National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Wright Brothers National Memorial

Acoustical Monitoring 2011

Natural Resource Report NPS/NRSS/NRR—2014/879

ON THE COVER
Wright Brothers National Memorial sculpture garden, taken in 2013
Photograph courtesy NPS

Wright Brothers National Memorial

Acoustical Monitoring 2011

Natural Resource Report NPS/NRSS/NRR—2014/879

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13. ABSTRACT (Maximum 200 words) During the winter of 2011(September - November) baseline acoustical data were collected at Wright Brothers National Memorial (WRBR) at two sites deployed for approximately 30 days each. The baseline data collected during these periods will help park managers and planners estimate the effects of future noise impacts and will help to inform future park planning objectives such as creating acoustic resource management plans, as well as the development of an Air Tour Management Plan (ATMP), which provides for the regulation of commercial air tours. The sound sources of concern at WRBR include developments near park boundaries, air tours, commercial and private aircraft activities, and requests for special use permits for noisy activities. This document summarizes the results of the noise measurement study.				
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Table of Contents

Figures

Page

Tables

Executive Summary

During September to November of 2011, two acoustical monitoring systems were deployed in Wright Brothers National Memorial (WRBR). The purpose of this monitoring effort was to characterize existing sound levels, estimate natural ambient sound levels and identify audible sound sources in WRBR. This report provides a summary of results of these measurements, representing the soundscape of WRBR's winter season.

In determining the current conditions of an acoustical environment, the National Park Service (NPS) examines how often sound pressure levels exceed certain values that relate to human health and speech. The NPS uses these values for making comparisons; they should not be construed as thresholds of impact. Table 1 and Table 2 report the percent of time that measured levels were above four sound level values at each of the Wright Brothers measurement locations for the winter season in dBA and dBT. The first value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis, et. al., 2008). The second value is based on the World Health Organization's recommendation that noise levels inside bedrooms remain below 45 dBA (Berglund, et. al., 1999). The third value, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (Environmental Protection Agency, 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m (3 ft). Hikers and visitors in the park would likely be conducting such conversations.

Table 1. Percent Time Above Metrics (dBA).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
WRBR001	Croatan Hwy	100.0	99.2	66.6	2.4	100.0	65.2	24.5	0.7
WRBR002	Airstrip Hill	100.0	35.6	3.8	0.8	97.4	11.6	2.6	0.1

Table 2. Percent Time Above Metrics (truncated spectra – dBT).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
WRBR001	Croatan Hwy	100.0	97.6	54.7	1.3	99.6	58.5	17.5	0.3
WRBR002	Airstrip Hill	100.0	15.0	2.1	0.5	70.3	2.2	0.2	0.0

Table 3 and Table 4 summarize the daytime and nighttime acoustical observer log data (off-site listening and *in situ* logging combined) and provide an indication of the amount of time that certain sources are audible at each site. The *in situ* logging is performed during visits to the site itself; off-site listening is performed in an office environment using the audio files collected at each site.

Table 3. Summary of daytime acoustical observer log data (*in situ* and off-site listening combined).

Site ID	Site Name	% Time Audible: Daytime (7 am to 7 pm)			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
WRBR001	Croatan Hwy	5.9	1.2	90.5	2.4
WRBR002	Airstrip Hill	8.7	1.3	77.1	12.9

Table 4. Summary of nighttime acoustical observer log data (off-site listening).

Site ID	Site Name	% Time Audible: Nighttime (7 pm to 7 am)			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
WRBR001	Croatan Hwy	0.3	0.9	86.0	12.8
WRBR002	Airstrip Hill	0.8	0.8	69.2	29.2

Acknowledgments

The authors of this report wish to express their sincere gratitude to the National Park Service (NPS), Natural Sounds and Night Skies Division (NSNSD), for their coordination and support for this study.

List of Terms

Acoustical Environment
The actual physical sound resources, regardless of audibility, at a particular location.

Amplitude
The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

Audibility
The ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, the masking effects of other sound sources, and by the frequency content and amplitude of the sound.

dBA
A-weighted decibel. A-Weighted sum of sound energy across the range of human hearing. Humans do not hear well at very low or very high frequencies. Weighting adjusts for this.

dBT
Truncated decibel. A measure of sound energy in the range of frequencies where transportation noise is most often focused (20 - 1250 Hz). Transportation is often a major contributor of low frequency sound, but this range does not correspond to a specific vehicle or type of transportation.

Decibel
A logarithmic measure of acoustic or electrical signals. The formula for computing decibels is: $20*(\text{Log}_{10}(\text{sound level/reference sound level}))$. 0 dB represents the lowest sound level that can be perceived by a human with healthy hearing. Conversational speech is about 65 dB.

Frequency
The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound/ Wavelength.

Hearing Range (frequency)
By convention, an average, healthy, young person is said to hear frequencies from approximately 20 Hz to 20000 Hz.

Hertz

A measure of frequency, or the number of pressure variations per second. A person with normal hearing can hear between 20 Hz and 20,000 Hz.

Human-Caused Sound
Any sound that is attributable to a human source.

L_{eq}
Energy Equivalent Sound Level. The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.

L_x
A metric used to describe acoustical data. It represents the level of sound exceeded x percent of the time during the given measurement period.

Masking
The process by which the threshold of audibility for a sound is raised by the presence of another sound.

Noise-Free Interval
The period of time between noise events (not silence).

Noise
Sound which is unwanted, either because of its effects on humans, its effect on fatigue or malfunction of physical equipment, or its interference with the perception or detection of other sounds (Source: McGraw Hill Dictionary of Scientific and Technical Terms).

Off-site Listening
The systematic identification of sound sources using digital recordings previously collected in the field.

1. Introduction

An important part of the National Park Service (NPS) mission is to preserve and/or restore the natural resources of the parks, including the natural soundscapes associated with units of the National Park system. The collection of ambient sound level data provides valuable information about a park's acoustical conditions for use in developing acoustic resource management plans.

Ambient sound level data are also required to establish a baseline from which noise impacts can be assessed. The National Parks Air Tour Management Act of 2000 provides for the regulation of commercial air tour operations over units of the national park system through air tour management plans (ATMPs). The objective of the ATMPs is to develop acceptable and effective measures to mitigate or prevent significant adverse impacts, if any, of commercial air tour operations upon the natural and cultural resources of and visitor experiences in national park units as well as tribal lands (those included in or abutting a national park).[1]

Ambient data were collected by NPS, Natural Sounds and Night Skies Division (NSNSD) personnel in Wright Brothers National Memorial (WRBR) during September to November 2011. A map of the area managed by WRBR is shown in Figure 1. The purpose of this report is to provide a summary of the results of these measurements that will be used to represent WRBR's winter season.

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the NPS, NSNSD and Federal Aviation Administration (FAA), Western-Pacific Region (AWP) in the analysis of ambient sound level data.

[1] WRBR is currently exempt from ATMP development.

Figure 1. Map of WRBR (National Park Service 2014).

2. Study Area

Two acoustical monitoring systems were deployed during September to November 2011 to represent WRBR's winter season. These sites were selected based on discussions between NSNSD and WRBR personnel and are shown in Table 4.

Table 5. Measurement site locations in Wright Brothers.

Site ID	Site Name	# Days of Data	NLCD[2] Classification	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
WRBR001	Croatan Hwy	75 days	Scrub/Shrub	36.01748° / 75.66532°	3 m (9 ft)
WRBR002	Airstrip Hill	46 days	Barren Land	36.01662° / 75.67418°	14 m (45 ft)

[2] With the goal of potentially facilitating future data transferability between parks, all baseline acoustical data collected have been organized/classified in accordance with the National Land Cover Database (NLCD). Developed by the U.S. Geological Survey (USGS), the NLCD is the only nationally consistent land cover data set in existence and is comprised of twenty-one NLCD subclass categories for the entire U.S. (Homer, et. al., 2004).

3. Methods

3.1 Automatic Monitoring

Larson Davis 831 sound level meters (SLM) were employed for continuous acoustical monitoring over the monitoring period at Wright Brothers. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and one-third octave-band data, and exports these data to a portable storage device (thumb drive). These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards (American National Standards Institute 1990).

In addition to the Larson Davis SLM, each acoustical sampling station consisted of:

- Microphone with environmental shroud
- Preamplifier
- Multiple 12V NiMH rechargeable battery packs
- Anemometer
- MP3 recorder
- Meteorological data logger
- Photo voltaic panels

Each acoustical sampling station collected:

- Sound level data in the form of A-weighted decibel readings (dBA) every second
- Continuous digital audio recordings
- One-third octave-band data every second ranging from 12.5 Hz – 20,000 Hz
- Meteorological data

3.2 Source Identification/Observer Logging

In characterizing natural and non-natural acoustical conditions in a park, knowledge of the intensity, duration, and distribution of the sound sources is essential. Thus, during sound-level data collection, FAA and NPS have agreed that periods of observer logging "*in situ*" (i.e., on site and in real-time) and/or off-site using high-quality digital recordings will be conducted in order to discern the type, timing, and duration of different sound sources. *In situ* observer logging takes full advantage of human binaural hearing capabilities, allows identification of sound source origin, simultaneous sound sources, and directionality, and closely matches the experience of park visitors. Off-site audio playback observer logging allows for sampling periodically throughout the entire measurement period (e.g., 10 seconds every 2 minutes) and repeated playback of the recordings (e.g., when the sound is difficult to identify). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment.

3.3 Calculation of Sound Level Descriptors

All sound-level data were analyzed in terms of the following metrics (also refer to the List of Terms section for definitions):

- L_{Aeq}: The equivalent sound level determined by the logarithmic average of sound levels of a specific time period;
- L_{50}: A statistical descriptor describing the sound level exceeded 50 percent of a specific time period (i.e., the median); and
- L_{90}: A statistical descriptor describing the sound level exceeded 90 percent of a specific time period.

For each descriptor, both the broadband A-weighted sound level is determined along with its associated one-third octave band un-weighted spectrum from 12.5 to 20,000 Hz. The process of computing the un-weighted one-third octave-band spectrum is virtually identical to the process for computing the broadband A-weighted sound level descriptors. The only difference is that the sound-level value is computed for un-weighted frequency-based sound levels rather than for broadband A-weighted sound levels. Specifically, the un-weighted sound level is computed individually for each one-third octave-band. The 33 un-weighted one-third octave-band sound levels (12.5 to 20,000 Hz) define the un-weighted sound level spectrum. This method of constructing the sound level spectrum means it is not an actual measured one-third octave band spectrum associated with a particular measurement sample, but a composite spectrum using the computed descriptor for each one-third octave-band.

3.4 Definitions of ambient

The following four types of "ambient" characterizations are generally used and considered sufficient by the FAA and NPS in environmental analyses related to transportation noise (Fleming, et. al., 1999), (Fleming, et. al., 1998) (Plotkin, 2002).

- *Existing Ambient:* The composite, all-inclusive sound associated with a given environment, excluding only the analysis system's electrical noise (i.e., aircraft-related sounds are included);
- *Existing Ambient Without Source of Interest:* The composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical noise and the sound source of interest, in this case, commercial air tour aircraft (fixed-wing aircraft and helicopters);
- *Existing Ambient Without All Aircraft (for use in assessing cumulative impacts):* The composite, all-inclusive sound associated with a given environment, excluding the analysis system's electrical noise and the sounds produced by the sound source of interest, in this case, all types of

aircraft (i.e., commercial air tours, commercial jets, general aviation aircraft, military aircraft, and agricultural operations);[3] and

- *Natural Ambient:* The natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excluding all human and mechanical sounds.

