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DEVELOPMENT OF IMPROVED AMBIENT COMPUTATION METHODS IN SUPPORT OF THE NATIONAL PARKS AIR TOUR MANAGEMENT ACT

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13. ABSTRACT (Maximum 200 words) Approximately 85 National Park units with commercial air tours will need Air Tour Management Plans (ATMPs). The objective of an ATMP is to prevent or mitigate significant adverse impacts to National Park resources. Noise impacts must be characterized in relation to representative baseline ambient sound levels. Computing ambient sound levels for acoustic conditions in National Parks is not straightforward. The National Park Service and Federal Aviation Administration, both supported by the Volpe Center, are evaluating current methods and developing standards for computing ambient sound levels in National Parks. This report describes the results of several on-going analyses: (1) Analysis of ambient data measured under high-wind conditions; (2) Quantification of the differences between in situ observer logging versus offline review of digital recordings; and (3) Computation of natural ambient and existing ambient without air tours.			
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

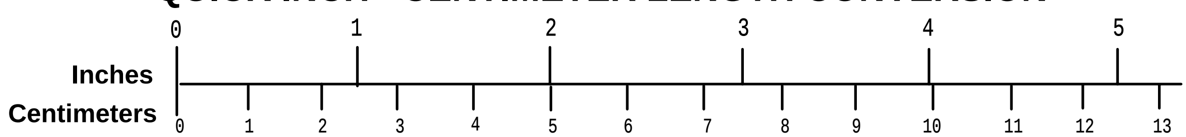
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

This document summarizes the findings of three separate, but intrinsically related, analyses using ambient sound-level data measured in support of the Air Tour Management Plans (ATMP) project. The objective of an ATMP is to prevent or mitigate significant adverse impacts, including noise, to resources of a National Park. Noise impacts must be characterized in relation to a representative baseline sound level, or ambient sound level. Computing ambient sound levels for acoustic conditions in National Park units is not straightforward. The identification and removal of data contaminated by wind and human-caused sounds is particularly challenging. The NPS and FAA are evaluating the potential shortcomings of the current methods and developing standards for computing robust, accurate ambient sound levels in National Park units. The analyses contained herein are part of the evaluation; they are intended to provide guidance for the processing of ambient data to identify and remove the contributions of some human-caused sounds and wind-induced measurement system noise.

Specifically, the analyses encompass:

A. The identification, and possible utilization of, ambient data contaminated by wind-induced measurement system noise;

B. The comparability of results from two methods of identifying human-caused sounds; *in situ* observer logging and offline review of digital recordings; and

C. The comparability of results from two methods of the removal of some human-caused sounds for the computation of natural ambient.

The findings of these analyses indicate that some adjustments and/or improvements can be made to the current methods. Specifically:

A. Examination of the data measured at ‘barren’ sites confirms that wind-induced measurement system contamination begins to affect the measured sound levels above the 5 m/s wind-speed threshold that has traditionally been observed for the ATMP project. The nature of the contamination is such that it can not be definitively identified and separated or removed from the naturally-occurring sounds. As a result, the wind-speed threshold is essential for measurements where the collection of uncontaminated data is of the utmost priority, such as measurements for the documentation of sound levels from a specific source. However, the intent of the ATMP project is the characterization of the *entire* ambient sound level environment, including those instances where wind may drive natural noise sources.

Therefore, some contamination may be tolerable in order to incorporate natural, wind-induced sounds. Further examination of the data reveals that a portion of the high-wind data measured when winds are above the 5 m/s threshold can be incorporated. This ensures the ambient estimate is most representative of conditions at a particular site. In addition, this may improve the number of ‘good’ hours which can be included in the estimate, reducing the length and resources required for measurements.

Based on the results of Section 2.1, the method depicted in Figure 1 is recommended for the processing of ambient data which includes data measured under high-wind conditions (>5 m/s). This method assumes that data are processed on an hourly basis. *It is further recommended that the development of a procedure to correct wind-induced measurement system contamination in the measured spectral data be further examined.* This would require measurements at high-wind sites, which could be performed during baseline ambient data collection at future ATMP parks.

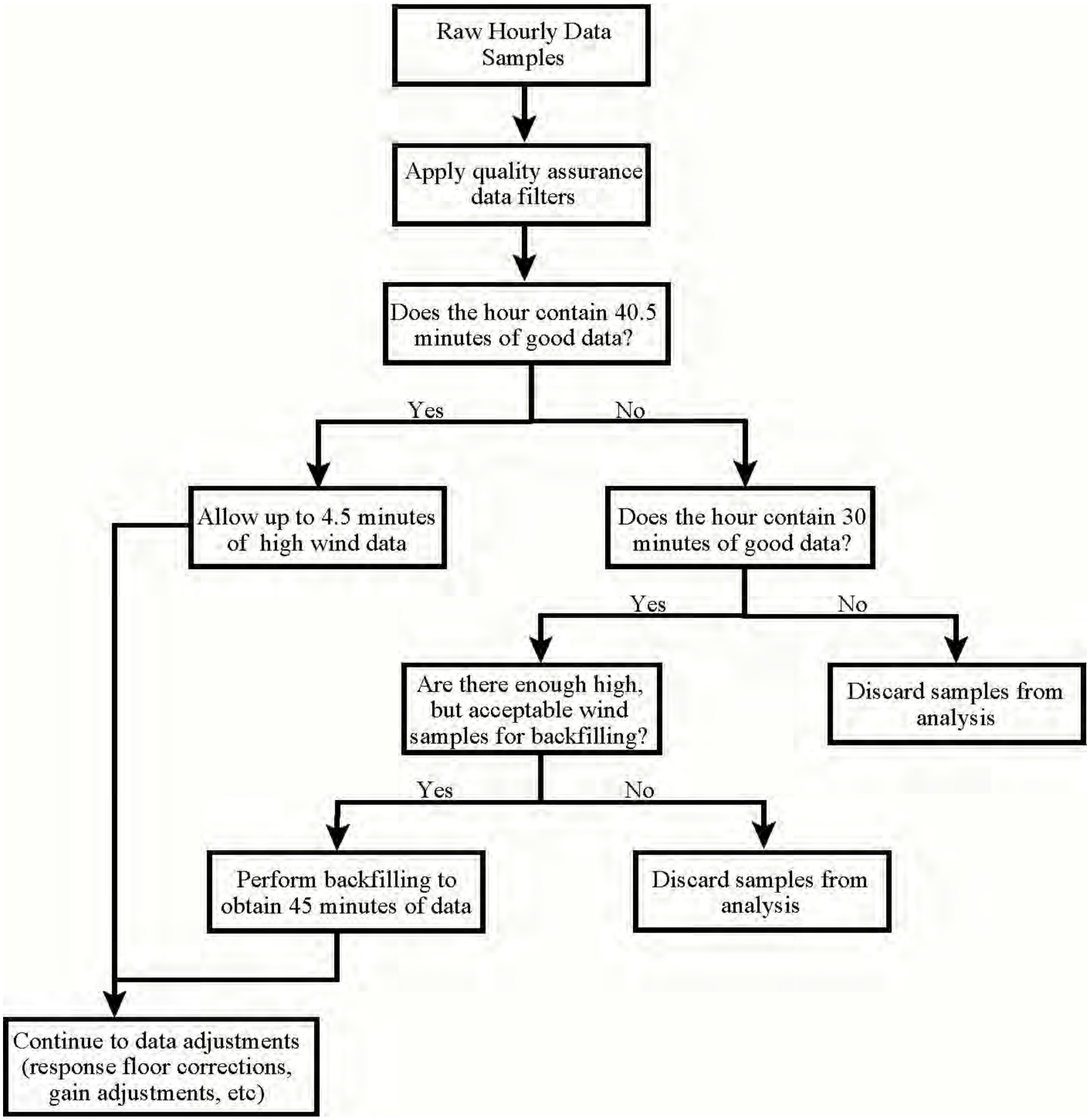


Figure 1. Recommended method for the processing of high-wind data.

B. There is little difference in the natural ambient computed with *in situ* observer logging versus offline review of digital recordings by an experienced listener. Although both methods are labor intensive, there may be instances where, logistically or otherwise, one method may have its advantages. The knowledge that either method may be used can provide personnel with more flexibility when planning measurements. *Either method is recommended.*

C. There is little resultant difference between the two methods used to remove of some human-caused sounds for the computation of natural ambient. *Therefore, it is recommended that Method 2*[*]*, which simply assumes that human-caused sounds are louder than natural, and removes the loudest percentage (determined from the percent time audible of human-caused sounds in the short term observer logs) of sound-level data should be utilized.* This method is conceptually straightforward, produces intuitive results, and requires less time and resources for data processing. It should be noted that more recently, NPS has been looking into automating the estimation of the natural ambient by using the statistical mode, which characterizes the most commonly observed sound level value. *Thus, it is also recommended that additional analysis be performed to compare ambient estimations computed using the statistical mode with Method 2.* Future research on the masking effects of different sound sources may also reveal potential improvements to the approach.

Pending FAA and NPS agreement, the above recommendations will be utilized in the processing of ambient data collected since Lake Mead and for future ATMPs. Both the FAA and NPS acknowledge that additional research is needed to develop better methods for these calculations, and will continue to strive to develop such methods. Pursuant to the National Environmental Policy Act (NEPA) and National Parks Air Tour Management Act of 2000 (NPATMA), the best-available scientific methods are being used.

[*] Method 1 utilizes short-term measurement data, collected with detailed acoustic state logs, to develop short-term distributions of ambient data as a function of acoustic state, and apply these short-term distributions to the long-term dataset. The assumption is that the statistical measure (not the level) is representative of what would be obtained over the long term. The actual ambient level would be based on the long-term data, and the short-term data would only be used to determine the statistical index.

1. INTRODUCTION

Congress passed the National Parks Air Tour Management Act of 2000 (NPATMA) to regulate commercial air tour operations over units of the National Park System.[1] The National Park Service (NPS), Natural Sounds Program (NSP) has been working cooperatively with the FAA, Western Pacific Regional Office (AWP) in the development of Air Tour Management Plans (ATMPs), with support from the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center). Approximately 85 park units will require that ATMPs be developed. The Grand Canyon National Park (GCNP), tribal lands within or abutting the GCNP, Rocky Mountain National Park, and national park units located in Alaska are exempt from the NPATMA.

The objective of an ATMP is to prevent or mitigate significant adverse impacts to resources of a National Park. Noise impacts must be characterized in relation to a representative baseline sound level, or ambient sound levels for each park. Computing ambient sound levels for acoustic conditions in National Park units is not straightforward. Data can be inadvertently contaminated and in such instances should be remover prior to computing ambient. The simplest approach, to remove data that fail to meet certain criteria, has the clear potential to bias the resulting ambient level estimates, and this potential has been realized in practice. The NPS and FAA are evaluating potential shortcomings of the current approach and developing standards for computing robust, accurate ambient sound levels in National Park units.

1.1 Scope

To date, the ATMP project has supported measurements of sound pressure levels in fifteen national parks across the continental United States and Hawaii. The NPS and FAA have not agreed upon a common reference condition since the two agencies assess noise impacts differently, so parallel analyses are being carried forward in ATMPs – the NPS prefers an estimate of natural ambient level (when the contributions of all human sounds have been removed); the FAA prefers an estimate of existing ambient without air tour contributions (which includes all other human-caused sound, including non-air-tour aviation noise). In both cases, the data characterizing the existing ambient must be processed to remove the contributions of some human-caused sounds. The data also have to be processed to remove wind-induced measurement system noise.

In order to measure ambient sound levels, the NPS and FAA have agreed to use one-third octave-band sound levels (i.e., sound level data in each one-third octave frequency band in 1-second, L_{eq} samples) to characterize ambient conditions. One-third octave-band sound levels approximate the frequency selectivity of human hearing and allow for detailed frequency analysis and compatibility with the techniques used for the modeling of aircraft noise and audibility in the FAA's INM. These measurements are supplemented with observer identification of human-caused sounds. Observer identification of human-caused sounds is sometimes realized by *in situ* field observations, but logistic constraints often require these observations be obtained by listening to field recordings in the laboratory. These observer logs identify temporal intervals of the one-third octave-band data in which specific human-caused sounds were heard. To simplify noise modeling, NPS and FAA have agreed to use the median, one-third octave ambient levels as an unvarying reference to which modeled aircraft noise is compared. Thus, the FAA seeks an estimate of L_{50} that would be obtained without the sound source of interest (i.e., without air tours for ATMPs), and the NPS seeks an estimate of L_{50} that would be obtained if no human-caused sounds were present. This document describes the results of several on-going analyses using ambient data measured in support of the ATMP project. It is intended that this document be used by the NPS, the FAA, and the aviation community to assist in the characterization of the ambient/soundscape environment in National Parks for use in determining potential noise impacts.

The ambient sound level estimates are used by the FAA's Integrated Noise Model (INM Version 6.2 or later)[2,3,4] as reference values for the computation of metrics characterizing noise exposure scenarios. INM 6.2[*] was identified by the Federal Interagency Committee on Aircraft Noise (FICAN), as the best-practice modeling methodology for evaluating aircraft noise in National Parks.[5,6]

[*] INM Version 6.2 was the latest version of the INM at the time of this determination. Since then, INM Version 7.0a has been released.

1.2 Objectives

The objective of this report is to provide guidance for establishing ambient sound levels in the National Parks. This report describes the results of several on-going analyses using ambient data measured in support of the ATMP project:

- Analysis of ambient data measured under high-wind conditions;
- Quantification of the differences in results between *in situ* observer logging versus offline review of digital recordings; and
- Computation of natural ambient and existing ambient without air tours.

1.3 Report Organization

The presentation of this report, entitled "Development of Improved Ambient Computation Methods in Support of the National Parks Air Tour Management Act," begins with an executive summary. Section 1 presents an introduction, scope, objectives, and organization of this document. Section 2 discusses the analysis of ambient data measured under high-wind conditions. Section 3 discusses the differences in results between *in situ* observer logging and offline listening and review of digital recordings. Section 4 discusses the computation of natural ambient and existing ambient without air tours. Appendix A provides photographs of the measurement sites used in the analysis. Appendix B discusses the prior analysis used to determine the acceptable, wind-speed threshold. Appendix C provides additional spectra supporting the high-wind analysis discussed in Section 2. Appendix D presents pertinent terminology used throughout the document. All related references are presented at the end of this document.

2. HIGH-WIND ANALYSIS

To date, the ATMP project has supported measurements of sound pressure levels within fifteen national parks across the continental United States and Hawaii. Prior to detailed data reduction and analysis, several quality assurance filters, checks, and adjustments are applied to the acoustic data to ensure that any questionable data is identified and that only "good" data are reduced and analyzed. Questionable data includes data where the associated 1-second average wind speeds are greater than 11 mph (5 m/s), the predetermined, acceptable, wind-speed threshold (see Appendix B and Reference 7). This threshold was established to identify sound-level data, which may be contaminated by measurement system noise (microphone-induced distortion and turbulence generated by the windscreen and microphone faring) resulting from high-wind conditions. The approach currently being utilized under the ATMP project is to remove this data. Removing this data has the clear potential to underestimate the median (L_{50}) ambient sound level estimate because high winds elevate the natural ambient sound levels. Discarding all the high-wind data will also limit the useful data from high-wind sites, such as along a coastline or in alpine areas. Since the cost of field data collection is expensive and time consuming, it is desirable to use as much data as possible from these sites.

Both the NPS and FAA acknowledge that additional research is needed to determine if a more refined approach is necessary to account for data collected during high-wind conditions for ***future*** ATMP parks. An in-depth analysis of sound pressure levels collected to-date at "windy" sites was conducted to determine if data collected during conditions outside the acceptable bounds could be utilized in the computation of ambient sound level. The analysis sought to answer the following questions:

1) When, and to what extent, does wind-induced measurement system noise begin to influence measured sound levels?
2) Can wind-induced measurement system noise be identified in the measured spectral data?

Additionally, contingent on the answers to Questions 1 and 2,

3) Is there a method by which high-wind data could be incorporated into the calculation of ambient sound level without contaminating the overall results?

This analysis is summarized in the following three report Sections. Section 2.1 seeks answers to questions 1 and 2 through an analysis of the data collected to-date in support of the ATMP program. Section 2.2 analyzes two approaches for incorporating high-wind data into ambient sound-level calculations. Section 2.3 uses these approaches and outlines a recommended procedure for the future processing of high-wind data in support of the ATMP project.

