National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Montezuma Castle National Monument

Acoustical Monitoring 2010

Natural Resource Technical Report NPS/NRSS/NRTR—2013/709

ON THE COVER
Montezuma Castle National Monument

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Acoustical Monitoring 2010

Natural Resource Technical Report NPS/NRSS/NRTR—2013/709

Prepared For:

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Natural Sounds and Night Skies Division
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U.S. Department of the Interior
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During the summer of 2010 (July-August), the Volpe Center collected baseline acoustical data at Montezuma Castle National Monument (MOCA) at two sites deployed for approximately 30 days each. The baseline data collected during this period 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 soundscape 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.</td></tr>
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Table of Contents

Tables

Page

Figures

Page

Executive Summary

During July-August of 2010, two acoustical monitoring systems were deployed in Montezuma Castle National Monument (MOCA) by Volpe National Transportation Systems Center personnel. The purpose of this monitoring effort was to characterize existing sound levels and estimate natural ambient sound levels in these areas, as well as 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, representing MOCA's summer season.

In determining the current conditions of an acoustical environment, the National Park Service (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 should not be construed as thresholds of impact. Table 1 and Table 2 report the percent of time that measured levels were above four decibel values at each of the MOCA measurement locations for the summer season in dBA and in dBT. The first decibel value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis et al. 2008). The second value addresses the World Health Organization's recommendations 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 (EPA 1974) speech interference threshold for speaking in a raised voice to an audience at 10 meters. 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 1. Percent Time Above Metrics (dBA)

Site ID	Site Name	% Time above sound level: 7:00 am to 7:00 pm				% Time above sound level: 7:00 pm to 7:00 am			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
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

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

Site ID	Site Name	% Time above sound level: 7:00 am to 7:00 pm				% Time above sound level: 7:00 pm to 7:00 am			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
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

Table 3 summarizes the acoustic observer log data (office listening and in-situ logging combined) and provide an indication of the amount of time that certain sources are present at each site. The in-situ logging is performed during visits to the site itself; office listening is performed in the office using audio files that were collected at each site.

Table 3. Summary of acoustic observer log data (in situ and office listening combined) for all sites for the summer season

Site ID	Site Name	% Time Audible			
		Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
MOCA001	Montezuma Castle	9.8	10.8	65.2	14.3
MOCA002	Montezuma Well	14.3	15.8	37.8	32.1

Acknowledgements

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 Finally, thanks to Christopher Scarpone, Paige Mochi, and Christopher Reichlen (Volpe Center), and Robert “Skip” Ambrose (Computer Sciences Corporation),who also participated in the field measurement effort.

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 acoustic conditions for use in developing soundscape 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, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the Federal Aviation Administration (FAA), Western-Pacific Region (AWP) and NPS, Natural Sounds and Night Skies Division (NSNSD) Office in the development of ATMPs.

Ambient data were collected by Volpe personnel in Montezuma Castle National Monument (MOCA) during –July-August 2010. A map of the areas managed by MOCA is shown in Figure 1. The purpose of this report is to provide a summary of the results of these measurements and will be used to represent MOCA's summer season.

Figure 1. Map of MOCA*

* http://www.nps.gov/MOCA

2. Study Area

Two acoustical monitoring systems were deployed during August - September 2010. These sites were selected based on discussions between Volpe, NSNSD, and MOCA personnel and are shown in Table 4.

Table 4. Measurement site locations

Site ID	Site Name	# Days of Data	NLCD* Classification	Coordinates (latitude/longitude in decimal degrees)	Elevation (m)
MOCA001	Montezuma Castle	31 days	Shrubland	34.61160° / 111.84286°	1,002 m (3,287 ft)
MOCA002	Montezuma Well	31 days	Shrubland	34.65048° / 111.75446°	1,091 m (3,580 ft)

* With the goal of potentially facilitating future data transferability between parks, all baseline acoustic 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. (Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel, Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources, Photogrammetric Engineering and Remote Sensing, 67:650-652, 2001.)

3. Methods

3.1 Automatic Monitoring

Larson Davis 824 sound level meters (SLM) were employed over the thirty day monitoring periods at MOCA. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and 1/3 octave band data, and exports these data to a portable storage device (flash drive). These Larson Davis-based sites met American National Standards Institute (ANSI) Type 1 standards.

Each Larson Davis sampling station at MOCA consisted of:

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

Each acoustic 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 acoustic 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 post measurements 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 acoustic environment.

3.3 Calculation of Sound Level Descriptors

All sound-level data were analyzed in terms of the following metrics (refer to the Terminology 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 and only the quietest 10 percent of the sample can be found below this point.

For each descriptor, both the broadband A-weighted sound level is determined and its associated ⅓-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 ⅓-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 ⅓-octave band spectrum associated with a particular measurement sample, but a composite spectrum using the computed descriptor for each ⅓-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. 1998, Fleming et al. 1999, 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;
- *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);* 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 presented in Section 6.1 and the four types of ambient characterizations above, twelve ambient descriptors could potentially be computed as shown in Table 5.

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

Table 5. 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 ($L_{Existw/oTours}$) – Descriptor 5 from the table above; and
- Natural Ambient (L_{Nat})– Descriptor 11 from the table above.

3.5 Calculation of Ambients

From the twelve potential ambient descriptors in Table 5, 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). Using the data in the acoustic observer logs, different characterizations of ambient can be *estimated* from the sound level data. This method was developed by performing a detailed data analyses conducted by the Volpe Center, working closely with the NPS, in 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 acoustic 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):

$$L_x = \frac{100 - \%TA}{2} + \%TA$$

For example, if non-natural sounds are audible for 40% of the time, L0 to L40 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 with the Volpe method, 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 Lx approaches L_{50}; as it approaches 100 percent, the L_x approaches L_{100}. A concern with this approach is that 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 Sound Source of Interest using the percentage of time sounds from the source of interest, e.g., air tour aircraft, are audible from short-term in situ and off-site observer logging, and Existing Ambient Without All Aircraft using the percentage of time all aircraft are audible from the observer logging) is a similar process.

4. Results

This section summarizes the results of the study. Included is an overall summary of the final, ambient sound levels for each measurement site, Time Above analysis, temporal trends, and the acoustic 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[*] L_{50} sound level computed for each site with all days included for the summer season (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[†];
- Table 6 presents a tabular summary of daytime and nighttime and computed ambients for the summer season; and
- Table 7, Figure 3 and Figure 4 present the associated spectral data for these ambient maps.

[*] 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 7:00 am to 7:00 pm unless otherwise specified by the NPS and FAA.

[†] 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.

