National Park Service
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Natural Resource Stewardship and Science

Montezuma Castle National Monument

Acoustical Monitoring 2010 and 2012

Natural Resource Report NPS/NRSS/NRR—2014/872

ON THE COVER
Montezuma Castle National Monument, taken in 2010
Photograph courtesy Volpe Center

Montezuma Castle National Monument

Acoustical Monitoring 2010 and 2012

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13. ABSTRACT (Maximum 200 words) During the summer of 2010 (July-August)and winter of 2012 (March-May) baseline acoustical data were collected at Montezuma Castle National Monument (MOCA), 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 MOCA 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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Executive Summary

The National Park Service (NPS) Natural Sounds and Night Skies Division (NSNSD) and the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) performed acoustical monitoring during July-August 2010 and March-May of 2012 to characterize existing sound levels and estimate natural ambient sound levels representing summer and winter seasons, respectively, for Montezuma Castle National Monument (MOCA). This monitoring effort also serves to identify audible sound sources in support of the potential development of an air tour management plan (ATMP). This report provides a summary of results of these measurements.

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; 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 Montezuma Castle measurement locations for each 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
Summer season (2010)									
MOCA001	Montezuma Castle	71.4	11.2	1.9	0.1	98.8	65.1	2.7	0.0
MOCA002	Montezuma Well	21.2	2.8	0.4	0.0	30.5	2.8	0.1	0.0
Winter season (2012)									
MOCA001	Montezuma Castle	76.4	3.6	0.5	0.0	36.9	0.9	0.1	0.0
MOCA002	Montezuma Well	13.4	1.4	0.3	0.0	2.8	0.2	0.0	0.0

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
Summer season (2010)									
MOCA001	Montezuma Castle	25.5	2.2	0.4	0.0	5.5	0.3	0.0	0.0
MOCA002	Montezuma Well	11.6	1.8	0.3	0.0	3.5	0.2	0.0	0.0
Winter season (2012)									
MOCA001	Montezuma Castle	38.8	2.0	0.3	0.0	5.0	0.3	0.01	0.0
MOCA002	Montezuma Well	11.3	1.2	0.2	0.0	2.4	0.2	0.0	0.0

Table 3 and Table 4 summarize the daytime and nighttime* acoustical observer log data (off-site listening and in-situ logging combined) which 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
Summer season (2010)					
MOCA001	Montezuma Castle	9.8	10.8	65.2	14.3
MOCA002	Montezuma Well	14.3	15.8	37.8	32.1
Winter season (2012)					
MOCA001	Montezuma Castle	21.5	4.7	50.6	23.2
MOCA002	Montezuma Well	8.6	13.5	39.4	38.5

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
Winter season (2012)					
MOCA001	Montezuma Castle	0.0	12.9	20.3	66.8
MOCA002	Montezuma Well	0.0	10.2	41.0	48.8

* Nighttime acoustical observer logs are not available for the 2010 summer season.

Acknowledgments

The authors of this report wish to express their sincere gratitude to all who helped make this a successful study. The National Park Service (NPS), Natural Sounds and Night Skies Division, provided invaluable coordination and support. We would also like to thank Lelaina Marin, Charles Schelz, Theresa Ely, Kathy Davis and the entire team at the Flagstaff Parks for their expertise and assistance during site selection and deployment.

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 resources of the parks, including the natural and cultural 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 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).

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the Federal Aviation Administration (FAA), Western-Pacific Region (AWP) and the NPS, Natural Sounds and Night Skies Division (NSNSD) in the development of ATMPs.

Ambient data were collected in Montezuma Castle National Monument, AZ (MOCA) by Volpe personnel during July to August of 2010 to represent the summer season and by NPS, NSNSD personnel during March to May of 2012 to represent the winter season. A map of the area surrounding Montezuma Castle National Monument 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 MOCA's summer and winter seasons. Measurements representing MOCA's summer season were summarized previously in a separate document (National Park Service 2013a).

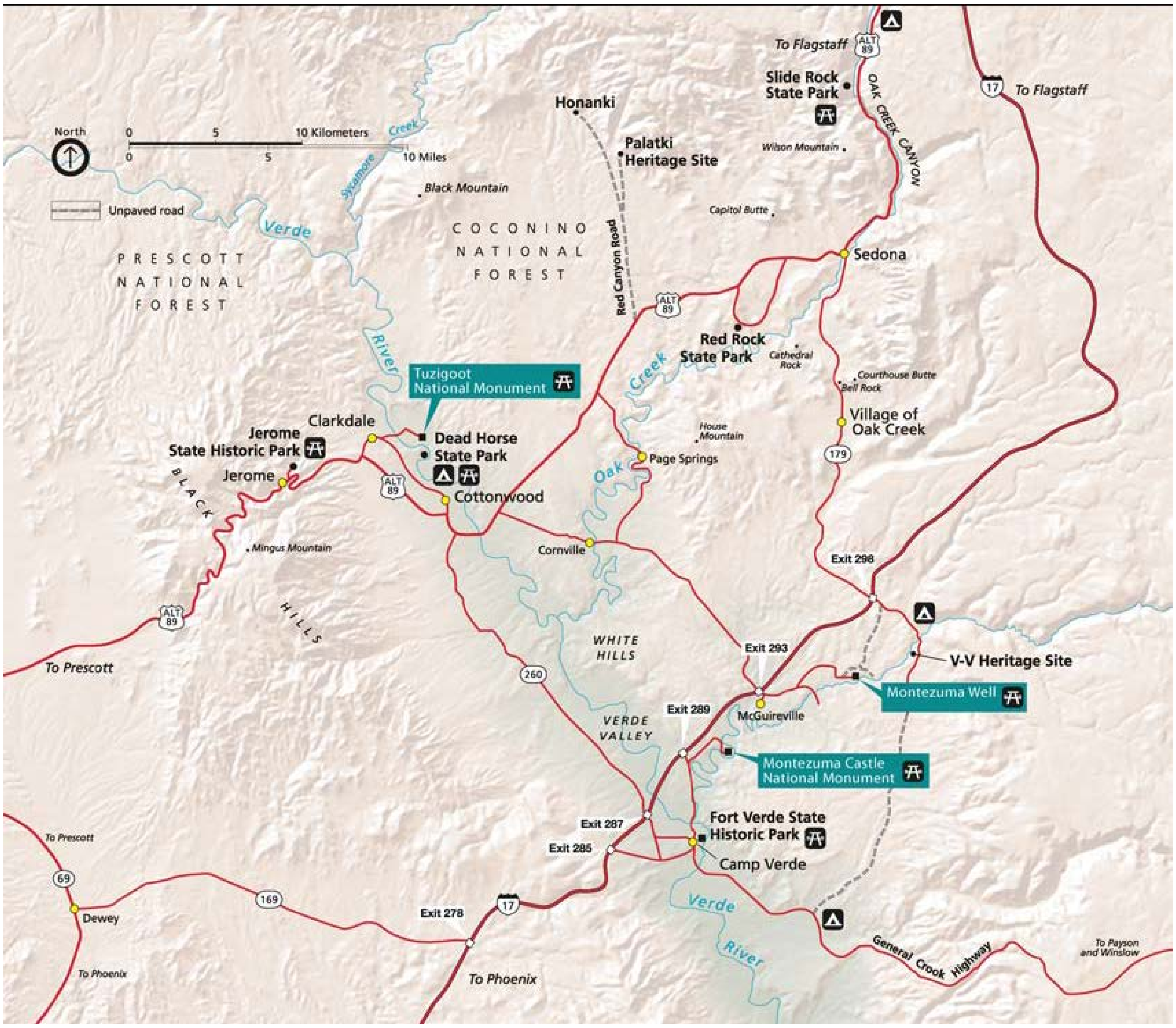

Figure 1. Map of area surrounding Montezuma Castle National Monument (National Park Service 2014).

2. Study Area

Two acoustical monitoring systems were deployed during each season at nearly identical locations. These sites were selected based on discussion between Volpe, NSNSD, and MOCA personnel and are shown in Table 5.

Table 5. Summary of measurement sites selected for Montezuma Castle.

Site ID	Site Name	# Days of Data	NLCD[2] Classification	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
Summer season (2010)					
MOCA001	Montezuma Castle	31 days	Scrub/Shrub	34.61160° / 111.84286°	1,002 m (3,287 ft)
MOCA002	Montezuma Well	31 days	Scrub/Shrub	34.65048° / 111.75446°	1,091 m (3,580 ft)
Winter season (2012)					
MOCA001	Montezuma Castle	56 days	Scrub/Shrub	34.61165° / 111.84305°	983 m (3,225 ft)
MOCA002	Montezuma Well	57 days	Scrub/Shrub	34.65053° / 111.75440°	1,086 m (3,563 ft)

[2] With the goal of potentially facilitating future data transferability between parks, all baseline acoustical data collected for the ATMP program 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 both monitoring periods at Montezuma Castle. 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 are 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.

Each descriptor is computed from the broadband A-weighted sound level and the 33 un-weighted one-third octave-band sound levels (12.5 to 20,000 Hz) which define the un-weighted sound level spectrum. The process of computing descriptors using the un-weighted one-third octave-band spectrum is virtually identical to the process for computing the broadband A-weighted sound level descriptors. Specifically, the un-weighted sound level descriptor is computed individually for each one-third octave-band. This method of constructing the sound level spectrum means the reported spectrum 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

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

- *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 6.

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:

- L_{50}, Existing Ambient Without Source of Interest – Descriptor 5 from the table above; and
- L_{50}, 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-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. As mentioned earlier, 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 Without Air Tours, 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 season-to-season and site-to-site comparisons:

- Figure 2 presents a plot of the overall daytime[4] L_{50} sound level computed for each site and both summer and winter seasons (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 indicate the 95% confidence interval on the results;[5]
- Table 7 presents a tabular summary of the daytime and nighttime and computed ambient; and
- Table 8 contains a summary of overall ambient spectral data at each site;
- Figure 3 through Figure 6 present the associated spectral data for these ambient maps.

[4] For most parks, the majority of air tour operations occur during the day, the NPS and FAA have agreed that the impact assessment will be conducted using ambient sound levels during the time that the air tour operations occur. Accordingly, all ATMP analyses are based on daytime ambient data. In general, daytime refers to the time period of 7 am to 7 pm unless otherwise specified by the NPS and FAA.

[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.

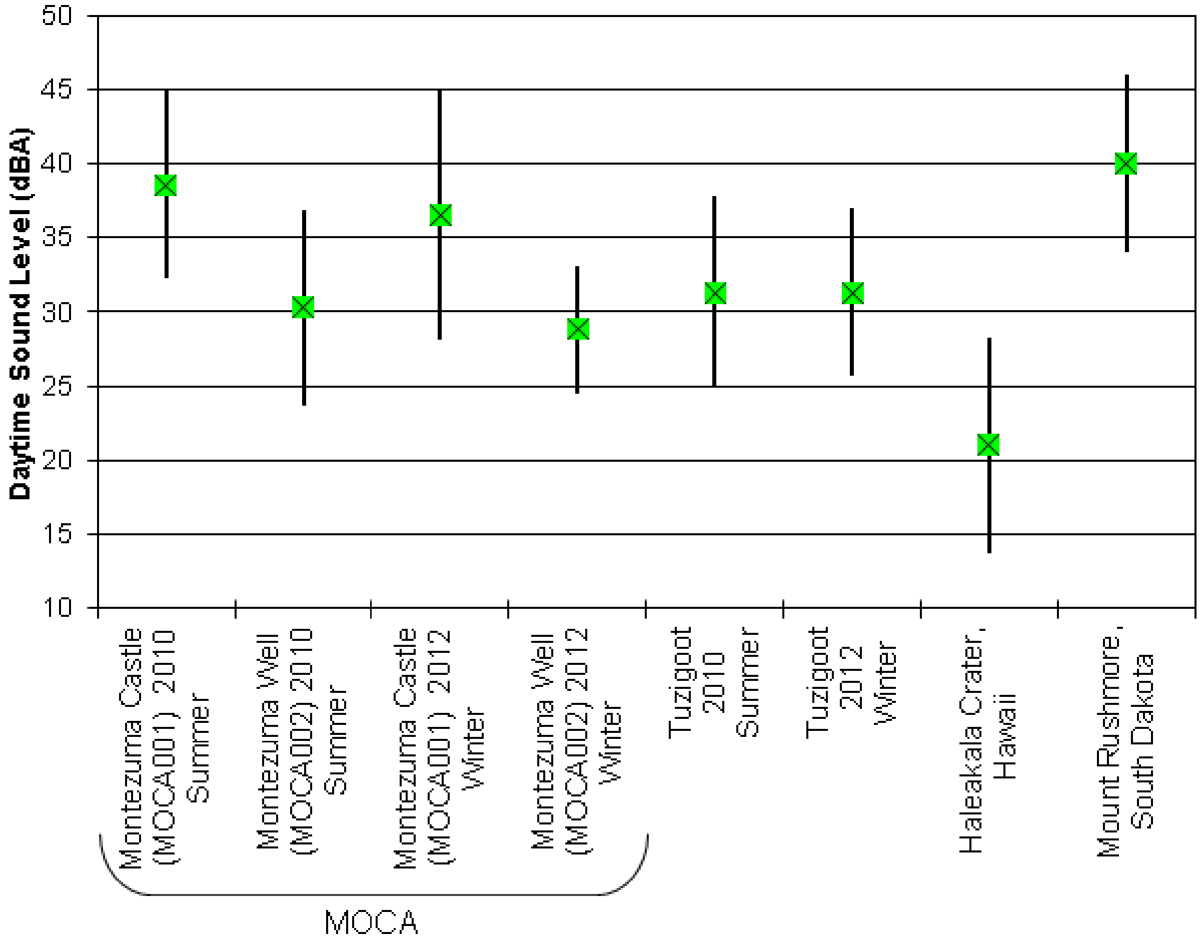

Figure 2. Comparison of overall daytime L_{50} sound levels.