2.1 Detailed Analyses of Measured High-Wind Data

The analyses contained in this section seek to identify and characterize only the wind-induced , measurement system noise and its effect on measured sound levels. Therefore, the analysis concentrates only on data collected at sites with minimal wind-induced vegetation sounds, allowing for identification of contamination from non-natural sources. From the available pool of data from the ATMP project, data from fourteen sites at seven parks which exhibited high-wind conditions and were mostly barren (bare rock/sand/clay)[8] with limited vegetation were included in this analysis. These fourteen sites provided approximately 375 days of data, which equates to over 16 million 1-second L_{eq} samples. Such a volume of data would have been unnecessarily large and somewhat unmanageable; consequently, the data were randomly sampled (with no wind limits or other selectivity in place) to create a subset of more manageable size, consisting of 5.8 million, 1-second L_{eq} sound pressure levels. This dataset of 5.8 million samples[*] was used for all further analyses in this section and will subsequently be referred to as the 'high-wind dataset'. The locations and wind conditions at the sites contained in this dataset are summarized in Table 1. A more detailed description of these sites, with photos, can be found in Appendix A.

[*] Due to the unmanned nature of the measurements, the dataset may consist of some non-natural sounds (i.e., park visitor activity, aircraft flyovers, and automobile traffic), in addition to naturally occurring sounds.

Table 1. Summary of sites with high winds, i.e., high-wind dataset.

Park Name	Site ID (Location)	% of Dataset	Range of Measured Wind Speeds (m/s)	Average Wind Speed (m/s)	% Data > 5 m/s
Hawaii Volcanoes National Park	1B (Shoreline)	13.2	0 – 30	11.2	99%
	3A (Mauna Iki Trail)	13.7	0 – 16	2.4	10%
	9A (Pu`u Huluhulu)	7.6	0 – 14	1.8	3%
Haleakala National Park	ST6 (Silversword Loop)	6.2	0 – 14	1.9	4%
	ST7 (Kalahaku Overlook)	5.3	0 – 24	3.8	29%
Badlands National Park	B03 (Cedar Butte)	3.9	0 – 15	1.9	9%
Lake Mead National Recreation Area	L02 (Pinto Valley)	6.8	0 – 12	1.3	1%
	L03 (Bonelli Bay Landing)	3.0	0 – 21	3.5	16%
	L07 (Indian Pass)	5.3	0 – 24	4.3	31%
	L08 (Katherine Landing)	6.5	0 – 14	2.0	7%
Canyon de Chelly National Monument	CC1 (First Ruin)	5.7	0 – 17	1.5	5%
Petrified Forest National Park	PF1 (Painted Desert)	6.0	0 – 14	1.6	4%
	PF2 (Agate Bridge)	6.6	0 – 19	2.4	17%
Acadia National Park	A03 (Cadillac Mountain)	10.4	0 – 14	2.3	4%
			All Sites	**3.6**	**21%**

The analyses contained in the following Sections seek to answer Questions 1 and 2, namely: 1) “When, and to what extent, does wind-induced measurement system noise begin to influence measured sound levels?”, and 2) “Can wind-induced measurement system noise be identified in the measured spectral data?”. Section 2.1.1 details an analysis of the sound-level data distributions and scatter plots, which may provide answers to Question 1. Section 2.1.2 details an analysis of the frequency content of the measured sound levels, which may provide answers to Question 2.

2.1.1 Characterization of Overall Sound Level as a Function of Wind Speed

To determine when and to what extent wind-induced measurement system contamination begins to influence measured sound levels, the high-wind dataset was first examined by documenting the characteristics and behavior of the 1-second sound level measurements as they relate to wind speed. The sound-level distributions of this dataset are detailed in Section 2.1.1.1, while scatter plots and sound level vs. wind-speed trends are detailed in Section 2.1.1.2

2.1.1.1 Sound Level Distributions

Figure 2 and Figure 3 display the wind speed versus sound level distributions of the 1-second sound pressure level samples contained in the high-wind dataset described in Table 1 of Section 2.1.

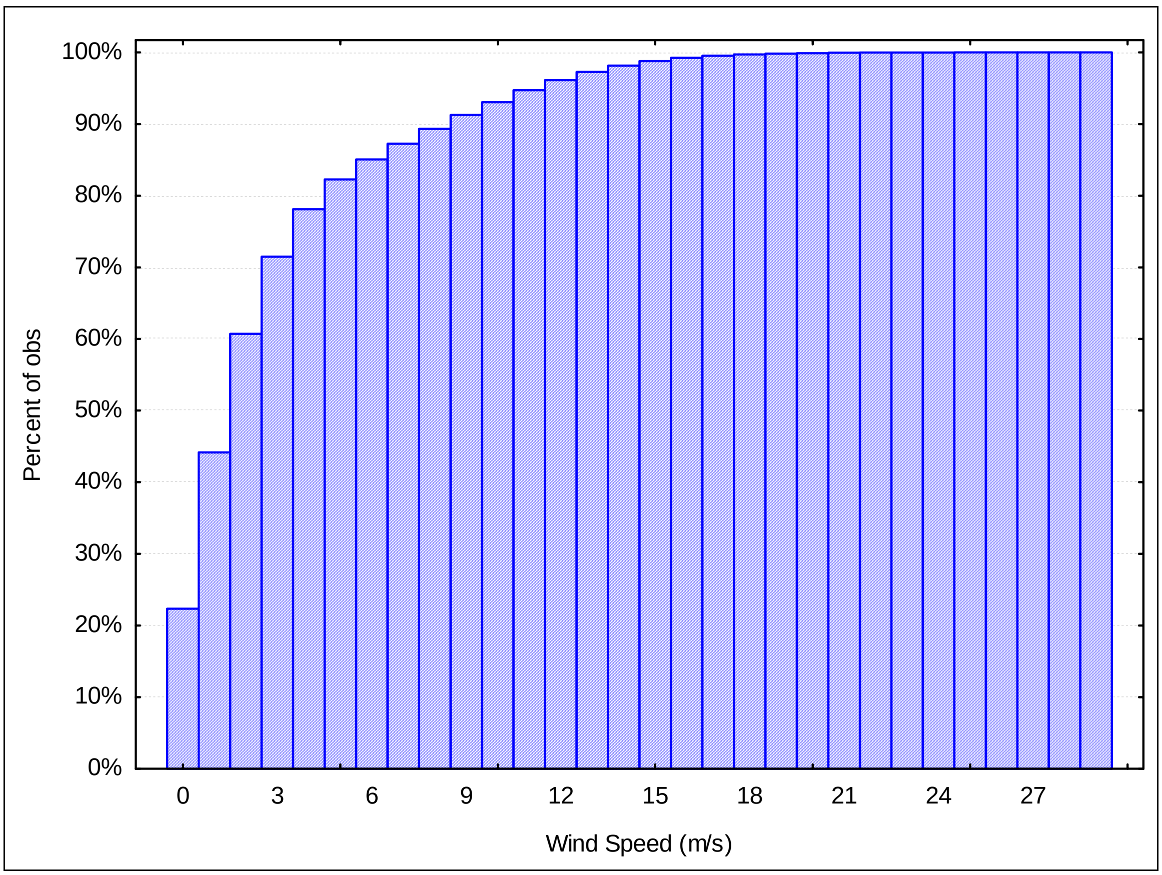


Figure 2. Cumulative wind-speed distribution of high-wind dataset.

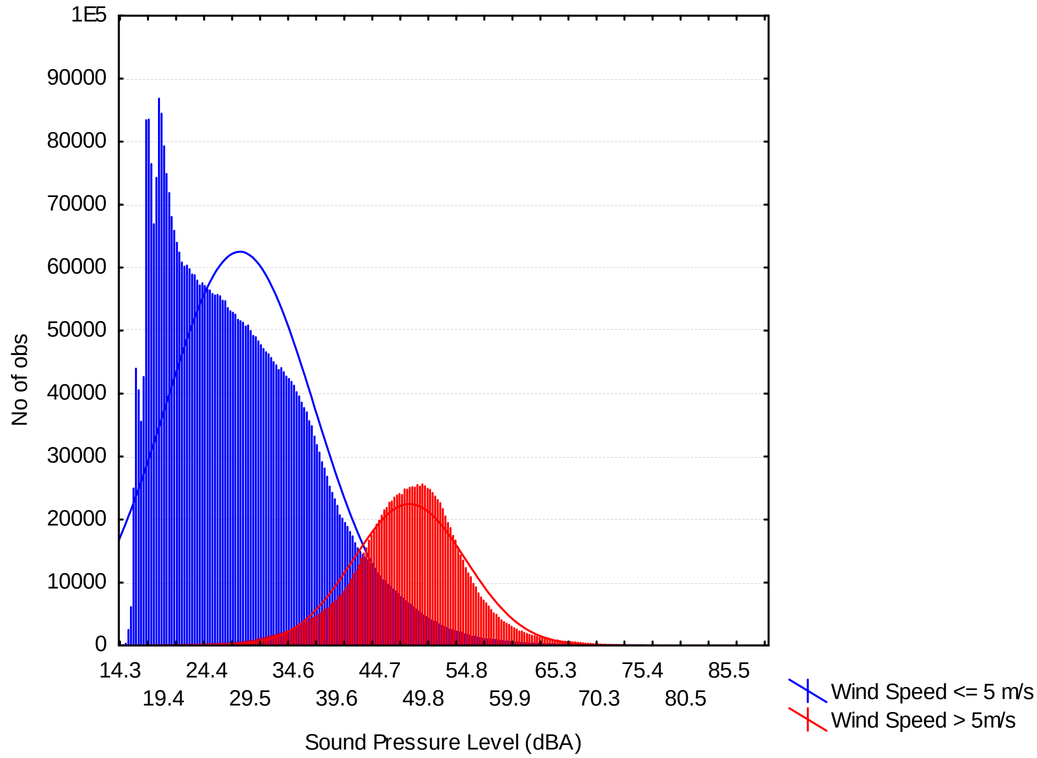


Figure 3. Distribution of sound pressure levels in high-wind dataset.

Figure 2 indicates that, although the majority of the dataset (79 percent) was measured during winds below 5 m/s, the dataset does include sound-levels measured during winds as high as 30 m/s (67 mph).

Figure 3 depicts the sound pressure level distribution and Gaussian curvefit (for comparative purposes) in two groups: those measured when winds were below 5 m/s (blue) and those measured when winds were above 5 m/s (red). These distributions are clearly different. The low wind-speed portion of the dataset is lower in sound level, with a median (L_{50}) of 26.9 dBA and an energy-average (L_{Aeq}) of 43.9 dBA. Additionally, it peaks at the low end of the range, at approximately 18 dBA. This peak is related to the noise floor of the field-measurement instrumentation used to collect the data. The high-wind portion of the dataset is substantially higher in sound level and approximately normally distributed, with a median (L_{50}) of 48.2 dBA and an energy-average (L_{Aeq}) of 53.5 dBA.

Figure 4 and Figure 5 provide a site-by-site breakdown of the sound level distribution for the wind speed groups depicted in Figure 3. The low-wind distribution graphic (Figure 4) shows that Sites 3A, ST6, B03, and L02 are the primary source of the lower sound-level content (< 20 dBA) in the dataset. The high-wind distribution graphic (Figure 5) shows that site 1B (a coastal site) is the source of the majority of the sound pressure level content at the upper wind speeds. Due to its relative contribution, this site has the potential to bias results and conclusions about the behavior of high wind measurements. Further examination of the data from this site continues in Section 2.1.1.2.

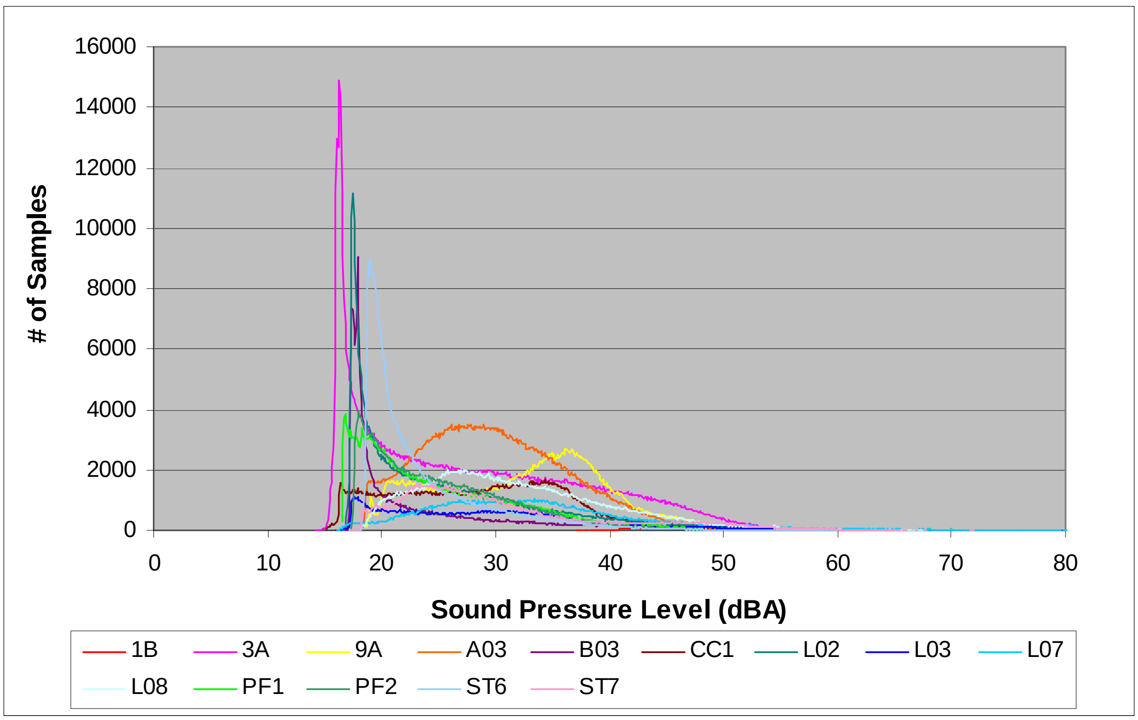


Figure 4. Sound pressure level distribution by site for low wind speeds (< 5 m/s).

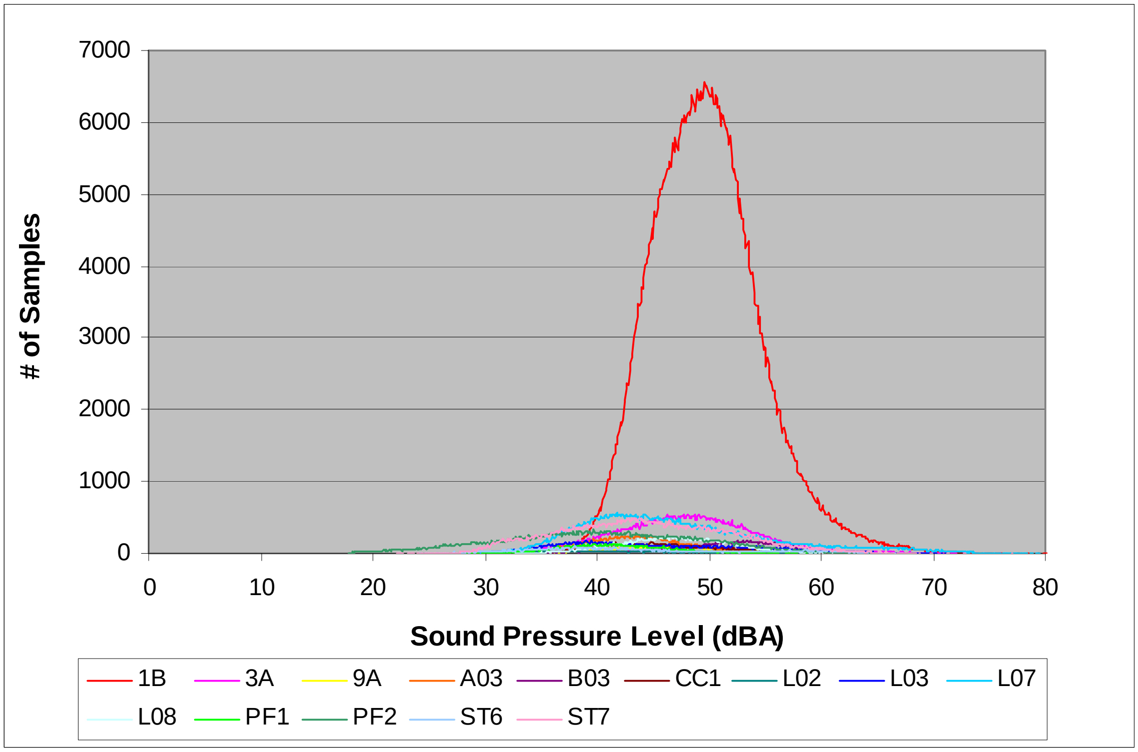


Figure 5. Sound pressure level distribution by site for high wind speeds (> 5 m/s)

2.1.1.2 The relationship between sound level and wind speed

To examine the relationship between sound level and wind speed, a scatter plot was developed and is displayed in Figure 6. This scatter plot displays the relationship on a site-by-site basis. Before any conclusions can be drawn from the observations in Section 2.1.1.1, the possibility of site influences must be further examined. Because the dataset was developed by incorporating a number of sites from a variety of parks, with the intention of determining the overall or average effect of high wind speeds at relatively barren sites, there exists the possibility that a site bias was inadvertently introduced and was influencing the observations. That is, there could have been a single site(s) included in the dataset, which dominates the shape of the observed trends. Examination of the relationship between sound level and wind speed on a site-by-site basis can help one to understand the significance of site-to-site variability on trends observed.