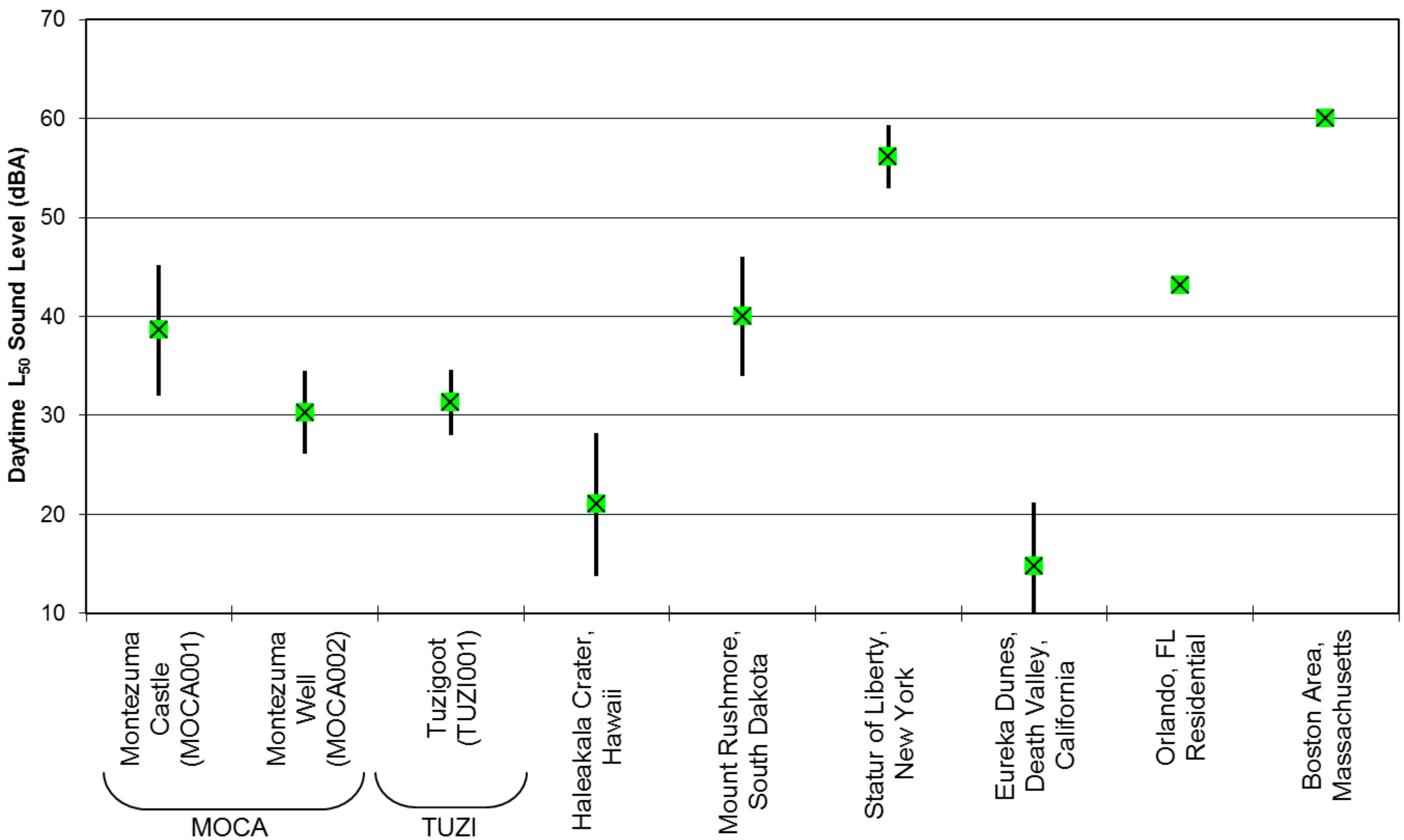

Figure 2. Comparison of overall daytime L_{50} sound levels for all sites[*]

[*] Confidence intervals for Orlando and Boston are not shown due to the limited amount of data represented (2 days and 1 week, respectively). Ambient data at ATMP parks, such as Montezuma Castle, are typically measured for at least 25 days.

Table 6. Summary of ambient sound level data*

Site ID	Site Name	Total # Days	Existing Ambient						Existing Ambient Without Air Tours (Daytime Data 7:00 am to 7:00 pm)	Existing Ambient Without All Aircraft (Daytime Data 7:00 am to 7:00 pm)	Natural Ambient (Daytime Data 7:00 am to 7:00 pm)
			Daytime Data Only: 7:00 am to 7:00 pm			Nighttime Data Only: 7:00 pm to 7:00 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)
MOCA001	Montezuma Castle	29	47.1	38.6	31.5	48.6	45.2	38.9	37.8	37.1	31.4
MOCA002	Montezuma Well	30	44.7	30.3	24.9	39.9	34.0	27.1	29.3	28.3	25.9

* 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 7. Summary of measured, daytime (7:00 am to 7:00 pm), ambient sound level spectral data*

Frequency (Hz)	Existing Ambient Without Air Tours L_{50} (dB)		Natural Ambient L_{50} (dB)	
	MOCA001	MOCA002	MOCA001	MOCA002
12.5	37.2	38.5	34.3	35.5
16	37.3	38.3	34.5	35.3
20	35.5	37.5	32.6	34.6
25	34.9	36.6	31.3	33.2
31	35.2	35.8	30.5	32.5
40	33.4	35.5	29.1	31.6
50	31.7	34.4	27.7	31.2
63	31.8	34.3	28.5	30.9
80	29.2	33.5	25.4	30.6
100	27.6	31.3	24.0	28.5
125	26.8	29.1	23.2	26.5
160	25.2	30.0	21.0	28.3
200	24.4	24.3	21.4	21.5
250	24.4	22.0	21.6	19.5
315	23.4	18.4	20.6	16.2
400	24.4	16.9	22.0	15.3
500	25.1	16.3	22.0	14.6
630	24.3	16.4	20.9	14.7
800	23.7	15.8	20.4	14.4
1000	22.4	14.8	19.3	13.3
1250	20.8	12.8	17.8	11.4
1600	20.1	10.8	17.3	9.3
2000	20.4	9.7	16.5	8.1
2500	21.1	8.8	16.7	6.3
3150	20.4	8.5	15.9	5.5
4000	20.1	8.1	16.7	4.9
5000	26.5	8.8	22.2	5.4
6300	18.3	10.5	14.1	6.2
8000	17.1	8.3	13.4	6.4
10000	17.0	8.9	13.4	7.6
12500	14.8	8.4	13.0	7.4
16000	13.7	7.3	12.1	6.4
20000	15.0	8.9	13.9	8.4

* 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.

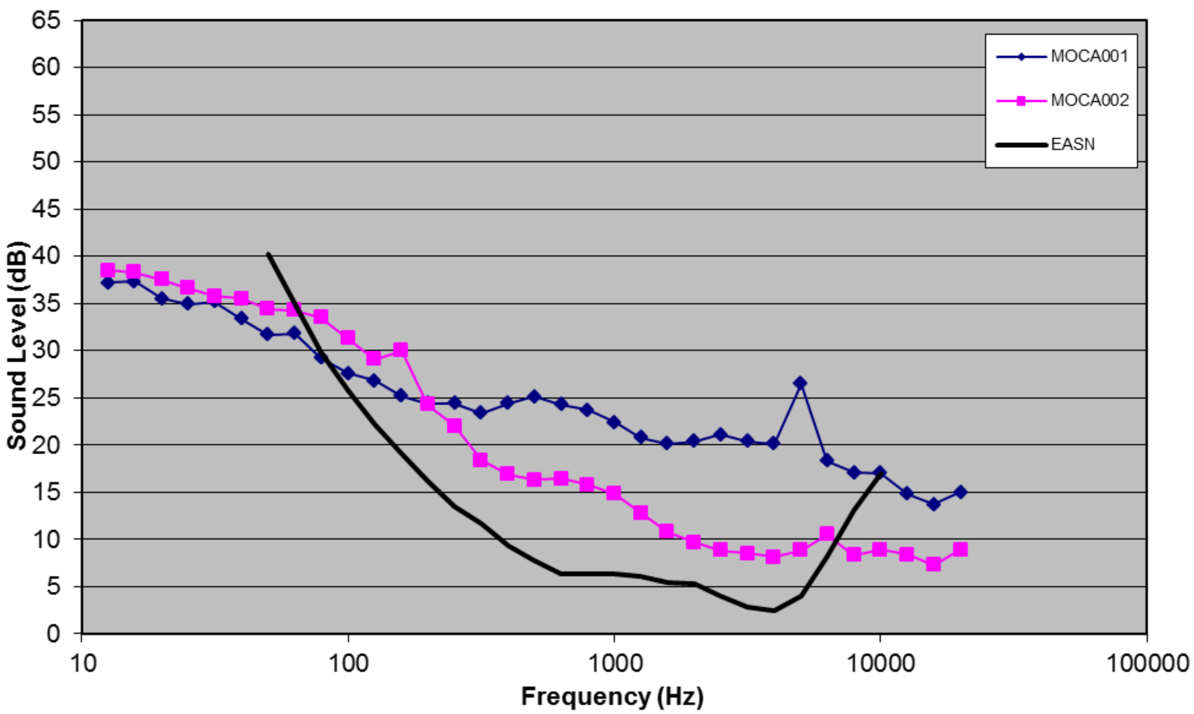

Figure 3. Spectral data for the Existing Ambient Without Air Tours (L_{50}) for each site*

