Colebrook Wind Farm Monthly

Noise Compliance Measurement Study

Colebrook, Connecticut

March, 2016

Prepared for:

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Executive Summary

A cold weather ("leaf off") noise monitoring study was completed for two 2.85 MW turbines installed at Wind Colebrook South in Colebrook, CT during March 2016. In this report, we have reviewed applicable noise standards and criteria and described the measurements made at the location. Given the data collected as a result of this study, it is our professional opinion that acoustic impacts from the wind turbines in Colebrook of 40-45 dBA are in compliance with and well below the maximum allowable noise level during both day and nighttime periods at all locations. Noise levels from the turbines were at about the level of the wind in the trees background at two locations under windy operating conditions, and well below the background level from highway noise sources at another. The turbine noise levels were about 10 decibels below the levels from frequent plane overflights. Infrasound levels were not measurable with the equipment, but under typical operating conditions levels should be below levels normally detected by the human ear.

Based on this study, we conclude the following:

- L90 Operational levels from the turbines at maximum noise levels were below the appropriate Connecticut standards during both day and nighttime periods at all locations. Peak sound levels at the closest residence including traffic and tree noise were found to be about 5-7 dBA below the project noise limits, while peak levels from the turbines only were nearly 8 dBA below the project noise limits.

- The turbine noise levels of about 40-45 dBA were well below levels expected from aircraft flyovers in the area, about 50-55 dBA, and below the 45 dBA level usually considered to define turbine annoyance. Background levels under wind turbine operational conditions from wind and tree noise were between 30 and 50 dBA, but were often comparable to or exceeded turbine noise levels at 2 of 3 monitoring locations under operational conditions. These are nearly the same levels as those expected from the turbine itself at the monitoring locations, indicating that much of the turbine sound was masked by the background under typical operating conditions.

1 Introduction

Wind Colebrook South (“WCS”), located at 17 and 29 Flagg Hill Road in Colebrook, CT is an operational wind farm. This wind farm consists of two 2.85 MW wind turbines with 103 meter diameter blades and 98.3 meter hub heights which feed power into the Connecticut power grid. WCS began commercial operations on November 4, 2015. It is possible that a third wind turbine, located to the southwest of the two operational ones, may go up during 2017. In this case, additional monitoring near this turbine may be needed, which would be done at that time.

Dr. Howard Quin was contracted by BNE Energy to perform a cold weather noise study for the wind turbine installations. The study takes place over the months of January-March 2016. Each report summarizes noise measurements made during each of these months; this report summarizes the results for March 2016. Long-term monitoring will also be conducted at two locations over a one year period and the report will be filed in late 2016 when the study is completed; relevant winter measurements were done in January and February 2016. In this report, we review applicable noise standards and criteria, and summarize the measurement noise data at the site. Appendix A provides a description of various noise metrics.

2 Noise Standards and Criteria

Generally speaking, noise standards are usually defined as either absolute levels or amount over ambient background. Ambient is usually defined as the background A-weighted sound level that is exceeded 90 percent of the time (i.e. L90) measured during equipment operating hours, although in some cases is defined using the average level (the Leq). For the case where the turbines run continuously, as they did for many hours during the operational testing, the turbine sound is usually the ambient, depending on locations and other background sources. A wind turbine only operates when there is sufficient wind speed to run it, which is generally 4 meters per second (m/s) (9 mph) measured at a height of 10 meters (m), or about 5 m/sec at hub height. Therefore, it is appropriate to report sound levels when winds are blowing at speeds of 5 m/s or higher at hub height for purposes of comparison to the turbine noise emissions, if possible. Typically turbines would create peak sound levels near full production levels between 10 and 12 m/sec.

The noise monitoring program was conducted to demonstrate that the operation of the wind turbines at Colebrook South will meet the Connecticut Department of Energy and Environmental Protection’s (DEEP) noise control regulations (Title 22a, §§ 22a-69-1 to 22a69-7), which are contained in the Regulations of Connecticut State Agencies. These regulations are summarized below in Table 1.

Table 1

Noise Zone Standards, L90 (dBA)

	Table 1			
	Noise Zone Standards, L90 (dBA)			
	Class A Daytime	**Class A Nighttime**	**Class B**	**Class C**
Emitter Zone				
Class A (Residential)	55	45	55	62
Class B (Commercial)	55	45	62	62
Class C (Industrial)	61	51	66	70

Source: Control of Noise (Title 22a, Section 22a-69-1 to 22a-69-7.4), Regulations of Connecticut

The Emitter Zone for Colebrook South is Class C (Industrial) which shall not emit noise exceeding the levels stated in Table 1 at the adjacent noise zones. The relevant sound limits from the table are 61 dBA daytime and 51 dBA nighttime. In measuring compliance with Noise Zone Standards, the following short-term noise level excursions over the noise level standards established by these Regulations shall be allowed, and measurements within these ranges of established standards shall constitute compliance.

Allowable levels (dBA)	Time period of above standards such levels (minutes/hour)
3	15
6	7 ½
8	5

3 Measurement Program

A total of four sites were chosen for weekly sound measurements near the two turbines on Flagg Hill Road. Three of these sites were to have weekly monitors for one week intervals during the monthly monitoring program, while a fourth was to have seasonal monitors for one week each quarter. These sites were chosen after a site visit on December 22, 2015 by BNE and Howard Quin. Figure 1 shows the turbines and monitoring locations. The two turbines are shown as T1 and T2. The monitoring locations were as follows;