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

Site ID	Site Name	Total # Days	Existing Ambient						Existing Ambient Without Air Tours (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)
Summer season (2010)											
MOCA001	Montezuma Castle	31	47.1	38.6	31.5	48.6	45.2	38.9	37.8	37.1	31.4
MOCA002	Montezuma Well	31	44.7	30.3	24.9	39.9	34.0	27.1	29.3	28.3	25.9
Winter season (2012)											
MOCA001	Montezuma Castle	56	43.2	36.3	34.6	43.8	34.9	31.3	35.9	35.8	34.7
MOCA002	Montezuma Well	57	36.6	28.3	24.2	31.9	26.3	21.8	27.9	27.3	25.3

[6] As stated earlier, two ambient definitions 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 Air Tours L_{50} (dB)				Natural Ambient L_{50} (dB)			
	Summer season (2010)		Winter season (2012)		Summer season (2010)		Winter season (2012)	
	MOCA001	MOCA002	MOCA001	MOCA002	MOCA001	MOCA002	MOCA001	MOCA002
12.5	37.2	38.5	37.0	44.3	34.3	35.5	33.6	39.0
16	37.3	38.3	36.9	42.4	34.5	35.3	34.1	38.4
20	35.5	37.5	36.2	40.8	32.6	34.6	33.5	37.1
25	34.9	36.6	34.6	40.0	31.3	33.2	31.8	36.3
31	35.2	35.8	33.9	38.8	30.5	32.5	31.0	34.9
40	33.4	35.5	33.0	37.6	29.1	31.6	29.6	33.8
50	31.7	34.4	30.5	36.3	27.7	31.2	27.5	32.7
63	31.8	34.3	29.9	35.4	28.5	30.9	27.0	32.2
80	29.2	33.5	27.7	34.4	25.4	30.6	24.7	31.2
100	27.6	31.3	26.8	31.3	24.0	28.5	23.9	28.3
125	26.8	29.1	25.4	28.8	23.2	26.5	23.0	25.2
160	25.2	30.0	25.0	26.9	21.0	28.3	22.1	22.9
200	24.4	24.3	25.4	23.8	21.4	21.5	23.7	19.8
250	24.4	22.0	26.5	21.4	21.6	19.5	24.8	18.2
315	23.4	18.4	26.1	20.0	20.6	16.2	24.6	17.3
400	24.4	16.9	27.0	20.2	22.0	15.3	25.4	18.0
500	25.1	16.3	28.0	20.3	22.0	14.6	26.5	18.5
630	24.3	16.4	27.7	19.2	20.9	14.7	26.3	17.4
800	23.7	15.8	27.2	17.4	20.4	14.4	26.1	15.4
1000	22.4	14.8	26.5	14.9	19.3	13.3	25.7	12.8
1250	20.8	12.8	25.6	11.7	17.8	11.4	24.8	9.1
1600	20.1	10.8	24.3	8.4	17.3	9.3	23.4	6.6
2000	20.4	9.7	22.3	6.2	16.5	8.1	21.3	4.8
2500	21.1	8.8	19.5	5.1	16.7	6.3	18.3	4.3
3150	20.4	8.5	16.9	5.1	15.9	5.5	15.3	4.5
4000	20.1	8.1	16.5	5.5	16.7	4.9	14.3	5.2
5000	26.5	8.8	13.6	5.8	22.2	5.4	11.5	5.6
6300	18.3	10.5	11.5	7.9	14.1	6.2	9.6	6.9
8000	17.1	8.3	10.0	6.3	13.4	6.4	8.6	6.1
10000	17.0	8.9	9.0	6.7	13.4	7.6	8.1	6.5
12500	14.8	8.4	7.8	6.9	13.0	7.4	6.9	6.7
16000	13.7	7.3	4.2	5.8	12.1	6.4	3.3	5.6
20000	15.0	8.9	0.8	3.5	13.9	8.4	0.5	3.3

[7] As discussed in Section 3.5, the spectral data associated with the L_{50} exceedence 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.

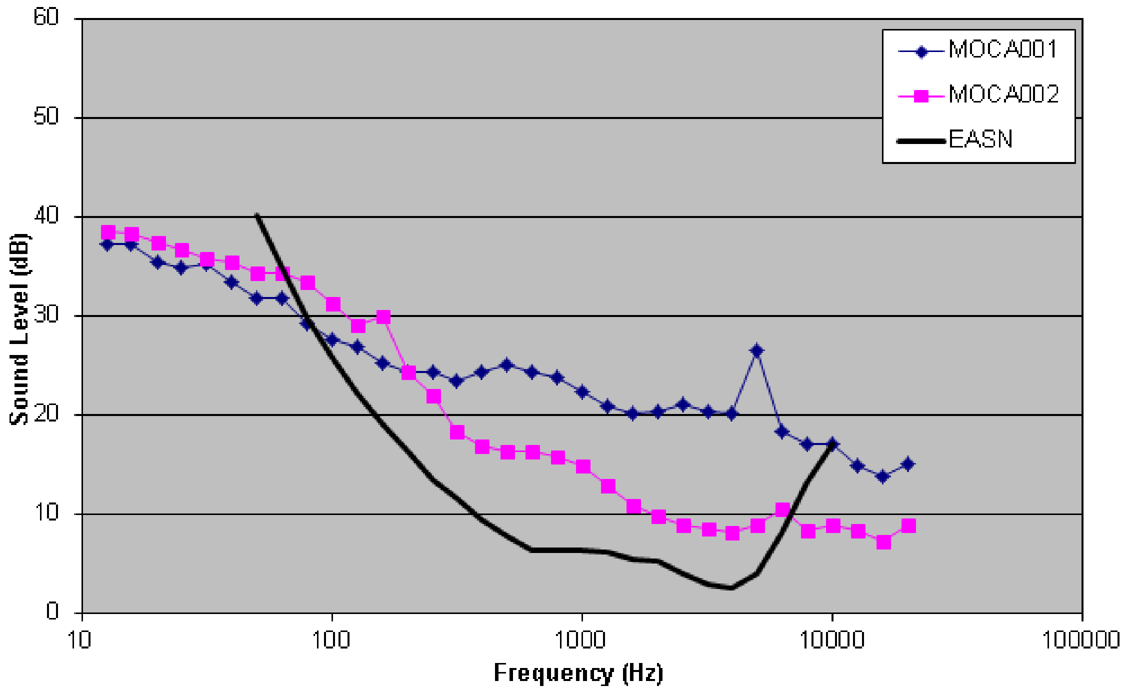

Figure 3. Spectral data for the Existing Ambient Without Air Tours (L_{50}), summer season (2010). [8]

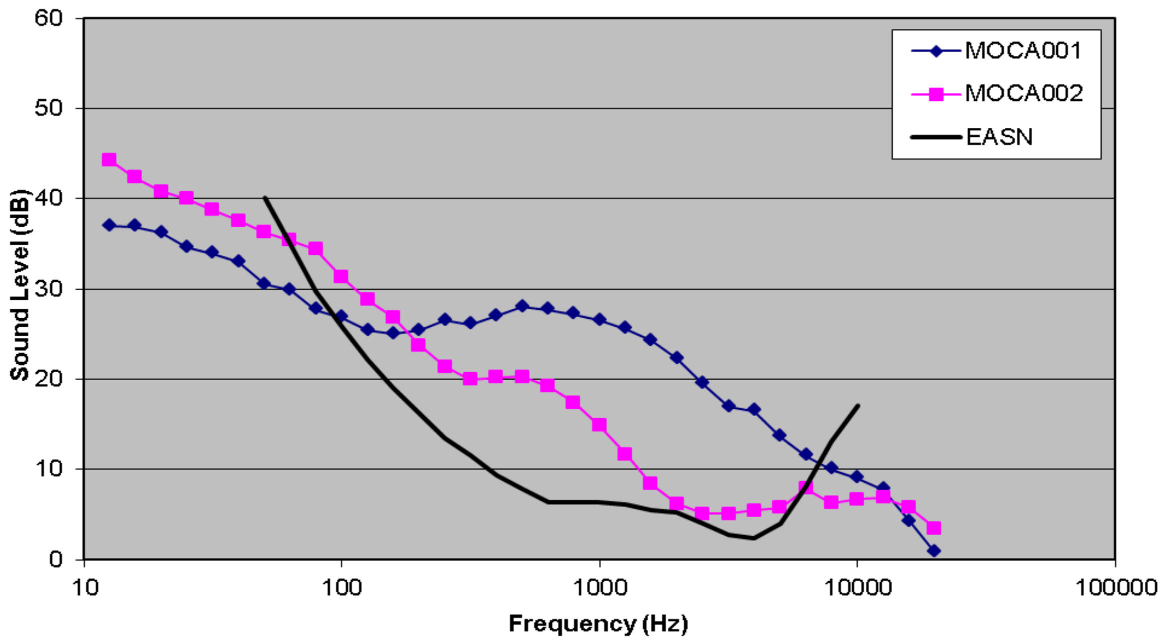

Figure 4. Spectral data for the Existing Ambient Without Air Tours (L_{50}), winter season (2012). [7]

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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.

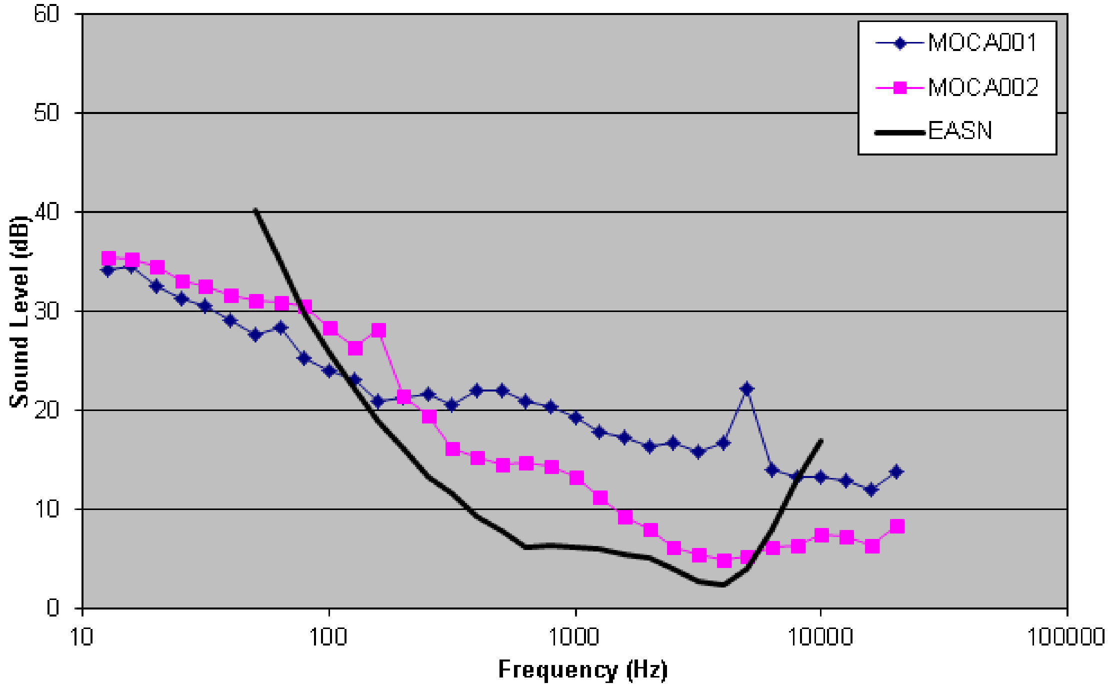

Figure 5. Spectral data for the Natural Ambient (L_{50}), summer season (2010). [9]

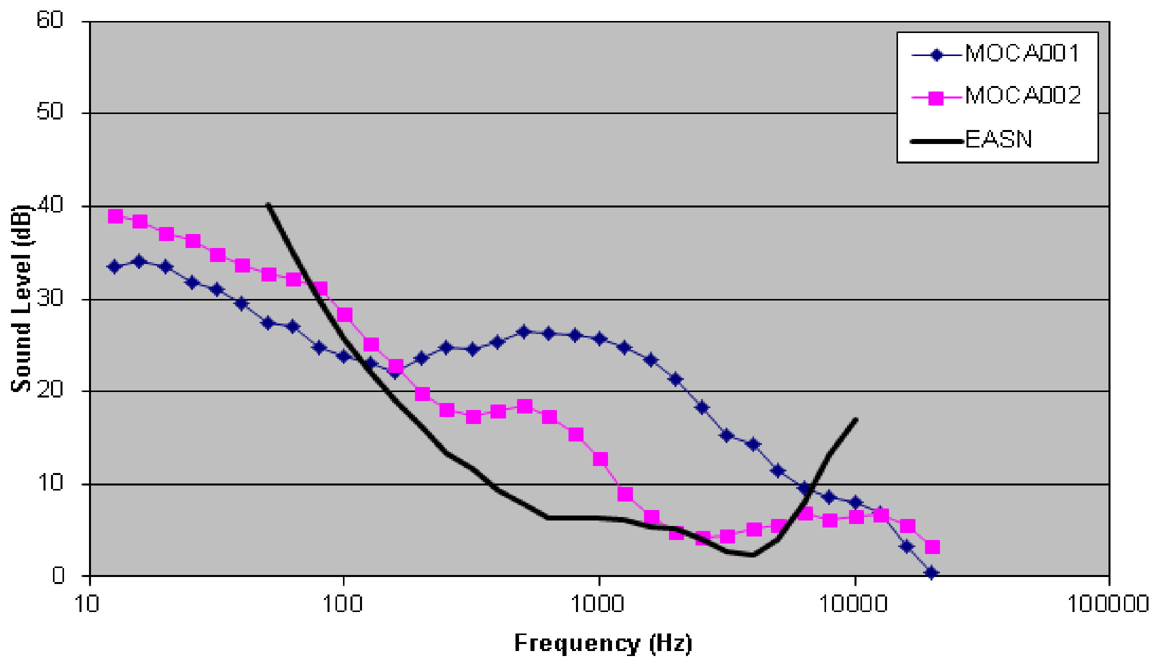

Figure 6. Spectral data for the Natural Ambient (L_{50}), winter season (2012). [8]

[9] 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 9 and Table 10 report the percent of time that measured levels were above four sound level values at each of the Montezuma Castle measurement locations for each 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 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
Summer season (2010)									
MOCA001	Montezuma Castle	71.4	11.2	1.9	0.1	98.8	65.1	2.7	0.0
MOCA002	Montezuma Well	21.2	2.8	0.4	0.0	30.5	2.8	0.1	0.0
Winter season (2012)									
MOCA001	Montezuma Castle	76.4	3.6	0.5	0.0	36.9	0.9	0.1	0.0
MOCA002	Montezuma Well	13.4	1.4	0.3	0.0	2.8	0.2	0.0	0.0

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
Summer season (2010)									
MOCA001	Montezuma Castle	25.5	2.2	0.4	0.0	5.5	0.3	0.0	0.0
MOCA002	Montezuma Well	11.6	1.8	0.3	0.0	3.5	0.2	0.0	0.0
Winter season (2012)									
MOCA001	Montezuma Castle	38.8	2.0	0.3	0.0	5.0	0.3	0.0	0.0
MOCA002	Montezuma Well	11.3	1.2	0.2	0.0	2.4	0.2	0.0	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 7 presents the daily median Existing Ambient (i.e., the L_{50} with all sounds included). 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 on an hourly basis in Figure 8. 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.