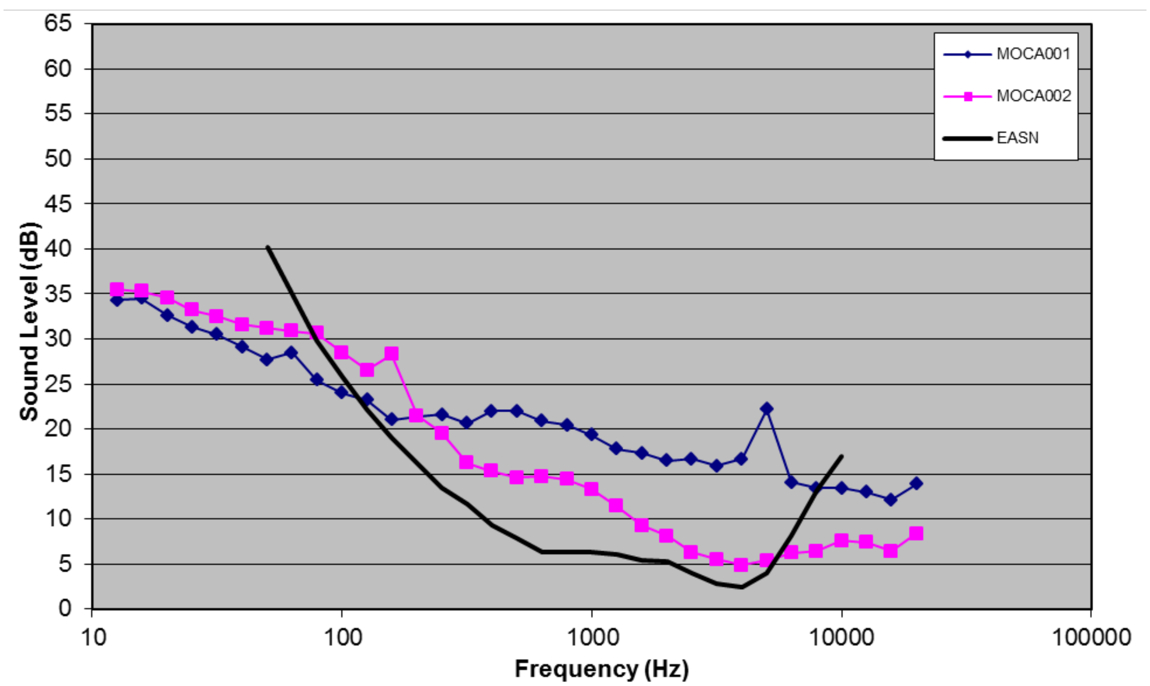

Figure 4. Spectral data for the Natural Ambient (L_{50}) determined for each site *

* 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 reports the percent of time that measured levels were above four decibels values at each of the MOCA measurement locations for the summer season. The first decibel value, 35 dBA, addresses the health effects of sleep interruption (Haralabidis et al. 2008). The second value addresses the World Health Organization's recommendations 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 (EPA 1974) speech interference threshold for speaking in a raised voice to an audience at 10 meters. 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 8. Percent Time Above Metrics (dBA)

Site ID	Site Name	% Time above sound level: 7:00 am to 7:00 pm				% Time above sound level: 7:00 pm to 7:00 am			
		35 dBA	45 dBA	52 dBA	60 dBA	35 dBA	45 dBA	52 dBA	60 dBA
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

Table 9. Percent Time Above Metrics (truncated spectra - dBT)

Site ID	Site Name	% Time above sound level: 7:00 am to 7:00 pm				% Time above sound level: 7:00 pm to 7:00 am			
		35 dBT	45 dBT	52 dBT	60 dBT	35 dBT	45 dBT	52 dBT	60 dBT
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

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 summer 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 (e.g., storm). There data are useful in visually identifying potential anomalies in the data. Data anomalies would then be further examined from data recorded by the sound level meter and/or recorded audio samples.

Diurnal trends are shown 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 a running river, generators or shoreline surf. This information is also useful in visually identifying potential anomalies in the data. No constant sound sources were noted in the observer logs for MOCA.

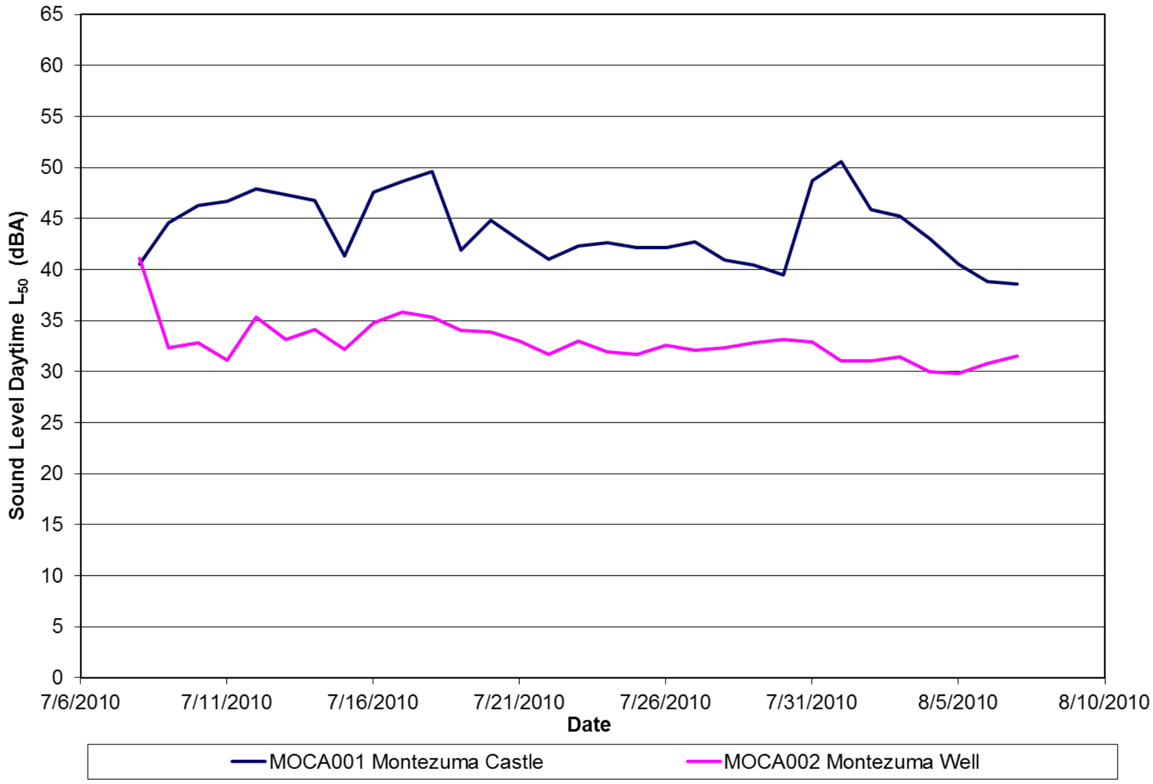

Figure 5. Comparison of daily L_{50} sound levels for all sites

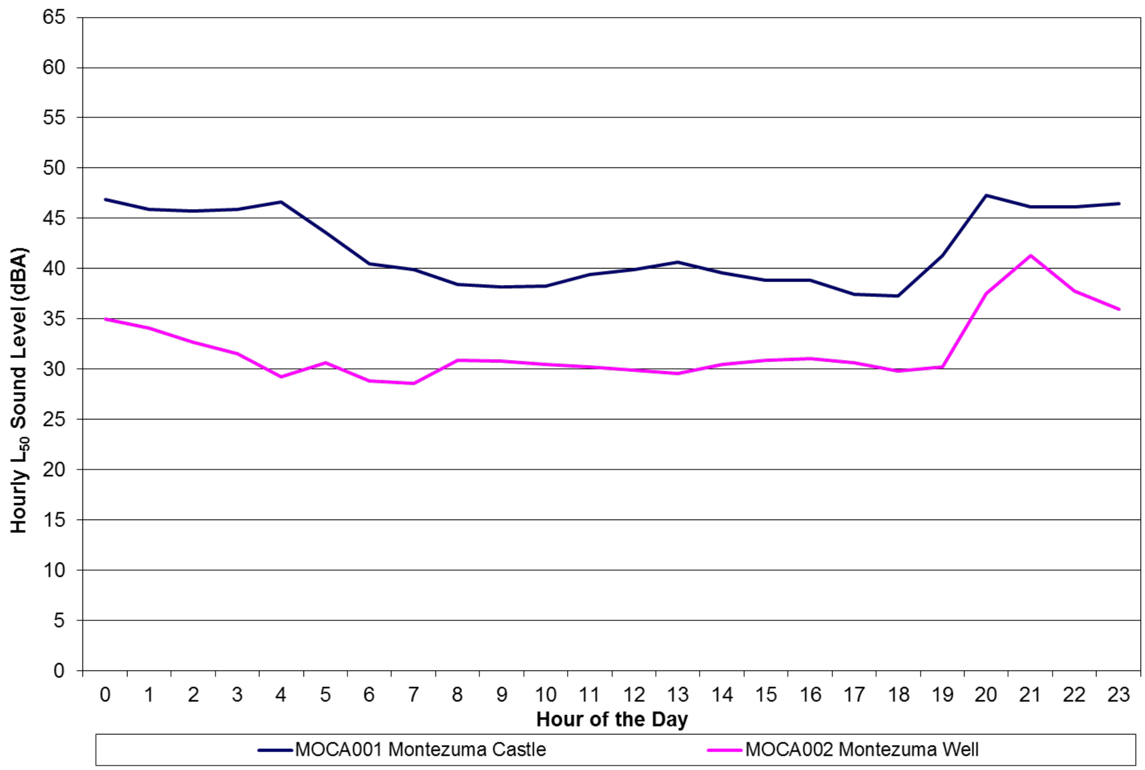

Figure 6. Comparison of hourly L_{50} sound levels for all sites

4.4 Acoustic Observer Logging Results

Table 10 summarizes the office listening and in-situ logging results and provide an indication of the amount of time that certain sources are present 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 office 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. Table 10 summarizes the combined listening results for the summer measurements; these are the results determined from a review of the audio files and the in-situ sound source logs that were collected live and at each site.