Overlaid on the data are computed "distance-weighted least-squares" (DWLS) line fits, which provide the approximate (arithmetic) average of the sound level versus wind speed data for each site. This helps to illustrate the general shape of the data without making any assumptions about the functional form of this dependency. Because the density of the points does not allow for easy visualization of these lines, Figure 7 shows these lines in the absence of the underlying data points.

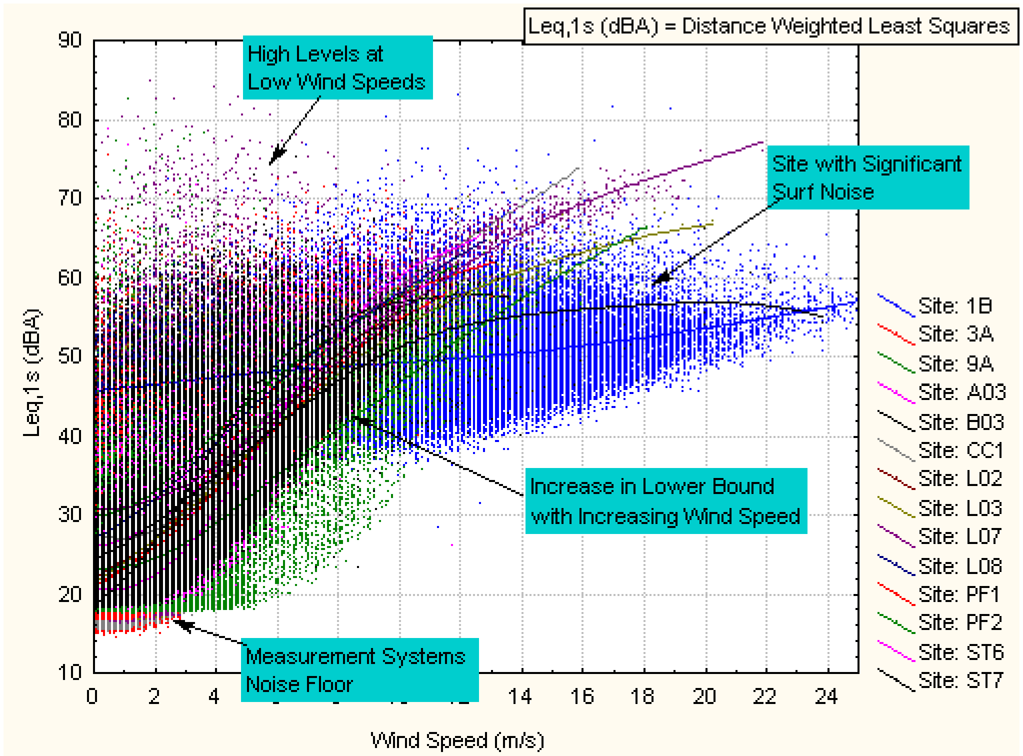


Figure 6. Scatter plot of high-wind dataset by site.

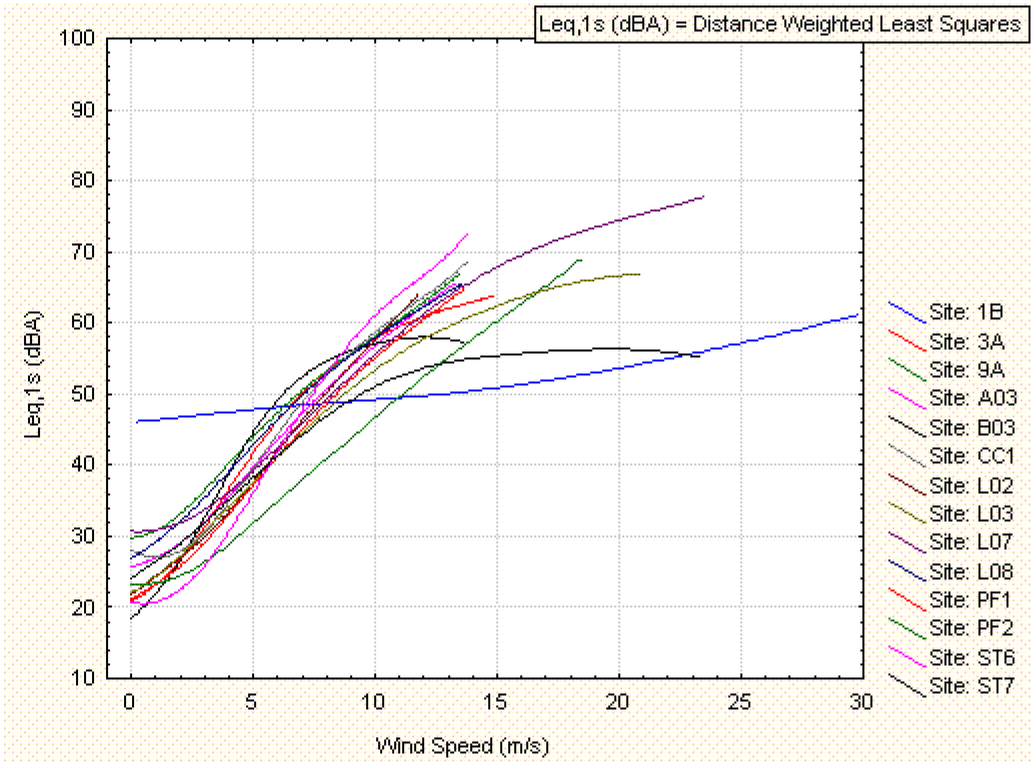


Figure 7. Distance-weighted least-squares line fits by site.

Figure 7 shows that, with the exception of site 1B, the trends are very similar, indicating that none of these sites should bias the conclusions of this analysis. The dissimilar line fit to the data from Site 1B is primarily due to the small amount of sound level data at low wind speeds. In addition, the relationship between sound level and wind speed is relatively constant, which may be a result of the site's shoreline location, where high-wind conditions and constant wave sounds were prevalent. Because the goal of this analysis is to isolate non-natural measurement system contamination, the possibility of the occurrence of high-level, natural sounds at site 1B makes this site un-suitable for analysis. Consequently, the data from this site was removed from further consideration.

Figure 8 again shows the scatter plot in the absence of site 1B, with an overall DWLS line fit overlaid on the data.

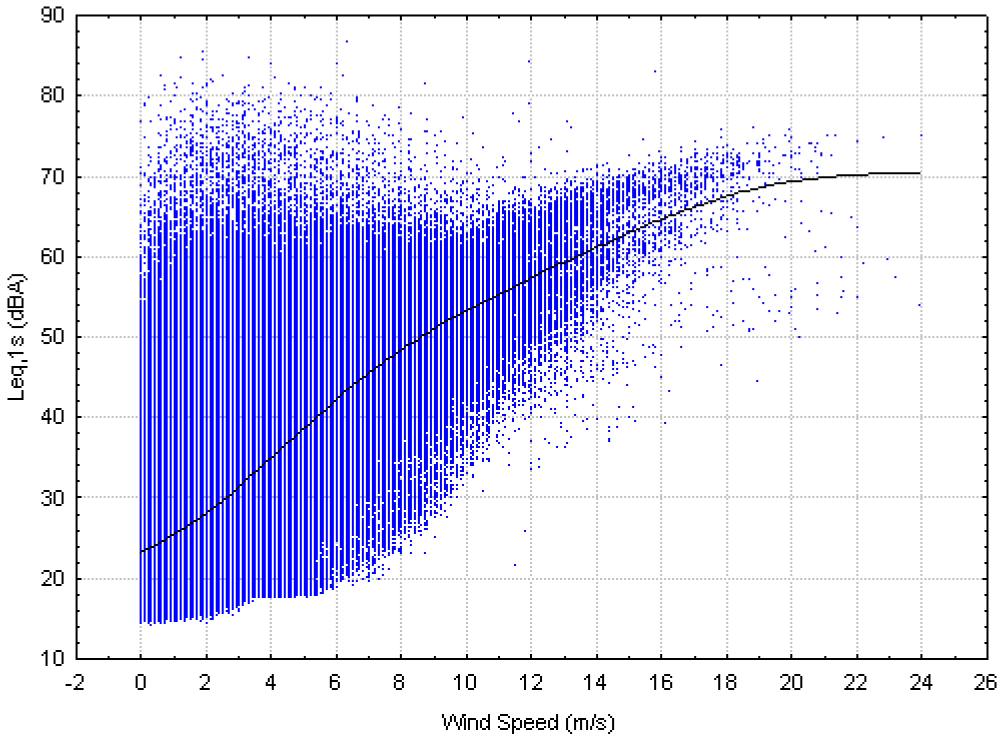


Figure 8 Cumulative wind-speed distribution of high-wind test dataset

Figure 8 indicates that:

- As a whole, sound level increases almost linearly with wind speed at a rate of approximately 3 dBA per m/s, up to at least 15 m/s,
- The maximum $L_{eq,1s}$ (dBA) values do not increase with wind speed. Rather, the highest levels occur during times of both low-wind and high-wind conditions. Thus, "loud" sounds/events are not "missed" when the 5 m/s cutoff criterion is imposed, and
- The measurement system noise floor is no longer apparent in the measurements above 5-6 m/s. This indicates that the low sound level conditions either 1) do not exist (i.e., the natural sounds have increased in level), or 2) cannot be measured due to wind-induced contamination. Because we have included only barren sites, it is unlikely that (1) is the cause. Rather, it is more likely that wind-induced contamination has begun to affect the measured sound levels.

By definition, the above DWLS line represents the approximate *arithmetic* average of the measured sound-level data. Because the arithmetic, sound-level average is not a commonly used acoustic descriptor, similar lines were developed for commonly used acoustic descriptors: L_{50} (the median of the data) and L_{Aeq} (the energy-average of the data). Figure 9 displays these lines, developed by computing the sound-level metrics in 1 m/s wind-speed increments (or "bins") from 0 to 20 m/s (0 to 45 mph).

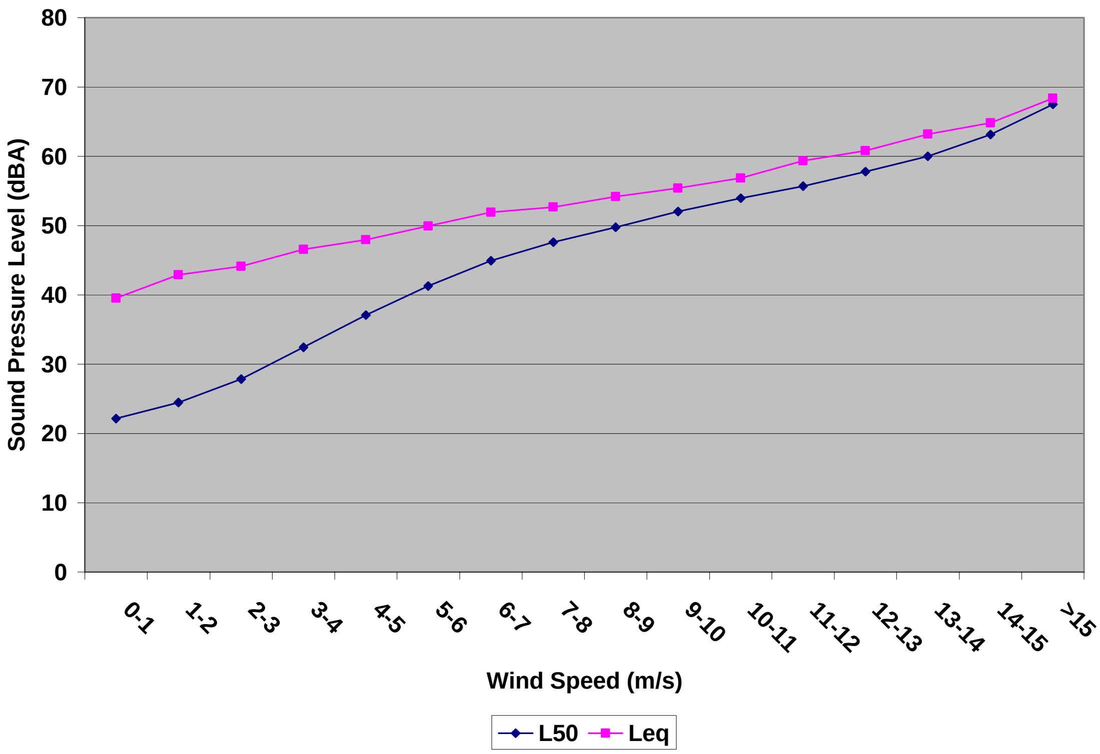


Figure 9. Computed L_{50} and L_{Aeq} for wind speeds in 1 m/s bins.

As was the case for the DWLS curve, the L_{Aeq} and L_{50} sound levels increase roughly linearly with increasing wind speed from 0 to 15 m/s. The L_{50} plot mimics the DWLS line in the previous figure; not unexpectedly, since they are both calculated from a roughly Gaussian distribution using arithmetic measures. As shown in Figure 9, sound levels calculated using the L_{50} metric increase by approximately 3 dBA per m/s, while levels calculated using the L_{Aeq} metric increase less drastically, 1-2 dBA per m/s. This is due to the fact that, as stated above, 1) high sound levels occur during both low- and high-wind conditions and 2) L_{Aeq} is an energy-average, and is influenced most by high sound-levels.

2.1.2 Characterization of the Frequency Components in the High-Wind Ambient Data

As stated at the beginning of this section, one of the objectives of this analysis was to answer the question: Can wind-induced measurement system noise be identified in the measured spectral data? Wind-induced measurement system noise may include: 1) direct flow of wind over microphone diaphragm (popping), 2) turbulence generated by wind passing through windscreens (whooshing), and 3) turbulence generated by wind passing over measurement cables and fairings (whistling). It is believed that each of these components may occur in a specific portion of the frequency spectrum. Popping would most likely occur in the very low frequencies, whooshing in the low frequencies, while whistling is high-frequency in nature. If examination of the frequency content of the measured data shows these phenomena occur predictably and can be definitively identified, it may then be possible to develop a correction procedure which would allow them to be removed from the measurement data. However, there are wind induced natural sounds which may occur in these same portions of the spectrum, confounding the results. These sounds may include: 1) turbulence generated by wind passing over/through irregular surfaces such as vegetation and rocks, and 2) bending of vegetation due to direct flow (rustling of leaves and creaking of branches). By selecting barren sites for this analysis, the sounds generated by vegetation should be negligible, however, turbulence generated by rocks and irregular ground surfaces can not be ruled out.

Section 2.1.2.1 details an additional set of measurements which were conducted, deliberately during a period of high-wind, to determine identifying characteristics of "popping" in sound spectra. Spectral analysis examining wind-induced non-natural sounds in the high-wind dataset is detailed in Section 2.1.2.2

2.1.2.1 Measurement of Wind-Induced "Popping"

Popping occurs in a measurement system when wind causes a large deflection of the microphone diaphragm. This type of wind-induced contamination can be identified by listening to the waveform of a recorded sound* or by looking for identifying

* A wind-induced popping event sounds similar to the sound heard when lightly tapping on the diaphragm of a stethoscope with the pad of a finger while listening through the ear tips.

characteristics in the measured spectrum. In order to identify characteristics of popping in sound spectra, measurements were conducted using a NoiseLogger™ Plus system[24] with a G.R.A.S 40AQ random incidence ½-inch microphone during high winds. The NoiseLogger™ Plus system has the added capability to record periodic audio files for later listening. The wind speed during the measurements ranged from 0.1 to 9.5 m/s (0.2 to 21.3 mph). When using a windscreen, popping was not observed in the sound recording.[*] To induce measurement recordings with popping, the windscreen was removed and popping was then observed for wind speeds greater than 2 m/s (4.5 mph). Comparisons between sample one-third octave band spectra for uncontaminated ambient measurements and measurements with popping are shown in Figure 10. The ambient levels are indicated by green squares, while popping sounds are indicated by blue circles. Popping sounds are further categorized by wind speed, where popping sounds occurring at wind speeds below 4 m/s (9 mph) are indicated by light blue unfilled circles and popping sounds occurring at wind speeds above 4 m/s are indicated by dark blue filled circles. Note that the sound pressure level of popping increases roughly linearly with increasing wind speed, as can be seen in Figure 11.