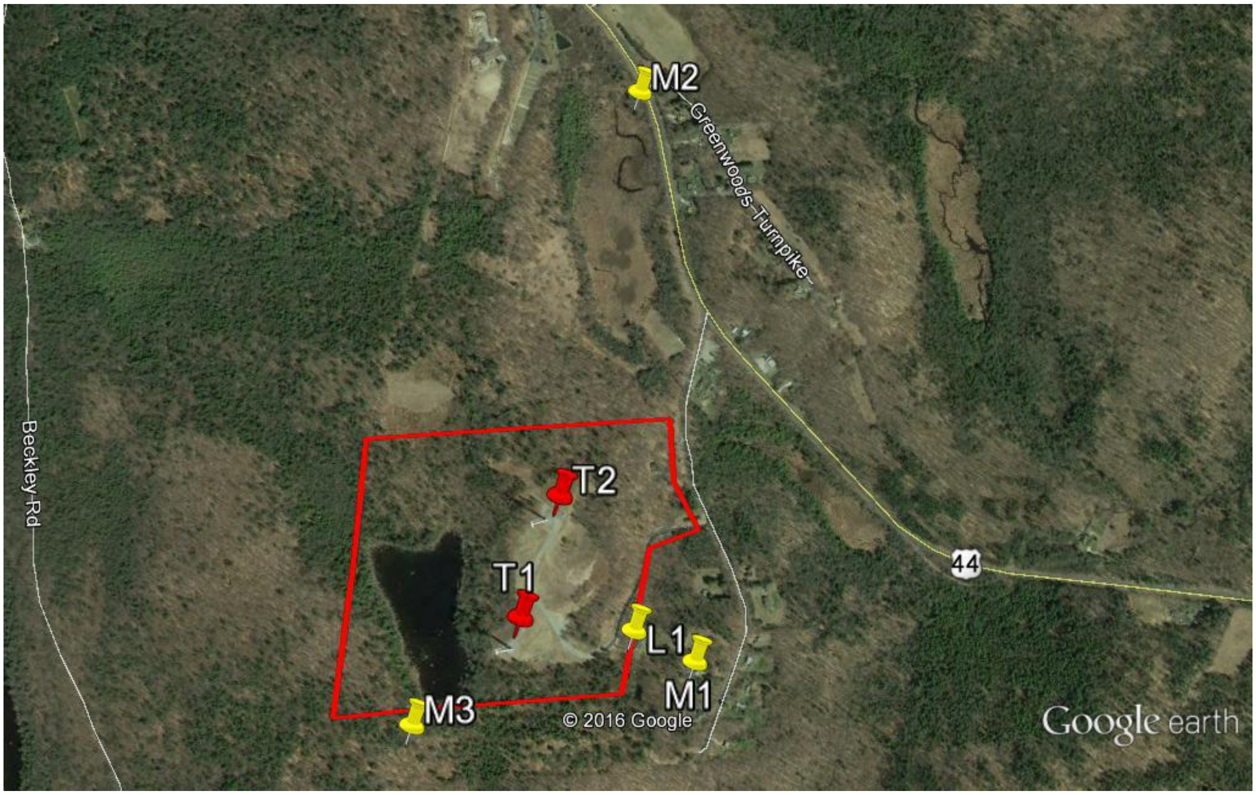


Figure 1.

Monitoring Sites and Property Line Near Wind Colebrook South

M1 – Located near the closest Residence on 45 Flagg Hill Road. Identified as Receptor Location 5 (R5) in the Noise Report dated October 2010. This was at
41° 57.709'N Latitude, 73° 8.488'W Longitude.

M2 – Located on the west side of the road (nearer the turbines) near the Residences on Greenwoods Turnpike. Identified as Receptor Location 2 (R2) in the Noise Report. This was at 41° 58.363'N Latitude, 73° 8.569'W Longitude.

M3 – Located near the property line of the Residence on Beckley Road. Identified as Receptor Location 7 (R7) in the Noise Report. This was at 41° 57.641'N Latitude, 73° 8.910'W Longitude.

L1 – Located near the closest Residence to the turbines on 29 Flagg Hill Road, which has a Wind Farm Neighbor Agreement with Wind Colebrook South, and is the closest residence to Turbine 1. This is the seasonal monitoring location where measurements are being conducted for one week during each season. It was not monitored during this program.

Note that actual monitoring locations M1 and M2 were considerably closer to the turbines than the closest nearby residents or property lines, while location M1 is significantly closer than any other nearby residence on Flagg Hill Road. Consequently, turbine sound levels measured at these locations are conservative; actual turbine sound levels at nearby relevant receptors would be lower.

At each location, long term data was collected in one hour intervals, in accordance with Connecticut DEEP requirements, with the meter on "slow" setting. As specified by DEEP requirements, the L90 metric was used to verify compliance. Since the Connecticut DEEP regulations also contain standards for shorter time intervals, the L10, L15, and L25 metrics were recorded to approximate the L90s for shorter time periods. Note that this is a conservative estimate; typically one hour L10s would have higher levels than six minute L90s in ten high wind periods over the same hour. The hourly Leq (average) levels were also collected.

Noise measurements were conducted with Larson Davis 831 octave band sound level meters/noise analyzers for intervals of one hour, in order to comply with the Connecticut monitoring requirements. Field calibrations with acoustic calibrators were conducted for all of the measurements. All instrumentation components, including microphones, preamplifiers and field calibrators have current laboratory certified calibrations traceable to the National Institute of Standards and Technology. Microphones were fitted with special 7 inch windscreens, which are usually used for wind turbine sound monitoring.

Attended short term monitoring was also made on-site. This was done with a Quest Sound Pro Type I sound meter for periods of 30 minutes at each location with the meter on "slow" setting. The short term monitoring was done to ensure that a technician was on-site to verify the actual relative contributions of sound from various sources during typical wind turbine operating conditions. This is important, as it is not always readily evident from an examination of long term hourly measurements where sound sources come from.

Two sets of short term monitoring data were collected, one on March 18, and another on March 21-22. The monitoring program actually only called for one set each month, but since we were not able to collect quality short term data in February due to equipment shutdowns, we did additional monitoring in March to give us more on-site observations of noise sources. We believe that the on-site monitoring data collected over the entire cold weather monitoring campaign is sufficient to conclusively establish the sources of all significant sound recorded during the monitoring program.

Figure 2. Sound Monitoring Site Photos

Monitoring Location M1 Behind 45 Flagg Hill Road

Monitoring Location M2 Across From Greenwoods Turnpike

Monitoring Location M3 Near SW Property Line

The long term measurement program was conducted by Dr. Howard Quin from March 18, 2016 to March 27, 2016. The sound levels measured are typical of those expected during dry winter and early spring conditions. Insect noise was absent during the winter. Meters were deployed for more than a week at each location, giving nine days of usable data at two locations (M1 and M3) and seven at a third (location M2). (Note some L10 data were lost at location M1 due to meter malfunction). This helped make up for a slight deficiency in earlier monitoring programs in January and February.

Weather varied significantly during the measurement period. Weather data was obtained from station KCTNORFO2, Great Mountain Forest, about 4 miles west near Tobey Pond; wind data was obtained on site from the wind turbine SCADA system. High temperatures ranged from about 35 degrees to 68 degrees Fahrenheit, while lows ranged from about 20 degrees to about 42 degrees. Leaves were off trees, and there was little to no snow on the ground. This is therefore typical of late winter/early spring conditions in the study area. Peak operational wind conditions occurred on several days during the study, most noticeably on March 21 and March 25, where the wind was about 11-13 m/sec at hub height. Lower operational wind conditions occurred on most other days during the monitoring period; wind speeds at hub height varied from around 4 to 8 m/sec most days, typical of cut-in to average wind turbine speed.