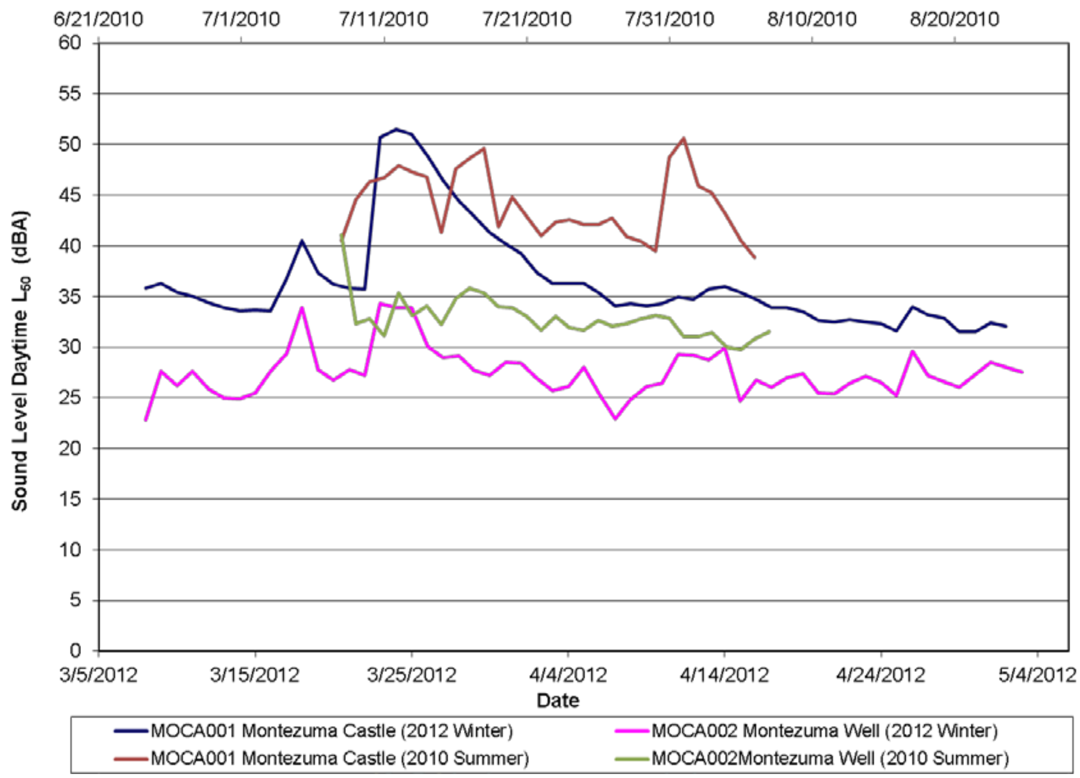

Figure 7. Comparison of daily L_{50} sound levels.

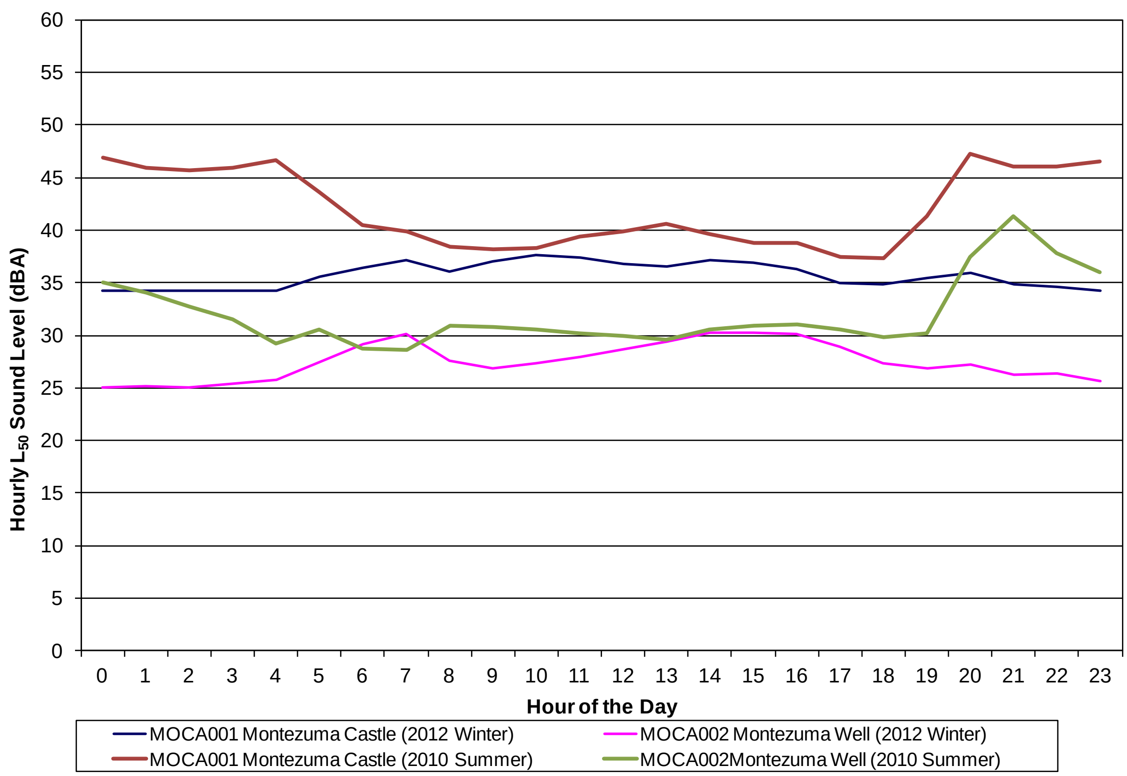

Figure 8. Comparison of hourly L_{50} sound levels.

4.4 Acoustical Observer Log Results

Table 11 summarizes the combined listening results determined from both *in-situ* and off-site sound source logs. This table provides an indication of the amount of time that certain sources are present at each site. *In-situ* logging occurs on-site; an observer logs the source, time and duration of audible sounds. Typically a limited amount of *in-situ* logging data is available due to measurement logistics. Off-site listening results are from a post-measurement review of the continuous 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. *In situ* logging was performed in 2010, off-site listening in 2012. Table 12 summarizes the nighttime off-site listening results for the winter measurements (nighttime off-site listening was not performed for the summer season data).

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

Site ID	Site Name	% Time Audible			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
Summer season (2010)					
MOCA001	Montezuma Castle	9.8	10.8	65.2	14.3
MOCA002	Montezuma Well	14.3	15.8	37.8	32.1
Winter season (2012)					
MOCA001	Montezuma Castle	21.5	4.7	50.6	23.2
MOCA002	Montezuma Well	8.6	13.5	39.4	38.5

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

Site ID	Site Name	% Time Audible			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
Winter season (2012)					
MOCA001	Montezuma Castle	0.0	12.9	20.3	66.8
MOCA002	Montezuma Well	0.0	10.2	41.0	48.8

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. For ATMPs, the FAA's Integrated Noise Model INM[10] will be used to model air tour aircraft activities and compute various noise-related descriptors (e.g., percentage of time aircraft sounds are above the ambient) and generate the sound-level contours that will be used in the assessment of potential noise impacts due to air tour operations.

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)[11] coordinates to set the initial grid area boundary.[12]
  - 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 Montezuma Castle, 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:

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[10] For ATMPs, the FAA and NPS have agreed to use the INM. The INM is a computer program used by over 700 organizations in over 50 countries to assess changes in noise impact. Requirements for INM use are defined in FAA Order 1050.1E, Environmental Impacts: Policies and Procedures, and Federal Aviation Regulations (FAR) Part 150, Airport Noise Compatibility Planning. In accordance with the results of the Federal Interagency Committee on Aviation Noise (FICAN) review ("Findings and Recommendations on Tools for Modeling Aircraft Noise in National Parks"), INM Version 6.2 is the best-practice modeling methodology currently available for evaluating aircraft noise in national parks and will be the model used for ATMP development.

[11] The UTM system provides coordinates on a worldwide flat grid for easy manipulation in GIS applications.

[12] 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.

- 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.

5.1 Assignment of Measured Ambient Data to Acoustical Zones

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 9 presents the acoustical zones that were developed and the location of the measurement sites for MOCA. The ATMP Act applies to all commercial air tour operations within the ½-mile outside the boundary of a national park.

Table 13 presents which measurement site data were applied to each acoustical zone based on best available data and geographical proximity.

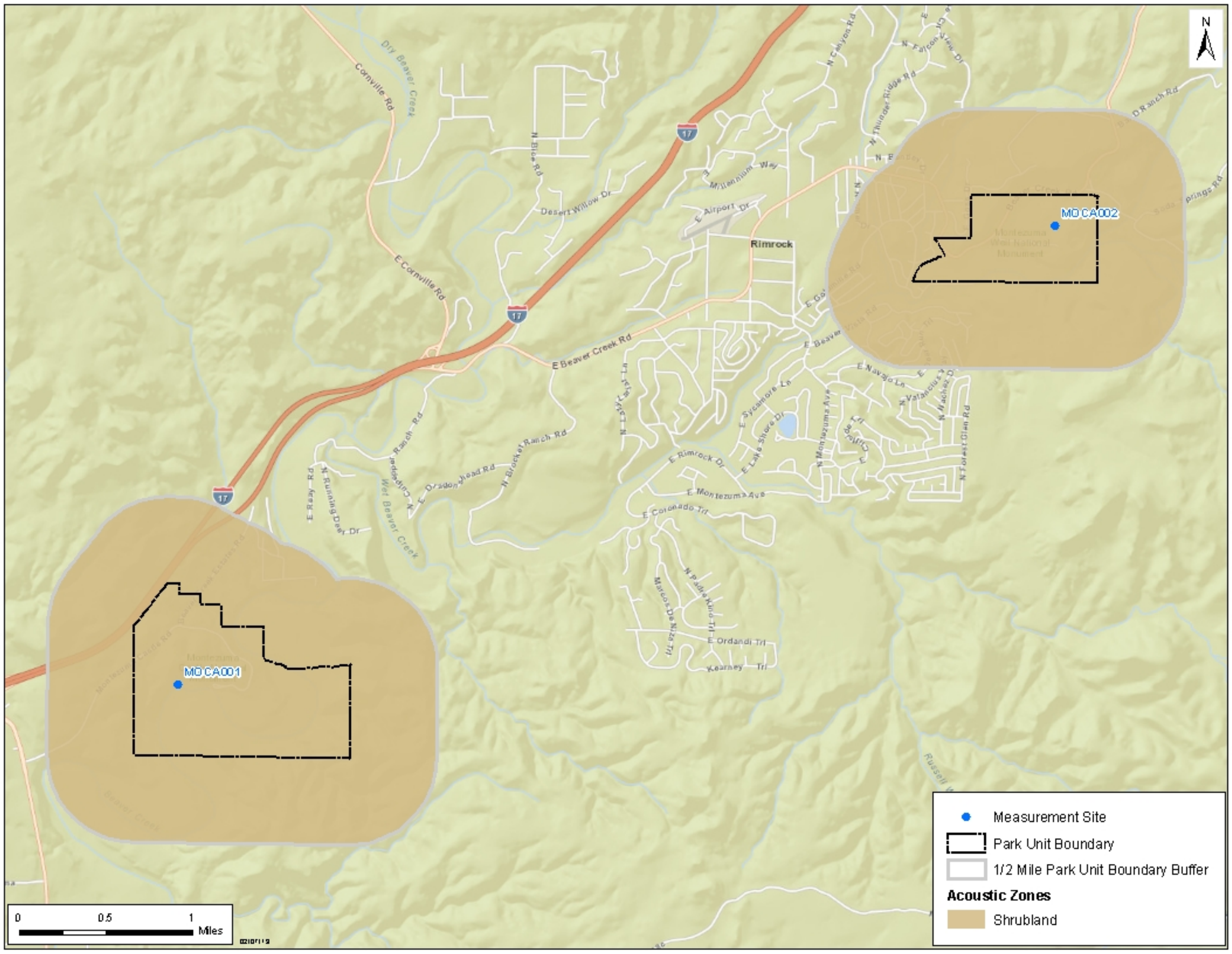

Figure 9. Acoustical zones and measurement sites for MOCA.

Table 13. Assignment of ambient data to acoustical zones.

Acoustical Zone	Site ID	Site Name
Shrubland (Montezuma Castle unit)	MOCA001	Montezuma Castle
Shrubland (Montezuma Well unit)	MOCA002	Montezuma Well

5.2 Ambient Mapping of Localized Sound Sources

The contributing effect of localized noise sources, primarily vehicles on roads, but may also include brooks, waterfalls, and river rapids, 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 14). 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 Sound Source of Interest	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 the Montezuma Castle unit, 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 Arizona Department of Transportation (AZDOT) (Arizona Department of Transportation 2013). Where data are available for multiple years, the year corresponding to the study year was chosen. The traffic volume for an average day during the peak winter month (February) and peak summer month (May) was obtained by using monthly visitation data obtained from the NPS Public Use Statistics Office website (National Park Service 2013b) to apportion the AZDOT annual traffic. Hourly volume is estimated by dividing the month's volume by the number of days in the month (28 and 31 respectively) and by 12 hours per day, which assumes the majority of traffic for MOCA 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 2013b); and (2) observations by field personnel during 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. When multiple speed limit signs showed varying speeds over a single road segment, an average. 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 Montezuma Castle.

Table 15. Estimated hourly roadway traffic volume and speed.