If one considers the three sound level descriptors and the four types of ambient characterizations above, twelve ambient descriptors could potentially be computed as shown in Table 5.

Table 6. Matrix of twelve potential ambient descriptors.

Metric	Ambient Type			
	Existing	Existing Without Air Tours	Existing Without All Aircraft	Natural
L_{Aeq}	1	4	7	10
L_{50}	2	5	8	11
L_{90}	3	6	9	12

From the above twelve potential ambient descriptors, only the first three can be readily computed. The computation of ambient types other than Existing Ambient is more challenging because different sound sources often overlap in both frequency and amplitude; there is currently no practical method to separate out acoustic energy of different sound sources (i.e., human-caused sounds imbedded with natural sounds). The two ambient descriptors agreed upon for use in ATMP analyses are:

- Existing Ambient Without Source of Interest – Descriptor 5 from the table above; and
- Natural Ambient (L_{Nat}) – Descriptor 11 from the table above.

3.5 Calculation of Ambients

Using the data in the acoustical observer logs, different characterizations of ambient can be *estimated* from the sound level data. This method was developed through detailed data analyses conducted by the Volpe Center, working closely with the NPS, comparing several approaches of estimating of the Natural Ambient and is comprised of the following steps: (Rapoza et. al., 2008)

1) From the short-term *in situ* and off-site logging, determine the percent time human-caused sounds are audible.
2) Sort, high-to-low, the A-weighted level data, derived from the short term, one-second, one-third octave-band data (regardless of acoustical state), and remove the loudest percentage (determined from the percent time audible of human-caused sounds in the short-term observer logs) of sound-level data. For example, if from Step 1 above, it is determined that at a particular site, the percent time audible of all human-caused sounds is 40 percent, then the loudest 40 percent of the A-

[3] The definition of Existing Ambient Without All Aircraft used in this report is consistent with FAA's historical approach for cumulative impact analysis.

weighted level data is removed. The L_{50} computed from the remaining data is the estimated A-weighted natural ambient. This L_{50}, computed from the remaining data, can be mathematically expressed as an L_x of the entire dataset as follows (%TA is the percent of time human-caused sounds are audible in the short-term observer logs):

$$L_x, \text{ where } x = 50 + \frac{\%TA}{2}$$

For example, if non-natural sounds are audible for 40% of the time, L_0 to L_{40} corresponds to the loudest (generally non-natural) sounds, and L_{40} to L_{100} corresponds to the quietest (generally natural) sounds. The median of L_{40} to L_{100} data is L_{70}. Therefore, the A-weighted decibel value at L_{70}, the sound level exceeded 70 percent of the time, would be used for the entire dataset to characterize the natural ambient sound level.

3) The associated one-third octave-band un-weighted spectrum from 12.5 to 20,000 Hz is constructed similarly, except the L_{50} is computed from the remaining data for each one-third octave-band. It is not an actual measured one-third octave-band spectrum associated with a particular measurement sample, but rather a composite spectrum derived from the L_x for each one-third octave-band.

This method for estimating the natural ambient is conceptually straightforward – as percent time audible approaches 0 percent, the L_x approaches L_{50}; as it approaches 100 percent, the L_x approaches L_{100}. A concern with this approach is that sporadic, loud natural sounds, such as thunder, could be removed from the data before calculating natural ambient sound levels, and the resulting calculated natural ambient sound levels could be an under-estimate of natural ambient sound levels. Although this is a valid concern, such events are rare relative to the entire measurement period (>25 days). Therefore, removing these data should not likely have a significant impact on calculations of natural ambient sound levels. This method also eliminates the possibility of having an estimated natural ambient level that exceeds the existing ambient level.

Based on the concept of the above method, the computation of the other ambient types (Existing Ambient Without Fixed-Wing Aircraft and Helicopters, and Existing Ambient Without All Aircraft) is a similar process.

4. Results

This section summarizes the results of the study. Included are an overall summary of the final ambient sound levels for each measurement site, time above analysis, temporal trends, and the acoustical observer data logged at each measurement site.

4.1 Summary Results

The following figures and tables are presented to show overall site-to-site comparisons:

- Figure 2 presents a plot of the overall daytime[4] L_{50} sound level computed for each site (a few points of interest outside the parks are also shown for comparison purposes only). The figure also shows a dark line above and below each plotting symbol, which indicates the 95% confidence interval on the results[5];
- Table 6 presents a tabular summary of the daytime and nighttime and computed ambients; and
- Table 7, Figure 3, and Figure 4 present the associated spectral data for these ambient maps.

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[4] FAA and NPS have agreed that impact assessment will be conducted using ambient sound levels during the time that the air tour operations occur – typically daytime hours. Daytime (as used in this report) will refer to the time period 7 am to 7 pm; nighttime will refer to the time period 7:00 pm to 7:00 am.

[5] The confidence interval is a measure of how certain one is of the value shown. The length of each of the dark lines indicate the day-to-day variability of the measurement for a particular site - the longer the line, the larger the day-to-day variability.

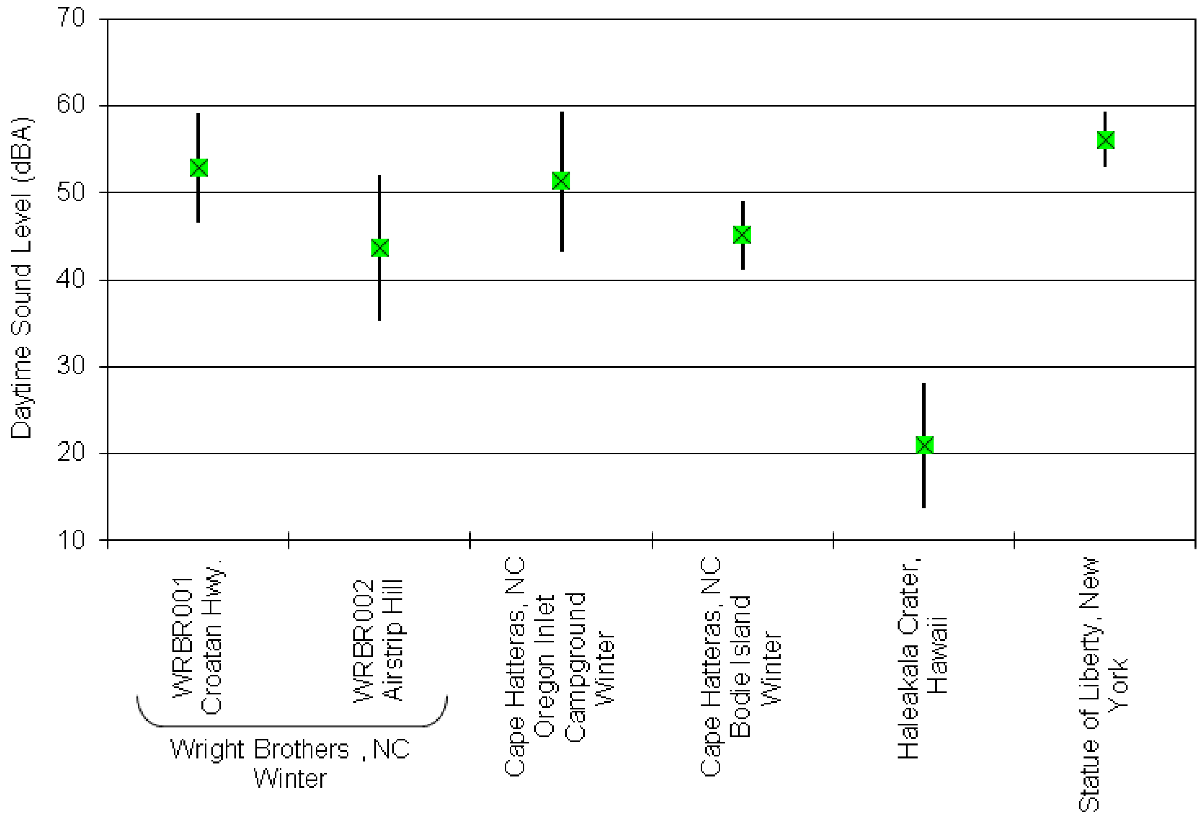

Figure 2. Comparison of overall daytime L_{50} sound levels.

Table 7. Summary of measured ambient sound level data. [6]

Site ID	Site Name	Total # Days	Existing Ambient						Existing Ambient Without Fixed-Wing Aircraft and Helicopters (Daytime Data 7 am to 7 pm)	Existing Ambient Without All Aircraft (Daytime Data 7 am to 7 pm)	Natural Ambient (Daytime Data 7 am to 7 pm)
			Daytime Data Only: 7 am to 7 pm			Nighttime Data Only: 7 pm to 7 am					
			L_{Aeq} (dBA)	L_{50} (dBA)	L_{90} (dBA)	L_{Aeq} (dBA)	L_{50} (dBA)	L_{90} (dBA)	L_{50} (dBA)	L_{50} (dBA)	L_{50} (dBA)
WRBR001	Croatan Hwy	75	55.5	53.3	49.2	51.6	47.6	38.7	53.1	53.0	49.2
WRBR002	Airstrip Hill	46	49.8	43.5	41.4	52.6	40.7	35.2	43.3	43.2	41.4

[6] As stated earlier, two ambient maps were agreed upon for use in ATMP analyses: the Existing Ambient Without Air Tours (L_{50}) and the Natural Ambient (L_{50}).

Table 8. Summary of measured, daytime (7 am to 7 pm), ambient sound level spectral data. [7]

Frequency (Hz)	Existing Ambient Without Fixed-Wing Aircraft and Helicopters L_{50} (dB)		Natural Ambient L_{50} (dB)	
	WRBR001	WRBR002	WRBR001	WRBR002
12.5	49.9	54.2	45.2	46.0
16	50.3	52.4	46.4	45.9
20	50.5	50.7	47.0	45.3
25	51.2	49.5	48.0	45.6
31	52.5	49.8	49.7	45.8
40	52.7	48.3	49.7	44.9
50	53.2	47.5	50.1	43.9
63	53.9	47.6	50.1	44.0
80	52.3	47.1	48.0	43.5
100	50.0	45.8	45.5	42.4
125	46.1	44.0	42.1	40.8
160	41.5	40.2	37.7	37.2
200	39.2	36.8	35.8	34.1
250	38.6	33.7	35.3	31.3
315	38.7	32.0	35.4	29.4
400	40.0	32.5	36.6	30.2
500	41.8	33.9	38.3	31.6
630	44.4	35.3	40.1	32.9
800	46.6	35.7	42.1	33.3
1000	46.1	34.5	42.0	32.2
1250	44.1	32.1	39.9	29.9
1600	40.8	29.0	36.6	26.9
2000	36.4	24.7	32.3	22.5
2500	31.5	20.1	27.5	18.0
3150	26.5	17.0	22.8	14.6
4000	22.3	19.7	18.3	14.7
5000	18.2	16.7	14.5	12.8
6300	15.3	12.9	11.5	9.5
8000	12.5	12.0	9.3	8.7
10000	10.9	10.5	8.6	7.7
12500	10.2	9.1	8.3	6.6
16000	9.2	6.2	7.2	3.9
20000	6.0	3.6	4.2	1.4