4 Measurement Results

Figures 3, 4, and 5 represent graphs of the L90, L10 and Leq at sites M1, M2, and M3 for each one hour period. Wind speed is shown in blue, while sound level is in red. The established project limits are in green. The conservative nighttime is 51 dBA, while the 15 minute limit of 54 dBA which is 3 dBA above the Connecticut hourly limit is shown on the L10 graph. The graph shows that, typical L90s varied from approximately 29 to 45 dBA at Location M1, from 30 to 49 dBA at M2 which was dominated by traffic noise, and from 30 to 47 at M3, with high wind noise producing the peaks at both locations. Note that noise recorded includes all sound on site, not just the turbine noise, including noise from wind in trees, cars, trucks and planes. ***The data shows that the turbines were in compliance with the most stringent (nighttime) levels at all times during the study period even when including background noise caused by the wind, trees, cars, trucks and planes.***

In order to examine compliance with various metrics employed by DEEP, we have correlated the wind speed with SCADA data obtained from the wind turbine hub. For this analysis, we have used data from turbine T1, which is closest to the residences; similar data was obtained from turbine T2. The SCADA data is obtained in 10 minute windows, which makes for ready comparison with various metrics. We have plotted the L10 metric against the highest hourly 10 minute wind speed increment, the Leq metric against the average wind speed for each hour, and the L90 metric against the lowest hourly 10 minute wind speed, which is the exact interval used for Connecticut compliance evaluation. It should be noted that there is not an exact correlation here; the L10 and L90 are the highest and lowest 10% levels over an entire hour, whereas the 10 minute wind speed averages are only the highest and lowest separate 10 minute intervals. Nonetheless, they are closely correlated with the actual wind occurring during the highest and lowest 10 percent times at locations where wind noise and turbine noise predominate. Note that the L10 is also relevant, as it is above two other compliance metric levels, the 15 and 7 ½ minute levels; if the L10 is in compliance, those levels will be in compliance too.

An examination of the data indicates that there is some correlation between the hub wind speed and the sound levels at two of the locations, the meter near the residence on 45 Flagg Hill Road, and the meter near the pond to the southwest of the turbines. However, it should be noted that this is by no means a one-to-one correspondence. This is due to the fact that the wind direction varies somewhat, and turbines are most affected by sound from the upwind direction. This means that the peak sound levels from the turbine at 45 Flagg Hill Road are from winds from the west, while peak sound levels from the turbine at the pond area to the Southwest are from winds to the east and northeast. The directionality effects in March were similar to those discussed in January and February.

The short term March attended monitoring results clearly allow for various relevant sound sources to be identified at each location. At location M1, the sound is almost entirely from the turbines and wind in the trees. Turbine noise varied from about 37-38 dBA under low speed operations to about 43-44 dBA near production operating speed. Wind in the trees added a few to several decibels to the recorded levels at this location, ranging from 46 to 51 dBA, indicating that the tree wind noise is actually as loud or louder than the turbine noise under typical conditions. For comparison, some plane overflights were about 53-55 dBA, similar to what was recorded in January and February, *indicating that under high wind conditions both the wind noise background and plane overflights were louder than the turbines.*

At location M2, the short term sound data was dominated almost entirely by sound from the highway, except for very late at night. Under both sets of daytime monitoring conditions, the turbine was virtually inaudible at almost all times; it was almost completely drowned out by the cars and wind background. During late night conditions, the turbine was audible as the background, ranging from about 32-37 dBA depending on production. However, wind in the trees was of about equal sound intensity, giving a combined level of about 35-43 dBA. ***The turbine is therefore almost completely inaudible indoors under nighttime operating conditions in this area. The data and on-site observations both show that in this area, sound is dominated by either the road or tree noise; the turbines contribute relatively little to the overall sound environment in this area*.**

At location M3, the short term data sound levels were similar to M1, being dominated by the turbines or by wind in the trees. Sound from the turbines ranged from 36-46 dBA, depending on wind direction and turbine speed. Wind in trees was typically low, around 41-43, but some gusts blew it as high as 51 dBA. For comparison, some gunfire in the distance was about 43-46 dBA (slow response). This occurs frequently in this area, indicating that gunfire is typically louder than the turbines in this area. In conclusion, *at no time during the attended monitoring were sound levels from the turbines shown to be higher than 46 dBA at any location, and were usually significantly less.*

TABLE 2.

FIRST SHORT TERM MONITORING RESULTS

Location	Date	Time	Leq	L90	L50	L25	L10
M1	March 18	2:08 P.M.	44.3	36.8	41.9	43.8	45.5
M2	March 18	4:29 P.M.	64.0	48.7	58.9	65.2	68.2
M3	March 18	3:37 P.M.	47.3	43.0	45.9	47.3	49.2
M1	March 18	10:35 P.M.	43.5	41.4	43.3	44.4	44.7
M2	March 18	11:39 P.M.	57.6	37.5	43.6	53.1	62.0