Roadway			Estimated hourly volume				
#	Name	Average Speed (mph)	Autos	Medium Trucks	Heavy Trucks	Buses	Motor-cycles
Summer season (2010)							
1	I-17 (Exit 285 General Cook Trail to Exit 287 SR-260, Camp Verde/Cottonwood)	75	1,994	80	46	2	65
2	I-17 (Exit 287 SR-260, Camp Verde/Cotton to Exit Middle Verde Rd)	75	2,260	91	52	3	74
3	I-17 (Exit 289 Middle Verde Rd to Exit 293 Cornville Rd. - McGuireville)	75	2,038	82	47	2	67
4	I-17 (Exit 293 Cornville Rd . McGuireville to Exit 298 SR-179 N)	75	1,772	71	41	2	58
5	Middle Verde Rd	35	222	9	5	0	7
6	SR260 (Cherry Rd to I-17 Exit 287)	55	1,196	48	28	1	39
7	SR260 (I-17 Exit 287 to Finnie Flat)	45	806	32	19	1	26
8	Montezuma Castle Rd	35	32	1	1	0	1
9	Montezuma Well/ Beaver Creek Rd	45	12	1	0	0	0
10	Montezuma Castle Hwy	35	222	9	5	0	7
11	SR260 (from Finnie Flat Rd to General Crook Tr)	45	470	19	11	1	15
12	SR260 (General Crook Tr to Main St)	45	558	22	13	1	18
Winter season (2012)							
1	I-17 (Exit 285 General Cook Trail to Exit 287 SR-260, Camp Verde/Cottonwood)	75	1,507	60	35	2	49
2	I-17 (Exit 287 SR-260, Camp Verde/Cotton to Exit Middle Verde Rd)	75	1,911	77	44	2	63
3	I-17 (Exit 289 Middle Verde Rd to Exit 293 Cornville Rd. - McGuireville)	75	1,543	62	36	2	51
4	I-17 (Exit 293 Cornville Rd . McGuireville to Exit 298 SR-179 N)	75	1,470	59	34	2	48
5	Middle Verde Rd	35	184	7	4	0	6
6	SR260 (Cherry Rd to I-17 Exit 287)	55	1,029	41	24	1	34
7	SR260 (I-17 Exit 287 to Finnie Flat)	45	808	32	19	1	26
8	Montezuma Castle Rd	35	28	0	0	0	0
9	Montezuma Well/ Beaver Creek Rd	45	10	0	0	0	0
10	Montezuma Castle Hwy	35	184	7	4	0	6
11	SR260 (from Finnie Flat Rd to General Crook Tr)	45	390	16	9	1	13
12	SR260 (General Crook Tr to Main St)	45	448	18	10	1	15

5.3 Final Ambient Maps

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

- Existing Ambient Without Air Tours (i.e., the Source of Interest); and
- Natural Ambient.

Figure 10 through Figure 13 present the ambient maps for the winter and summer seasons.

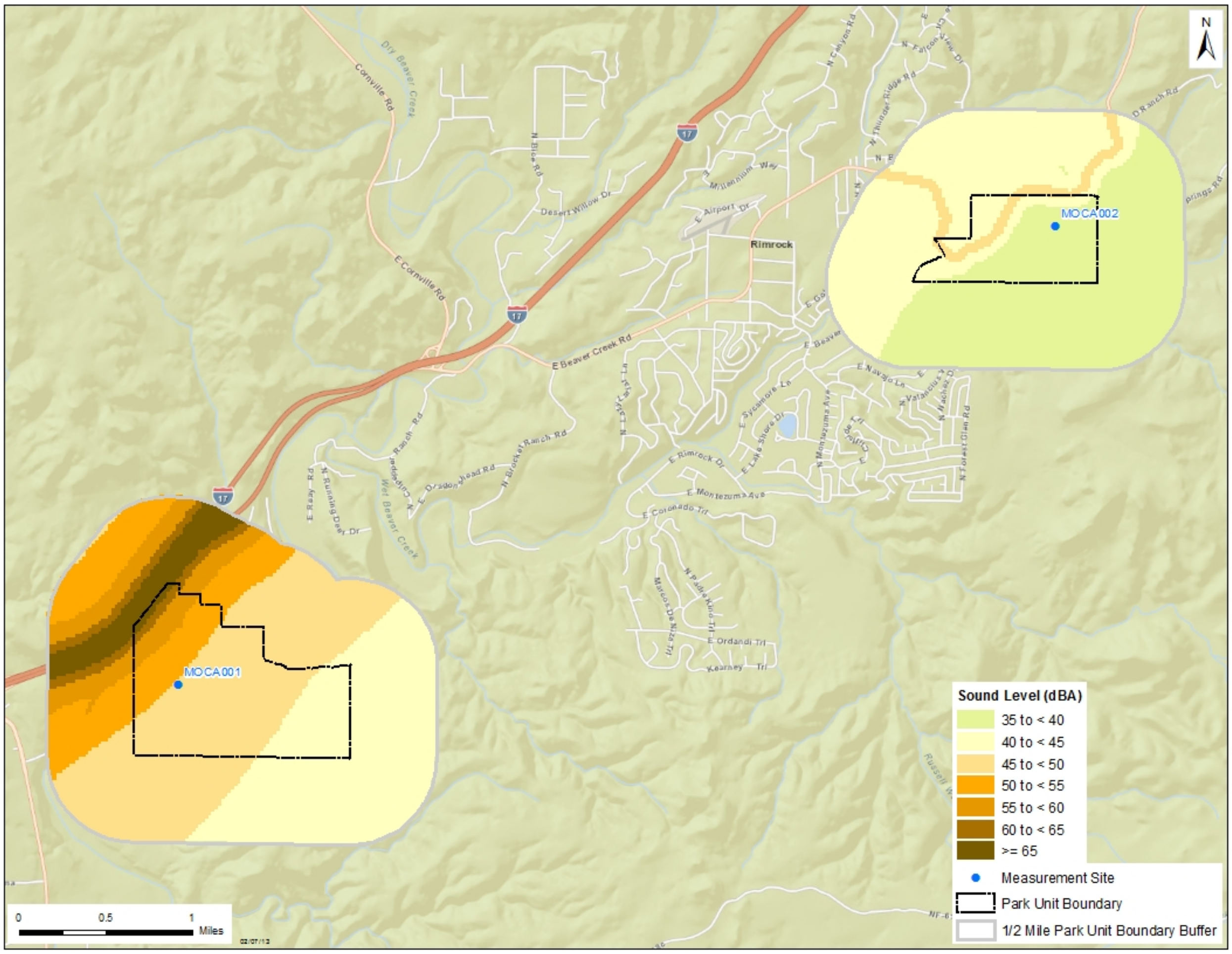

Figure 10. Baseline ambient map; Existing Ambient Without Air Tours (L_{50}), summer season (2010).

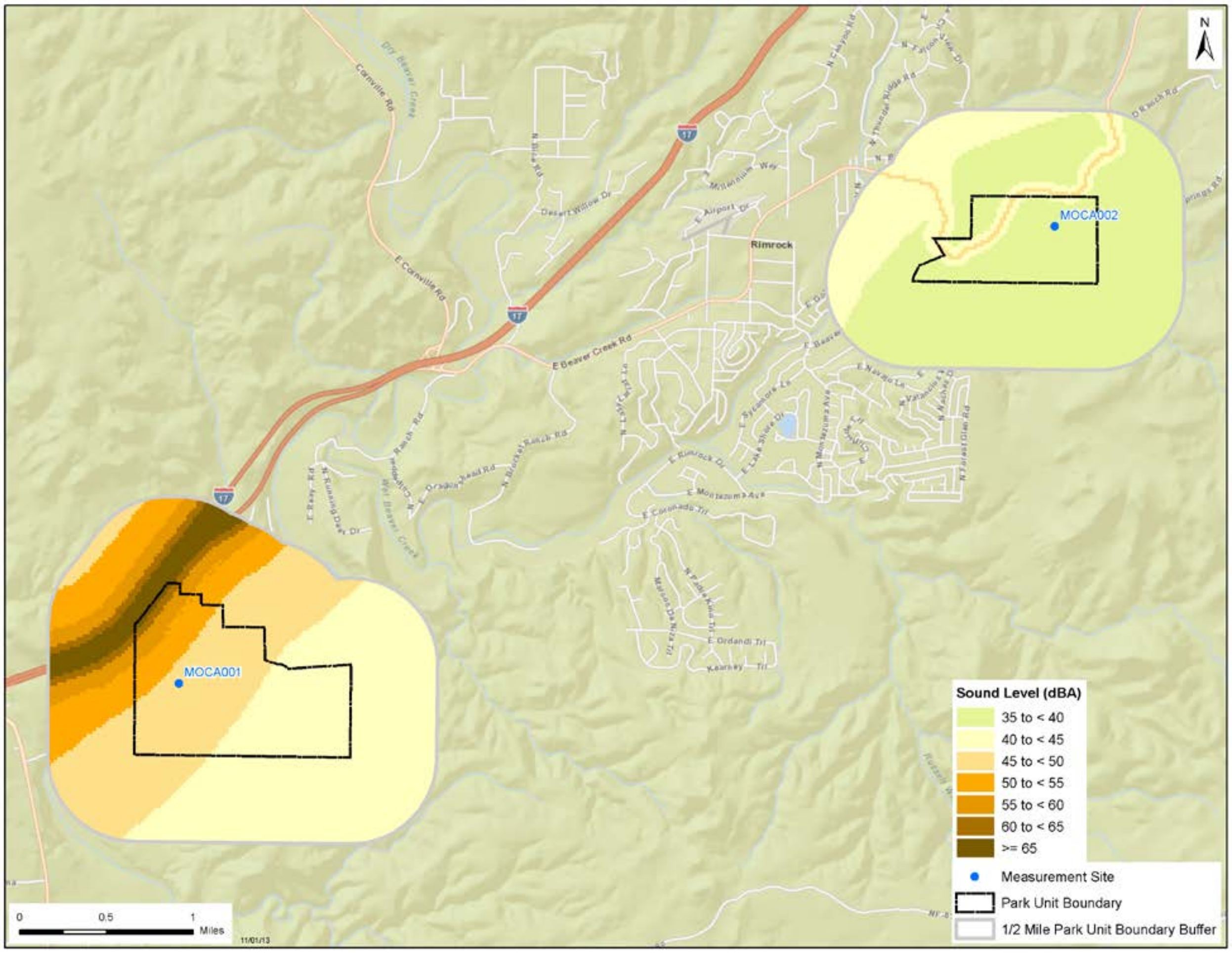

Figure 11. Baseline ambient map; Existing Ambient Without Air Tours (L_{50}), winter season (2012).

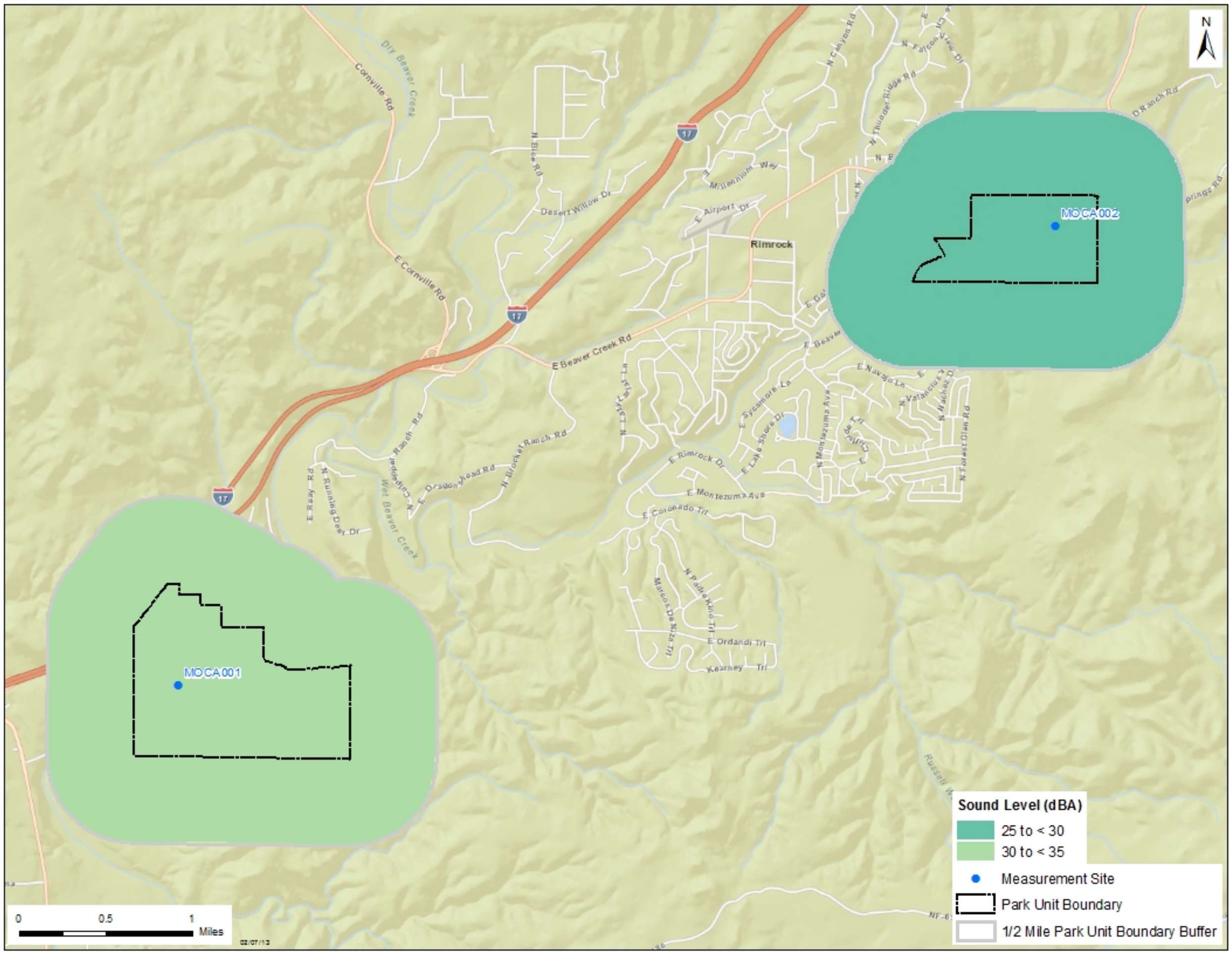

Figure 12. Baseline ambient map; Natural Ambient (L_{50}), summer season (2010).