[7] As discussed in Section 3.5, the spectral data associated with the L_{50} exceedance level is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

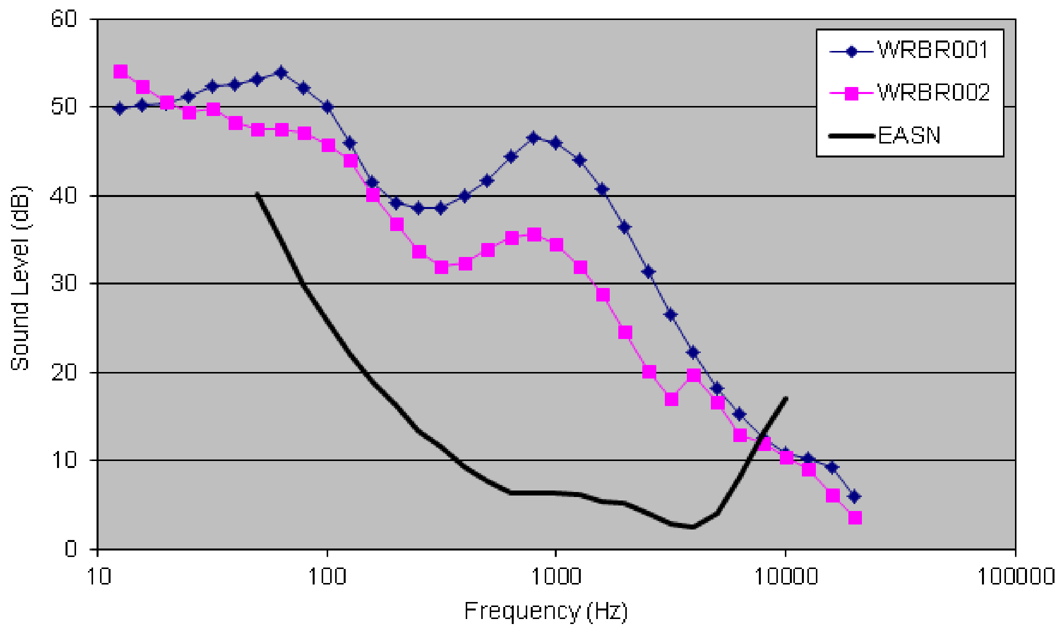

Figure 3. Spectral data for the Existing Ambient Without Fixed-Wing Aircraft and Helicopters (L_{50}) for each site. [8]

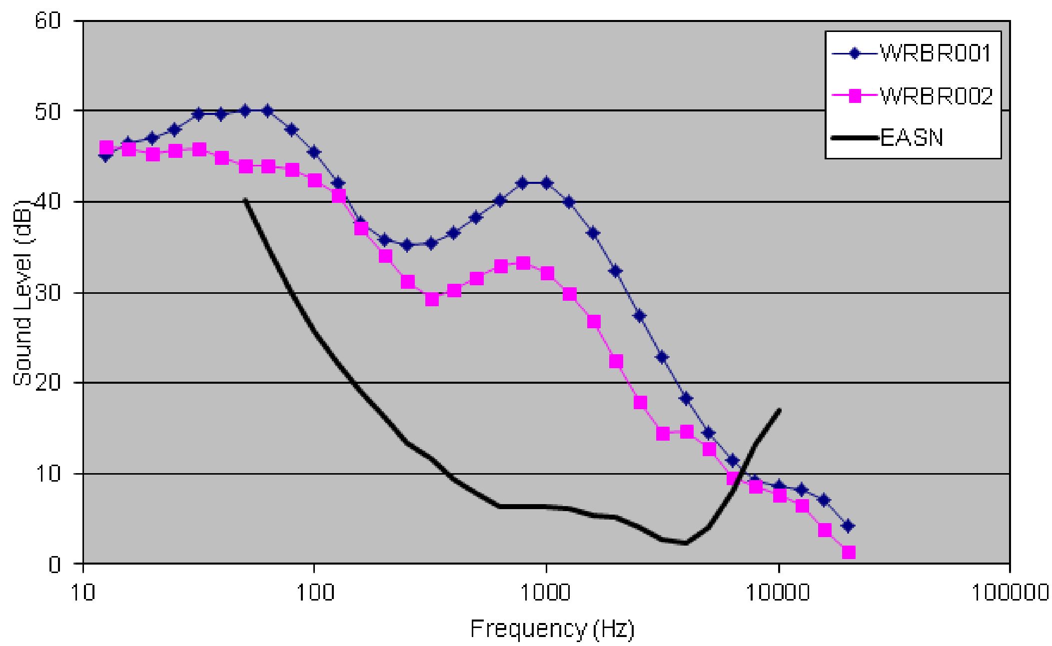

Figure 4. Spectral data for the Natural Ambient (L_{50}) for each site.[8]

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[8] Also shown in each figure is the Equivalent Auditory System Noise (EASN), which represents the threshold of human hearing for use in modeling audibility using one-third octave-band data.

4.2 Time Above Results

The Time Above metric indicates the amount of time that the sound level exceeds specified decibel values. In determining the current conditions of an acoustical environment, the NPS examines how often sound pressure levels exceed certain decibel values that relate to human health and speech. The NPS uses these values for making comparisons, but they should not be construed as thresholds of impact. Table 8 and Table 9 report the percent of time that measured levels were above four sound level values at each of the Wright Brothers measurement locations in dBA and dBT. The first value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis, et. al., 2008). The second value addresses the World Health Organization's recommendation that noise levels inside bedrooms remain below 45 dBA (Berglund, et. al., 1999). The third value, 52 dBA, is based on the Environmental Protection Agency's speech interference threshold for speaking in a raised voice to an audience at 10 meters (Environmental Protection Agency, 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dBA, provides a basis for estimating impacts on normal voice communications at 1 m (3 ft). Hikers and visitors viewing scenic vistas in the park would likely be conducting such conversations.

Table 9. Percent Time Above Metrics (dBA).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
WRBR001	Croatan Hwy	100.0	99.2	66.6	2.4	100.0	65.2	24.5	0.7
WRBR002	Airstrip Hill	100.0	35.6	3.8	0.8	97.4	11.6	2.6	0.1

Table 10. Percent Time Above Metrics (truncated spectra – dBT).

Site ID	Site Name	% Time above sound level: Daytime (7 am to 7 pm)				% Time above sound level: Nighttime (7 pm to 7 am)			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
WRBR001	Croatan Hwy	100.0	97.6	54.7	1.3	99.6	58.5	17.5	0.3
WRBR002	Airstrip Hill	100.0	15.0	2.1	0.5	70.3	2.2	0.2	0.0

4.3 Temporal Trends

This section discusses the daily and diurnal trends of the data. Daily trends are shown on a 24-hour basis. Figure 5 presents the daily median Existing Ambient (i.e., the L_{50} with all sounds included) for the winter season. For the purpose of assessing daily trends in the data, sound level descriptors are computed for each individual hour; then the median from the 24 hours each day is determined. Dips and increases in daily sound levels are usually an indication of passing inclement weather and localized events. This data is useful in visually identifying potential anomalies in the data. Data anomalies are further examined from data recorded by the sound level meter and/or recorded audio samples.

Diurnal trends are shown in Figure 6 on an hourly basis. Sites with a strong daytime diurnal pattern typically indicate the presence of human activity largely influencing the sound levels at those sites. Sites with a nighttime pattern typically indicate the presence of insect activity. Sites with little discernible pattern, e.g., somewhat constant across all hours, typically indicates a constant sound source. Examples of constant sound sources include nearby brook or river. This data is also useful in visually identifying potential anomalies in the data.

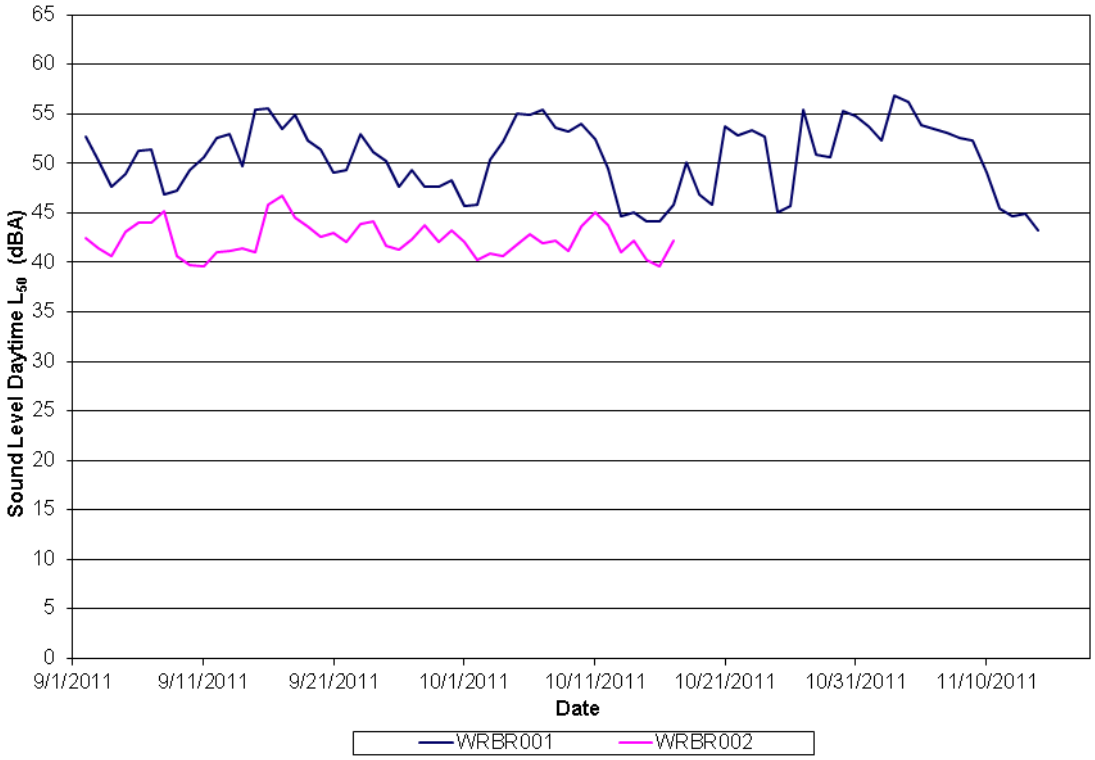

Figure 5. Comparison of daily L_{50} sound levels.