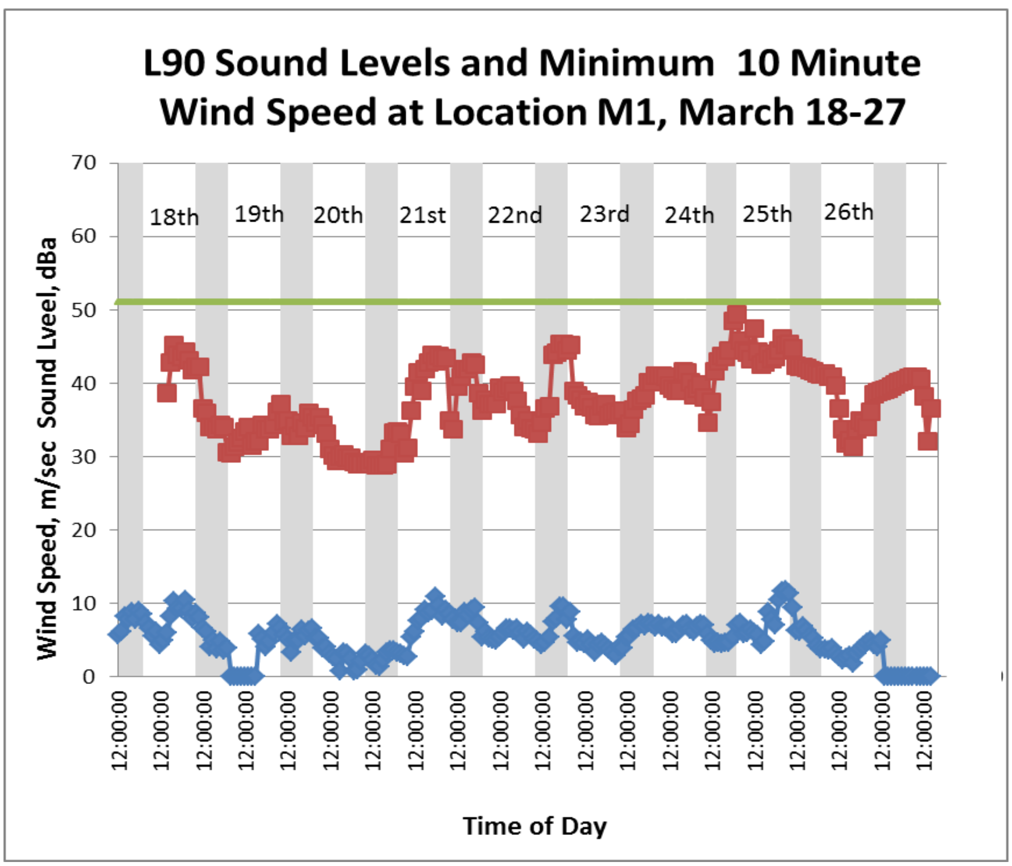
TABLE 3.

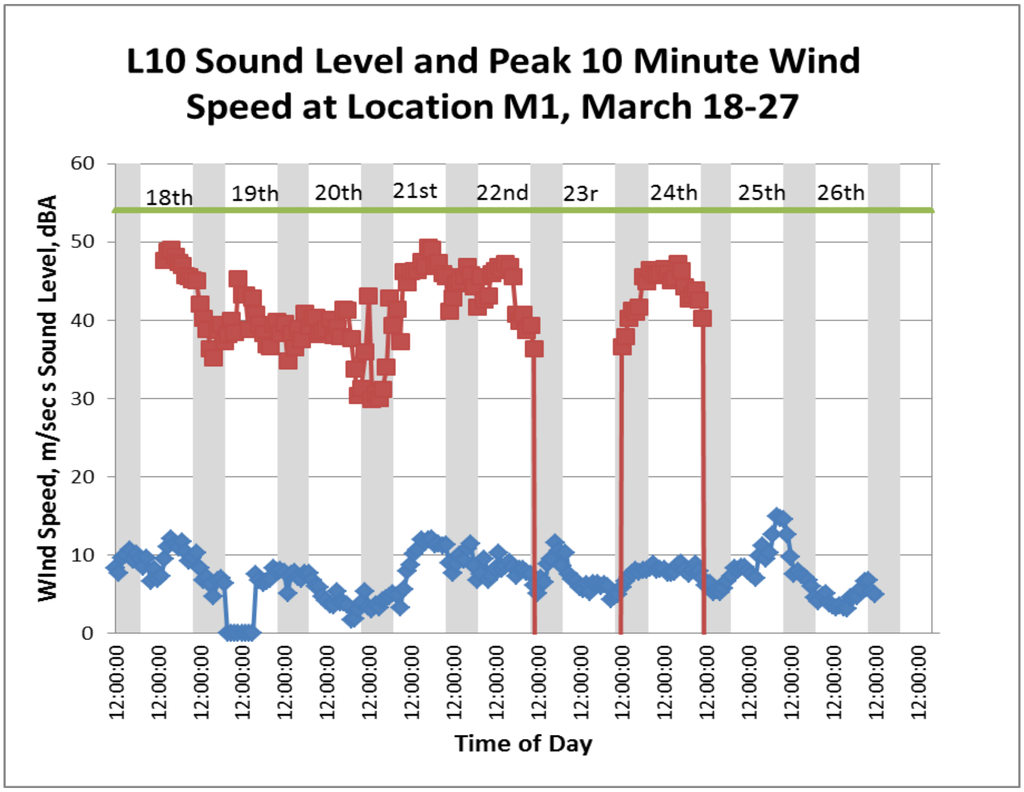
SECOND SHORT TERM MONITORING RESULTS

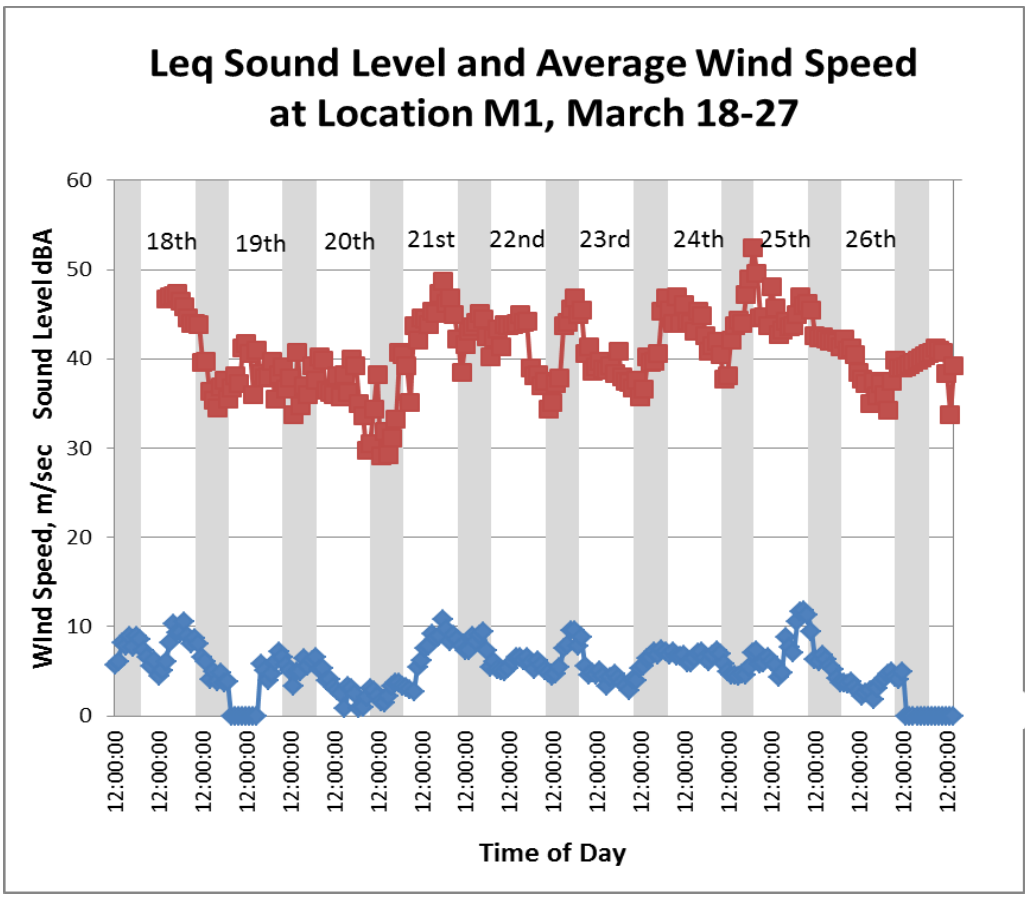
Location	Date	Time	Leq	L90	L50	L25	L10
M1	March 22	9:10 A.M.	43.6	37.2	40.4	42.7	45.7
M2	March 22	10:58 A.M.	62.2	41.0	52.4	61.0	66.1
M3	March 22	10:00 A.M	44.3	37.0	40.3	42.9	45.4
M1	March 21	9:30 P.M.	46.0	43.7	44.9	45.7	46.7
M2	March 22	12:00 A.M.	56.4	32.3	36.4	42.3	55.3