Referring back to Figure 10, it can be seen that below 200 Hz, the popping sounds have distinctly elevated sound pressure levels. This confirms that popping is predominantly a low frequency effect and analysis to identify its occurrence should focus on frequencies below 200 Hz. It can be observed for this measurement system[†] that popping levels are effectively independent of ambient levels below 20 Hz, that popping produces sound pressure levels between 80 and 90 dB below 20 Hz, and that the popping spectra converge with the ambient spectra as frequency increases.

[*] During field measurements, a 30-cm (12-in) diameter Musashi Kasei windscreen is used on NoiseLogger™ and NoiseLogger™ Plus measurement systems and a two-stage windscreen (outer cloth, inner foam) is used with the VoLARE system. Because the windscreens used for field measurements offer more protection than the single stage 9-cm windscreen used in this experiment, popping should not contaminate noise measurements with wind speeds less than 9.5 m/s, which was the maximum wind speed measured in this experiment.

[†] The sound pressure level of popping is dependent on the measurement system and wind speed. Higher wind speeds and more sensitive/compliant diaphragms will produce higher sound pressure levels than low wind speeds and less sensitive / stiff diaphragms.

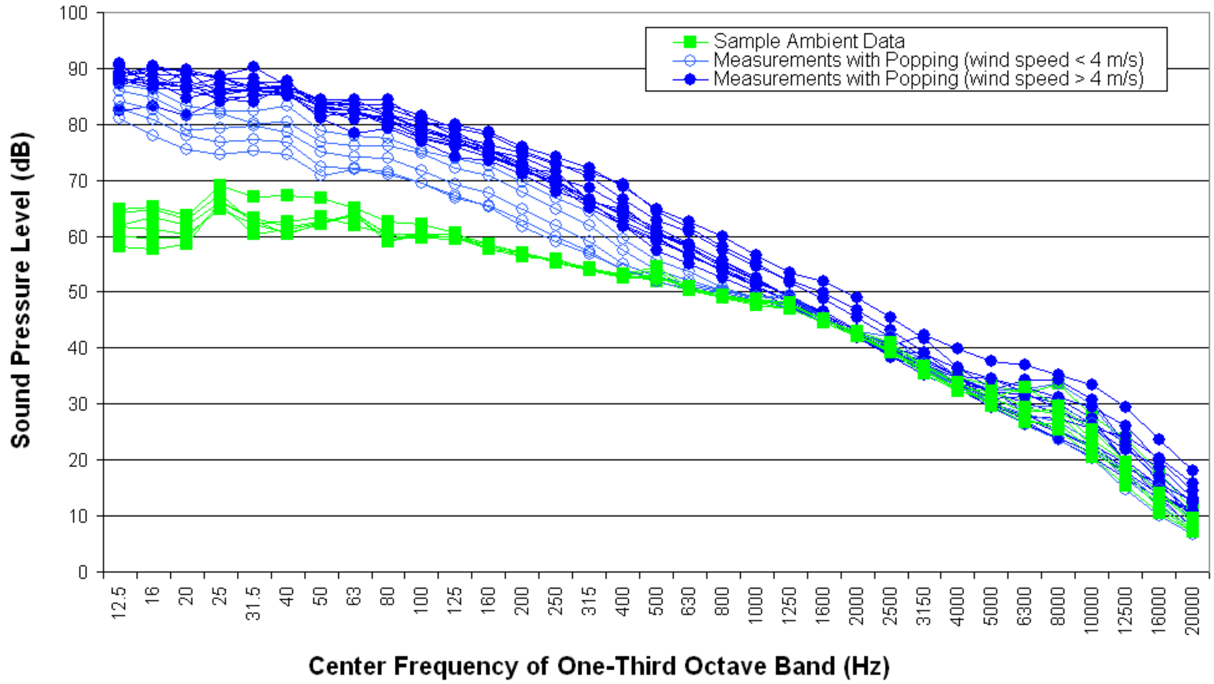


Figure 10. One-third octave band spectra for sample ambient data and measurements with popping.

When these characteristics occur in a spectrum for this measurement system, the measured sound should be considered to be contaminated by wind-induced popping. However, since the windscreen was removed during these measurements, the speed at which popping starts to occur for a protected microphone was not determined. The spectral characteristics of popping with and without a windscreen are expected to be similar.

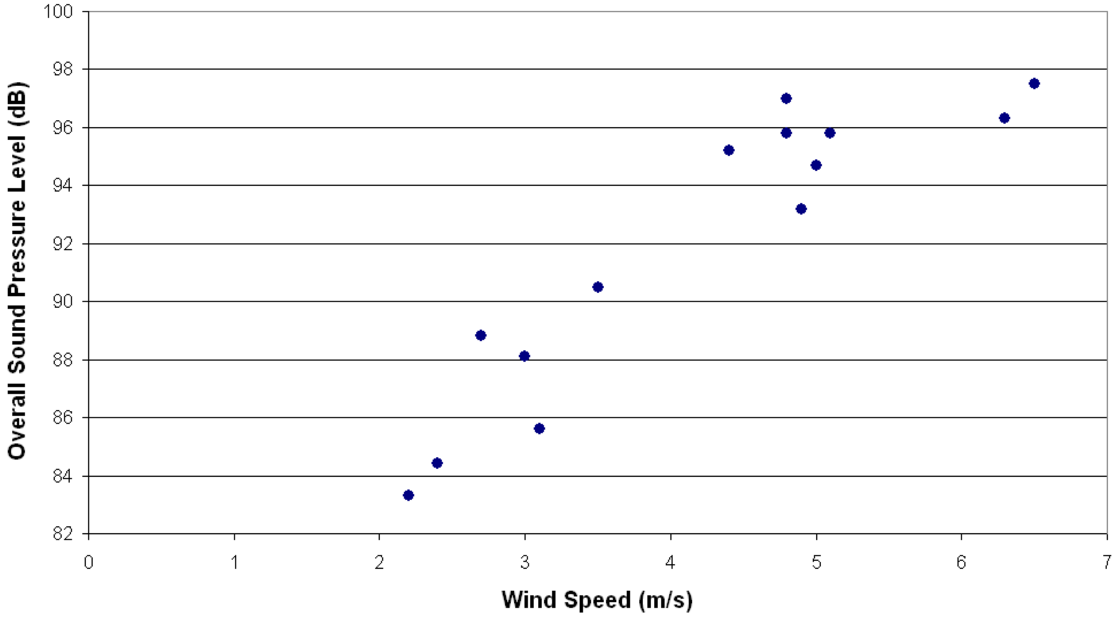


Figure 11. Relationship between wind speed and sound pressure level of popping sounds.

2.1.2.2 Spectral Analysis of the High-wind Dataset

This section presents the spectral analysis examining if wind-induced measurement system noise (as discussed in Section 2.1.2) can be predictably and definitively identified in the measured data. It explores the spectral characteristics of the 1-second samples of sound-level data measured in high-wind conditions. Figure 12 displays the un-weighted, energy-average L_{eq} spectra of the measured data for wind speeds in 1 m/s increments (or bins) from 0 to 20 m/s (0 to 45 mph).

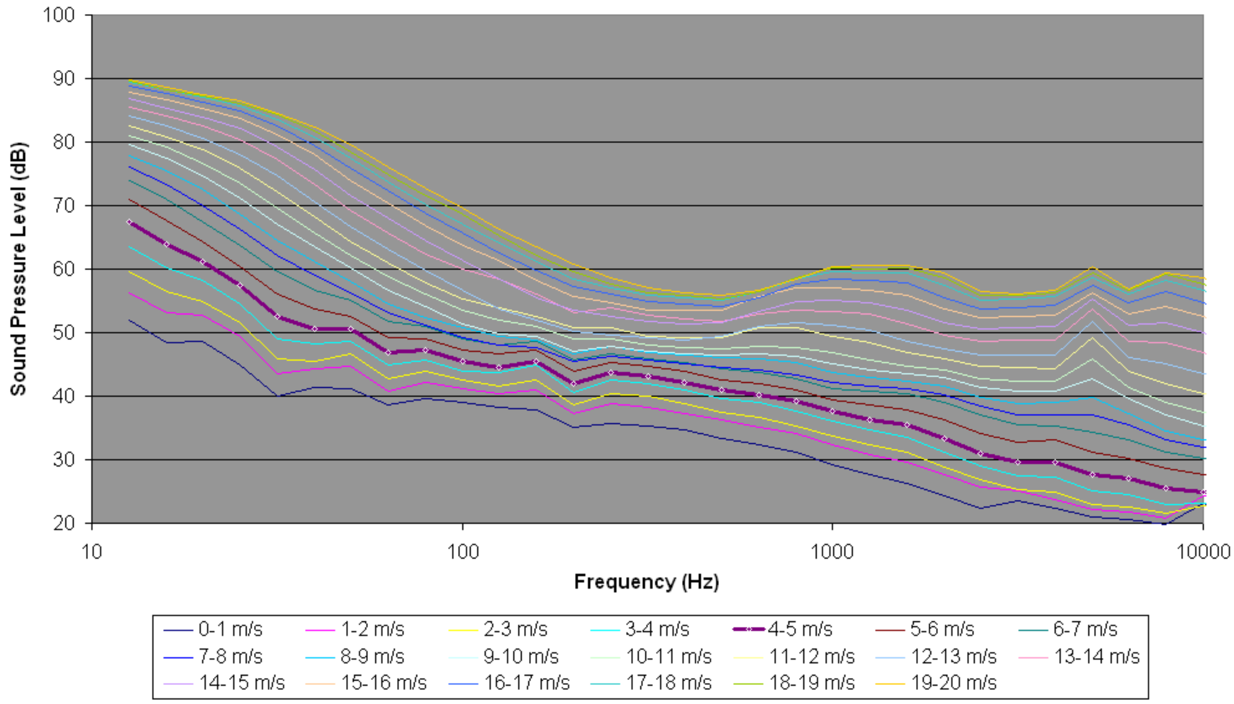


Figure 12. L_{eq} Spectra for all sites in 1-m/s wind speed bins.

This figure shows that, rather than exhibiting a few clearly identifiable peaks, there is a broad-spectrum increase in sound level as wind speed increases. However, the increase is not consistent. The low-frequency (<200 Hz) and high-frequency (>500 Hz) portions of the spectra increase by up to 45 dBA, while the mid-frequency portion in between increases by 25 dBA (when comparing the lowest wind-speed bin to the highest wind-speed bin. Because measurement system noise, if it occurs, is expected in the low-frequency and/or the high-frequency portion of the spectrum, the observed inconsistent increases may be evidence of measurement system noise. However, as a result of both the broad-spectrum increase, and the nature of the measurements (in-situ and unmanned), the specific types (popping, whooshing or whistling) of contamination cannot be predictably identified and separated from one another or from the naturally-occurring sounds.

Although the types of contamination cannot be definitively identified, some speculation on the source(s) of the sound level increases can be made. The peak in the 5,000 to 8,000 Hz frequency range may be the result of whistling of wind over fairings and/or insect activity. The low frequency increase may be the result of wind whooshing through and around the windscreen and/or over irregular ground surfaces. There is evidence of the popping phenomenon (as discussed in Section 2.1.2.1) below 50 Hz in the highest wind speeds (above 15 m/s).

Because there is a chance that pooling the sites may mask some of the effects, it is desirable to examine the spectral data on a site-by-site basis. Figure 13 through Figure 16 display the un-weighted, energy-average L_{eq} spectra of the measured data at several sites for wind speeds in 1 m/s increments (or bins) from 0 to 20 m/s (0 to 45 mph). For results at additional sites, refer to Appendix C.

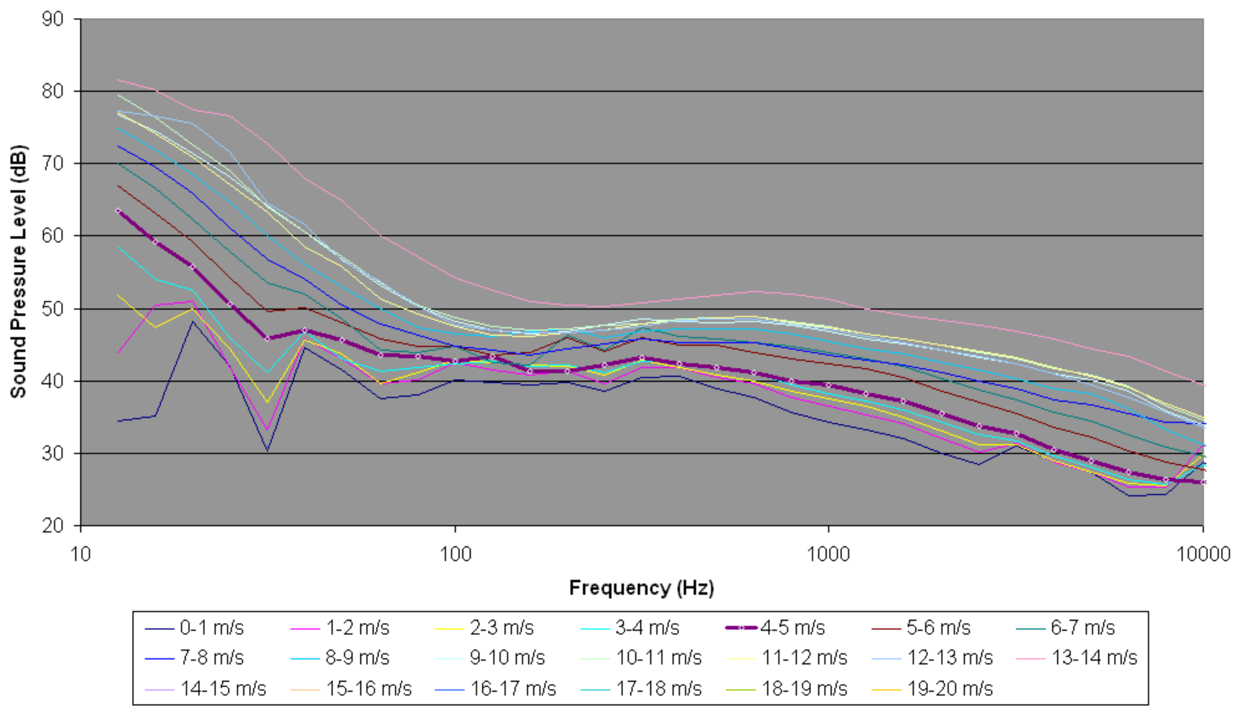


Figure 13. L_{eq} spectra for Hawaii Volcanoes Site 9A in 1-m/s wind speed bins.