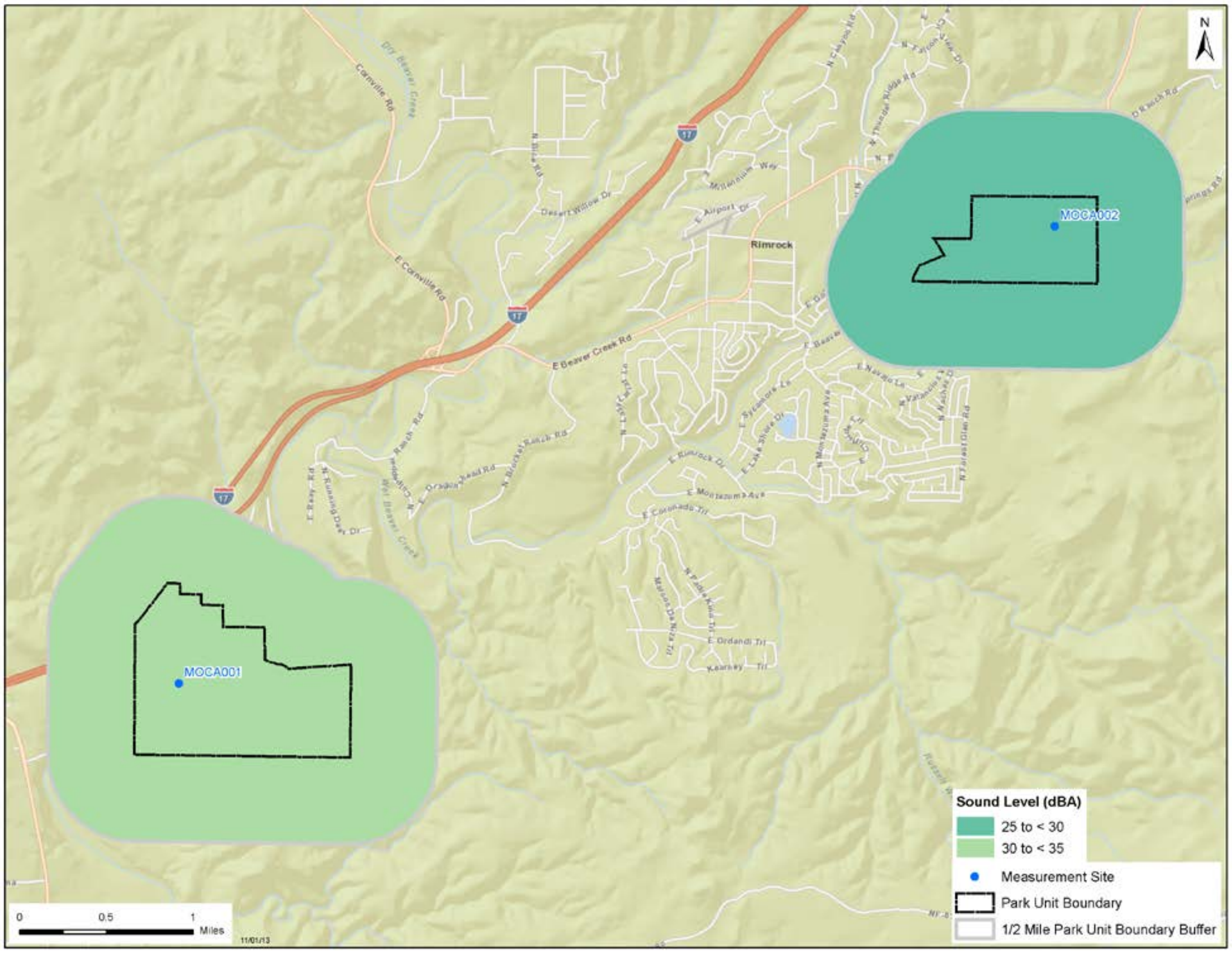

Figure 13. Baseline ambient map; Natural Ambient (L_{50}), winter season (2012).

6. Data for Individual Sites

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

- Figure 14, Figure 25: A photograph of the measurement site and a brief discussion of preliminary observations;
- Figure 15, Figure 16, Figure 26, Figure 27: A pie chart presenting a comparison of types of sound sources that were audible during observer logging;
- Figure 17, Figure 18, Figure 28, Figure 29: 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;
- Figure 19, Figure 20, Figure 30, Figure 31: A graphic presenting the daily sound levels using three hourly A-weighted 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;
- Figure 21, Figure 22, Figure 32, Figure 33: 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
- Figure 23, Figure 24, Figure 34, Figure 35: A graphic presenting the dB levels for each of 33 one-third octave-band frequencies over the day and night periods using three hourly A-weighted metrics (L_{10}, L_{50}, and L_{90}). The L_{10} exceedence 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 MOCA001 – Montezuma Castle

Figure 14. Photographs of Site MOCA001, summer 2010 (left) and winter 2012 (right).

The MOCA001 Montezuma Castle site was located just off Loop trail approximately ¼ mile from a parking lot, 0.4 miles from Interstate 17, and 40 yards from the Beaver Creek bed. The site's proximity to MOCA's main trail subjected it to regular park visitor noise. The measurement system collected data from July 8, 2010 to August 7, 2010 to represent the summer season and March 8, 2012 to May 2, 2012 to represent the winter season. The vegetation near the measurement system consisted of grass with no canopy cover during the winter and dry grasses with some canopy cover during the summer, at an approximate altitude of 3,250 ft. Daytime sources of sound included vehicle sounds, visitor sounds, birds, insects, commercial jet aircraft, propeller aircraft, wind and water related sounds.

Figure 15 and Figure 16 summarize on-site observations and off-site review of recorded audio data for daytime and nighttime hours (nighttime observer data are unavailable for the summer season). Aircraft were audible 21% of daytime hours during summer 2010; 26% of daytime hours and 13% of nighttime hours during winter 2012. Other human related sounds (mostly voices and vehicles) were audible 65% of the summer daytime hours during summer 2010; 51% of daytime hours and 20% of nighttime hours during winter 2012. 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 14% of summer daytime hours, 23% of winter daytime hours, and 67% of winter nighttime hours. Natural sounds audible at this site, which could have occurred concurrently with human sounds, included wind, water-related sounds from Beaver Creek, bird vocalizations, and insects.

The overall median daytime sound level for this site was 38.6 dBA during the summer 2010 and 36.5 dBA during the winter 2012. Daily (twenty-four hour) median sound levels (L_{50}) ranged from 38 to 51 dB during the summer and 32 to 52 during the winter (Figures 16 and 17). Elevated L_{50} sound levels correspond to storm activity in the area, including wind, precipitation, and thunder. Particularly loud days on March 23, 2012 and July 30-August 5, 2010 were caused by storm activity and increased water levels in Beaver Creek.

Hourly median sound levels during summer 2010 ranged from 28 to 41 dBA; nighttime increases are due to insect activity. Hourly median sound levels ranged from 34 during the overnight hours to 38 dBA at 10 am.

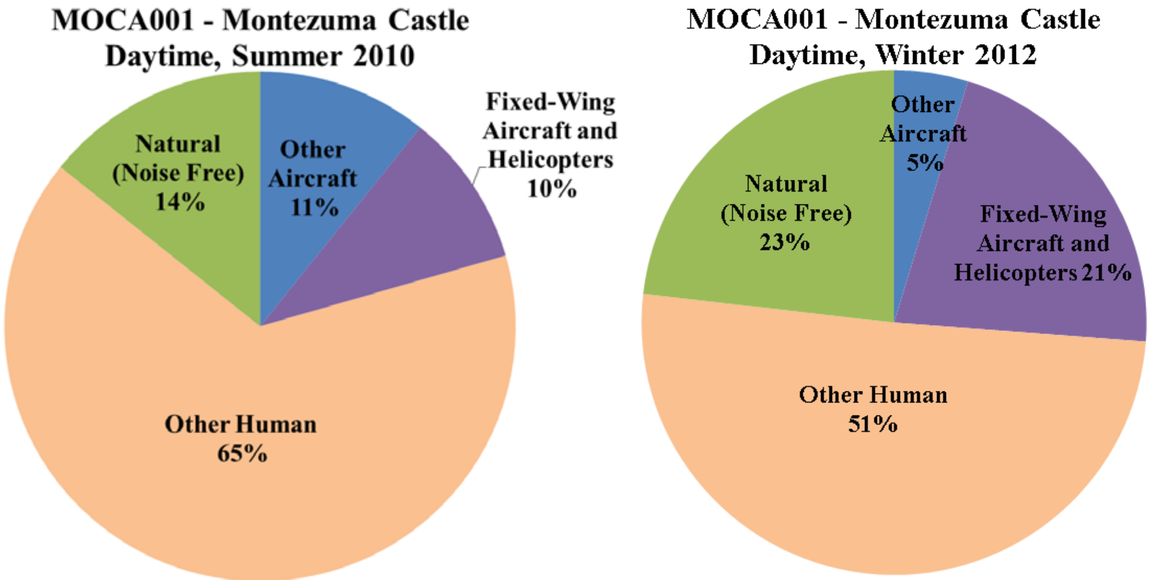

Figure 15. Distribution of daytime sound sources audible (*in situ* and off-site listening combined) for MOCA001, summer season (2010) (left) and winter season (2012) (right).

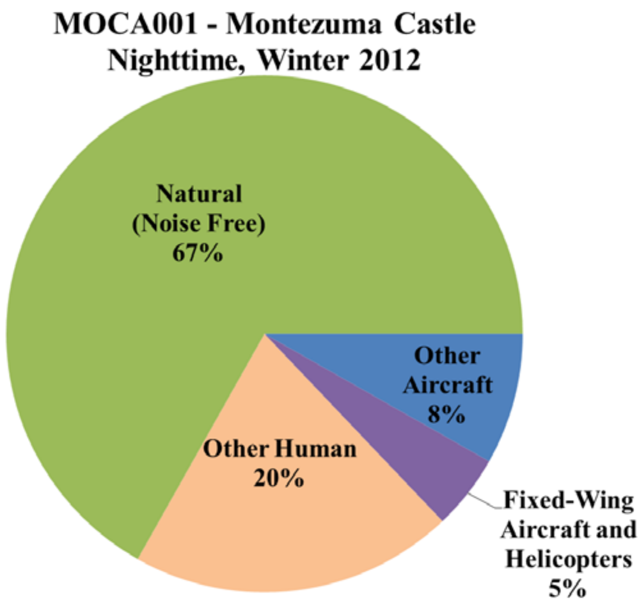

Figure 16. Distribution of nighttime sound sources audible (off-site listening) for MOCA001, winter season (2012) (summer season results unavailable).

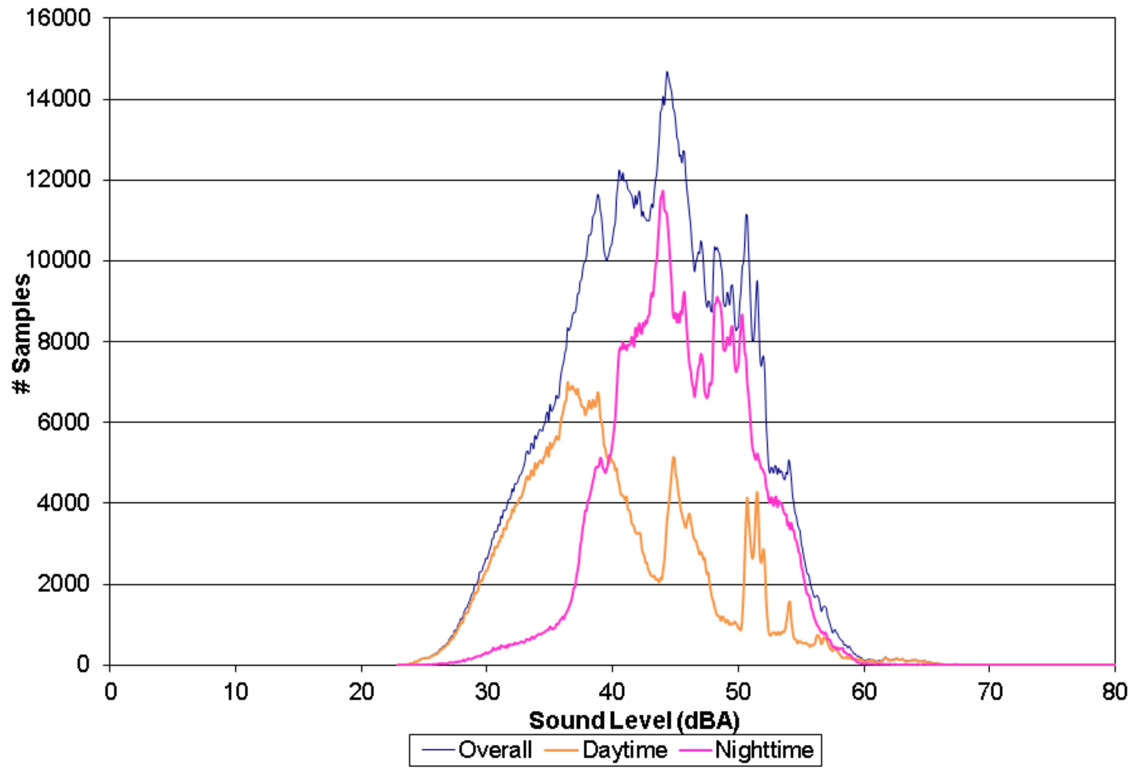

Figure 17. Distribution of sound level data for MOCA001, summer2010.

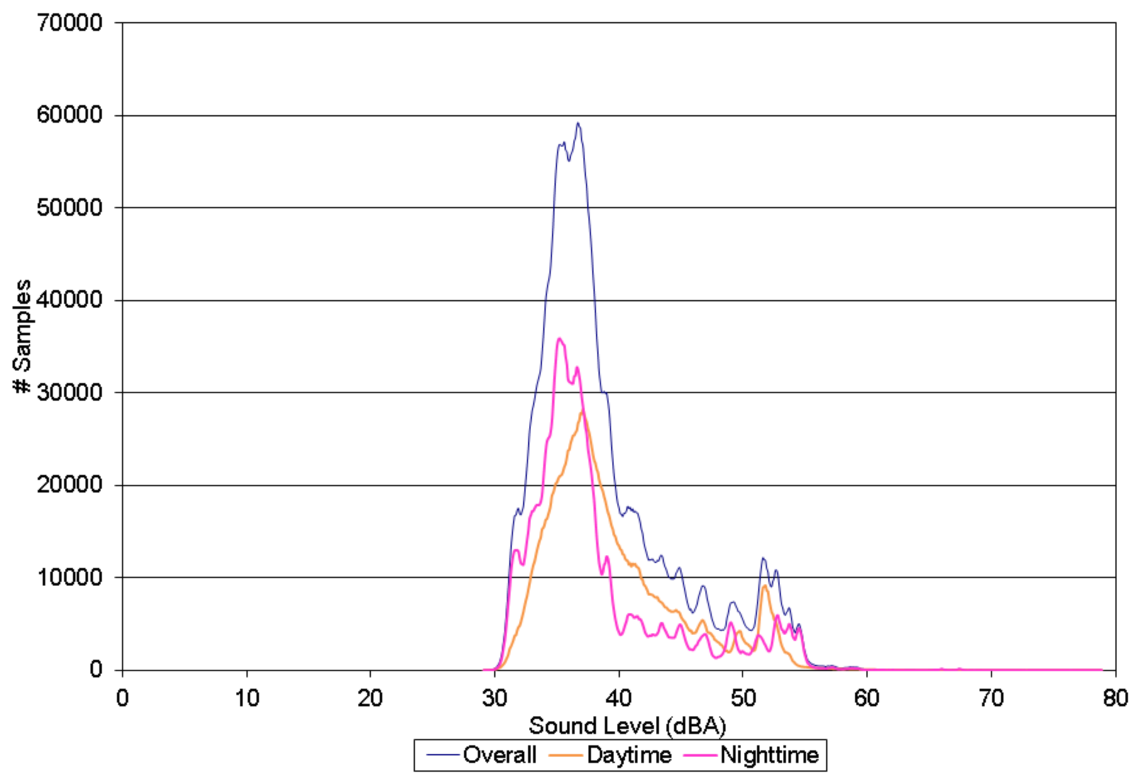

Figure 18. Distribution of sound level data for MOCA001, winter season (2012).