Note: Nighttime measurements were not made at location M3 due to access and safety issues. It is assumed that daytime levels there were similar to nighttime, as there is no change in background conditions from day to night

Figure 3.




L10 Sound Level and Peak 10 Minute Wind Speed at Location M1, March 18-27
WInd Speed, m/sec s Sound Level, dBA
Time of Day
18th
19th
20th
21st
22nd
23r
24th
25th
26th
0
10
20
30
40
50
60
12:00:00


Leq Sound Level and Average Wind Speed at Location M1, March 18-27
WInd Speed, m/sec Sound Level dBA
Time of Day
18th
19th
20th
21st
22nd
23rd
24th
25th
26th
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50
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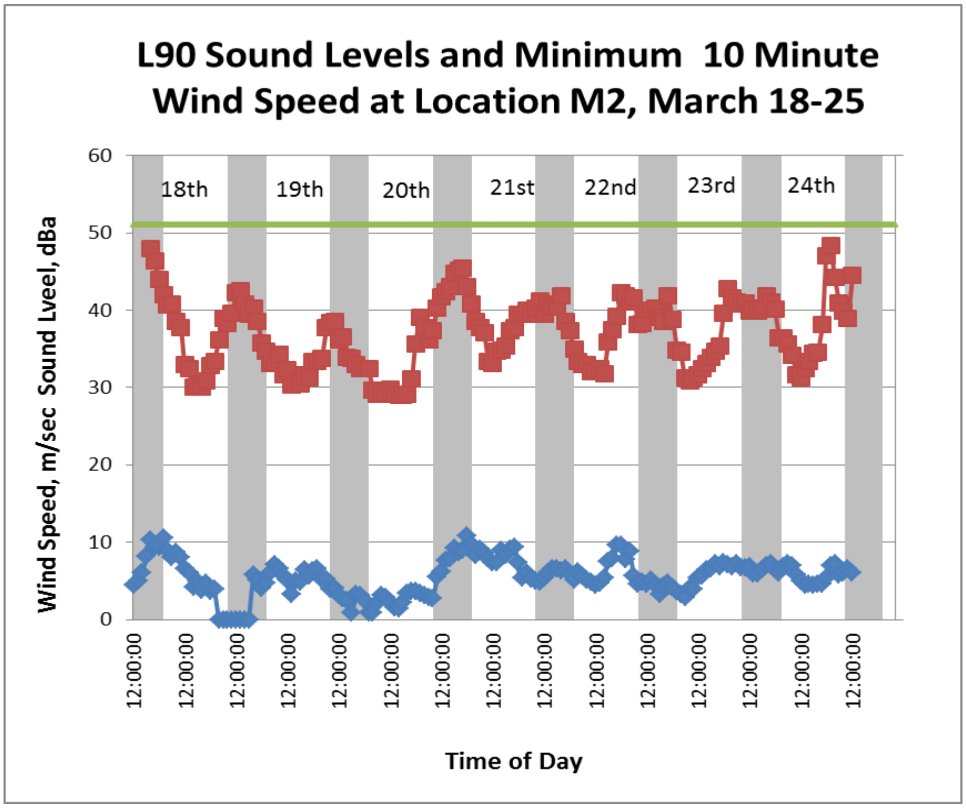
12:00:00

Figure 4.


L90 Sound Levels and Minimum 10 Minute Wind Speed at Location M2, March 18-25
Wind Speed, m/sec Sound Lveel, dBa
Time of Day
18th
19th
20th
21st
22nd
23rd
24th
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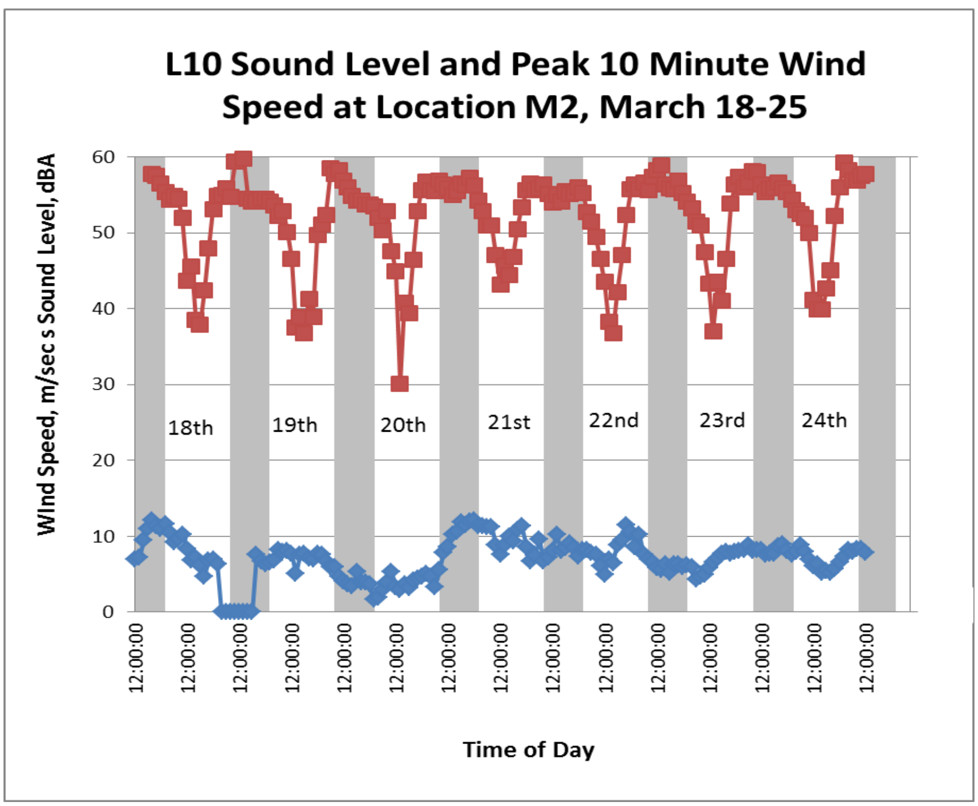
12:00:00