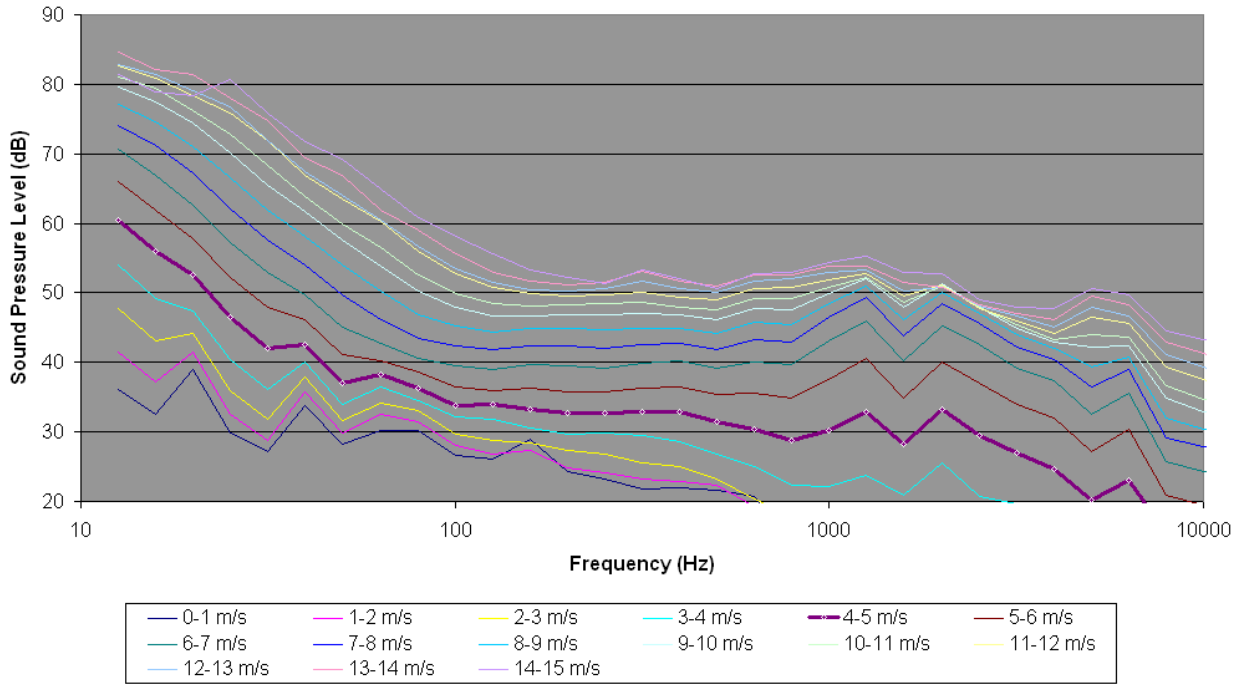


Figure 14. L_{eq} spectra for Haleakala Site ST6 in 1-m/s wind speed bins.

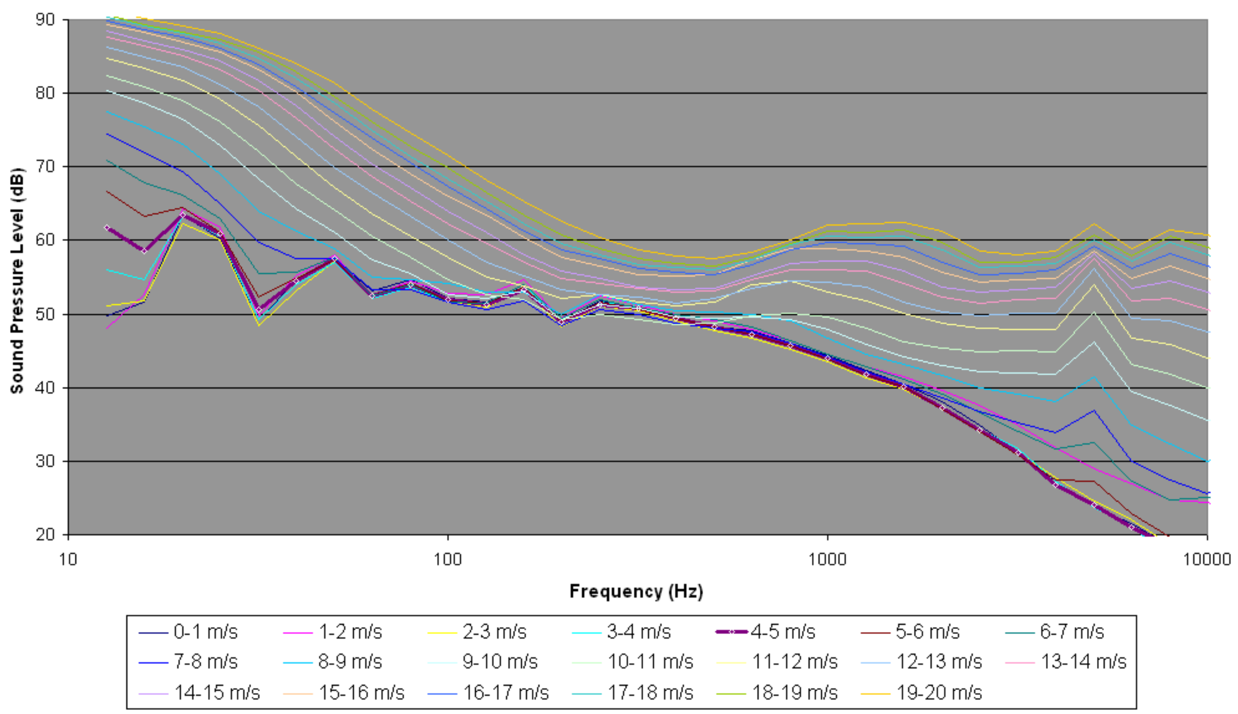


Figure 15. L_{eq} spectra for Lake Mead Site L07 in 1-m/s wind speed bins.

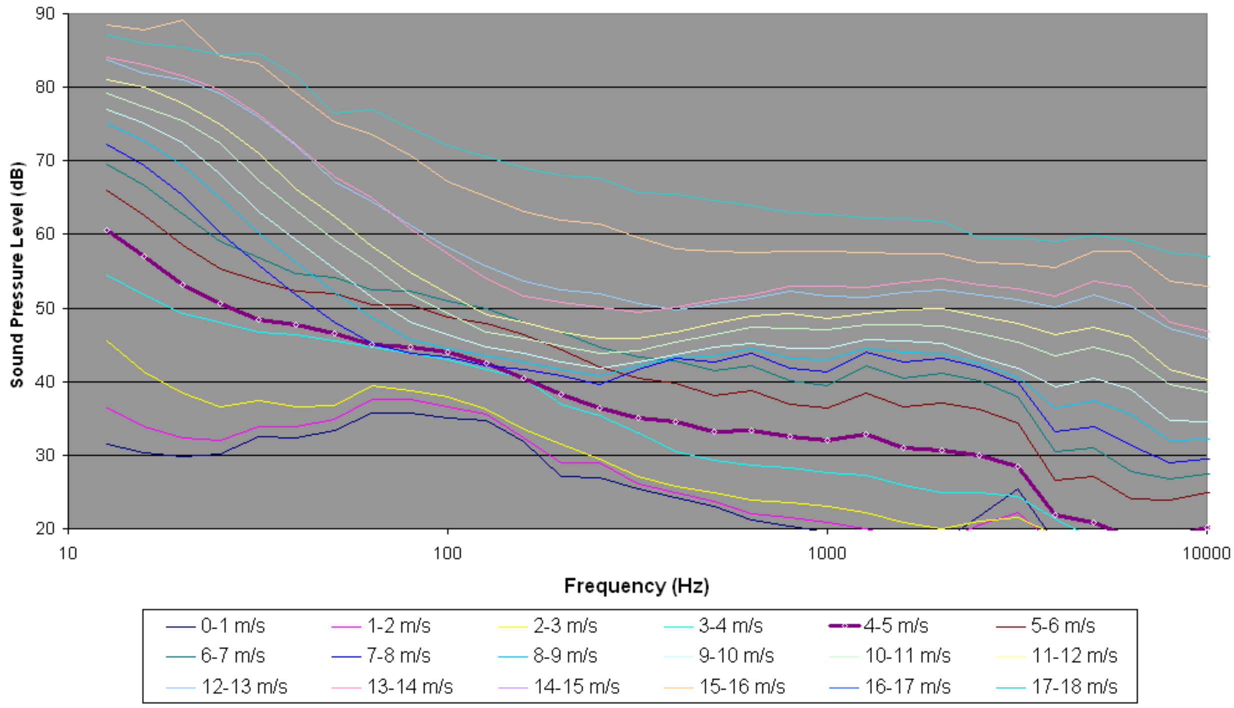


Figure 16. L_{eq} spectra for Canyon de Chelly Site CC1 in 1-m/s wind speed bins.

The following is observed in the above figures (see also Appendix C for additional sites):

- The spectra at individual sites show the same general characteristics as the pooled spectra.
- All of the sites appear to exhibit wind-induced noise below 50 Hz at wind speeds as low as 3 m/s (6.7 mph).
- At seven of the thirteen sites (9A, L02, L03, L06, A03, PF1, and PF2) ambient levels in the 50 to 500 Hz frequency range remain fairly constant below 5 m/s. Most helicopters and fixed-wing aircraft have prominent low-frequency components, which makes this an important range for audibility, a metric of particular importance to the ATMP project. Wind-induced noise becomes apparent in these frequencies above the 5 m/s speed bin.

To further examine the phenomena, Appendix C also contains the site-by-site data re-plotted for select one-third octave bands (12.5, 50, 100, 500, 1000, 5000, and 10000 Hz). From this data analysis, it can be seen that for most frequencies, the sound levels at wind speeds below 5 m/s are more widely scattered over the different sites than the sound levels above 5m/s. The divergence below 5 m/s may be an indication of individual site characteristics (i.e., natural sound sources), while the convergence between 5 and 10 m/s may be an indication that wind-induced measurement system contamination starts to dominate and, therefore, is independent of site. The high-frequency sound levels begin to diverge again above 10 m/s.

2.1.3 Summary of Results

The results of the previous analyses, which answer the questions stated at the onset of this section, are summarized as follows:

1) When, and to what extent, does wind-induced measurement system noise begin to influence measured sound levels?

When: Examination of the data measured at 'barren' sites confirms that wind-induced measurement system noise may begin to affect the measured sound levels above the 5 m/s wind-speed threshold (the threshold that has traditionally been observed for the ATMP project). This conclusion stems from the fact that the measurement system noise floor is no longer apparent in the measurements above 5 m/s, indicating that the low sound level conditions either 1) do not exist (i.e., the natural sounds have increased in level), or 2) cannot be measured due to wind-induced contamination. Because we have included only barren sites, it is unlikely that (1) is the cause. For these reasons, it is recommended that, to the extent possible, the traditional 5 m/s cutoff should be maintained.

This criterion is especially important, for measurements where the collection of uncontaminated data is of the utmost priority, such as measurements where sound levels of a specific source are to be documented. However, because the intent of baseline ambient sound-level collection in support of the ATMP project is to characterize the *entire* ambient sound level environment (natural and non-natural), increases in the ambient due to wind should be represented by the measurements. This is especially important in environments, such as along a coastline or in alpine areas, where the ambient sound levels are dominated by wind-induced effects. Therefore, it may be desirable to incorporate limited amounts of high-wind data in order to incorporate natural, wind-induced noise. Section 2.2 further examines the high-wind dataset to determine if, how much, and by what methods, high-wind data can be incorporated.

To what Extent: The median sound level, L_{50} increases linearly with wind speed at a rate of approximately 3 dBA per m/s, up to at least 15 m/s.

2) "Can wind-induced measurement system noise be identified in the measured spectral data?"

There is evidence of wind-induced measurement system contamination in the measured spectral data. Unfortunately this contamination appears to occur over a large frequency range, rather than manifesting itself as clearly-identifiable peaks, or being isolated to a narrow range of frequencies. As a result of both the broad-spectrum increase, and the nature of the measurements (in-situ and unmanned), the source and specific type of contamination cannot be predictably identified and separated from the naturally-occurring sounds. A correction procedure may be developed if additional data were available from high-wind environments.

2.2 Development of Processing Methods to Incorporate High-Wind Data

The benefits of including contributions from sounds which may naturally occur under high-wind conditions may outweigh the risk of potentially introducing measurement system contamination. As stated earlier, because the intent of baseline ambient sound-level collection in support of the ATMP project is to characterize the *entire* ambient sound level environment (natural and non-natural), increases in the ambient due to wind should be represented by the measurements. In addition, when deciding upon a wind limit, an additional factor must be considered – amount of resultant data loss. For most ATMP sites, the implementation of an upper wind-speed limit of 5 m/s would result in an insignificant amount of data loss – approximately 79 percent of the data would be retained as shown in Table 1. However there are sites, such as along coastal or alpine areas, where the amount of resultant data loss could be much greater. This section will, in response to Question 3, summarize the development of a method to process and incorporate high-wind data into ambient sound level estimates.

2.2.1 Incorporating High-Wind Data As-Measured

Due to the nature of L_{50} calculations, it is reasonable to assume that limited amounts of high-wind data can be incorporated without significantly affecting the ambient sound level estimates. For the purposes of developing a robust data processing procedure, it is desirable to determine an approximate amount of high-wind data that can be tolerated without significantly affecting the computed L_{50}. This amount can be empirically derived by examining, on a site-by-site basis, the effect of the incorporation of high-wind measurement data on the computed L_{50}. Table 2 presents a summary of the basic descriptive statistics of the high-wind dataset for each site with and without the incorporation of the high-wind measurement data.

Table 2. Summary statistics of dataset.

	All Data							Data with associated wind speeds < 5 m/s					Deltas	
Site	**% High Wind**	**Maximum Wind Speed (m/s)**	**Average Wind Speed (m/s)**	**Minimum Sound Level (dBA)**	**Maximum Sound Level (dBA)**	**L_{50} (dBA)**	**L_{Aeq} (dBA)**	**Average Wind Speed (m/s)**	**Minimum Sound Level (dBA)**	**Maximum Sound Level (dBA)**	**L_{50} (dBA)**	**L_{Aeq} (dBA)**	**L_{50} (dBA)**	**L_{Aeq} (dBA)**
All	10.0%	24.0	2.4	14.3	90.0	28.2	46.5	1.9	14.3	90.0	26.9	43.9	1.3	2.6
1B	98.6%	30.0	11.2	26.9	83.0	49.4	53.4	4.4	35.7	74.0	46.6	50.5	2.8	2.9
3A	9.6%	16.0	2.4	14.3	84.0	27.1	44.6	2.0	14.3	81.0	25.2	40.4	1.9	4.2
9A	2.7%	14.0	1.8	18.5	86.0	33.9	47.2	1.7	18.5	86.0	33.6	47.0	0.3	0.2
ST6	3.9%	14.0	2.1	16.9	66.0	21.6	39.6	2.0	16.9	64.0	21.4	32.3	0.2	7.3
ST7	29.0%	24.0	3.3	17.1	86.0	31.9	47.4	2.5	17.1	74.0	27.8	43.7	4.1	3.7
B03	8.7%	15.0	1.9	16.0	70.0	20.8	46.0	1.4	16.0	70.0	19.8	41.8	1	4.2
L02	1.0%	12.0	1.3	16.6	74.0	22.8	38.1	1.3	16.6	74.0	22.6	37.7	0.2	0.4
L03	16.2%	21.0	3.5	16.4	71.0	30.9	47.0	2.7	16.4	69.0	28.6	42.9	2.3	4.1
L07	31.1%	24.0	3.8	16.1	90.0	36.9	55.8	2.9	16.1	90.0	32.4	54.3	4.5	1.5
L08	7.1%	14.0	2.0	18.0	79.0	31.3	43.4	1.7	18.0	79.0	30.4	41.8	0.9	1.6
CC1	5.3%	17.0	1.9	15.1	76.0	29.5	39.9	1.6	15.1	72.0	28.8	35.3	0.7	4.6
PF1	3.9%	14.0	1.6	16.5	72.0	23.3	34.6	1.4	16.5	72.0	22.9	32.9	0.4	1.7
PF2	17.1%	19.0	3.1	17.4	71.0	25.6	40.5	2.2	17.4	71.0	23.8	32.8	1.8	7.7
A03	4.4%	14.0	2.3	18.1	82.0	29.7	39.3	2.0	18.1	82.0	29.4	38.1	0.3	1.2

When the high-wind measurement data are included in the dataset, which, as a whole, consists of 10 percent of the data measured above the 5 m/s wind-speed cutoff criterion, the L_{Aeq} increases by 2.6 dBA and the L_{50} increases by 1.3 dBA. The larger increase in L_{Aeq} can be attributed to the definition of this metric – L_{Aeq} is an energy average and is more influenced by high sound levels; whereas L_{50} is dependent only on data distribution.

With one exception (Site 3A), sites with less than 10 percent high-wind data exhibit less than 1.0 dBA increase in the L_{50} when the high-wind data is included in the dataset. L_{Aeq}, however, is much more sensitive to the addition of high wind data. Based on the data in Table 2, the increase in L_{Aeq} does not correlate well with % high-wind data added. As little as 3% high wind data can produce a significant increase in the calculated L_{Aeq}. Figure 17 shows this graphically.