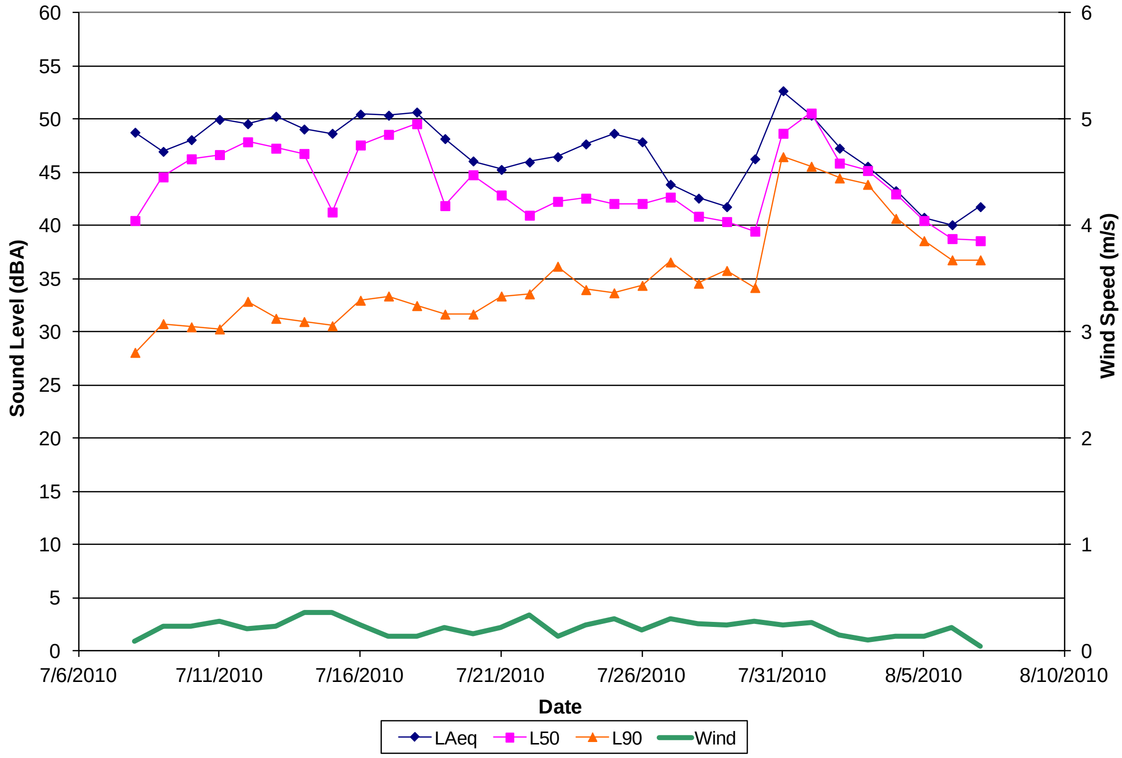

Figure 19. Daily sound levels and wind speeds for Site MOCA001, summer season (2010).

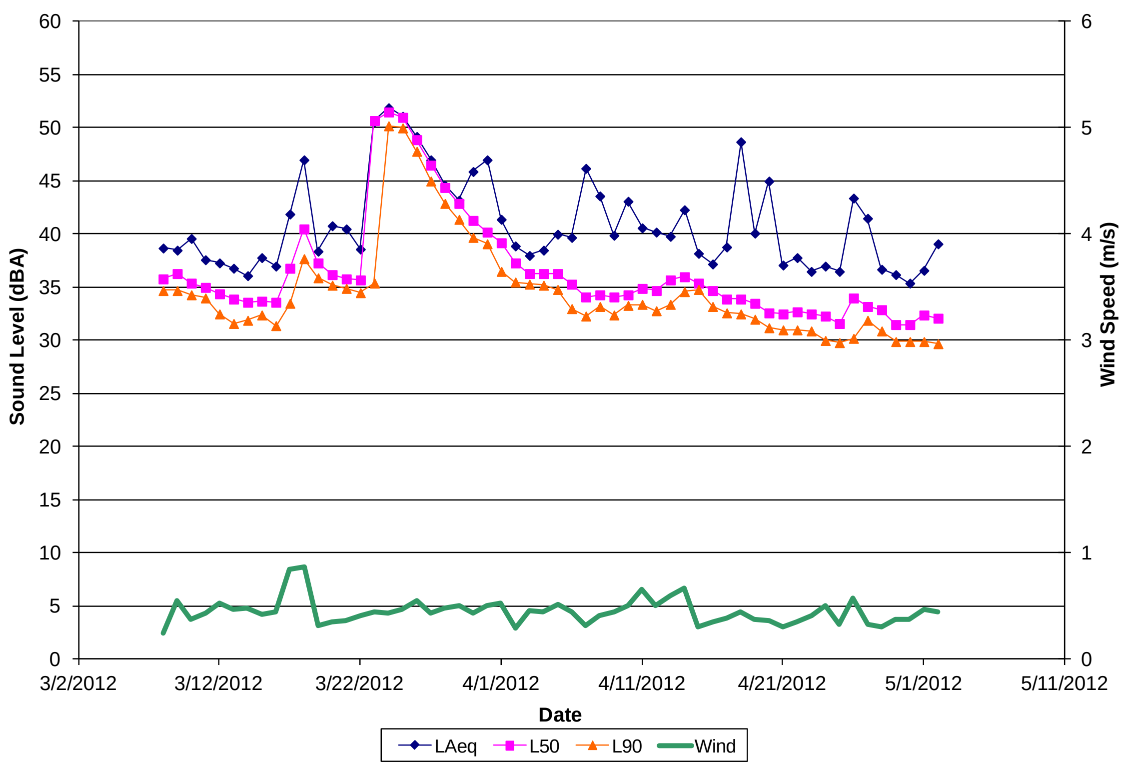

Figure 20. Daily sound levels and wind speeds for Site MOCA001, winter season (2012).

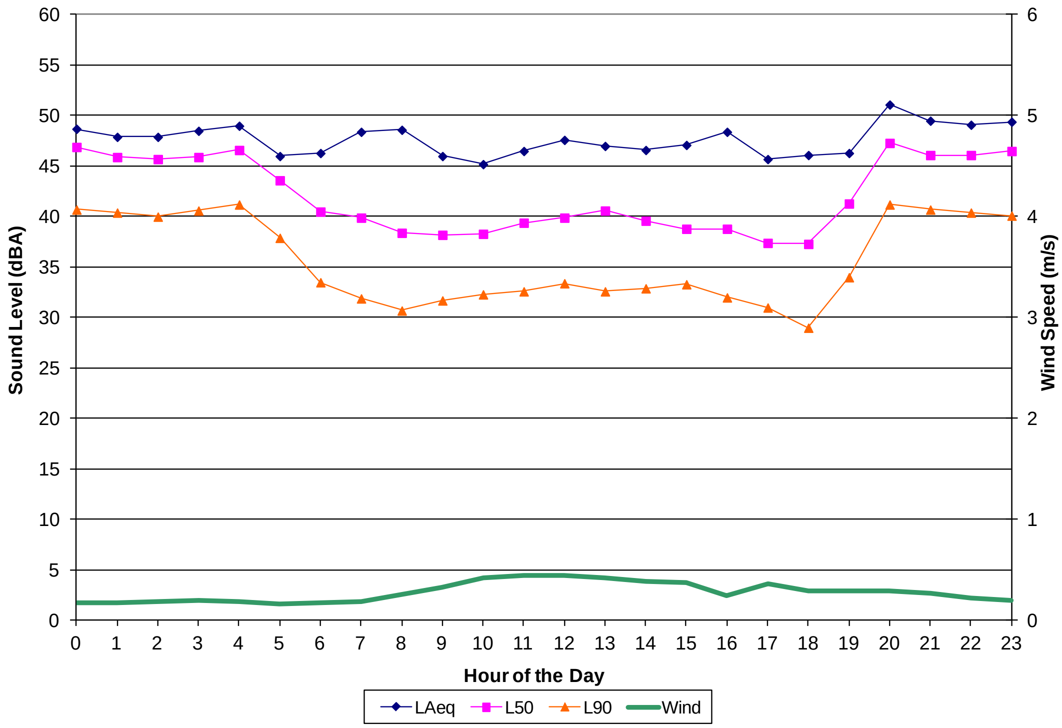

Figure 21. Hourly sound levels and wind speeds for Site MOCA001, summer season (2010)

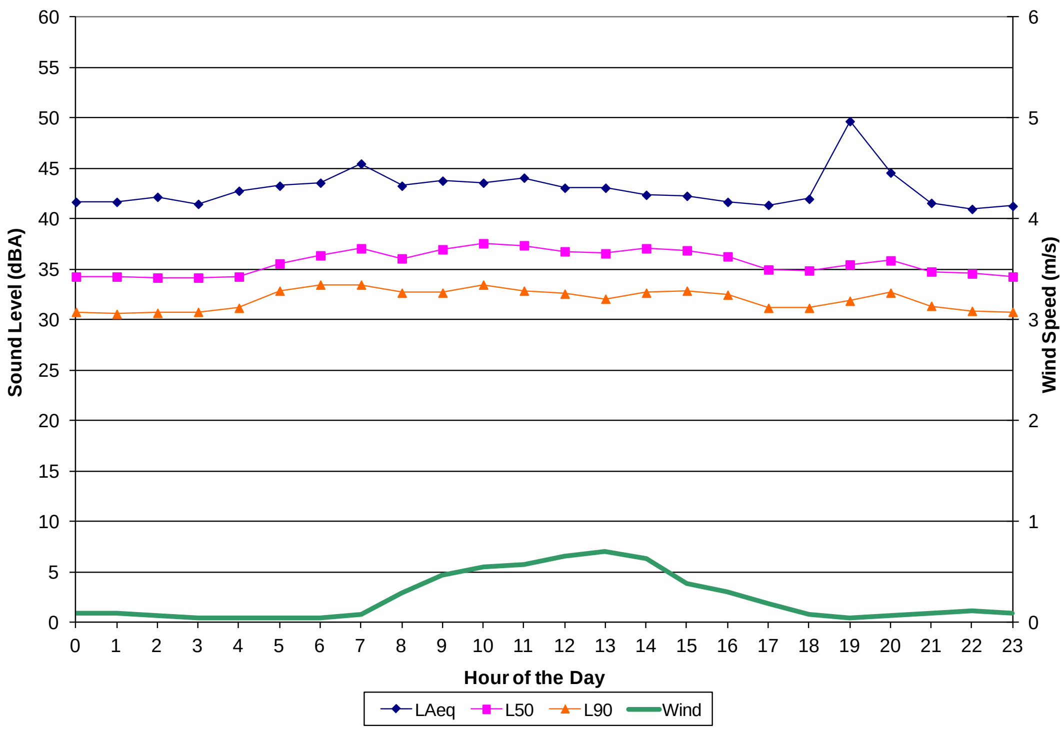

Figure 22. Hourly sound levels and wind speeds for Site MOCA001, winter season (2012).

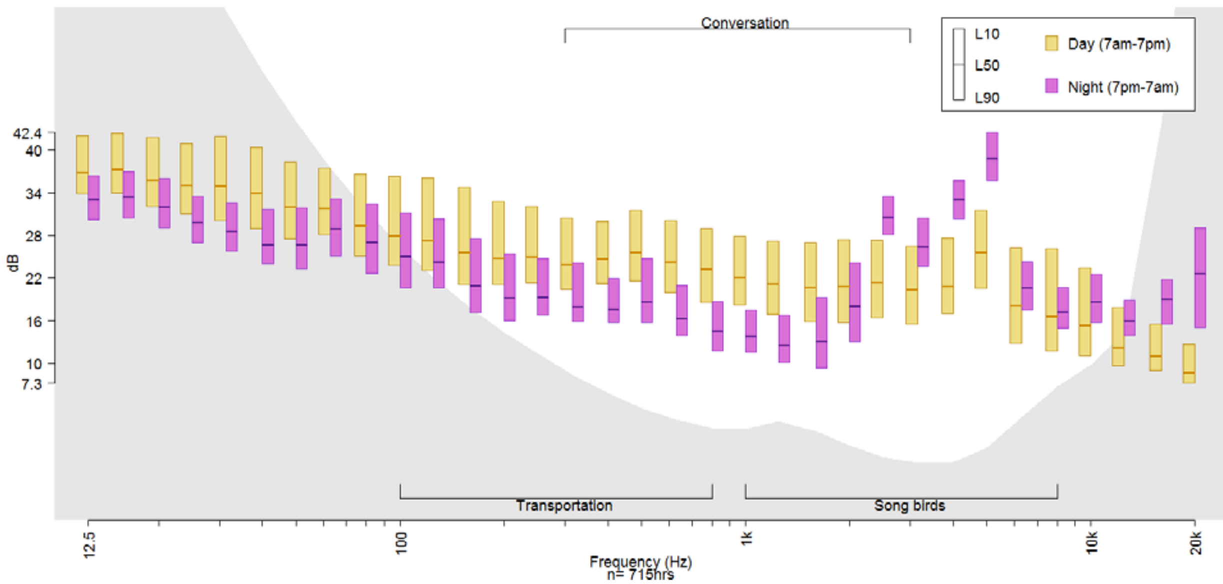

Figure 23. Sound spectrum for MOCA001, summer season (2010)

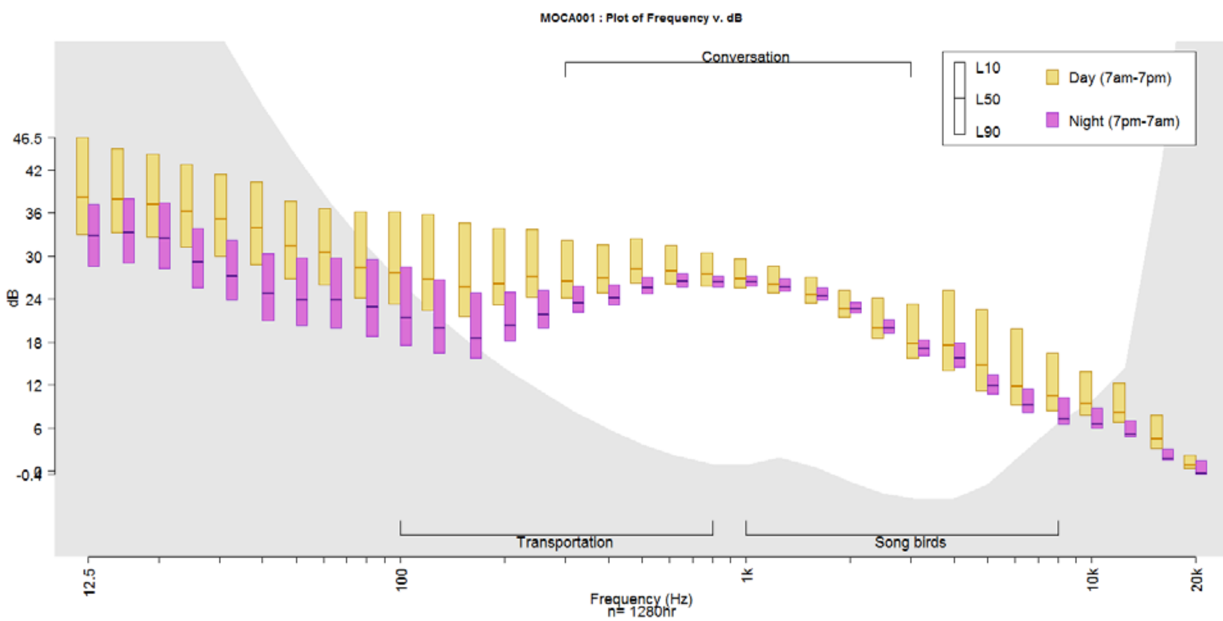

Figure 24. Sound spectrum for MOCA001, winter season (2012)

6.2 Site MOCA002 – Montezuma Well

Figure 25. Photograph of Site MOCA002, summer 2010 (winter 2012 photograph unavailable).