Table 10. Summary of acoustic observer log data (in situ and office listening combined) for all sites

Site ID	Site Name	# Days of Logging	% Time Audible			
			Fixed-Wing Aircraft and Helicopters	Other Aircraft Sounds	Other Human Sounds	Natural Sounds
MOCA001	Montezuma Castle	3	9.8	10.8	65.2	14.3
MOCA002	Montezuma Well	2	14.3	15.8	37.8	32.1

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 INM* 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) † coordinates to set the initial grid area boundary. ‡
  - 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. For MOCA, a grid spacing of 100 ft (30.5 m) was used.
  - Define the acoustic zone boundaries in UTM coordinates (see Section 5.1).
  - Define the location of each measurement site.
- Assign a "measured" ambient sound level (and its associated one-third octave-band, unweighted spectrum) computed in Section 3.5, to each acoustic 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 trains, 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, unweighted 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 final ambient maps are presented in Section 5.3.

* 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.

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

‡ 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 includes a ½-mile buffer.

5.1 Define Acoustic Zones and Assignment 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 "acoustic 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 acoustic zones. The following considerations are used in the determination of acoustic 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 acoustic 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 11 presents which measurement site data were applied to each acoustic zone based on best available data and geographical proximity.

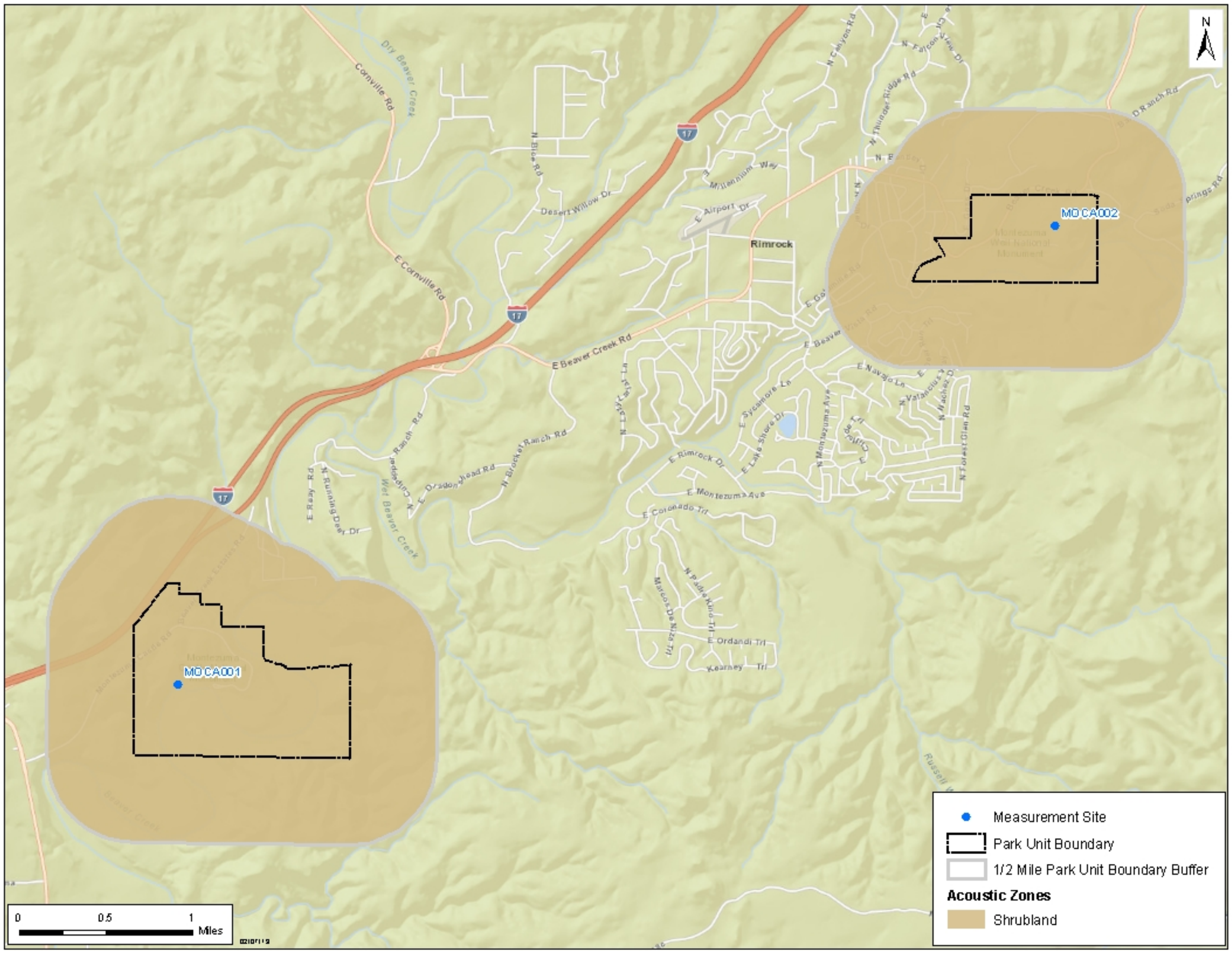

Figure 7. Acoustic zones and measurement sites for MOCA

Table 11. Assignment of ambient data to acoustic zones

Acoustic 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 trains, 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 12). 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) (Lee et al. 2004), 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. 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 12. Composite ambient maps

Metric	Ambient Type			
	Existing	Existing Without Air Tours	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 MOCA, 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 NPS and the Arizona Department of Transportation (AZDOT). The AZDOT (http://mpd.azdot.gov/mpd/data/aadt.asp). Where data are available for multiple years, the most current year was chosen. The traffic volume for an average day during the actual summer month (May) and the peak winter month (November) was obtained by using monthly visitation data obtained from the NPS Public Use Statistics Office website (http://www2.nature.nps.gov/stats/) to apportion the AZDOT annual traffic. Hourly volume is estimated by dividing the month's volume by the number of days in the month (31) and by 12 hours per day, which assumes the majority of traffic for Montezuma Castle occurs between 7:00 am and 7:00 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 (http://nature.nps.gov/stats/viewReport.cfm?selectedReport=ParkMonthlyReport.cfm; 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 Volpe 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 MOCA.

Table 13. Estimated hourly roadway traffic volume and speed

Roadway			Estimated Hourly Volume				
#	Name	Average Speed (mph)	Autos	Medium Trucks	Heavy Trucks	Buses	Motorcycles
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

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 8 and Figure 9 present the ambient maps for the summer season.