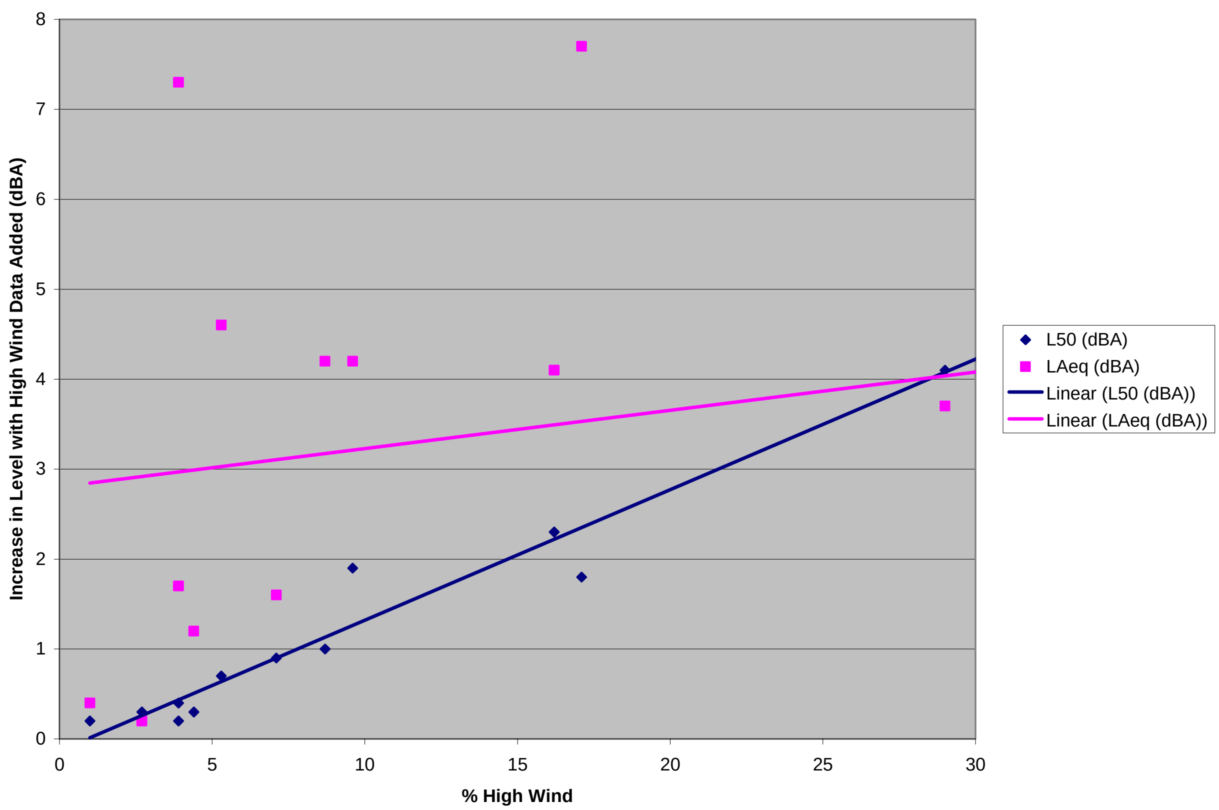


Figure 17. Increase in sound level as a function of % high-wind data added

As a result, it is recommended that no more than 10% high-wind data be incorporated into the dataset to ensure only a negligible (<1 dBA) increase in the L_{50} value. If the L_{Aeq} is of interest, it appears that high-wind data should not be included in the computation of ambient.

2.2.2 Replacing High-Wind Data (Backfilling)

The previous analysis was performed using pooled datasets from each site, where individual 1-second data of all the hours are combined into a single dataset. Because the FAA and NPS have agreed that ambient analysis for future ATMP parks will be performed using hourly summary data (see also Section 4), this section focuses on the effects of high-wind data on sound level descriptors based on hourly summary data. That is, sound level descriptors are computed for each individual hour. Then the median from individual hours across all days of the measurement period is determined. Although prior studies[9] have shown that results for pooled analyses are generally more conservative than results for an hourly analysis, analyzing ambient data by hour helps to ensure hour-to-hour and day-to-day variation is addressed.

As stated at the onset of Section 2.0, several quality assurance filters, checks, and adjustments are applied to the acoustic data to ensure that any questionable data is identified and that only "good" data are reduced and analyzed. These quality assurance filters and checks include the following:

- Data measured when the instrumentation's battery readings were less than the minimum voltage required to properly run the acoustic monitoring system;
- Data measured when the instrumentation's internal temperature readings were greater than the acoustic monitoring system's maximum operating temperature limit;
- Data whose associated 1-second average wind speeds indicate an anemometer error;
- Data whose associated 1-second Z-weighted sound levels exceeded the acoustic monitoring system's instrumentation noise "ceiling level" for the gain setting of the system;
- Data that were potentially contaminated by field personnel; and
- In previous analyses, data whose associated 1-second average wind speeds were greater than 11 mph (5 m/s), the predetermined, acceptable, wind speed threshold (see Section 2.1.3); and

For hourly data analyses, as an additional quality assurance filter, datasets are discarded for those hours that contain less than 45 minutes (75%) of "good" data. This criterion is based on analysis performed by Harris Miller Miller & Hanson, Inc. on potential measurement error caused by data gaps and is applied to ensure hours with only a few samples do not bias the analysis.[10] Because this approach can severely limit the number of 'good' hours of data from high-wind sites, such as along a coastline or in alpine areas, it is desirable to develop a method to incorporate and/or replace the high-wind data so that these sites can be accurately represented.

As summarized in the previous Section, up to 10% of any hourly measurement dataset can consist of high-wind data before a significant change to L_{50} is observed. For the majority of measurement hours, this will allow for almost all of the measured data to be used in the hourly estimate (i.e., at the majority of sites measured for the ATMP project, high-wind data represents less than 10% of the dataset). However, even with the addition of 10% high-wind data, there are still many occurrences where 45 minutes of data in each hour are not available for analyses. In order to recover a portion of the hours that do not meet this criteria, replacing, or "backfilling," data measured under high-wind conditions with data measured under high, but acceptable, wind conditions should be considered.

Backfilling may be desirable to ensure that the ambient calculated at naturally-windy sites is representative of windy conditions. The current method, which uses only data below the wind speed threshold, may bias the ambient by incorporating 'calm' measurements in an unrepresentative proportion. For example, if a measurement hour consisted of 30 minutes of data above the 5 m/s threshold ('windy'), 15 minutes between 3-5 m/s ('moderately windy'), and 15 minutes below 3 m/s ('calm') , the data used for ambient calculations would have a ratio of calm to moderately windy of 1:1. It would be more desirable to represent this hour by a ratio of calm to moderately windy of 1:3. In other words, the contaminated data, measured under high-wind conditions, should be replaced with the data measured under high, but acceptable wind conditions in order to maintain more reasonable proportions. This process has been termed "backfilling."

This Section outlines the development of a procedure for backfilling and examines the effects on both the sound level descriptors and the ambient spectra.

2.2.2.1 Effect of High-Wind Data on Overall Ambient Sound Level Descriptors Using Backfilling

To test how much data could be backfilled and its effects on descriptors, such as L_{Aeq} and L_{50}, the following exploratory methods and criteria were used:

- Hours to be tested for backfilling must contain a *reasonable* amount of good (below the 5 m/s threshold) data. At a minimum, a reasonable amount was initially defined as 25 percent, or 15 minutes of the hour. The initial amount was set purposefully low to test the limits of this approach.
- The source of the backfill data would be data measured when wind speeds were high, but acceptable (between 4 and 5 m/s).
- The backfill process would conclude when 45 minutes of data were available, thus making the hour acceptable for ambient calculations.

To focus the analysis on sites with many hours of data loss due to high winds, five sites from ATMP parks were chosen for this analysis*, summarized in Table 3. From these sites the hourly datasets between 12 pm and 4 pm were targeted for this analysis, since wind speeds tend to peak in the early afternoon.

Table 3. Summary of backfill test datasets

Park Name	Site ID (Location)	Total Hours of Data Between 12-4 pm	# Hours of Data Discarded Due to High Wind	# of Candidate Backfill Hours (Minimum 25% Good Data)
Hawaii Volcanoes National Park	1A	59	56	36
	6B	110	68	49
Haleakala National Park	ST7	59	8	8
Lake Mead National Recreation Area	L07	48	32	30
Petrified Forest National Park	PF2	36	28	15

The candidate hours were backfilled by replacing the 1-second samples measured under high-wind conditions (above the 5 m/s wind-speed limit) with randomly selected 1-second samples from the same measurement hour measured when wind conditions were between 4 and 5 m/s. This replacement continued until 45 minutes of data were available

* 3 of these sites are from the barren database used in the previous analyses. Site 6B, a vegetated site, was included to ensure that differences in the results were not occurring at vegetated sites. Site 1A, a coastline site, was included as a worst-case scenario.

for analyses. Figure 18 and Figure 19 present the differences in L_{Aeq} and L_{50} computed for each hour when: (1) only the original 'good' data was included; and (2) the good data and the backfilled data were included. Linear trend lines are overlaid on the data for each site for illustrative purposes.

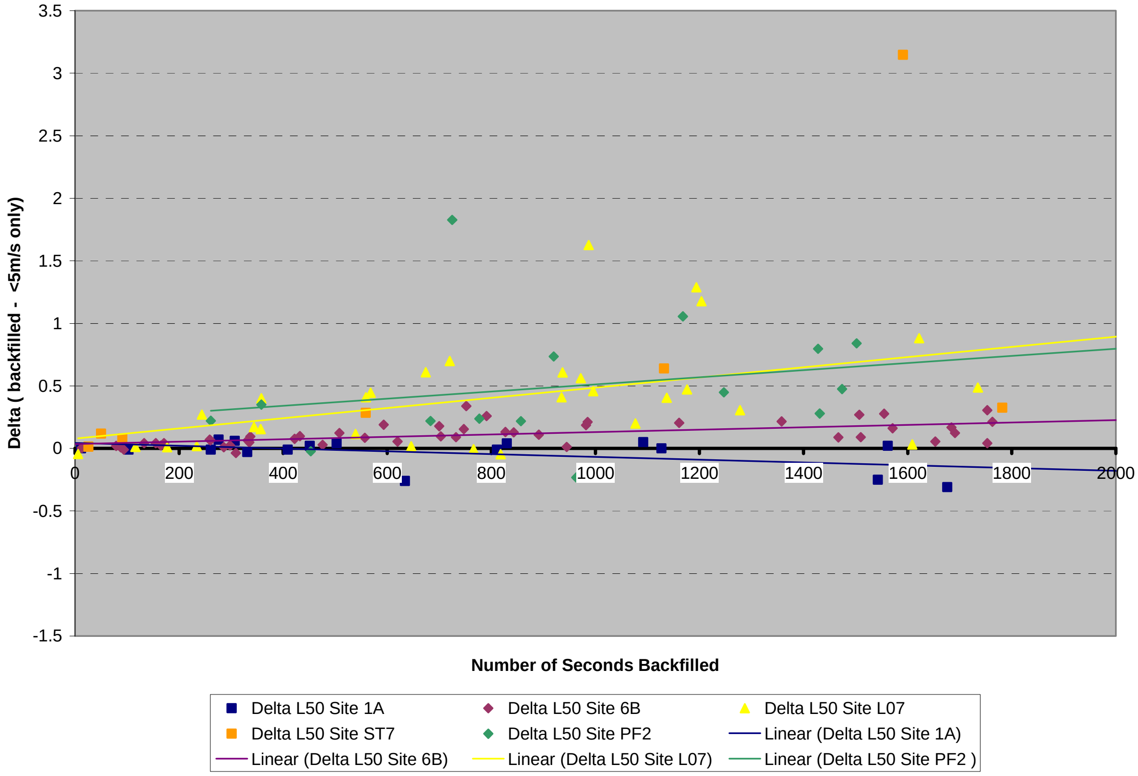


Figure 18. Comparison of L_{50} computed with and without backfilled data

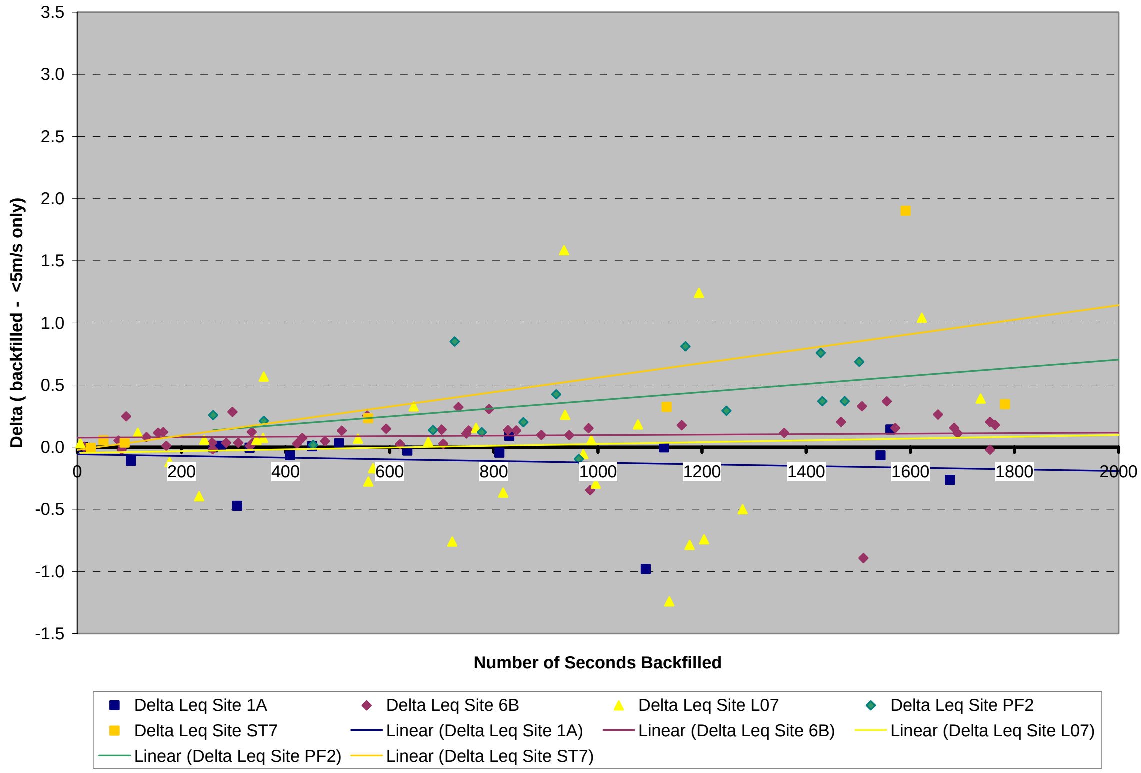


Figure 19. Comparison of L_{Aeq} computed with and without backfilled data

In the above figures, a positive delta indicates that the hourly sound levels increased as a result of the backfill process. A negative delta indicates that the hourly sound levels decreased as a result of the backfill process, which occurred for both metrics at Site 1A and the L_{Aeq} results for Site L07. Although this seems counter-intuitive, further examination of the data indicates that this result stems from situations where large fluctuations in sound levels, independent of wind speed, are experienced over time. In this case, the sites are generally very quiet, but experience frequent, high sound level events. In other words, data from low wind-speed conditions contain high sound level events which are, by chance, not present in the data from the backfill pool. As a result the backfilled data contains a larger portion of low-level natural ambient.

These figures illustrate several points: (1) backfilling high-wind data will slightly increase hourly sound levels; (2) the majority of hourly sound levels did not significantly change (most were less than 1.0 dBA); and (2) the scatter in sound level deltas broadens as the number of backfilled points increases, particularly when backfilling is used for more than 25 percent of an hour (15 minutes). Therefore, it is recommended that backfilling be limited to not more than 25 percent of the hour (i.e., a minimum 30 minutes of good data to start with). In the majority of cases, this would increase the L_{50} and L_{Aeq} sound levels by no more than 1.0 dBA.

However, there still exists at least one case, at site PF2, where the L_{50} ambient estimate increased by 1.8 dBA. The underlying cause of this larger increase is illustrated in the following wind distribution plots.

Figure 20 is an example of the common shape of the wind speed distribution for an hour where backfilling would be required. The majority of the data from this hour is in the 'moderately windy' range, between 4 and 5 m/s, with very little 'calm' data below 3 m/s. The backfill process for this hour resulted in an increase of 0.5 dBA in the L_{50}.