The MOCA002 Montezuma Well site was located in the Creosote desert approximately 0.1 miles north of the visitor parking area, 0.1 miles from the Montezuma Well, and 1.9 miles from Interstate 17. This location subjected the system to occasional noise from the visitor parking area and visitor center. The measurement systems collected data from July 8, 2010 to August 7, 2010 to represent the summer season and March 8, 2012 to May 3, 2012 to represent the winter season. The vegetation near the measurement system consisted of desert scrub at an altitude of approximately 3,570 ft. Daytime sources of sound included distant vehicle sounds (including all-terrain vehicles), distant train horns, visitor sounds, birds, insects, commercial jet aircraft, propeller aircraft, wind sounds.

On-site observations and off-site review of recorded audio data (Figure 26 and Figure 27) showed aircraft were audible 30% of daytime hours during summer 2010; 23% of daytime and 10% of nighttime hours during winter 2012. Other human related sounds were audible 38% of the summer 2010 daytime hours; 39% of daytime and 41% of nighttime hours during winter 2012. 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 32% of summer 2010 daytime hours; 38% of daytime and 49% of nighttime hours during winter 2012. Natural sounds audible at this site, which could have occurred concurrently with human sounds, included winds, bird vocalizations, and insects.

The overall median daytime sound level for this site was 30.3 dBA during summer 2010 and 28.8 dBA during winter 2012. Daily (twenty-four hour) median sound levels (L_{50}) ranged from 30 to 40 dB during the summer and 23 to 34 during the winter (Figure 30 and Figure 31). Thunderstorms occurred in the area on July 26 and 30, 2010, and this site experienced loud thunder events in the evening hours on those dates.

Hourly median sound levels during summer 2010 varied from 29 dBA to 40 dBA with louder hourly sound levels occurring in the morning and evening due to persistent insect activity during these hours. Hourly median sound levels during winter 2012 ranged from 25 during the overnight hours to 30 dBA during the early morning (caused by insects) and late afternoon (caused by winds).

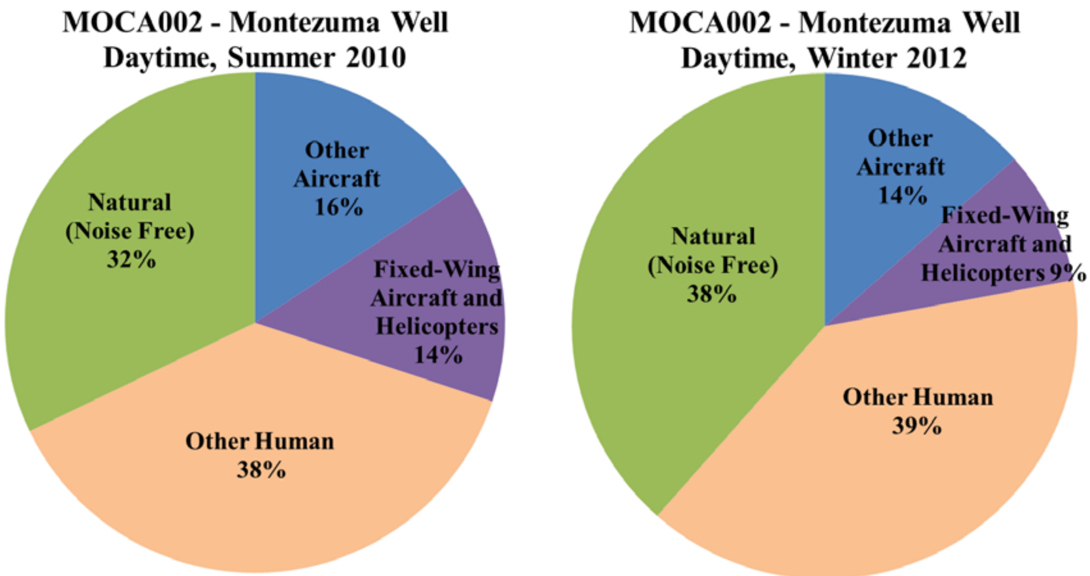

Figure 26. Distribution of daytime sound sources audible (*in situ* and off-site listening combined) for MOCA002, summer season (2010) (left) and winter season (2012) (right).

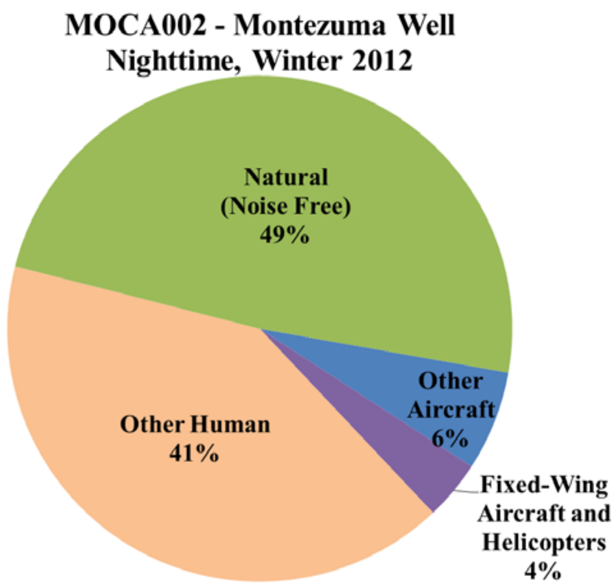

Figure 27. Distribution of nighttime sound sources audible (off-site listening) for MOCA002, winter season (2012) (summer season results unavailable).

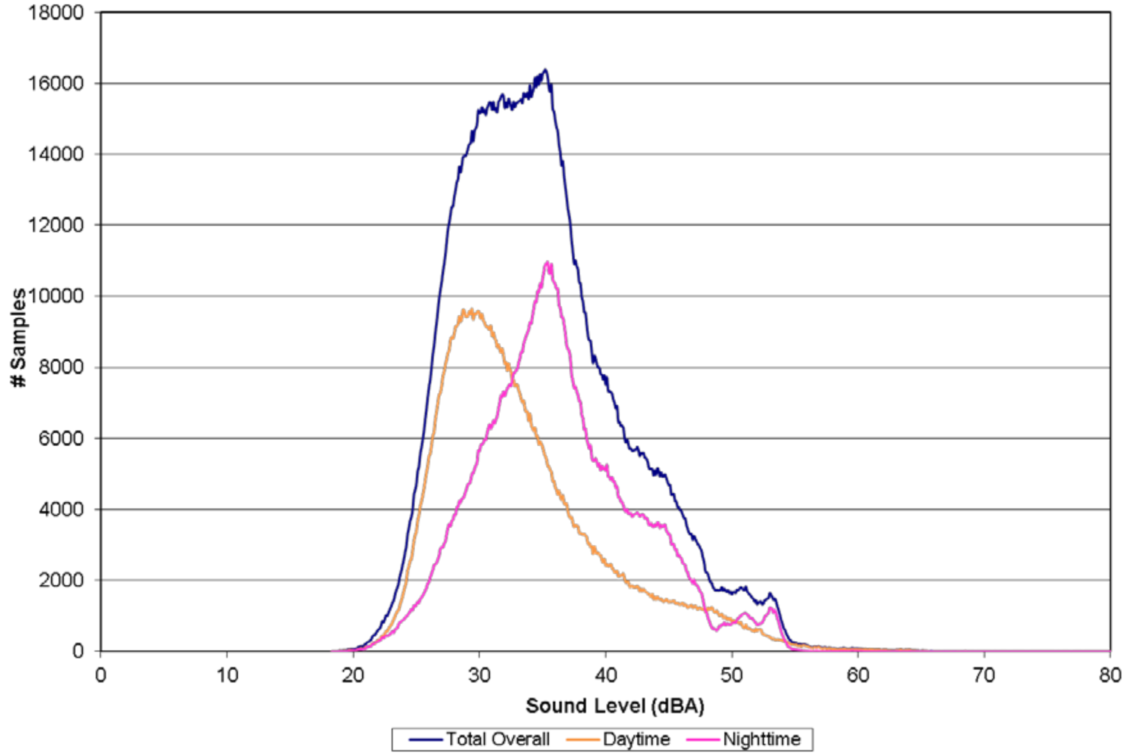

Figure 28. Distribution of data for MOCA002, summer season (2010).

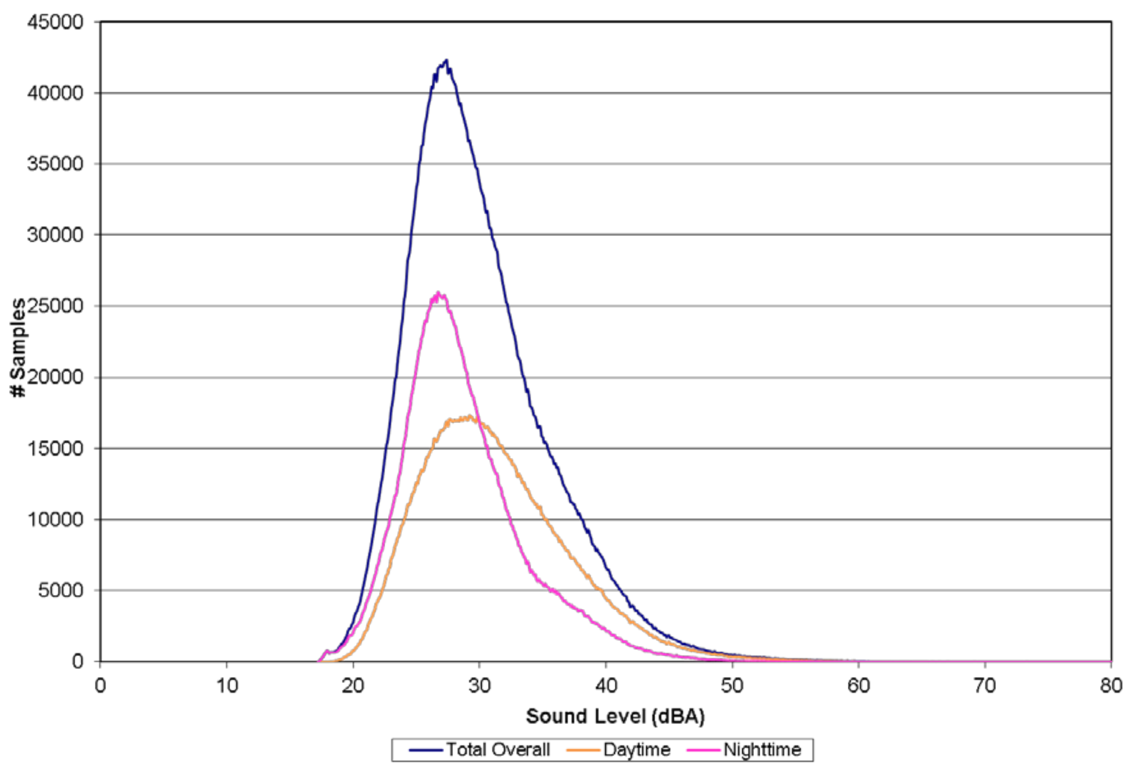

Figure 29. Distribution of data for MOCA002, winter season (2012).

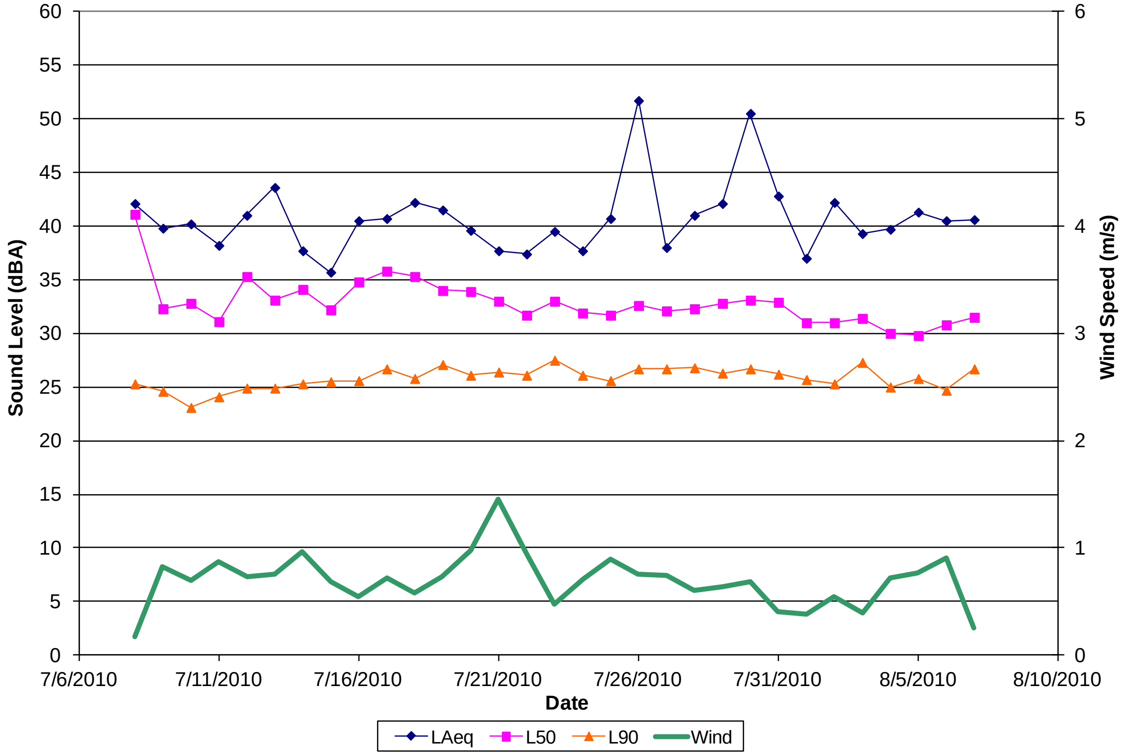

Figure 30. Daily sound levels and wind speeds for Site MOCA002, summer season (2010).