L10 Sound Level and Peak 10 Minute Wind Speed at Location M2, March 18-25
WInd Speed, m/sec s Sound Level, dBA
Time of Day
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19th
20th
21st
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23rd
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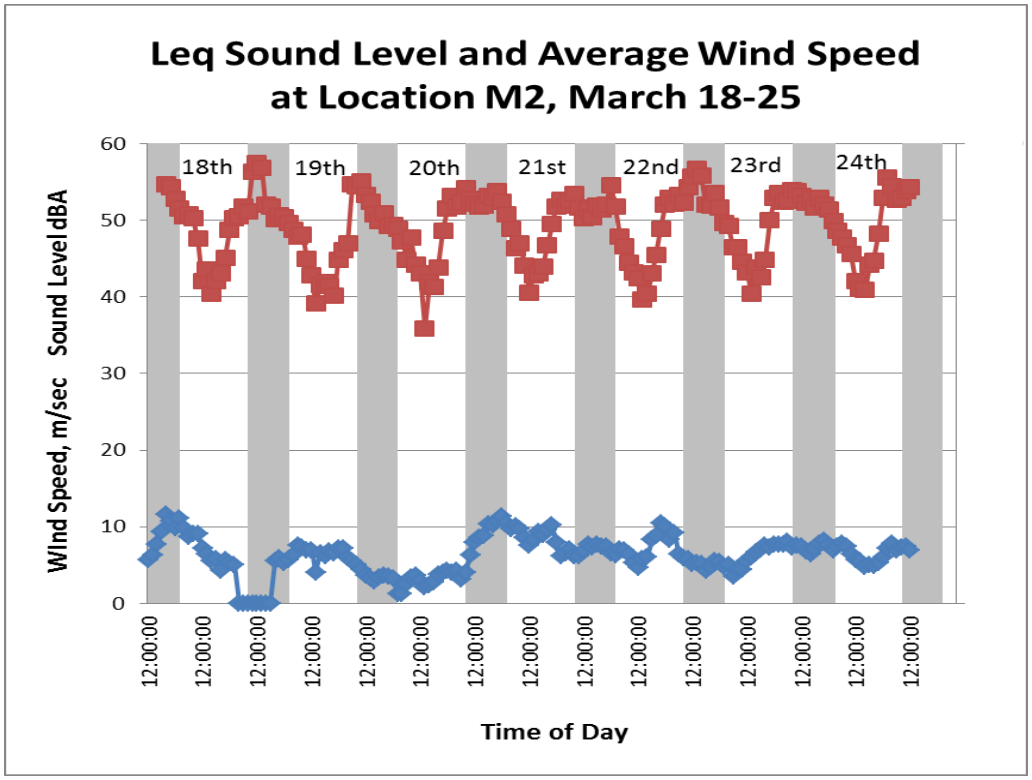
12:00:00


Leq Sound Level and Average Wind Speed at Location M2, March 18-25
Wind Speed, m/sec Sound Level dBA
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19th
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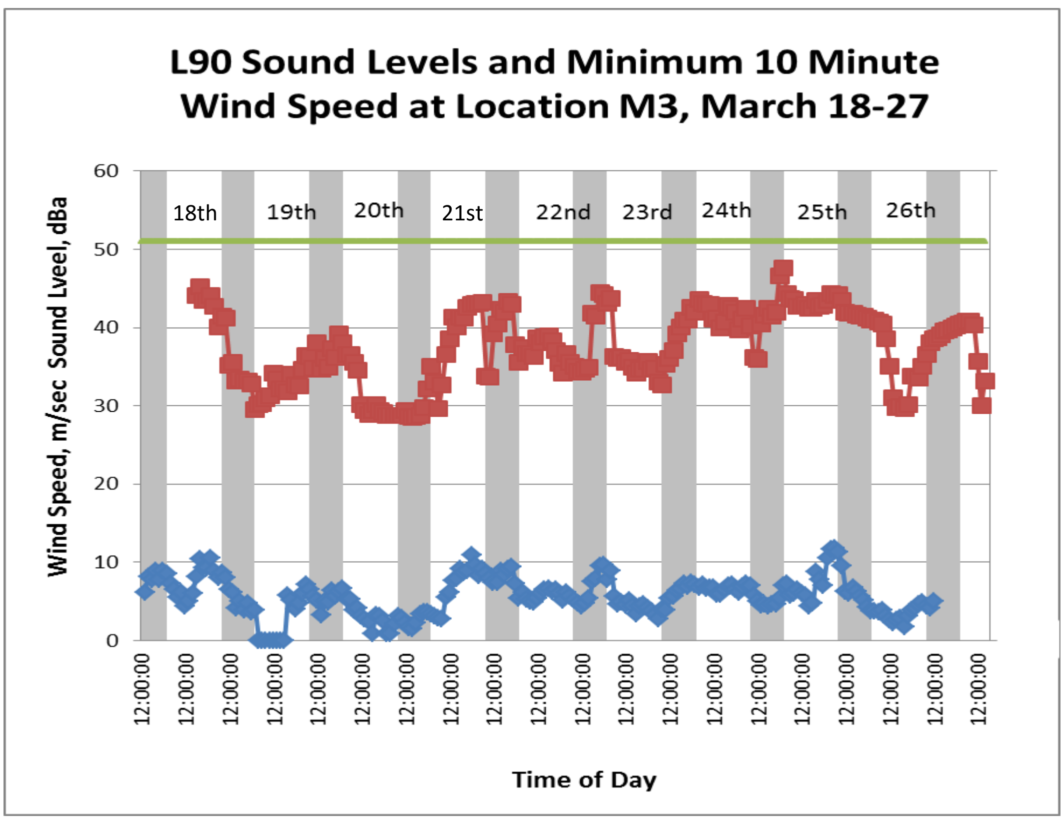
24th
12:00:00
Time of Day

Figure 5.