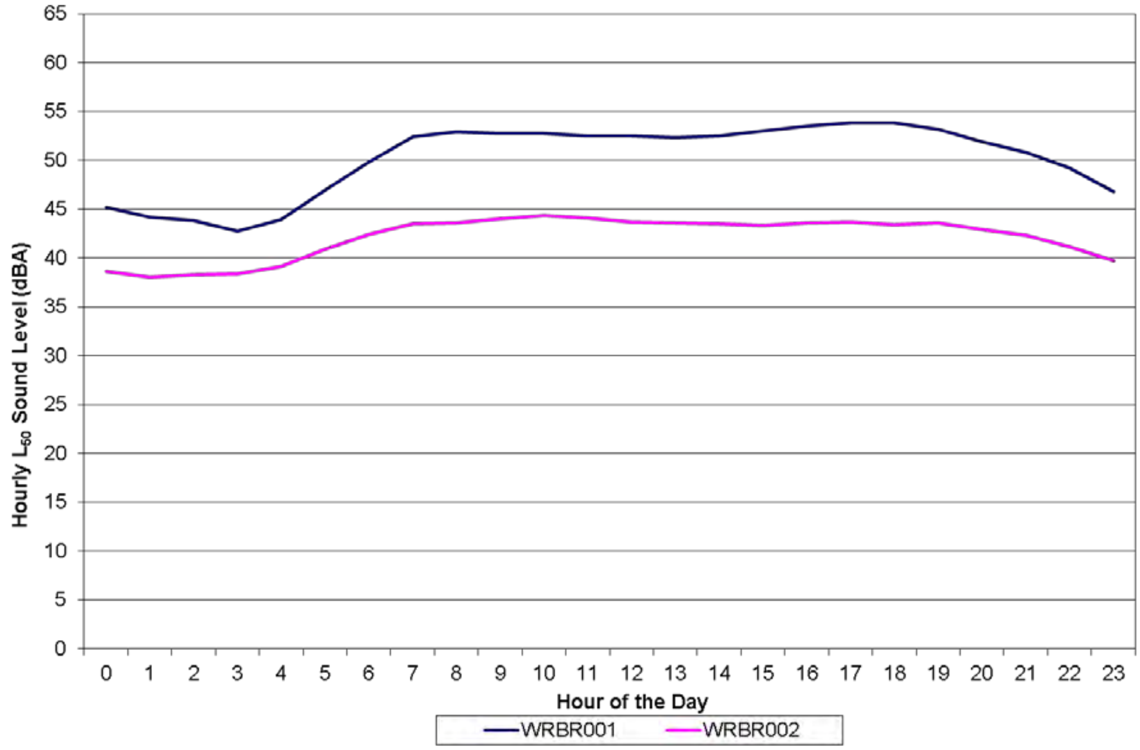

Figure 6. Comparison of hourly L_{50} sound levels.

4.4 Acoustical Observer Log Results

Table 10 and Table 11 summarize the day- and nighttime off-site listening and *in situ* logging results and provide an indication of the amount of time that certain sources are audible at each site. The *in situ* logging occurs at the site itself and consists of an observer that logs the time and duration of sounds that they hear at the site. Typically a limited amount of *in situ* logging is available due to logistics of the measurement and the days that the acoustic team is in the area. The off-site listening results are from a review of the audio files that were collected at each site. Continuous audio files were collected for the entire measurement and this allows a greater ability to listen and log sound sources for several days and any time period. These tables summarize the combined listening results for the winter measurements; these are the results determined from a review of the audio files and the *in-situ* sound source logs that were collected live at the site.

Table 11. Summary of daytime acoustical observer log data (*in situ* and off-site listening combined) for all sites.

Site ID	Site Name	% Time Audible			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
WRBR001	Croatan Hwy	5.9	1.2	90.5	2.4
WRBR002	Airstrip Hill	8.7	1.3	77.1	12.9

Table 12. Summary of nighttime acoustical observer log data (off-site listening) for all sites.

Site ID	Site Name	% Time Audible			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
WRBR001	Croatan Hwy	0.3	0.9	86.0	12.8
WRBR002	Airstrip Hill	0.8	0.8	69.2	29.2

5. Ambient Mapping

Using the ambient data measured at each site, a comprehensive grid of ambient sound levels throughout the park (i.e., an ambient "map") is developed. Ambient maps are useful to: (1) graphically characterize the ambient environment throughout an entire study area; and (2) to establish baseline, or background values in computer modeling.

The development of ambient maps is accomplished using Geographic Information System (GIS). In GIS, the following actions are performed:

- Define the input "objects":
  - Define the park boundary in Universal Transverse Mercator (UTM)[9] coordinates to set the initial grid area boundary.[10]
  - Divide the park into a regular grid of points at a desired spacing using a Digital Elevation Model (DEM), which is a digital representation of a topographic surface typically used in GIS applications. Each point is assigned an elevation value and UTM coordinates from the DEM. Note: For Wright Brothers, a grid spacing of 100 ft (30.5 m) was used.
  - Define the acoustical zone boundaries in UTM coordinates.
  - Define the location of each measurement site.
- Assign a "measured" ambient sound level (and its associated one-third octave-band, un-weighted spectrum), computed in Section 3.5, to each grid point within an acoustical zone.

For development of all ambient maps, except for Natural Ambient, three additional steps are performed:

- Define the location of localized noise sources, primarily vehicles on roads, but may also include brooks, waterfalls, and river rapids. The closest distance to each source is calculated and assigned to each grid point.
- Assign an ambient sound level (and its associated one-third octave-band, un-weighted spectrum) for each roadway to each grid point using the drop-off rates determined by computer modeling discussed in Section 5.2.
- Compute a combined measured and roadway ambient (and spectra). This is performed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition.

The resultant ambient maps are presented in Section 5.3.

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[9] The UTM system provides coordinates on a worldwide flat grid for easy manipulation in GIS applications.
[10] Because the ATMP Act applies to all commercial air tour operations within the ½-mile outside the boundary of a national park, the park boundary included a ½-mile buffer.

5.1 Define Acoustical Zones and Assign of Ambient Data

Because it is neither economically nor expeditiously feasible to manually collect noise data under all possible conditions throughout an entire park, areas of like vegetation, topography, elevation, and climate were grouped into “acoustical zones,” with the assumption that similar wildlife, physical processes, and other sources of natural sounds occur in similar areas with similar attributes. The primary goal of the site selection process was to identify the minimum number of field-measurement sites, which would allow for characterization of the baseline ambient sound levels throughout the entire park by assigning measured data stratified to these acoustical zones. The following considerations are used in the determination of acoustical zones:

- Vegetation/Land Cover: Sound propagates differently over different types of ground cover and through different types of vegetation. For example, sound propagates more freely over barren environments as compared with grasslands, and less freely through forest type environments. In addition, vegetation is typically dependent upon time-of-year, with foliage being sparser in the winter than other times in the year. Land cover can also affect wildlife activity.
- Climate Conditions: Climate conditions (temperature, humidity, precipitation, wind speed, wind direction, etc.) can also affect ambient sound levels. For example, higher elevation areas typically exhibit higher wind speeds resulting in higher ambient sound levels. Climate is also dependent upon daily and seasonal variations, which can affect ambient sound levels. For example, under conditions of a temperature inversion (temperature increasing with increasing height as in winter and at sundown), sound waves may be heard over larger distances; and winds tend to increase later in the day, and, as such, may be expected to contribute to higher ambient noise levels in the afternoon as compared with the morning.
- Park Resources/Management Zones: Park resources contribute, not only, to the multitude of sounds produced in certain areas of the park, but also to the serenity of other areas in the park. The way in which a park manages its resources can affect how potential impacts may be later assessed. It may also help identify where greater resource protection may be needed.

Based on the above considerations, Figure 7 presents the acoustical zones that were developed and the location of the measurement sites for WRBR. Locations in WRBR where human activity is greatest were assigned to a developed zone. This includes areas nearby the visitor center, monuments, flight markers, access roadways, First Flight Airport, and residential areas within the ½ mile buffer. The ATMP Act applies to all commercial air tour operations within the ½-mile outside the boundary of a national park. Table 12 presents which measurement site data were applied to each acoustical zone based on best available data and geographical proximity. WRBR001 represents the Developed Zone, but also serves as a proxy for the Water/Wetlands Zone which occurs within the ½-mile outside the park boundary. WRBR002 is representative of the Frontcountry Zone.

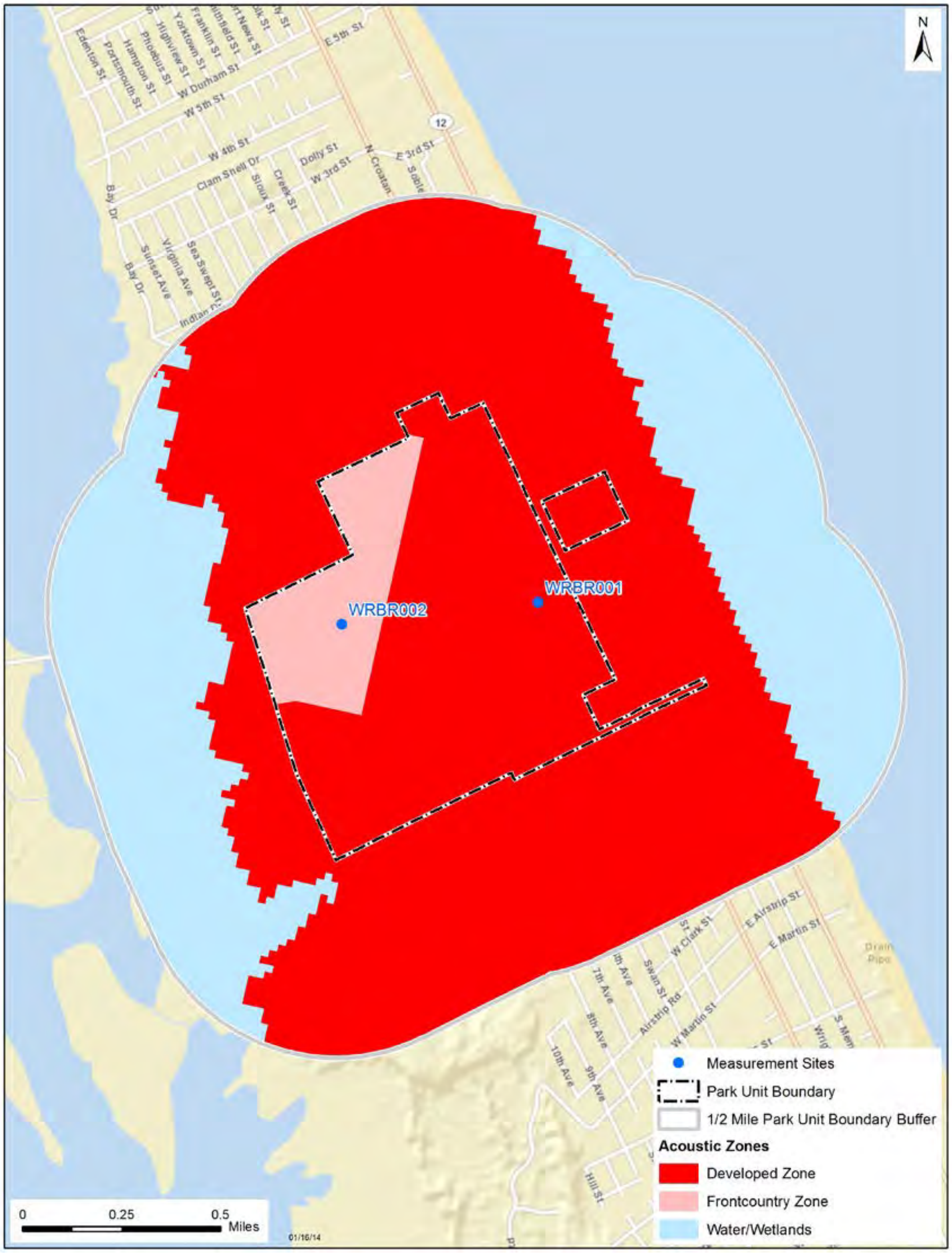

Figure 7 Acoustical zones and measurement sites for WRBR.

Table 13. Assignment of ambient data to acoustical zones.