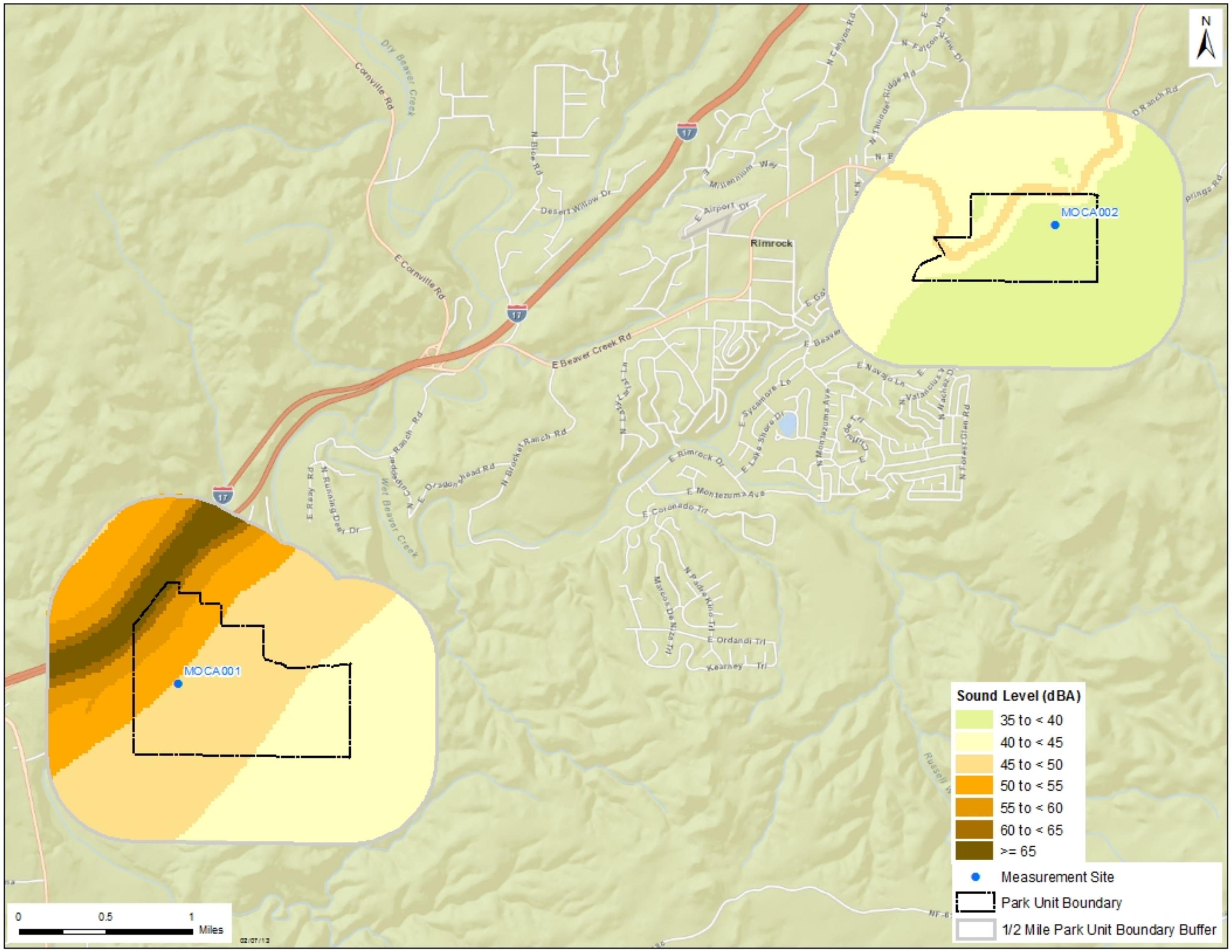

Figure 8. Baseline ambient map: Existing Ambient Without Air Tours (L_{50})

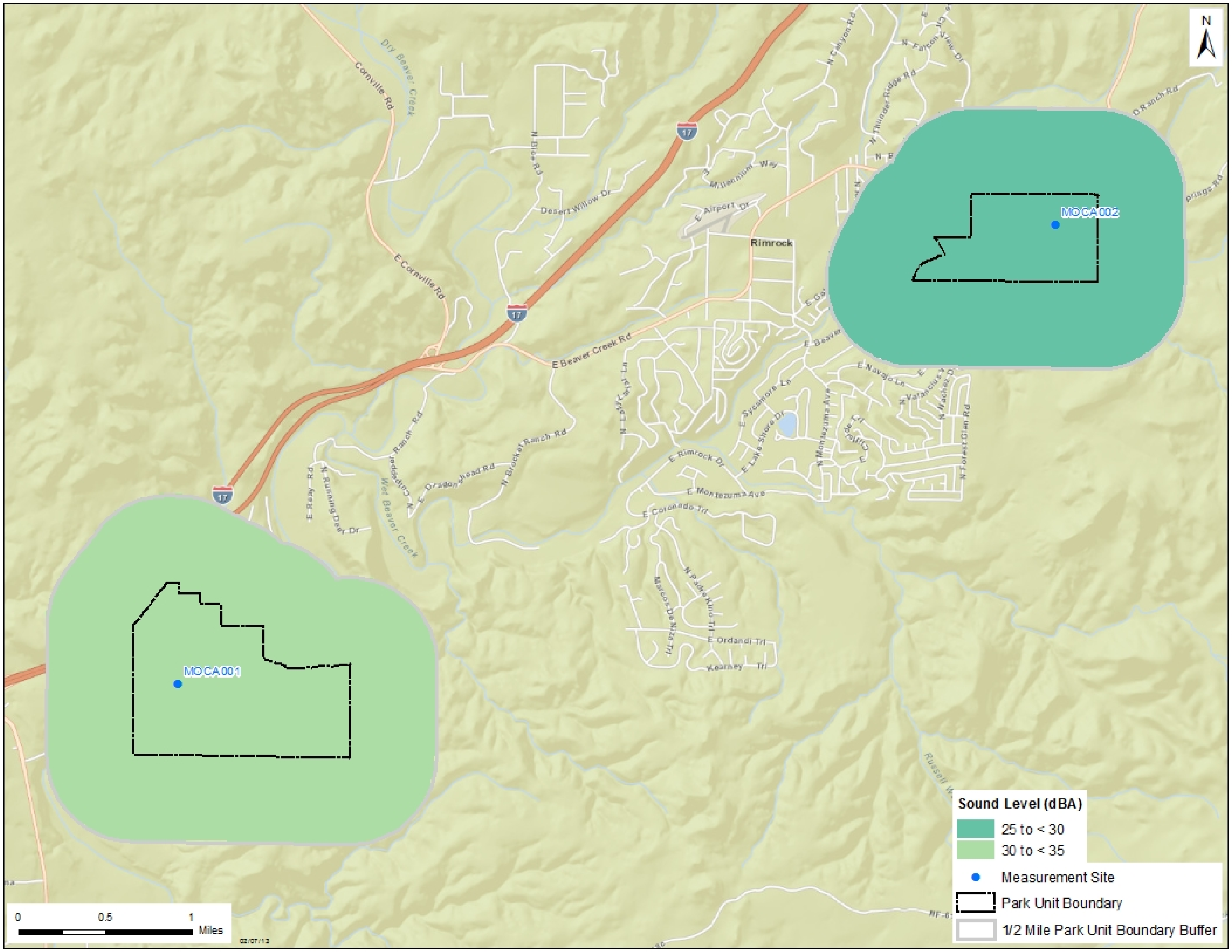

Figure 9. Baseline ambient map: Natural Ambient (L_{50})

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 hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to Section 3 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 Section 3 for definitions), as well as average hourly wind speeds over the entire measurement period; and
- 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} 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 Section 3 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 10. Photograph of Site MOCA001

Observations

The MOCA001 measurement site was located near the main loop trail, approximately 40 yards from the Beaver Creek bed, and 0.4 miles from Interstate 17. The site's proximity to MOCA's main trail subjected it to regular park visitor noise.

The overall median daytime sound level during the summer was 38.6 dBA. Daily (twenty-four hour) median sound levels ranged from 38 to 51 dBA. The sound level distributions and hourly median sound levels ranged from 28 to 41 dBA. Elevated L50 sound levels earlier in the deployment correspond to storm activity in the area, including wind, precipitation, and thunder. Additionally, nearby Beaver Creek became active with running water in late July (July 30, 2010) and continued to flow until approximately August 5, 2010. The creek acted as a constant source of sound during times when it was running high.

On-site observations and off-site review of recorded audio data concluded that aircraft related sounds were audible 21% of the daytime hours, and other human -related sounds were audible 65% of the daytime hours. Total human-related sounds were audible 86% of the daytime 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 14% of the daytime hours. The prevailing daytime natural sound sources audible at this site, which can occur concurrently, were water related sounds, birds, and insects.