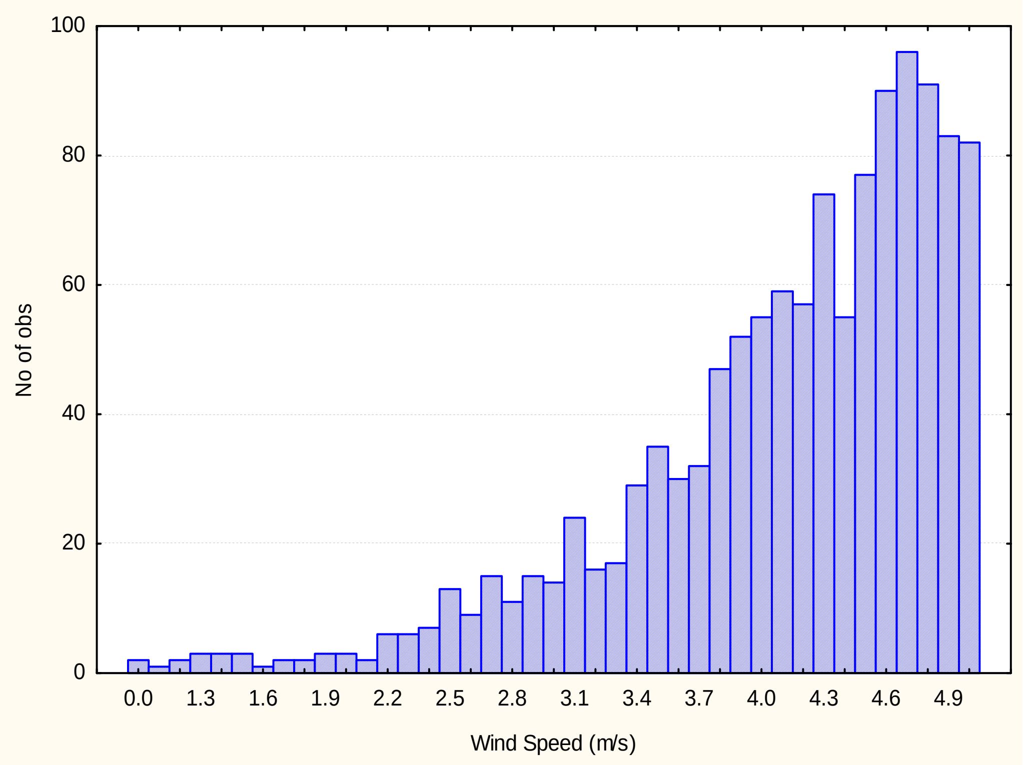


Figure 20. Wind Speed Distribution for 9/13, 1300 hour at Site PF2

In contrast, Figure 21shows the wind speed distribution from the hour where the L_{50} increased by 1.8 dBA due to backfilling. This distribution is somewhat counter-intuitive; the majority (45%) of the data is in the ‘calm’ range between 0 and 3 m/s, with very little ‘moderately windy’ data between 3 and 5 m/s. More specifically, this hour originally consisted of 27 minutes of data above the 5 m/s threshold (‘windy’), 6 minutes between 3-5 m/s (‘moderately windy’), and 27 minutes below 3 m/s (‘calm’). Before backfilling, the L_{50} would represent conditions where the ratio of calm to moderately windy was approximately 4.5:1. It would be more desirable to represent the conditions in this hour by a ratio of calm to moderately windy of 1:1. After backfilling, the ratio of calm to moderately windy was 1.4:1, much closer to the desirable proportion. This hour illustrates the situation for which the backfilling process was developed: the case where the natural ambient has been underestimated due to the over-representation of data collected under calm wind conditions.

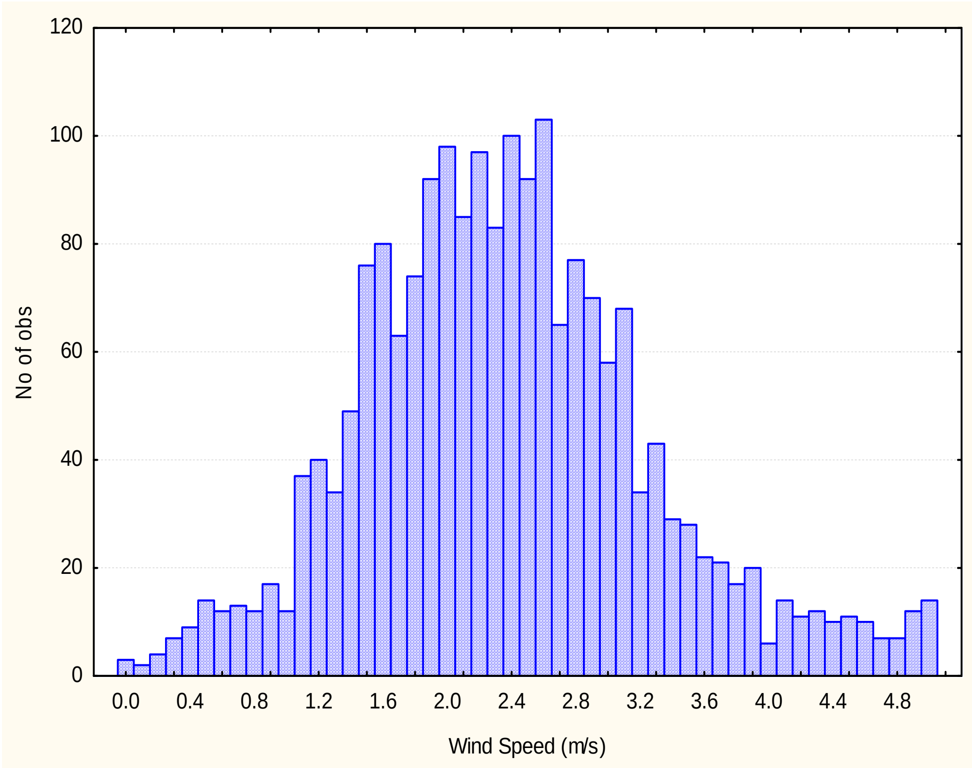


Figure 21. Wind Speed Distribution for 9/19, 1300 hour at Site PF2

This further examination reveals that, although the case from Figure 21 produces somewhat counter-intuitive results, it should not be excluded from the backfilling process. Rather, this is the situation for which the process was developed: the case where the natural ambient has been underestimated due to the elimination of the high-wind data.

The final methods and criteria recommended for backfilling sound level data measured during high-wind conditions are as follows:

- Candidate hours must contain at least 30 minutes (50%) of good data;
- The source of the backfill data would be data measured when wind speeds were high, but acceptable (between 4 and 5 m/s);
- The backfill process would conclude when 45 minutes (75%) of data are available, thus making the hour acceptable for analyses as discussed in Section 2.2.2.[10]

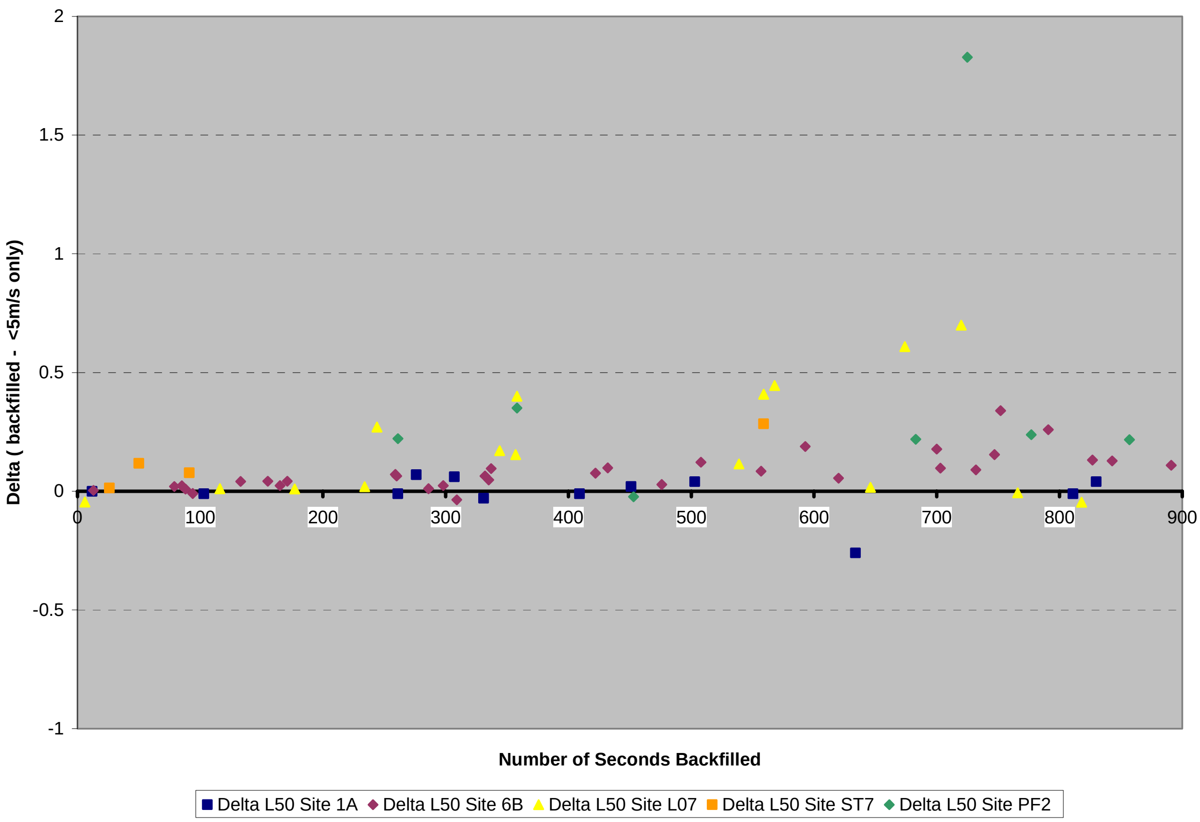


Figure 22. Change in L_{50} due to backfilling using the final procedure

2.2.2.2 Effect of High-Wind Data on Ambient Spectra Using Backfilling

In the previous section, the analysis was performed using the overall narrowband level for each 1-second sample. This section presents the effects on ambient spectra due to backfilling sound-level data. Using the procedure for backfilling developed in Section 2.2.2.1, Figure 23 provides comparisons between natural ambient spectra computed with and without backfilling.

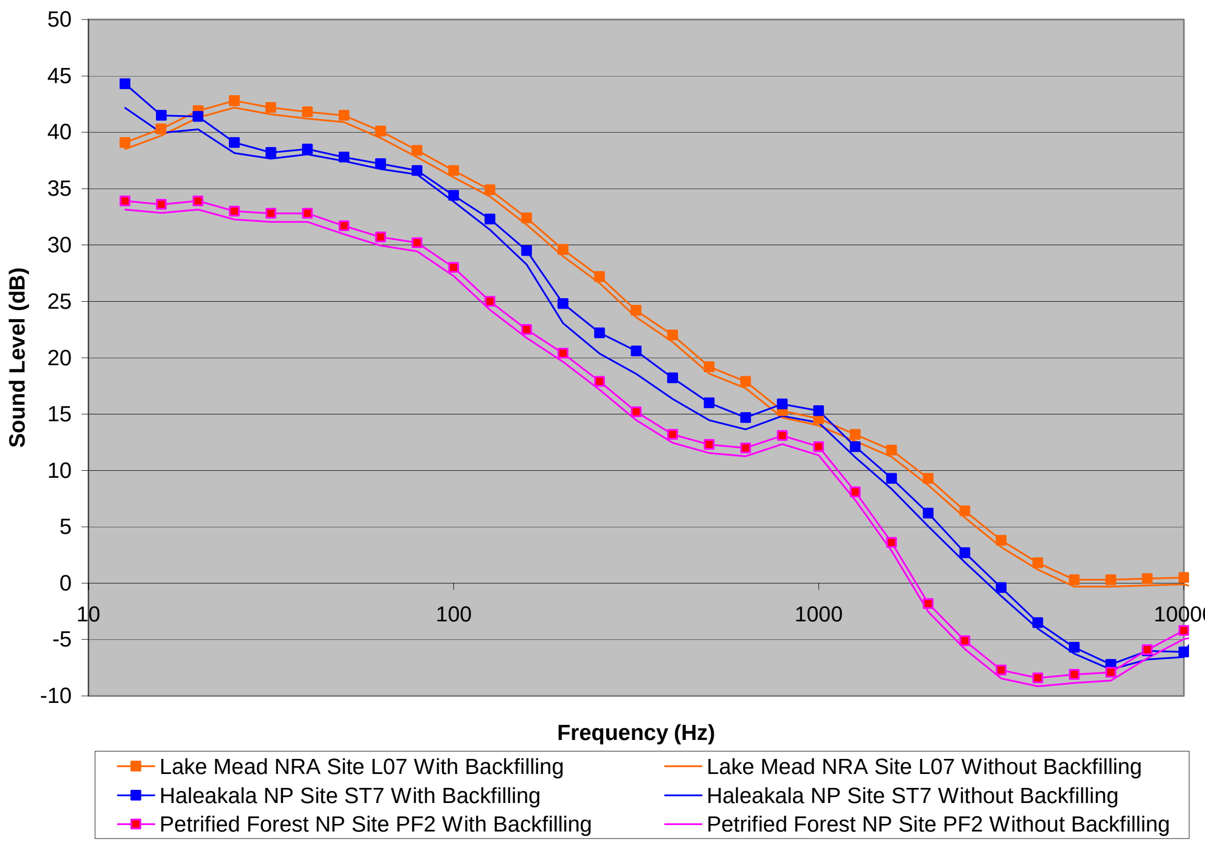


Figure 23. Comparison of natural ambient spectra with and without high-wind backfilling

As expected, Figure 23 does show that the ambient spectra increases as a result of the backfill process. This increase is generally within 1 dB for all frequencies. Thus, the backfill process provides a means to capture potentially louder, more representative, ambient conditions that occur under higher wind conditions without a complete rejection of such data.

2.3 Recommended Procedure for the Processing of High-Wind Data

Based on the results of Section 2.1, the procedure depicted in Figure 24 is recommended for the processing of ambient data which includes data measured under high-wind conditions (>5 m/s). This procedure assumes that data are processed on an hourly basis.

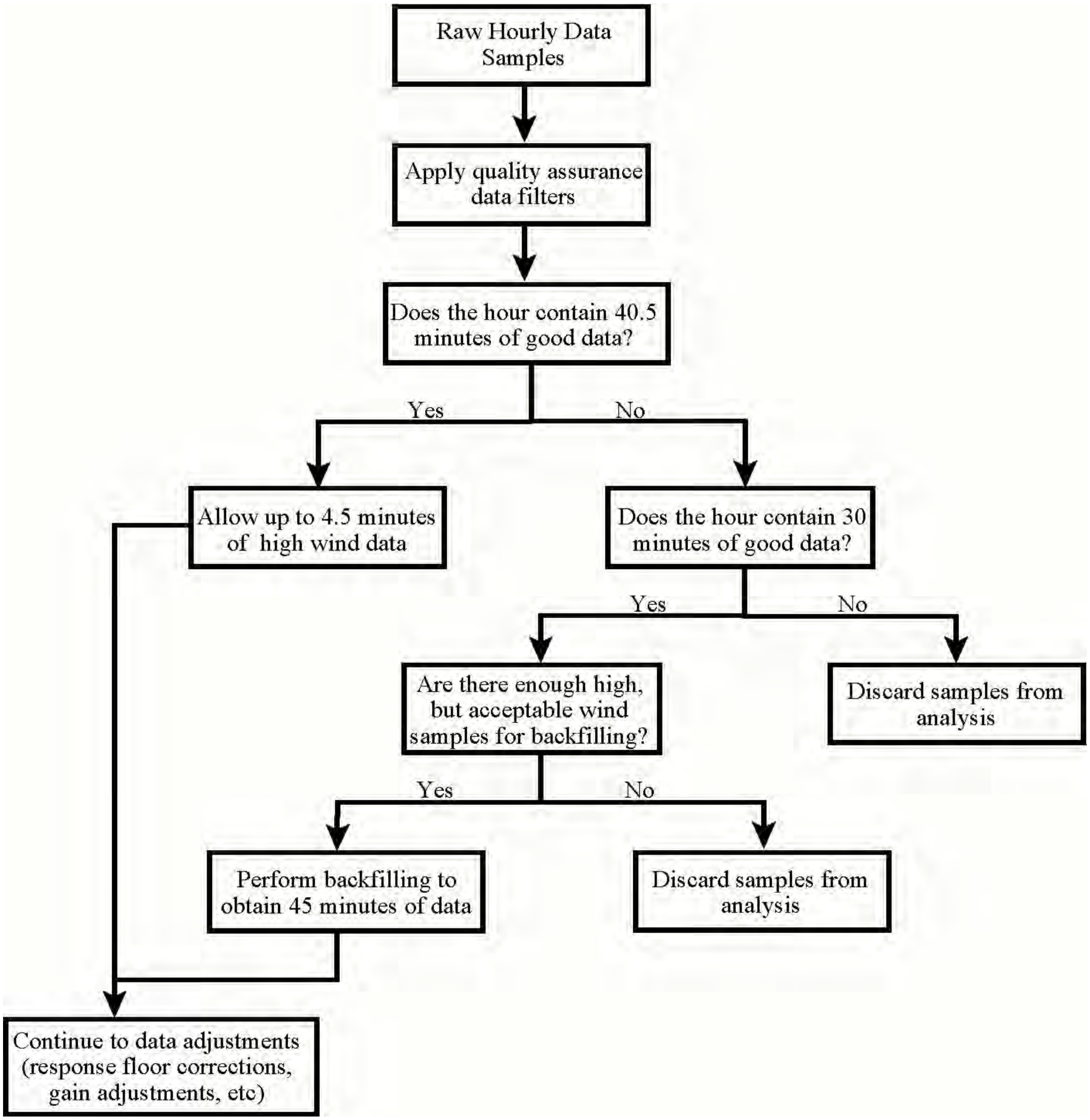


Figure 24. Recommended procedure for the processing of high-wind data.