Acoustical Zone	Site ID	Site Name
Developed	WRBR001	Croatan Hwy
Frontcountry	WRBR002	Airstrip Hill
Water/wetlands	WRBR001	Croatan Hwy

5.2 Ambient Mapping of Localized Sound Sources

The contributing effect of localized noise sources, primarily road vehicles, but possibly including trains, rivers, or water sources, are typically modeled and combined with the measured sound levels to develop a composite, baseline, ambient "map" of a park for all ambient maps, except natural ambient (see Table 13). The combined (measured plus roadway, for example) ambient are computed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition. Roadway sound sources were modeled using the Federal Highway Administration's Traffic Noise Model® (TNM) where the estimated drop-off rate, reflecting a continuous decrease in sound level as a function of increasing distance from each sound source, was computed (Lee, 2004). For a non-time-varying source, such as roadway noise, the TNM-computed L_{Aeq} sound level parameters may be conservatively assumed to be equivalent to the L_{50} and L_{90} and, thus, used interchangeably as the "roadway" ambient.

Table 14. Composite ambient maps.

Metric	Ambient Type			
	Existing	Existing Without Fixed-Wing Aircraft and Helicopters	Existing Without All Aircraft	Natural
L_{50}	Measured + Localized Noise Source(s)	Measured + Localized Noise Source(s)	Measured + Localized Noise Source(s)	Measured

In the vicinity of and within Wright Brothers, there were a number of roadways. The following general assumptions were made in the modeling:

- Roadway Traffic Volumes - Annual traffic volume on each roadway was determined using data collected by the North Carolina Department of Transportation (North Carolina Department of Transportation 2013). Where data are available for multiple years, the most current year was chosen or corresponding study year, whichever was closer to the measurement data. The traffic volume for an average day during the peak winter month (November) was obtained by using monthly visitation data obtained from the NPS Public Use Statistics Office website (National Park Service 2013) to apportion the NCDOT annual traffic. Hourly volume is estimated by dividing the month's volume by the number of days in the month (30) and by 12 hours per day, which assumes the majority of traffic for WRBR occurs between 7 am and 7 pm – typical commute hours.

- Roadway Traffic Mix and Speeds –The traffic mix and speeds on a given roadway were based on two sources: (1) The NPS Monthly Usage information (National Park Service 2013); and (2) observations by field personnel during pervious site visits. In some cases, a specific speed limit was determined using Google Maps using the “street view” to view an actual speed limit sign. In some specific cases, notations from the field notes en route to measurement site locations were used to determine speed limits over various segments. An average speed of 35 mph was assumed as the default within the park when another more specific speed limit could not be determined.
- Ground Impedance – An effective flow resistivity of 1000 cgs/rayls was used for Wright Brothers.

Table 15. Estimated hourly roadway traffic volume and speed.

Roadway			Estimated hourly volume				
#	Name	Average Speed (mph)	Autos	Medium Trucks	Heavy Trucks	Buse s	Motor-cycles
1	Main Park Entrance	25	16	0	0	0	0
2	US 158 (Tateway Rd to Forbes St)	50	1,590	55	32	9	33
3	US 158 (Tateway Rd to Eckner St)	50	1,312	45	26	8	27
4	12 N Virginia Dare Trail (Tateway Rd to Forbes St)	35	231	8	5	1	5
5	12 N Virginia Dare Trail (Tateway Rd to Eckner St)	35	167	6	3	1	3

5.3 Final Ambient Maps

The two ambient maps agreed upon for use in ATMP analyses are:

- Existing Ambient Without Fixed-Wing Aircraft and Helicopters (i.e., the Source of Interest); and
- Natural Ambient.

Figure 8 and Figure 9 present the two ambient maps for the winter season.

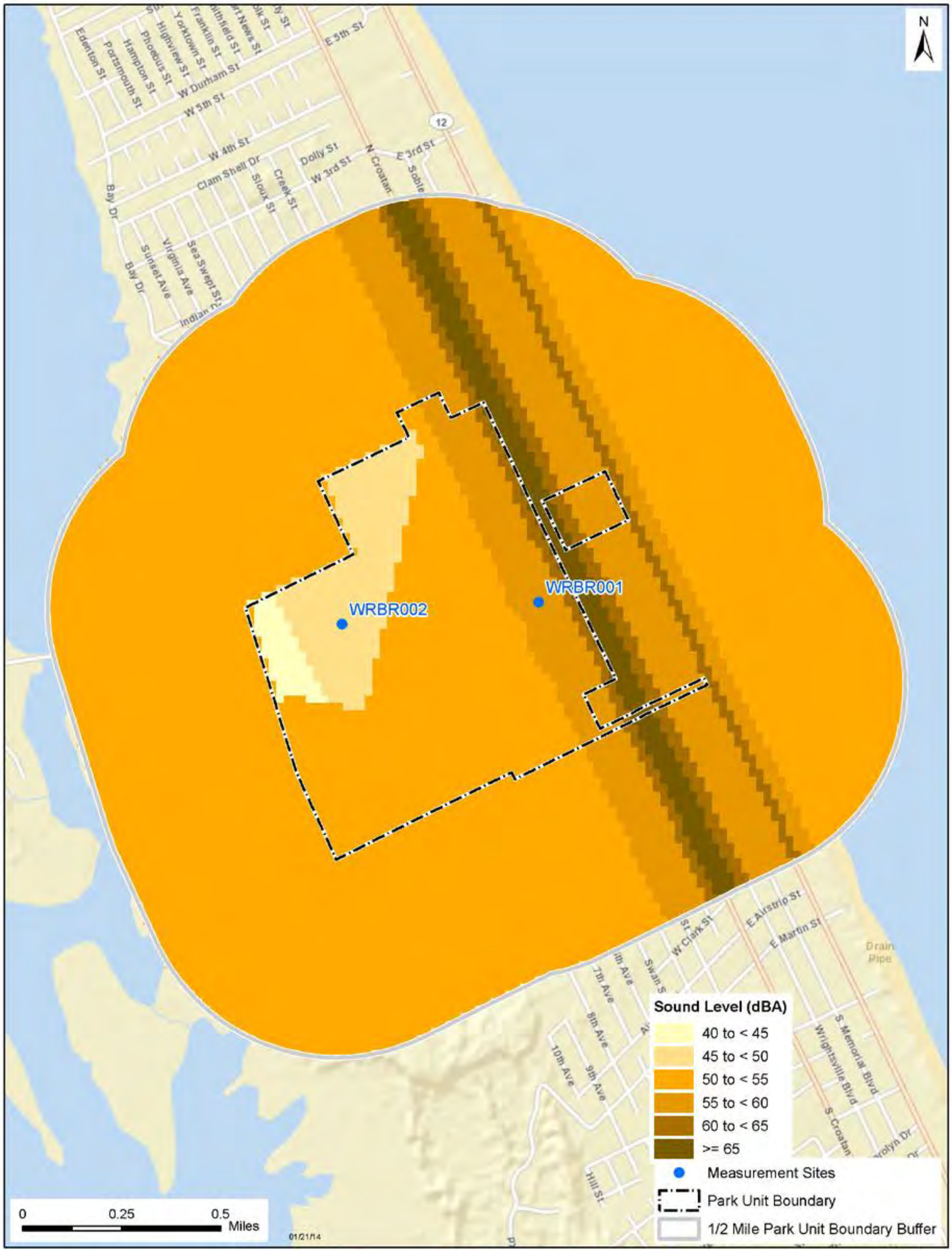

Figure 8. Baseline ambient map: Existing Ambient Without Fixed-Wing Aircraft and Helicopters (L_{50}).

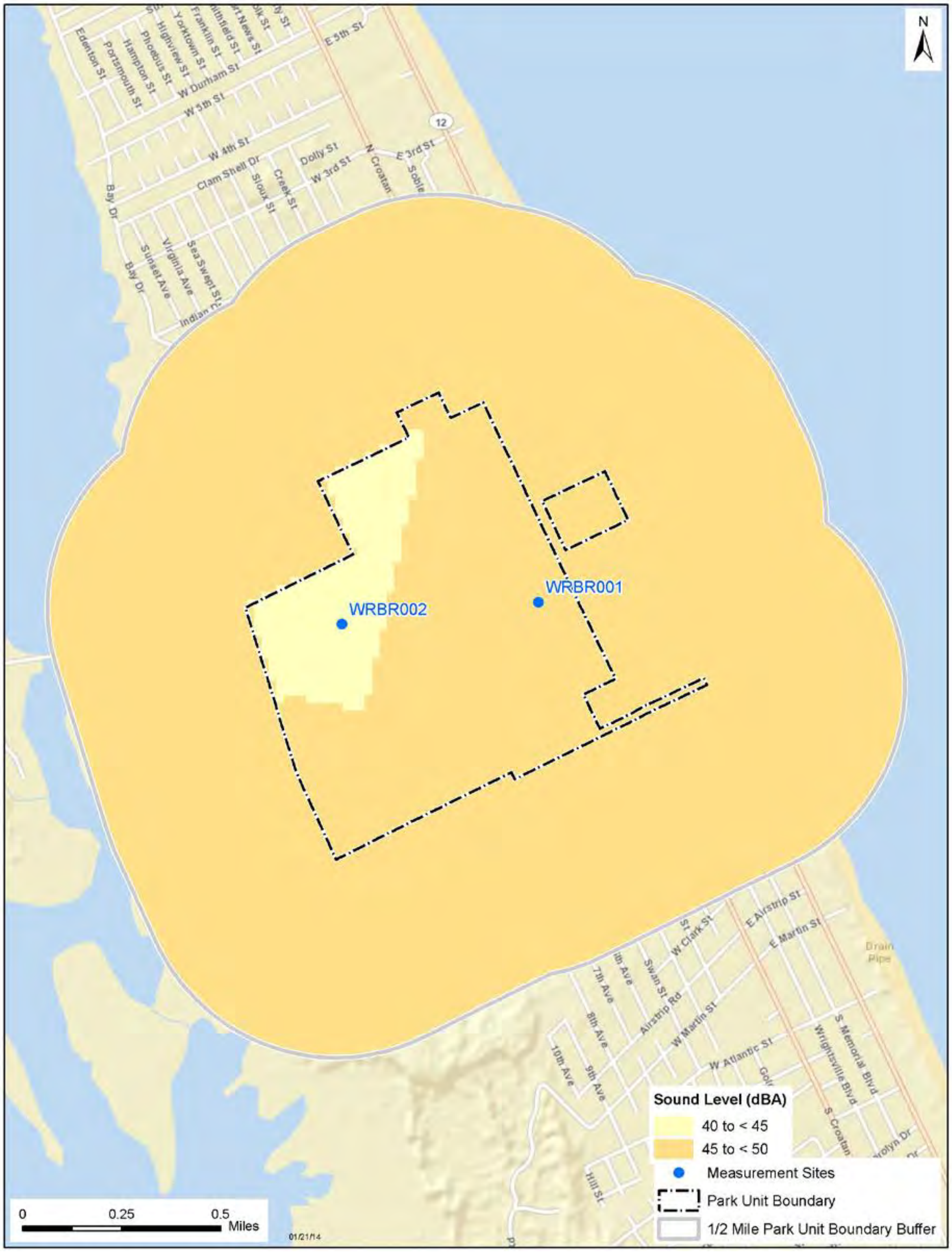

Figure 9. Baseline ambient map: Natural Ambient (L_{50}).