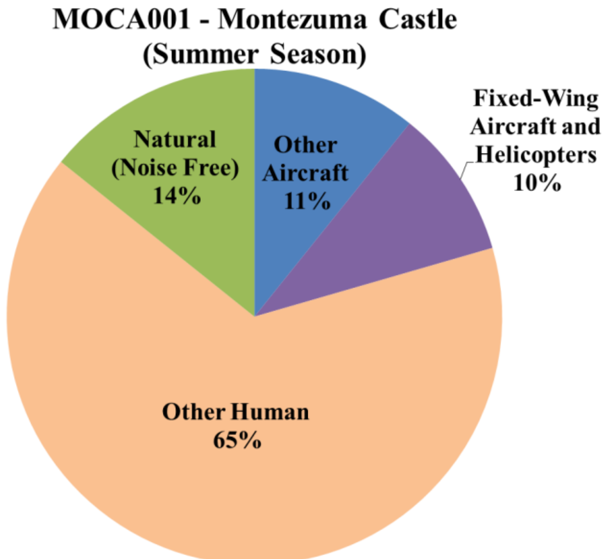

Figure 11. Distribution of sound sources audible (in situ and office listening combined) for Site MOCA001

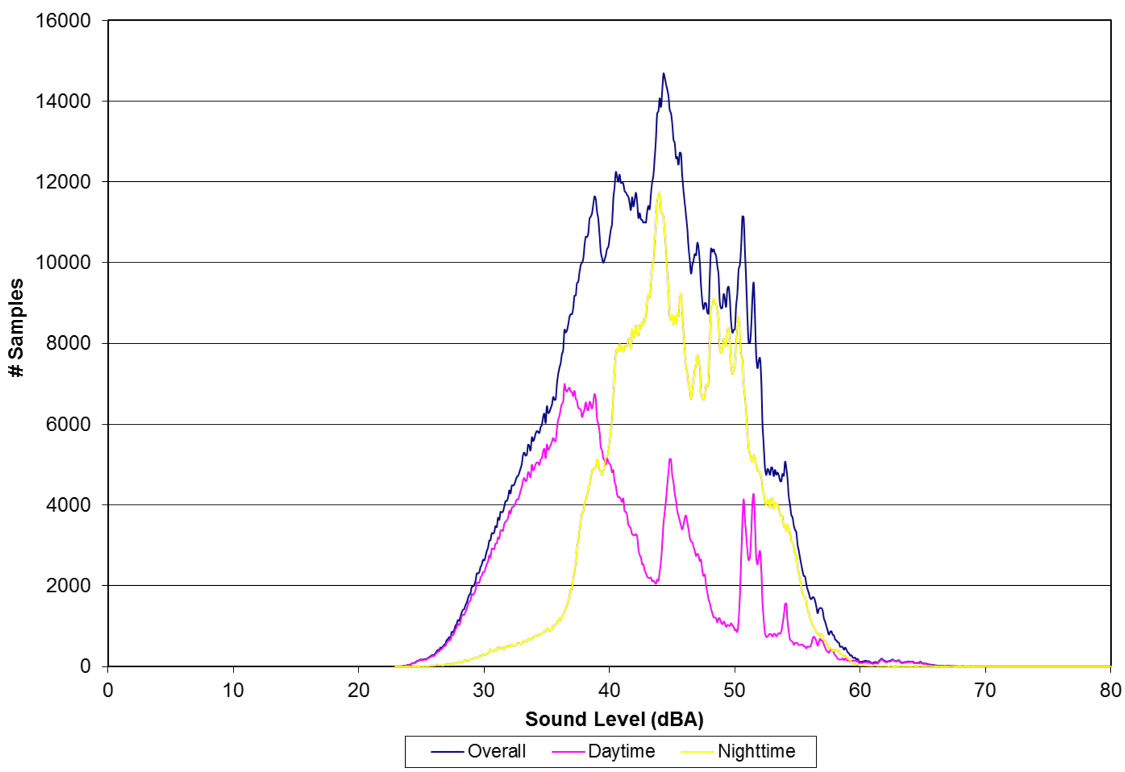

Figure 12. Distribution of data for Site MOCA001

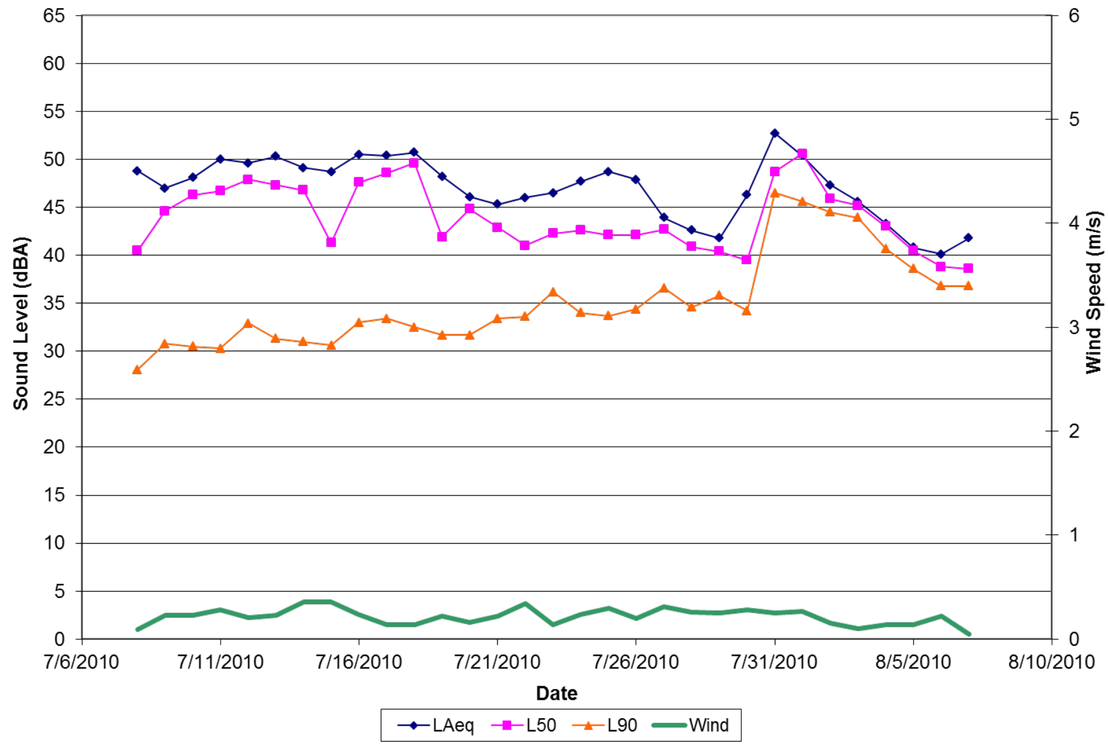

Figure 13. Daily sound levels and wind speeds for Site MOCA001

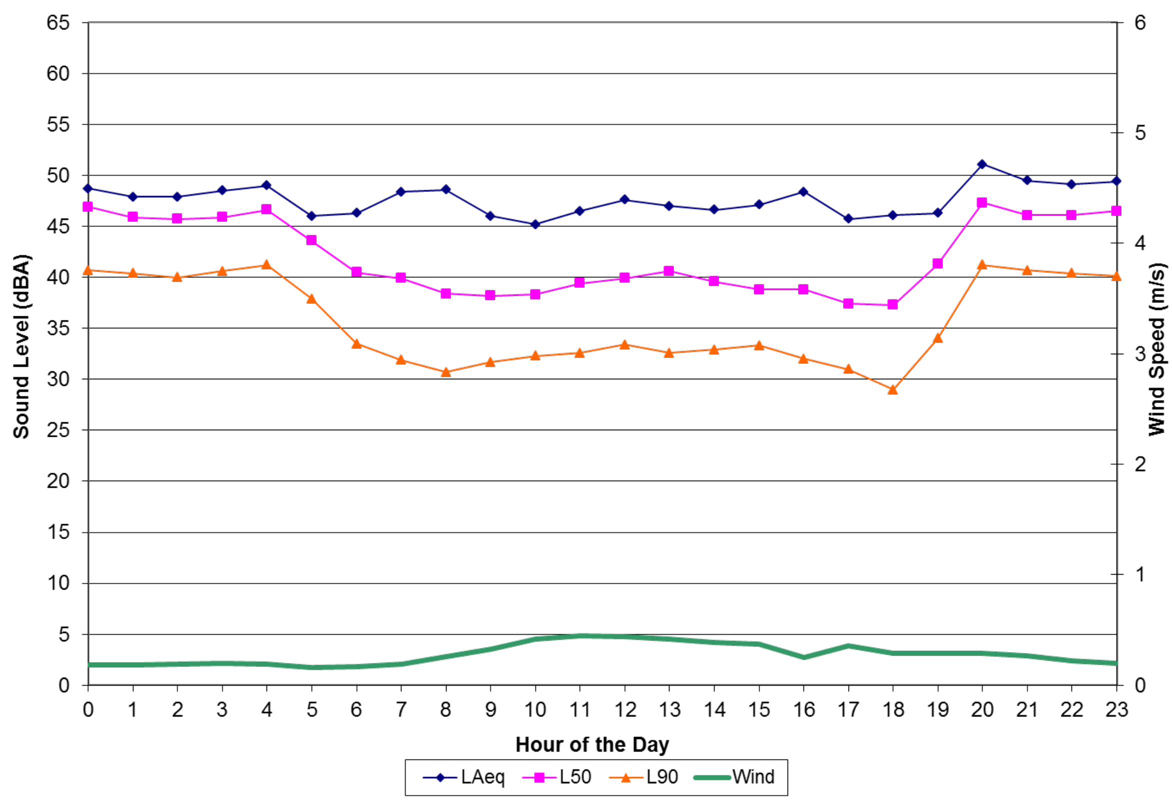

Figure 14. Hourly sound levels and wind speeds for Site MOCA001

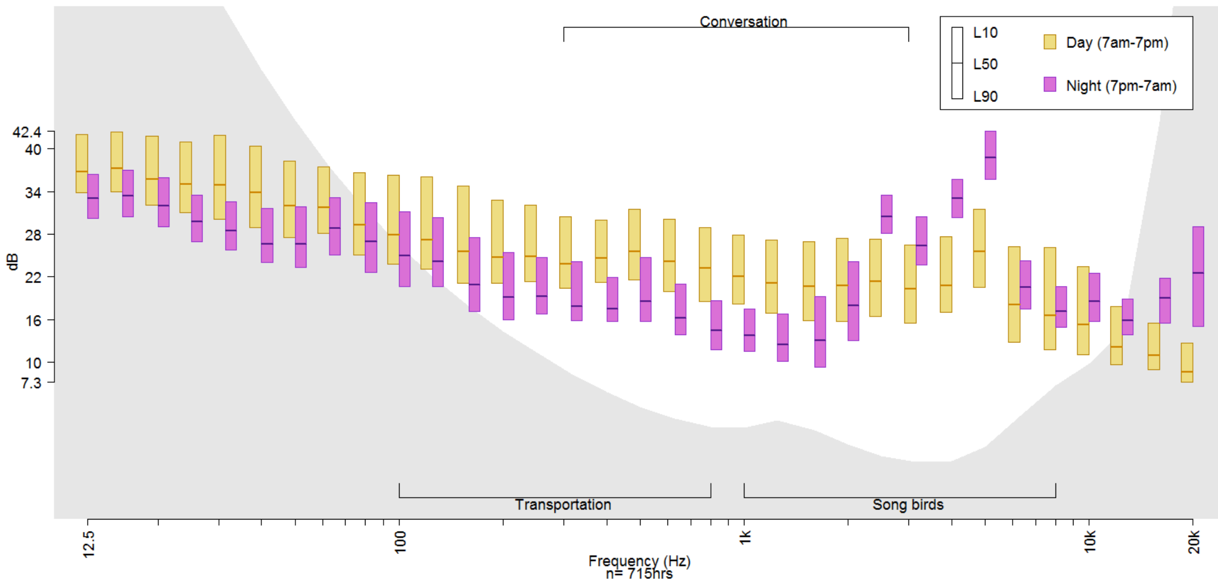

Figure 15. Sound spectrum for MOCA001

6.2 Site MOCA002 – Montezuma Well

Figure 16. Photograph of Site MOCA002

Observations

The Montezuma Well (MOCA002) site was located approximately 1.9 miles from Interstate 17 and 0.1 miles from the Montezuma Well. The measurement system's location subjected it to occasional noise from the visitor parking area and visitor center.

The overall median daytime sound level for this site was 30.3 dBA. Daily (twenty-four hour) median sound levels ranged from 30 dBA to 40 dBA. 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. Overall hourly sound levels (L50) 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.