L90 Sound Levels and Minimum 10 Minute Wind Speed at Location M3, March 18-27
Wind Speed, m/sec Sound Lveel, dBa
0
10
20
30
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50
60
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22nd
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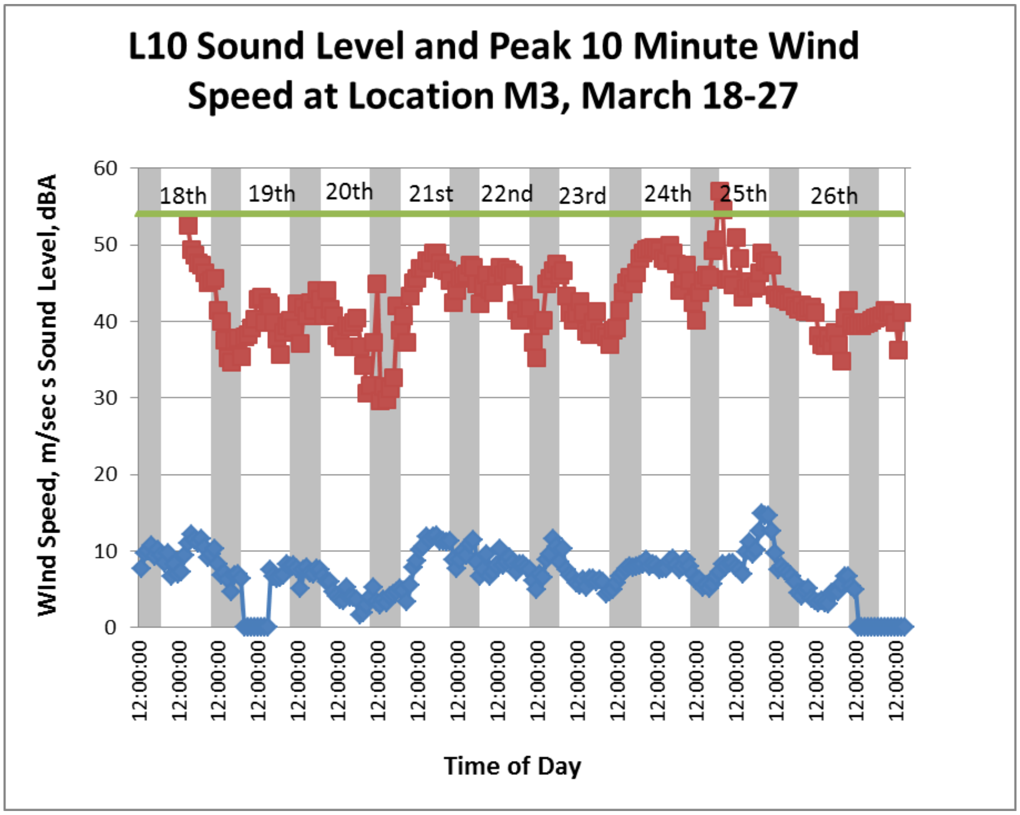
26th
12:00:00
Time of Day


L10 Sound Level and Peak 10 Minute Wind Speed at Location M3, March 18-27
WInd Speed, m/sec s Sound Level, dBA
60
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22nd
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24th
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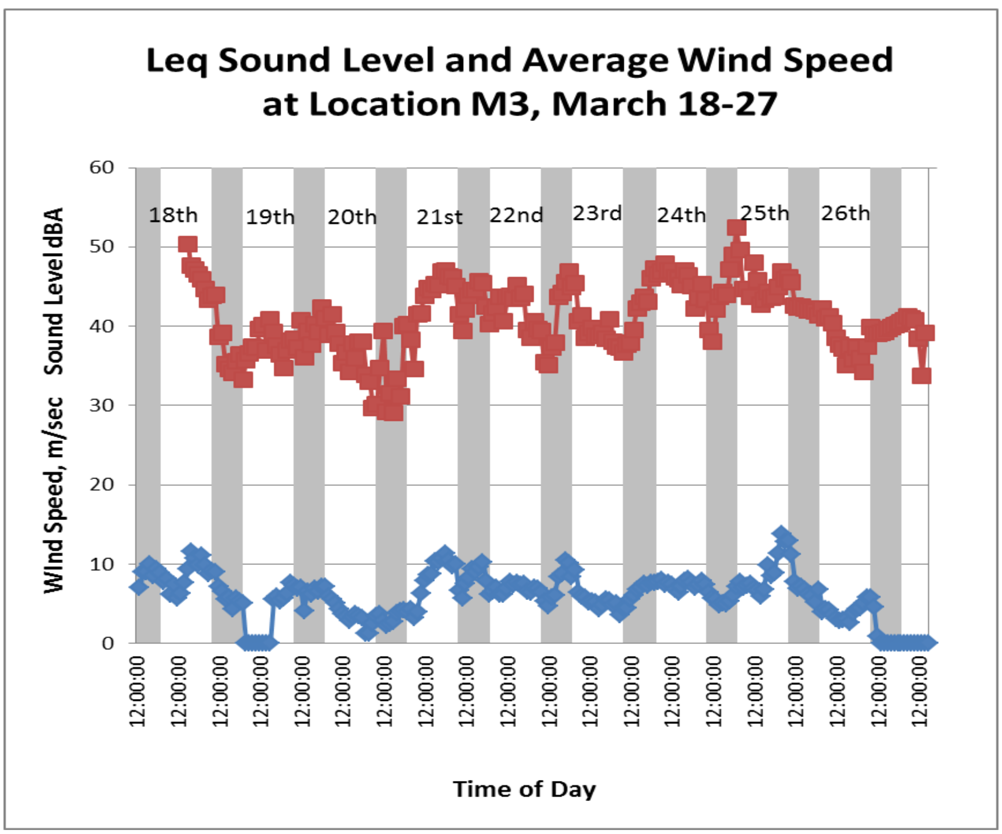
26th
12:00:00
Time of Day