6. Data for Individual Sites

This section provides more detailed information for each individual site. For each site, the following are included:

- A photograph of the measurement site and a brief discussion of preliminary observations;
- A pie chart presenting a comparison of types of sound sources that were audible during observer logging;
- A graphic presenting distribution plots of the number of 1-second samples of each sound pressure level measured during daytime and nighttime hours, and daytime/nighttime combined;
- A graphic presenting the daily sound levels using three A-weighted summary metrics (L_{Aeq}, L_{50}, and L_{90} - refer to Terminology for definitions), as well as average daily wind speeds over the entire measurement period;
- A graphic presenting the hourly sound levels using three hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to Terminology for definitions), as well as average hourly wind speeds over the entire measurement period; and
- A graphic presenting the sound levels for each of 33 one-third octave-band frequencies over the day and night periods using three A-weighted exceedance level metrics (L_{10}, L_{50}, and L_{90}). The L_{10} exceedance level represents the dB exceeded 10 percent of the time and 90 percent of the measurements are quieter than the L_{10}. Refer to Terminology for definitions of L_{50} and L_{90}. The grayed area represents sound levels outside of the typical range of human hearing.

6.1 Site WRBR001 – Croatan Hwy

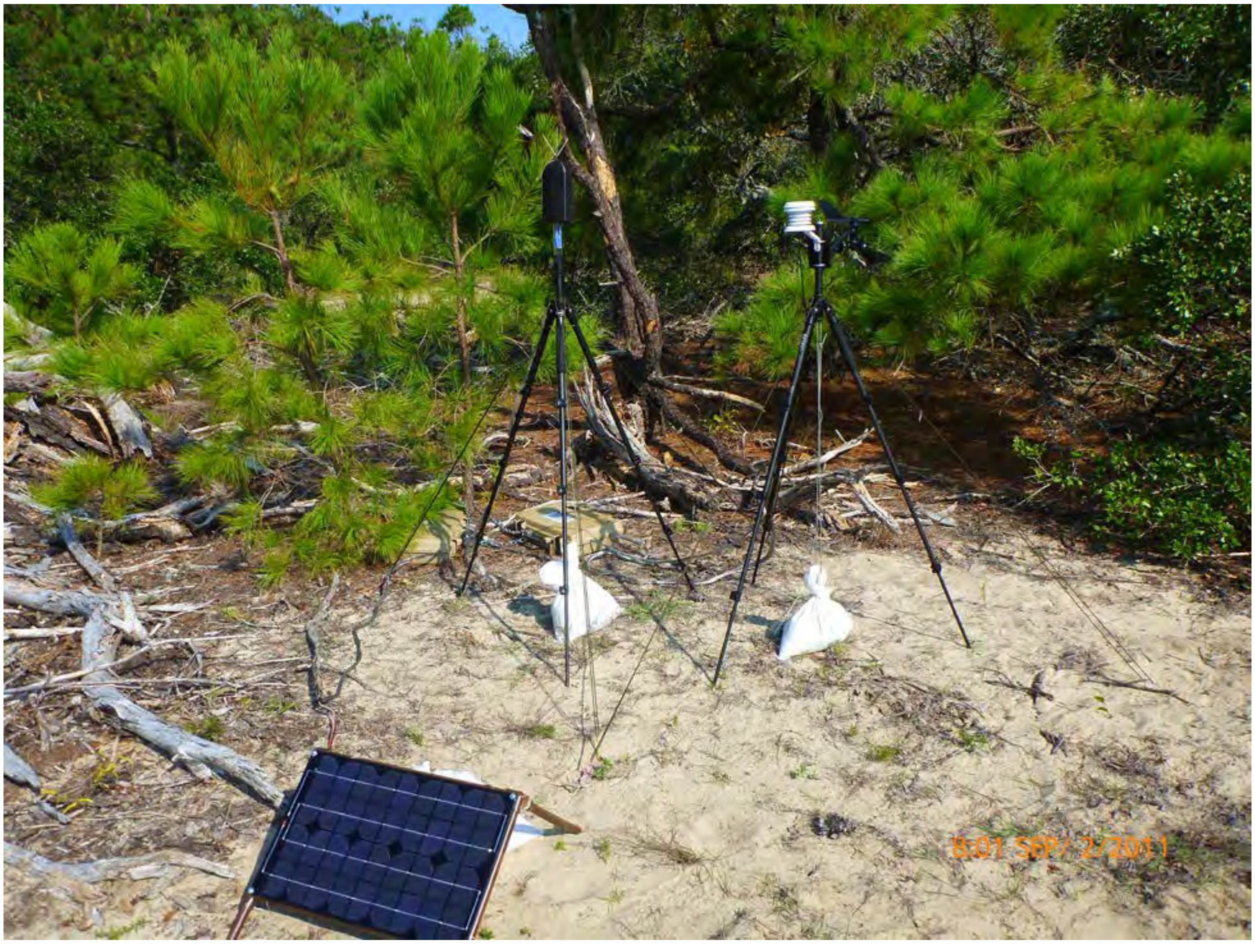

Figure 10. Photograph of site WRBR001.

The WRBR001 Croatan Hwy site was located between the monument and Croatan Highway. The measurement system collected data from September 2, 2011 to November 15, 2011 to represent the winter season. The vegetation near the measurement system consisted of dry grasses and the site was nearly at sea level (9ft.). Daytime sources of sound included vehicle sounds, birds, insects, aircraft, and wind related sounds. “Other Human” sounds shown in Figure 13 are almost exclusively due to automobile traffic from nearby roadways, primarily Croatan Highway.

On-site observations and off-site review of recorded audio data determined that aircraft were audible 7% of the daytime and 1% of the nighttime hours. Other human related sounds (mostly vehicles) were audible of 91% of daytime and 86% of nighttime hours. The period of time where no human sounds were audible is called the “Noise-free” component of the soundscape. Noise-free time periods accounted for 2% of daytime and 13% of nighttime hours. Natural sounds audible at this site, which could have occurred concurrently with human sounds, included wind, bird vocalizations, insects, and water-related sounds such as rain.

The overall median daytime sound level for this site was 53.3 dBA. Daily (twenty-four hour) median sound levels (L_{50}) at WRBR001 ranged from 43 dBA to 57 dBA. Hourly median sound levels varied from 43 dBA to 54 dBA. Higher sound levels during daytime hours correspond to increases in wind and vehicle traffic.

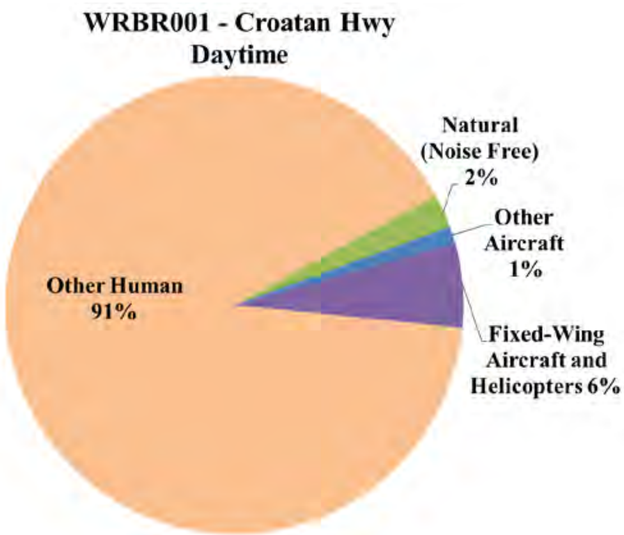

Figure 11. Distribution of sound sources audible (*in situ* and off-site listening combined) during daytime (left) and nighttime (right) hours for WRBR001.

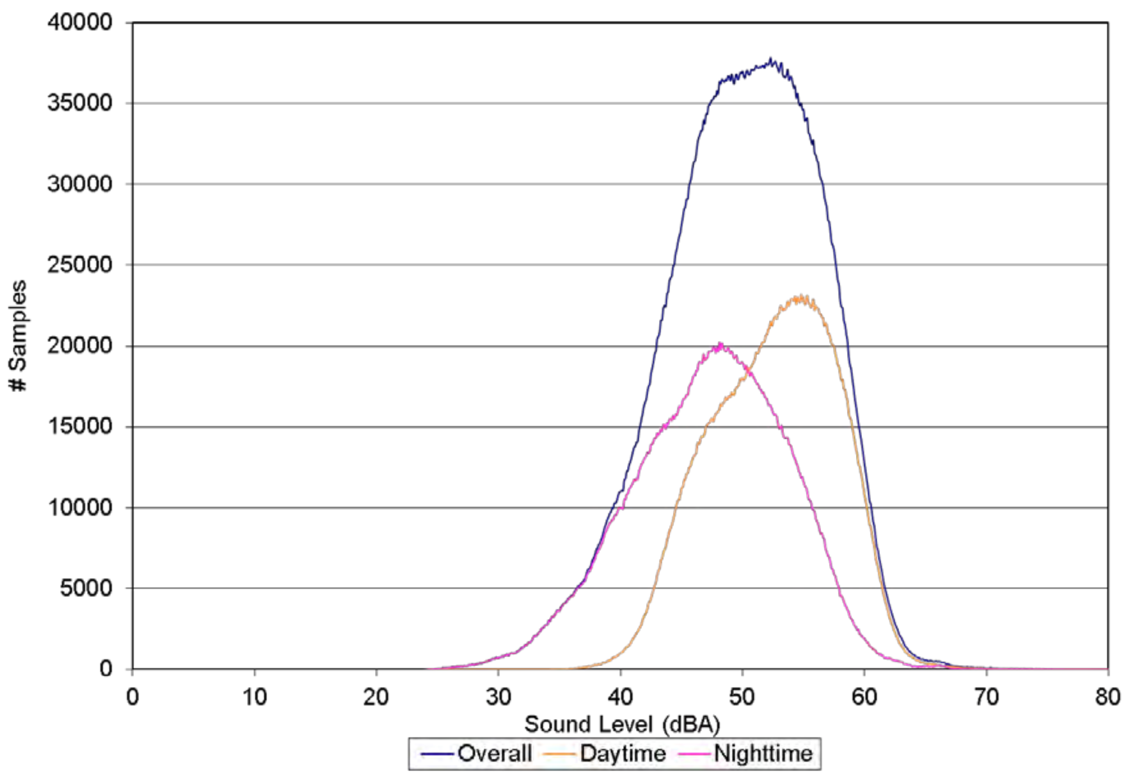

Figure 12. Distribution of 1-second sound pressure level data measured during daytime (orange) and nighttime (pink) hours, and daytime/nighttime combined (blue) for WRBR001.