On-site observations and off-site review of recorded audio data concluded that aircraft were audible 30% of the daytime hours at MOCA002. Other human related sounds were audible 38% of the daytime hours. The period of time where no human sounds were audible is called the "Noise-free" component of the soundscape. Noise-free intervals accounted for 32% of daytime hours. Audible natural sounds, which can occur concurrent with other natural and human sounds, at this site included wind, birds, insects, and water related sounds. Lower park unit visitation at MOCA002, and the measurement site's longer distance from the visitor trail are responsible for the much shorter time periods of visitor audibility as compared to MOCA001.

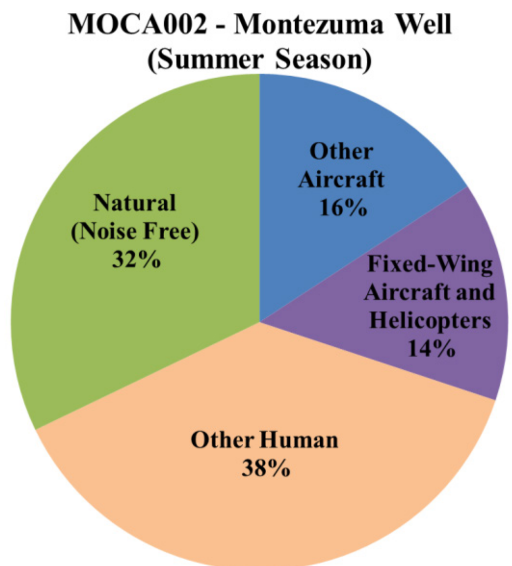

Figure 17. Distribution of sound sources audible (in situ and office listening combined) for Site MOCA002