Leq Sound Level and Average Wind Speed at Location M3, March 18-27
WInd Speed, m/sec Sound Level dBA
60
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40
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18th
19th
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21st
22nd
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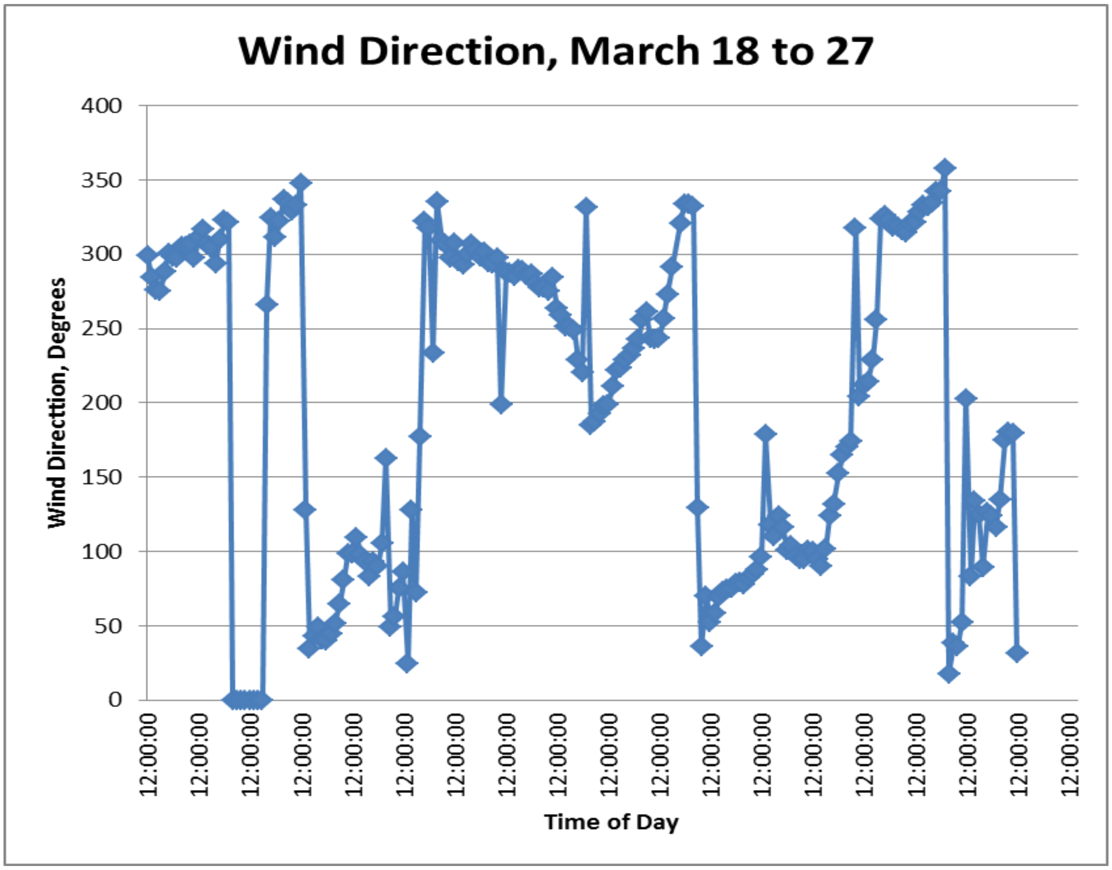
24th
25th
26th
12:00:00
Time of Day

Figure 6.


Wind Direction, March 18 to 27
Wind Directtion, Degrees
400
350
300
250
200
150
100
50
0
12:00:00
Time of Day

Appendix A: Description of Noise Metrics

This Appendix describes the noise metrics used in this report.

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.”

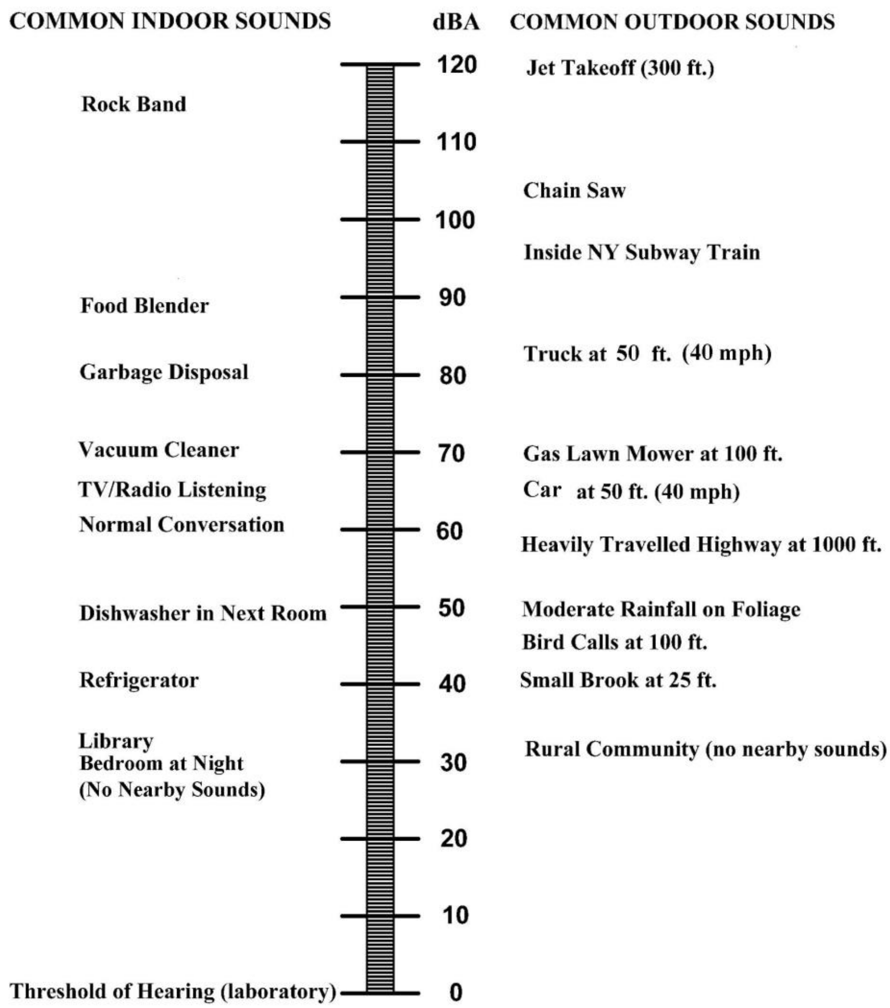
The human ear does not respond equally to identical noise levels at different frequencies. Although the normal frequency range of hearing for most people extends from a low of about 20 Hz to a high of 10,000 Hz to 20,000 Hz, people are most sensitive to sounds in the voice range, between about 500 Hz 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”, including C weighting, which is why C weighting is not usually used for wind turbine compliance analysis 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.

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.



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.