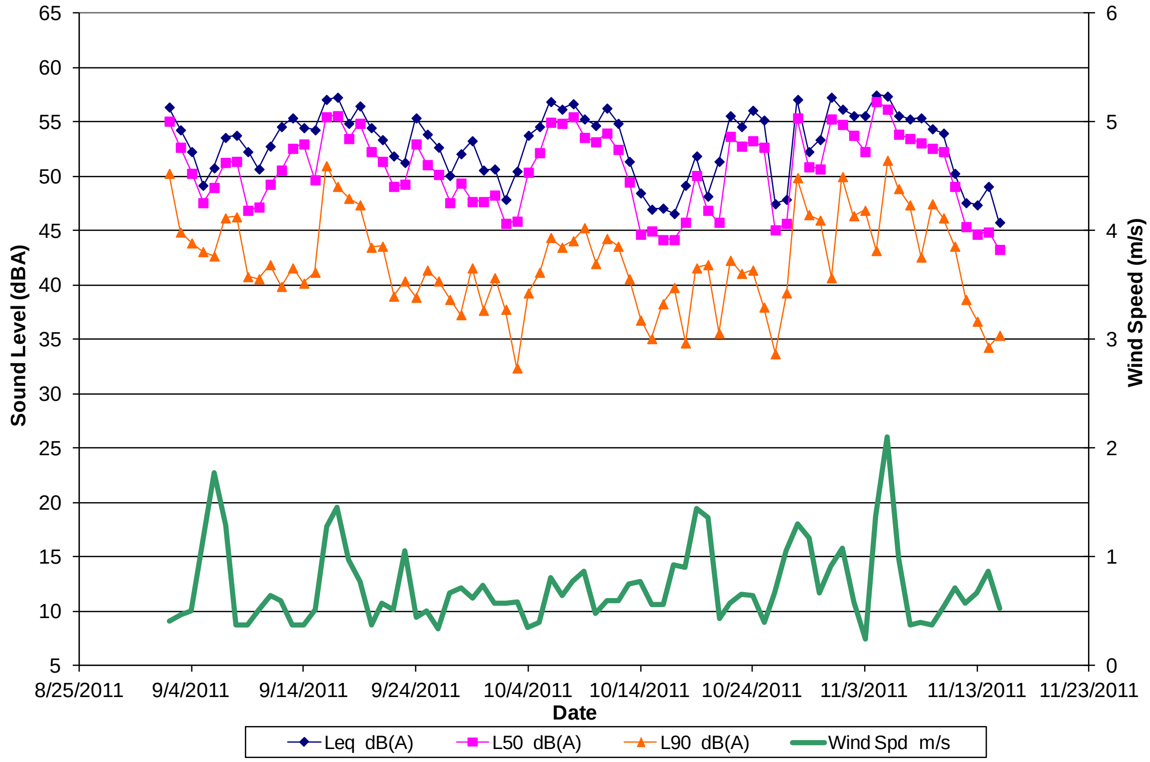

Figure 13. Daily sound levels and wind speeds for Site WRBR001.

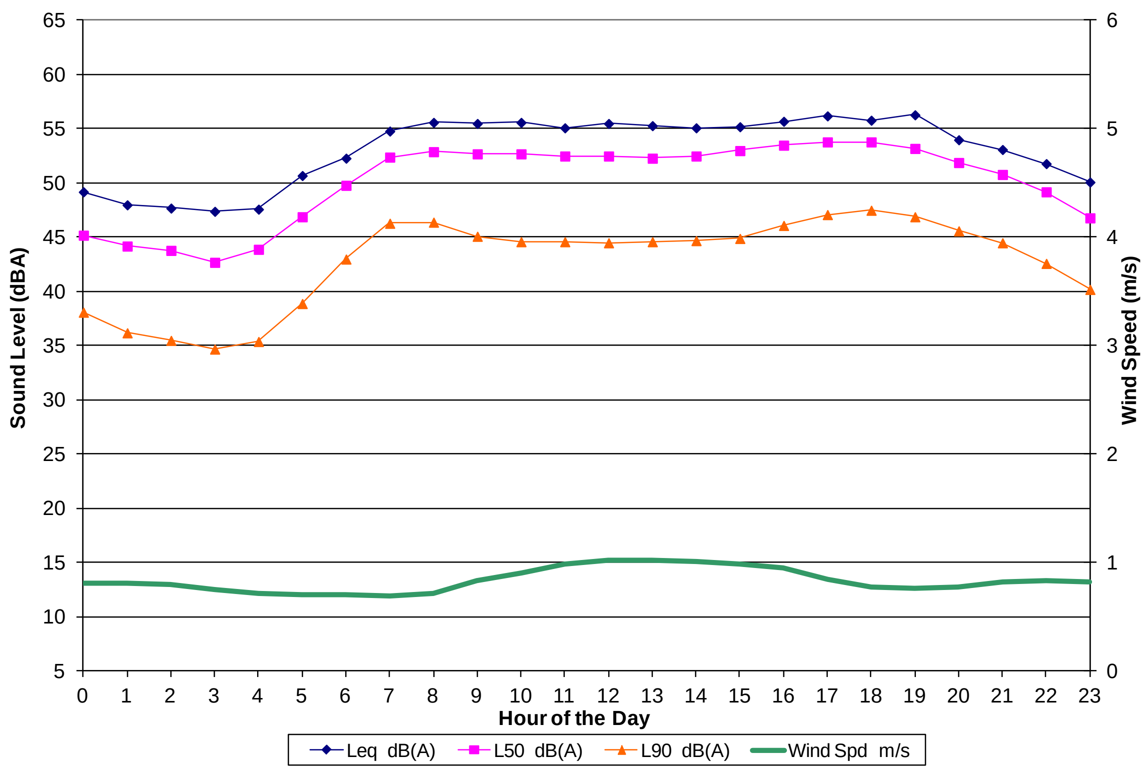

Figure 14. Hourly sound levels and wind speeds for Site WRBR001.

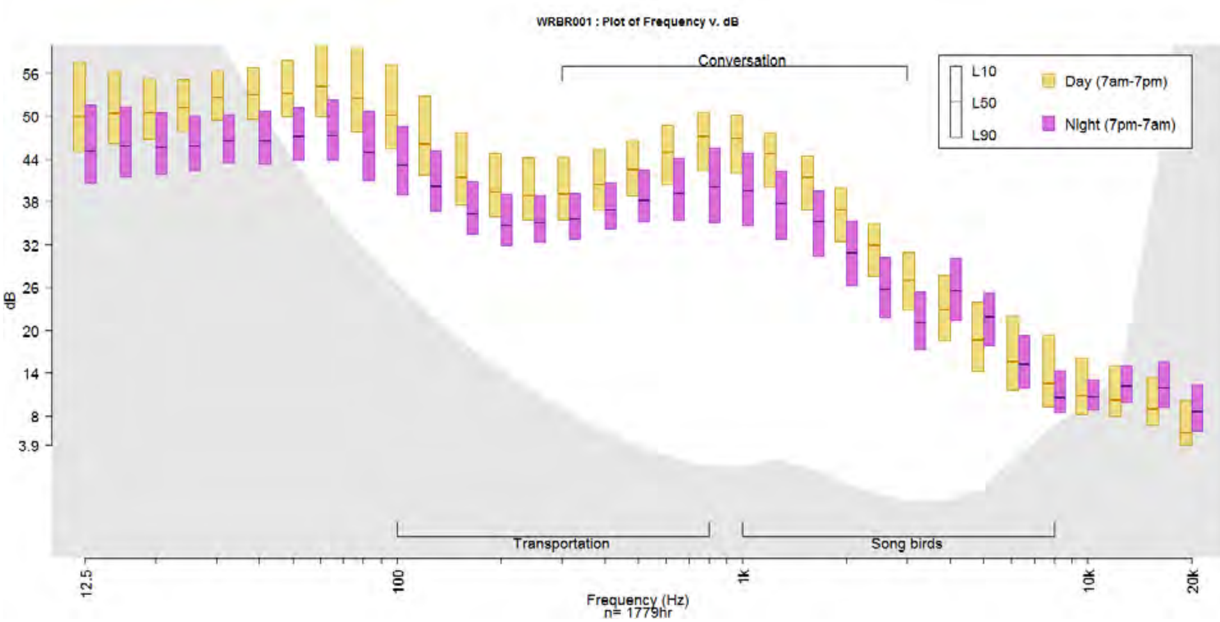

Figure 15. Sound spectrum for WRBR001.

6.2 Site WRBR002 – Airstrip Hill

Figure 16. Photograph of site WRBR002.

The WRBR002 Airstrip Hill site was located on a hill above the First Flight Airport. This general aviation airport reported an estimate of 103 operations per day during the period May 2011 – May 2012 (AirNav.com 2014). The measurement system collected data from September 2, 2011 to October 17, 2011 to represent the winter season. The vegetation near the measurement system consisted of dry grasses and forbs at an altitude of 45 ft. above sea level. Daytime sources of sound included vehicle sounds, visitor sounds, birds, insects, commercial jet aircraft, propeller aircraft, wind, and water related sounds.

On-site observations and off-site review of recorded audio data (Figure 15) showed aircraft were audible 10% of the daytime and 2% of nighttime hours. Other human related sounds (mostly vehicles) were audible of 77% of the daytime and 69% of the nighttime hours. The period of time where no human sounds were audible is called the "Noise-free" component of the soundscape. Noise-free time periods accounted for 13% of the daytime and 29% of nighttime hours. Natural sounds audible at this site, which could have occurred concurrently with human sounds, included wind, bird vocalizations, insects, and water related sounds such as rain.

The overall median daytime sound level for this site was 43.5 dBA. Daily (twenty-four hour) median sound levels (L_{50}) at WRBR002 ranged from 39 dBA to 47 dBA. Hourly median sound levels varied from 38 dBA to 44 dBA. Higher sound levels during daytime hours correspond to increases in wind and vehicle traffic. Noticeably elevated daily L_{Aeq} sound levels from 9/2/11 through 9/6/11 and during the 7 pm hour (corresponding to sunset) were due to loud insects (cicadas) in the vicinity of the measurement system. This insect activity declined after the date of 9/6/11.

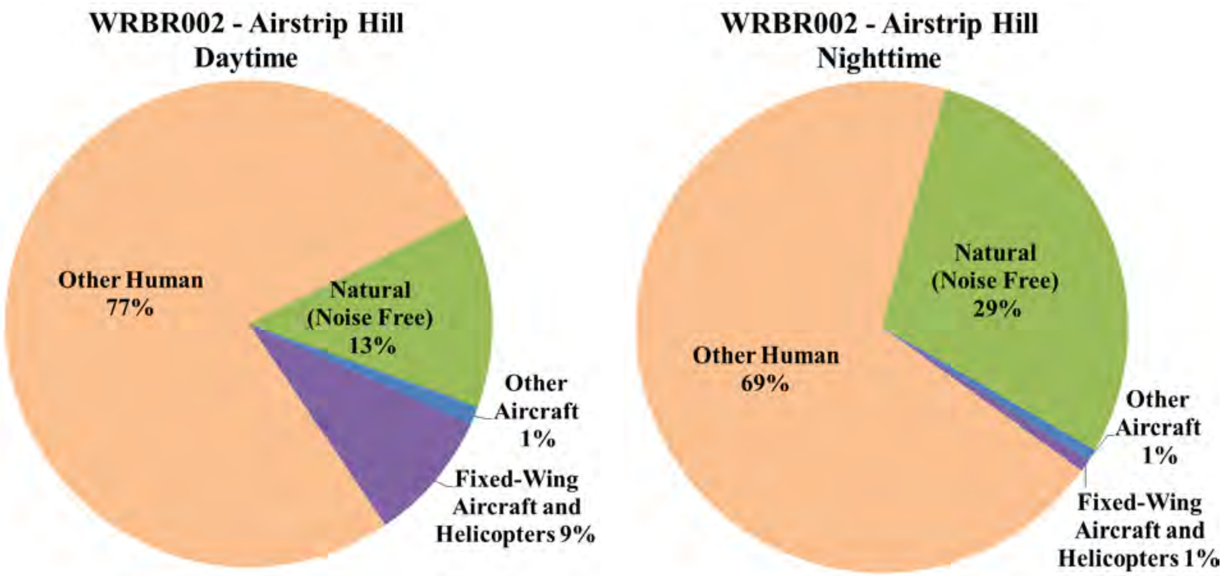

Figure 17. Distribution of sound sources audible (*in situ* and off-site listening combined) during daytime (left) and nighttime hours (right) for WRBR002.