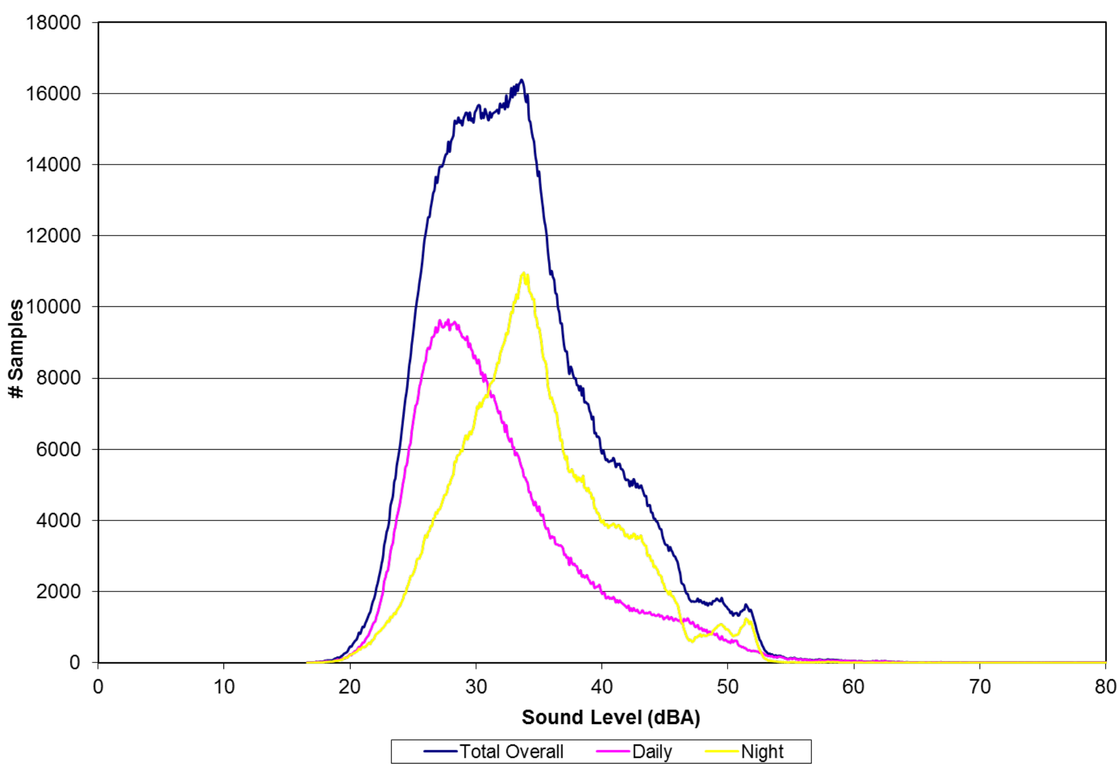

Figure 18. Distribution of data for Site MOCA002

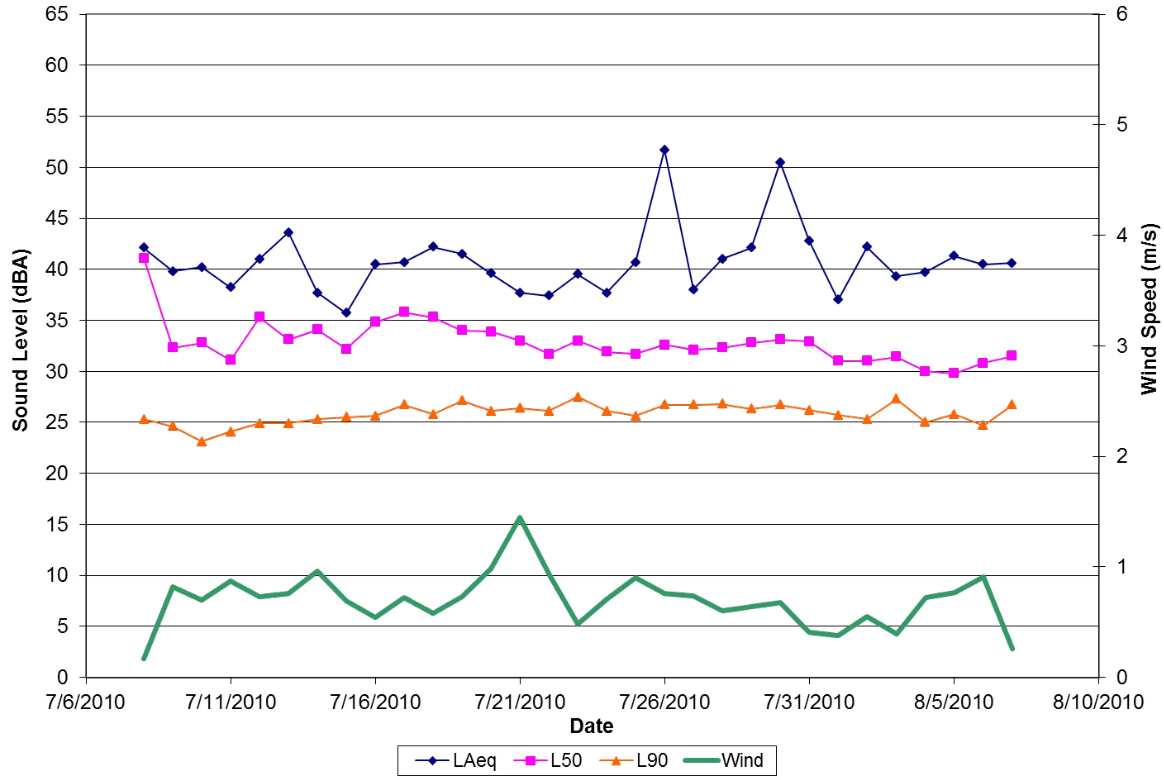

Figure 19. Daily sound levels and wind speeds for Site MOCA002

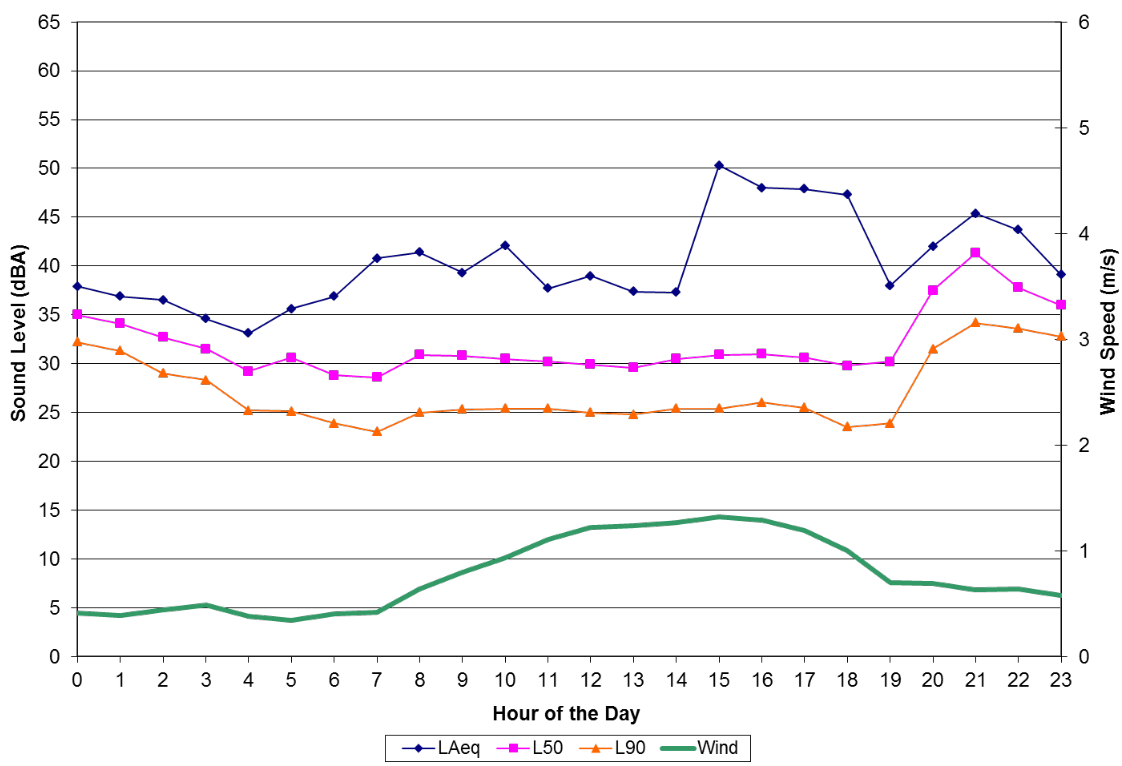

Figure 20. Hourly sound levels and wind speeds for Site MOCA002

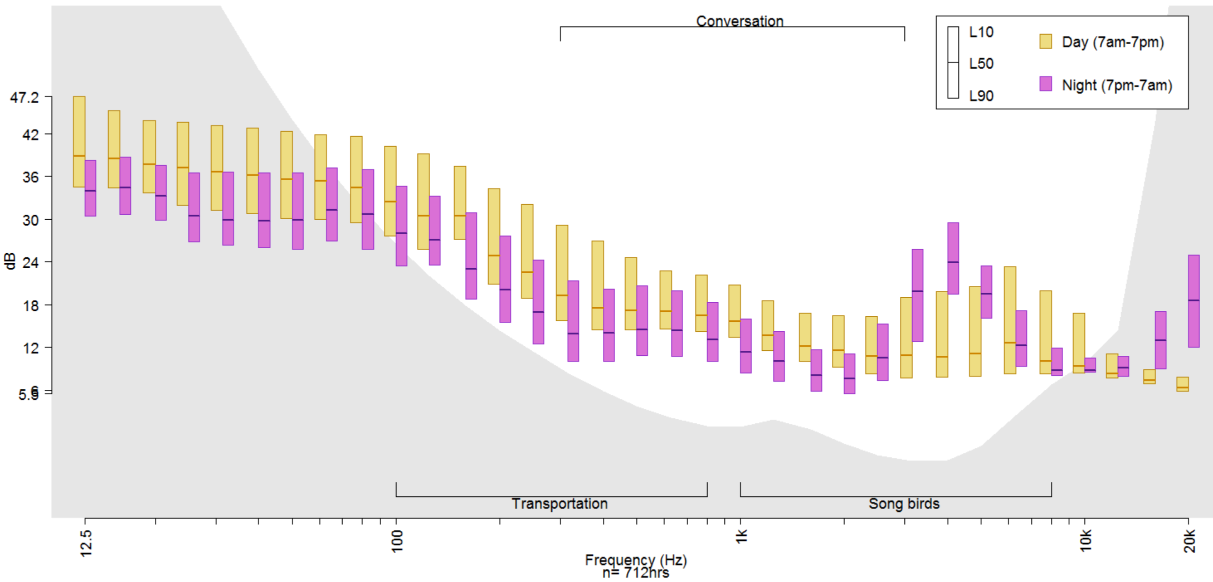

Figure 21. Sound spectrum for MOCA002

7. Glossary of Acoustical 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.

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

Extrinsic Sound
Any sound not forming an essential part of the park unit, or a sound originating from outside the park boundary.

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.

Intrinsic sound
A sound which belongs to a park by its very nature, based on the park unit purposes, values, and establishing legislation. The term “intrinsic sounds” has replaced “natural sounds” in order to incorporate both cultural and historic sounds as part of the acoustic environment of a park.

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 acoustic 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.

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