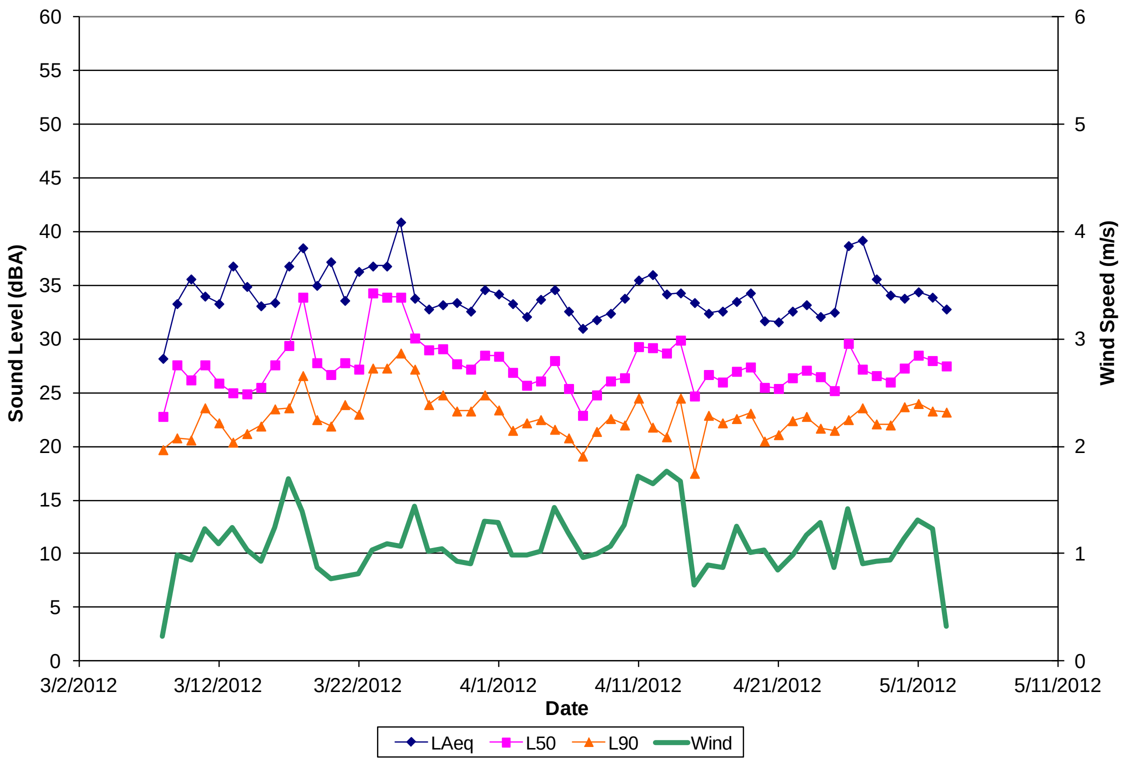

Figure 31. Daily sound levels and wind speeds for Site MOCA002, winter season (2012).

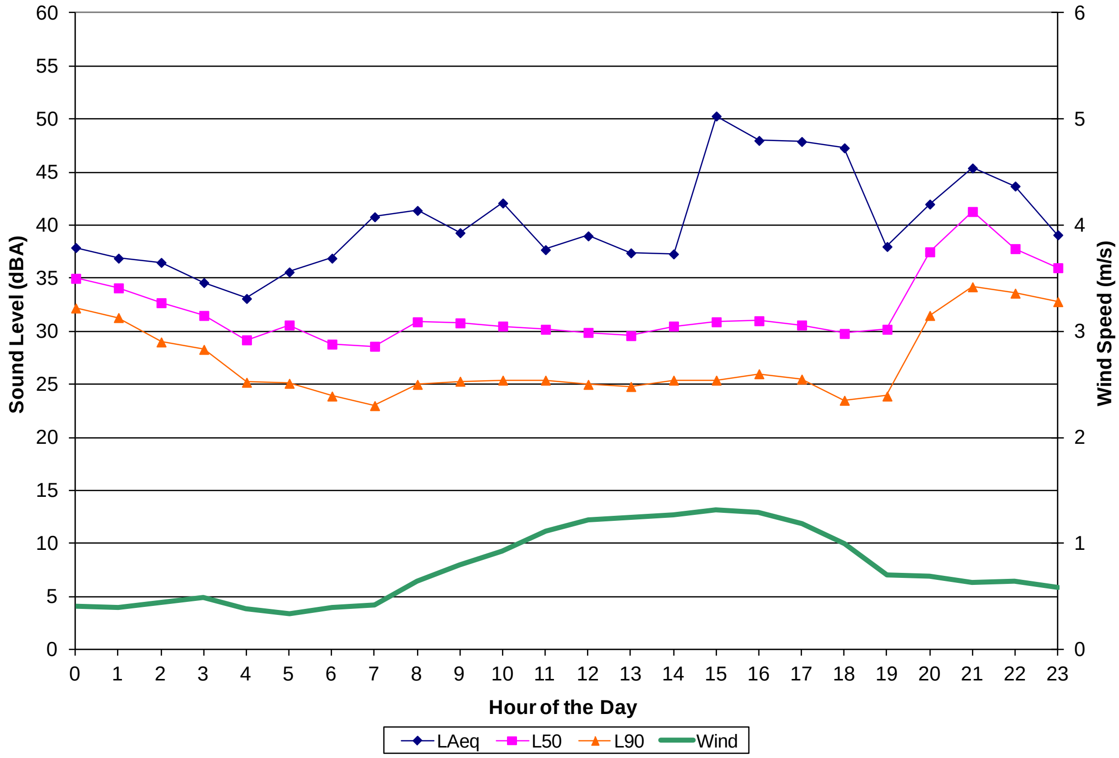

Figure 32. Hourly sound levels and wind speeds for Site MOCA002, summer season (2010).

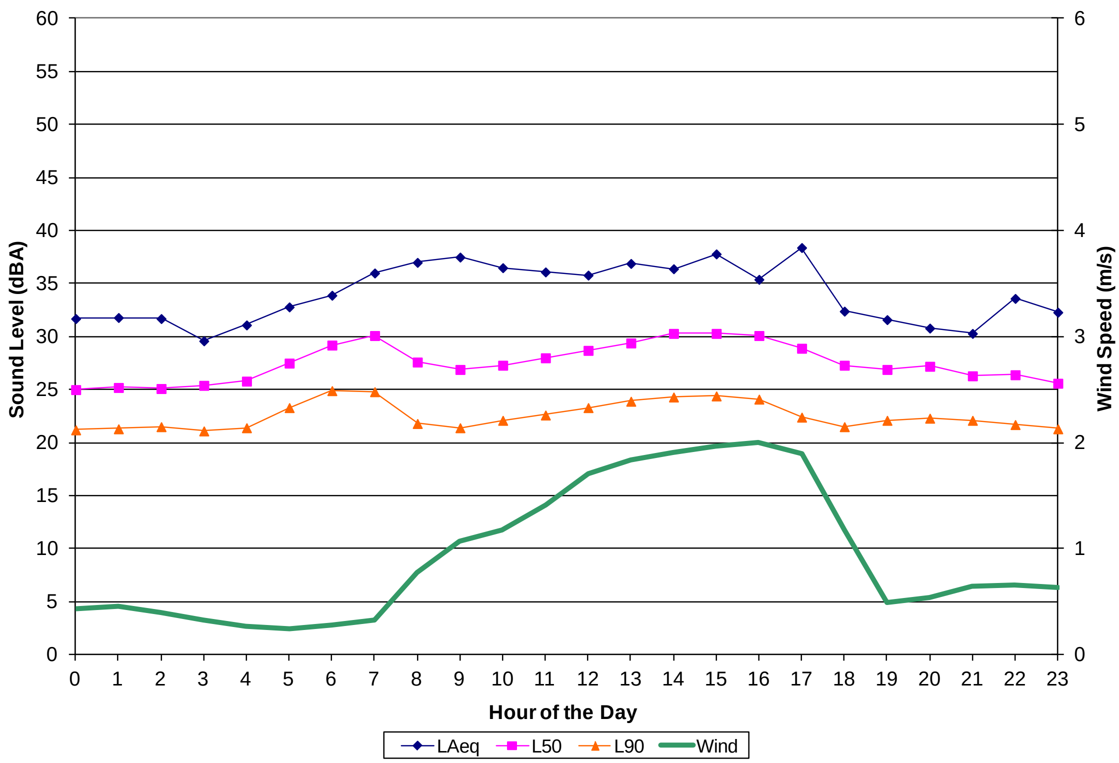

Figure 33. Hourly sound levels and wind speeds for Site MOCA002, winter season (2012).

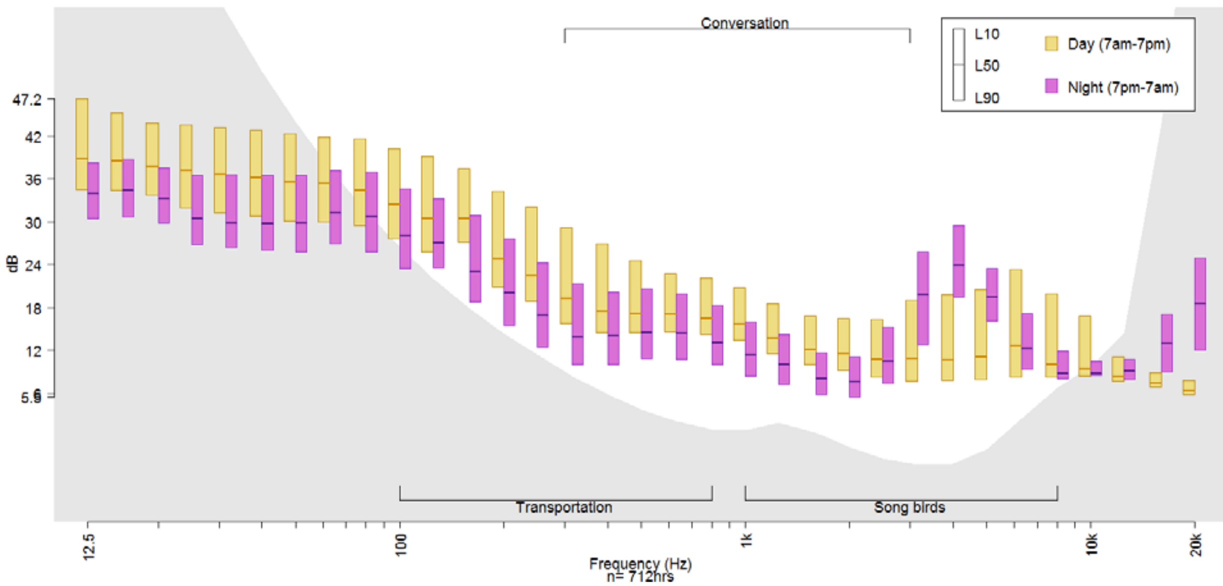

Figure 34. Sound spectrum for MOCA002, summer season (2010).

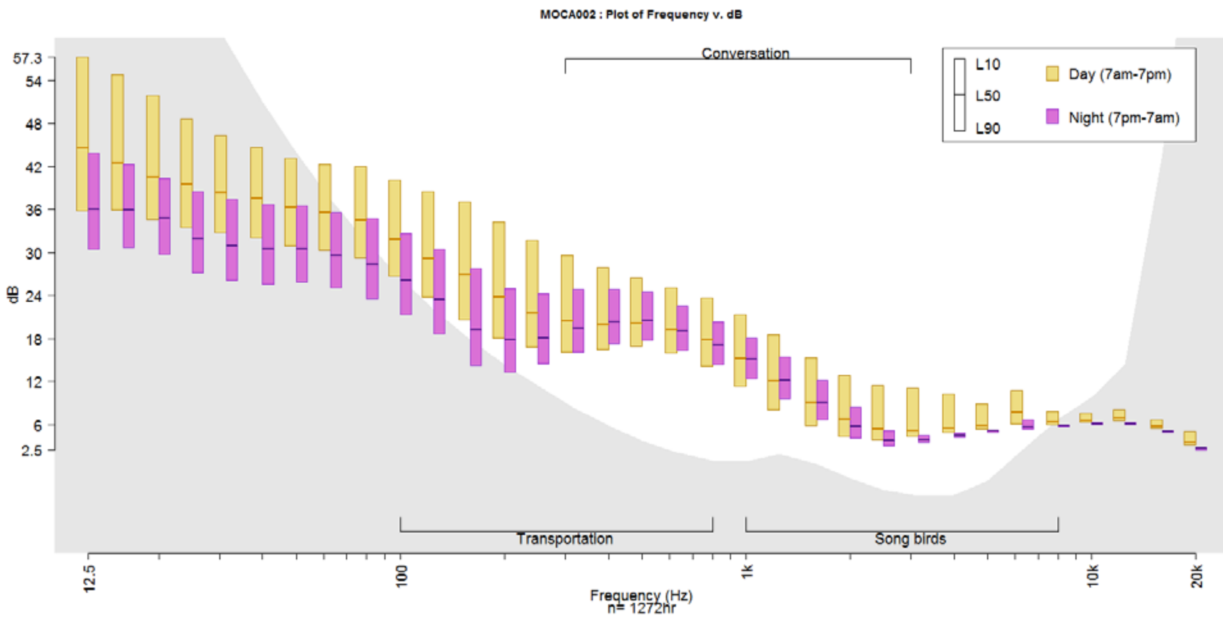

Figure 35. Sound spectrum for MOCA002, winter season (2012).

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