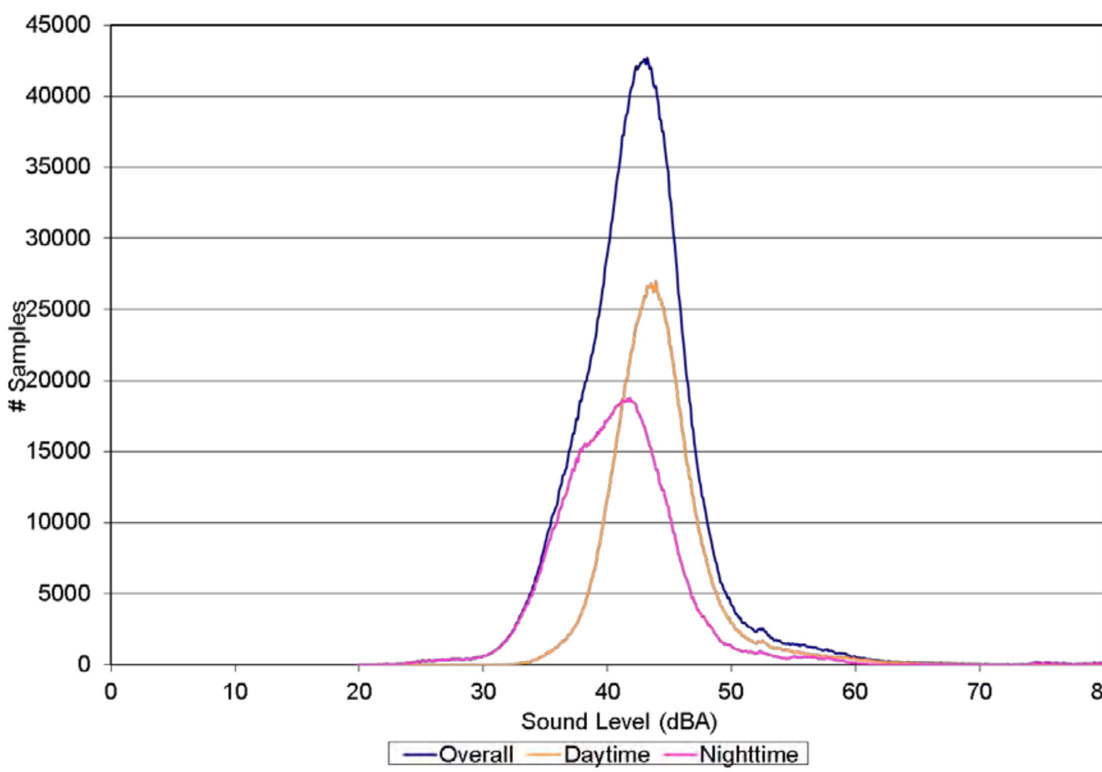

Figure 18. Distribution of data for WRBR002.

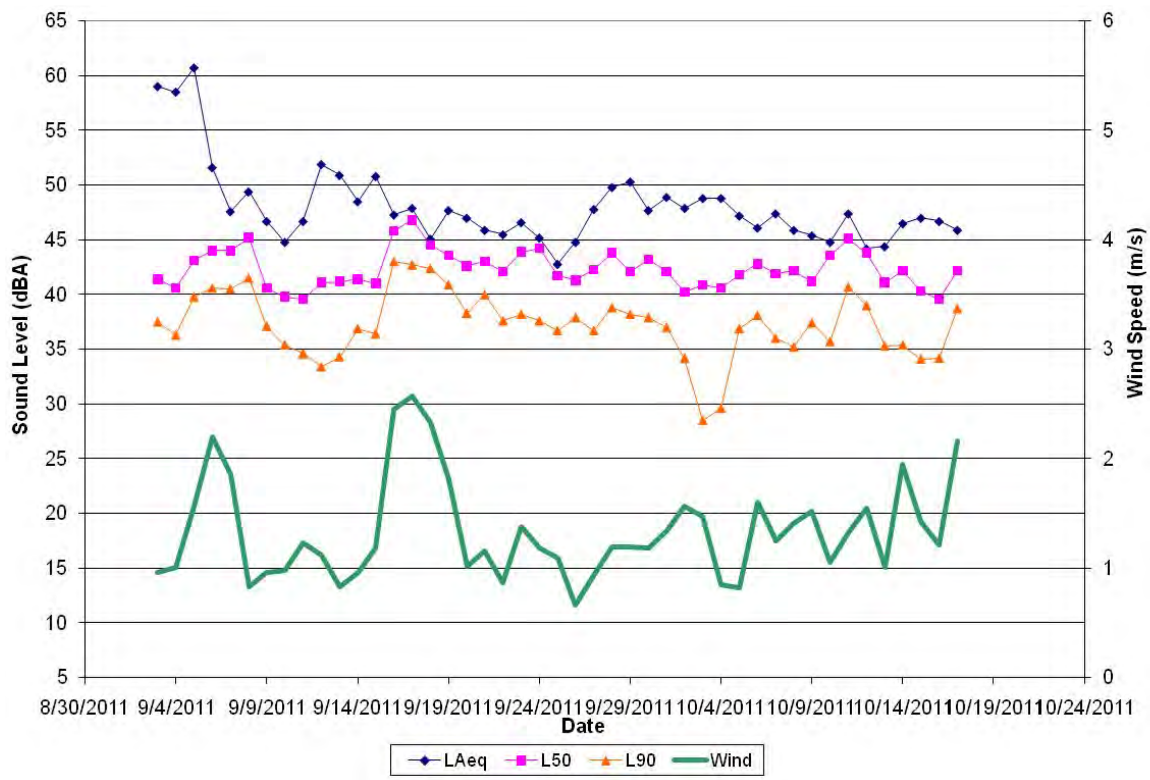

Figure 19. Daily sound levels and wind speeds for WRBR002.

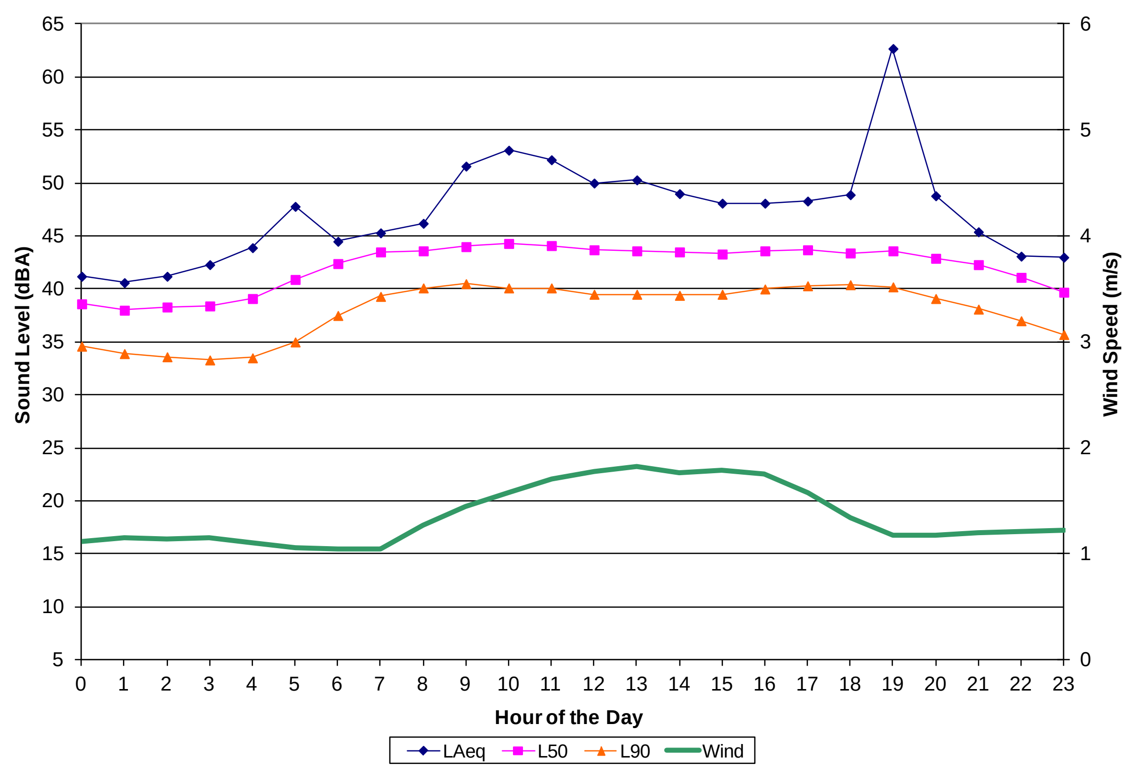

Figure 20. Hourly sound levels and wind speeds for Site WRBR002.

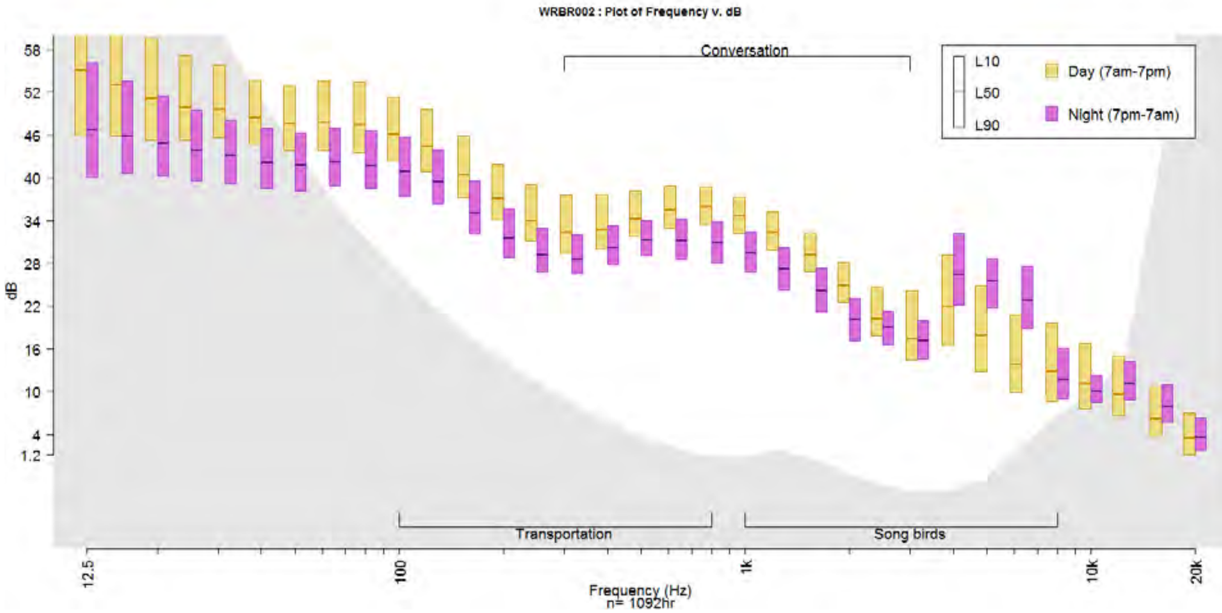

Figure 21. Sound spectrum for WRBR002.

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NPS 361/127136, November 2014

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