise Measurement Period