3. *IN SITU* AND WAVE-FILE 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 performing acoustic observer logging, all audible sounds are identified with a time stamp and one of three primary acoustic states, based on the following hierarchal order: (1) Aircraft intrusions; (2) Human intrusions; and (3) Natural sounds. Aircraft intrusions include air tour, commercial, general aviation, military, and other aircraft sounds. Non-aircraft (human) intrusions may include hikers, campers, motor vehicles, etc. The natural category was documented when no aircraft or other human-made sounds could be heard. If more than one sound within the *same* acoustic state category could be heard, the louder one (based on the observer's judgment) was logged with a notation of the other sounds that were present. An acoustic state would prevail until the current intrusion was no longer audible, or a new intrusion higher in the hierarchal order became audible to the observer.

The advantage to source data collected by an *in situ* acoustic observer is the opportunity to visually identify source origin, simultaneous sound sources, and directionality. The advantage to source data collected by digital recordings is the ability to collect data periodically throughout the entire measurement period (e.g., 30 seconds every 30 minutes) and repeated playback of the recordings (e.g. when the sound is difficult to identify). Neither method is perfect – observer logging can only practically be performed on a short-term basis; digital recordings may miss low-level non-natural sounds, or result in sounds not being attributed to the correct source (e.g., general-aviation versus commercial air tours). Both methods are labor intensive – observer logging requires less post processing labor; digital recordings require less labor during measurements.

This section is focused on quantifying the differences between *in situ* observer logging versus offline review of digital recordings.

3.1 *In Situ* Observer Logging

When observer logging is conducted *in situ*, observers are stationed at least 50 feet from the measurement system, so as not to contaminate the acoustic data. Typically, the logging is conducted in pairs so that a single observer is not required to maintain focus for the entire duration of 4 to 8 hours. A total 12-16 hours of logging is conducted over several days for each measurement site. This equates to approximately 2.5 percent of the total duration of the measurements. *In situ* logging allows for the use of both ears (binaural) to detect slightly different signals (dichotic), which can facilitate very accurate location of sources. When a sound is heard, but its source identification difficult, *in situ* observers are often able to visually or spatially confirm the identity of a sound source. Visual identification can also help in determining the operator of the aircraft (air tour, general aviation, etc). If the source is moving, as in the case of an aircraft, the motion of the source can be tracked. The observer has also had some time to become acclimated to the sounds of the site, so changes are may be easier to detect.

3.2 Off-Site Observer Logging Using Digital Audio Recordings

Observer logging using digital recordings is conducted off-site and typically after measurements have been completed. Digital recordings should be high quality (minimum 16-bit/44.1 kHz), sufficient to accurately record sounds between approximately 10 dBA and 100 dBA.[*] Recording instruments should have a signal-to-noise ratio greater than 80 dB and have the capability to provide accurate frequency coverage, at a minimum, between 20 Hz and 20,000 Hz. It should be noted that in ideal situations, ambient sound levels are well above (> 10 dB) the measurement system's noise floor (typically about 15-20 dBA). If ambient sound levels are close to or below the system noise floor, then off-site logging using digital recordings should be avoided in favor of *in situ* logging, whenever possible, to avoid system noise contamination.

Two types of recordings are typically analyzed: periodic recordings (e.g., 30 seconds recorded every 30 minutes) and threshold recordings (i.e., a recording is started when a sound-level threshold is exceeded). A total of 12-16 hours of recordings are collected over the course of the entire measurement duration. The sum total of the recordings equates to approximately 2.5 percent of the total duration of the measurements (consistent with the duration of *in situ* observer

[*] 16-bits has a dynamic range of 96 dB less overhead.

logging). Although these recordings are monaural (one ear or single channel) and the spatial information is lost, they do allow for repeated playback of sounds and provide a valuable archival record of the biological acoustics of the area. Recordings are played to the observer via a desktop computer using suitable software. The output from the computer's sound card is sent to a headphone amplifier and played through circumaural (completely covering the ear) headphones.[*]

3.3 Comparison of *In Situ* and Off-Site Observer Logging

In order to understand the relative merits of both *in situ* and off-site observer logging, both techniques were used for measurement sites at several ATMP parks. In addition to site-to-site variation, observer log variables (e.g., gain level applied during playback for off-site observer logging and the experience of the observer) were examined.

In Figure 25, *in situ* observer logging is compared with two sessions of off-site listening of digital audio wave file recordings at Acadia National Park Site A02. One off-site logging session was conducted by adjusting the level so that the recorded calibration tone was played back at the nominal level, i.e. 94 dB (i.e., 0 dB playback gain) and the other was conducted so that the calibration tone was played back 15 dB above the nominal level (i.e., 15 dB playback gain). The observer was the same experienced logger for both the *in situ* data and the off-site listening. Off-site logs for periodic and triggered recordings are compared with *in situ* logs for the same time intervals, for example, if a 30 seconds of sound were recorded on a .wav file from August 7, 2005 from 14:45:30 to 14:50:00, then the corresponding log event was included from the *in situ* log.

By comparing the results for 0 and 15 dB gain, it can be seen that there is little effect on the observer logs based on the playback level provided that the sounds are easily audible. The purpose of these gain adjustments was to test whether signal calibration is necessary to ensure accurate off-site listening results in comparison to *in situ* logging. The results in Figure 1 show that it is not. While calibration is recommended for consistency and traceability, if it is

[*] The Volpe Center uses Adobe's Audition 2.0 software, a SHURE FP22 stereo headphone amplifier, and Sennheiser HD580 headphones.

necessary to adjust the playback gain to avoid distortion or to insure that all sounds are audible, gain adjustments should be accepted. It can further be seen in Figure 25 that there is good agreement between the *in situ* logs and the off-site logs. (This will be examined further when discussing Figure 4.)

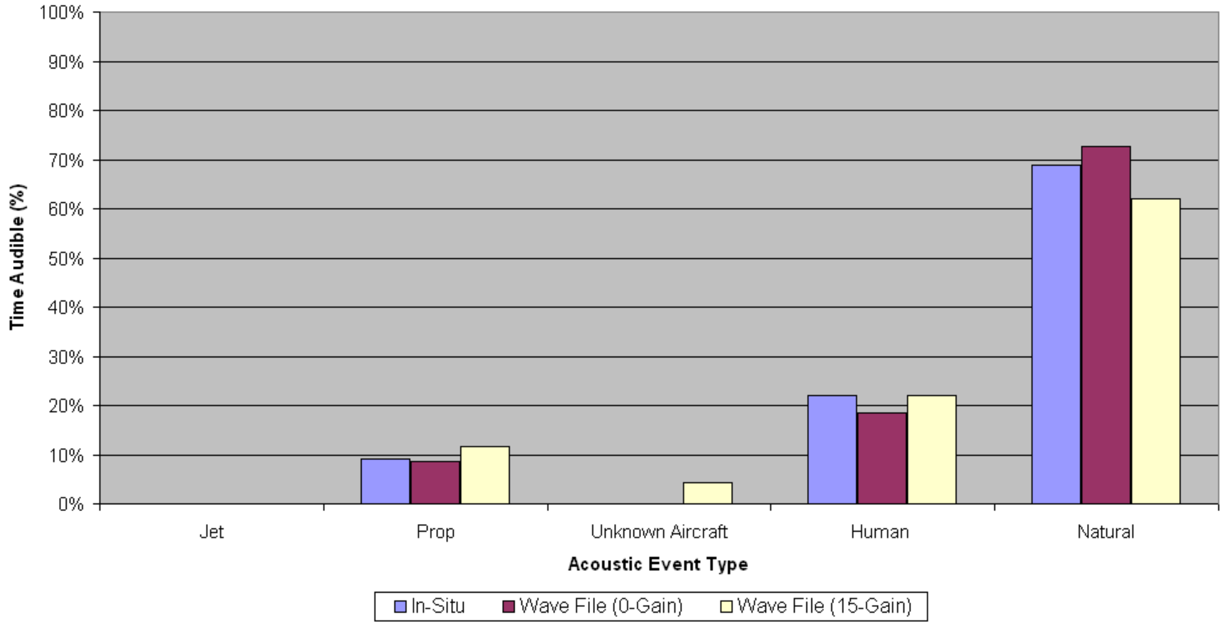


Figure 25. Comparison of *in situ* and off-site (using audio wave files) observer logging.

In Figure 26 and Table 4, *in situ* observer logging is compared with off-site listening performed by a highly experienced logger and a logger with less experience. Note: R^2 correlation is a measure of association between two variables, where higher R^2 values indicate better correlation. It can be seen that although there is in general very good agreement between the experienced and less experienced loggers, the less experienced logger had some difficulty determining specific aircraft types. When less experienced observers log *in situ*, visual cues, as well as source direction, can be used to compensate for their lack of experience. When less experienced observers listen off-site to recorded audio wave files, these additional cues are lost, which can make source identification more difficult. It is important to note, however, that if the purpose of logging is to simply document noise intrusions to the natural ambient, being able to identify details of aircraft type becomes less critical. When such distinctions are important, then an expert observer is recommended.

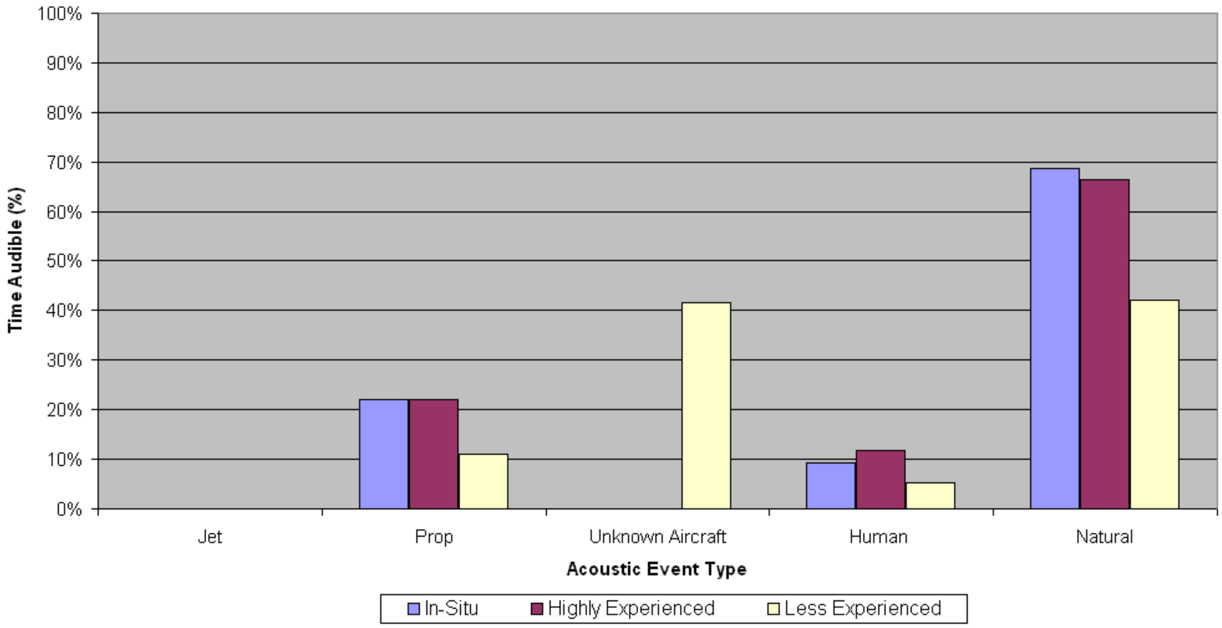


Figure 26. Comparison of *in situ* and off-site (using audio wave files) observer logging for different levels of observer experience.

Table 4. R^2 correlation of *in situ* and off-site (using audio wave files) observer logging for different levels of observer experience.

Observer Type	*In situ* Observer	Off-Site Listening by Highly Experienced Observer	Off-Site Listening by Less Experienced Observer
***In situ* Observer**	1	0.96	0.45
Off-Site Listening by Highly Experienced Observer		1	0.34
Off-Site Listening by Less Experienced Observer			1

Note: An R^2 value of 1 indicates perfect correlation.

The previous figures and table illustrate the general agreement between the two logging methods. In order to provide a larger statistical sample, additional *in situ* observer logs from Acadia National Park (Site A02) and Great Smoky Mountains National Park (Site GR4) were compared with corresponding off-site logs (playback at 15 dB gain). Figure 27 presents the results of the time audible comparison between the *in situ* and off-site observer logging for both sites over seven measurement days: August 7th, 19th, and 25th, 2005 for Site A02 and June 2nd, 16th, 25th and July 1st, 2006 for Site GR4. The trend line for the data shows that there is very good correlation, R^2 = 0.96, when results are compared over all days for the specified sites.

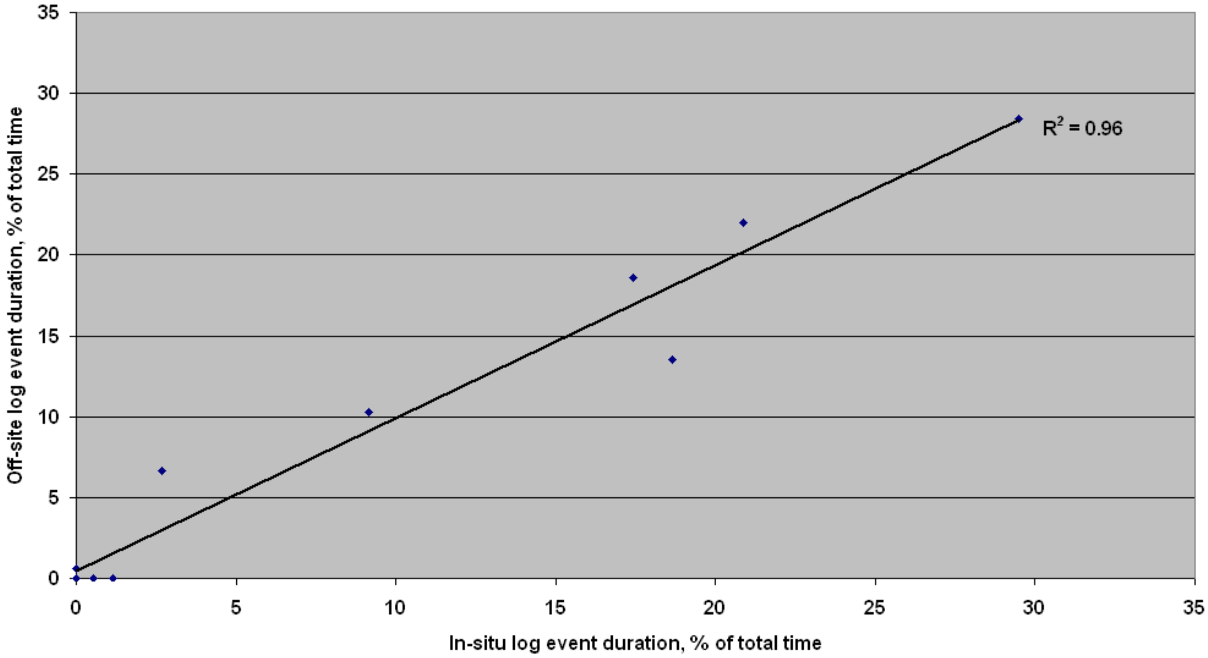


Figure 27. Audibility duration for observer logged events for Sites A02 and GR4 (Event durations are derived from a combination of logs from three days for A02 and four days for GR4).*

These analyses show that there was good correlation between *in situ* and off-site observer logs for identical time periods (i.e., synchronous comparisons). However, the majority of the time periods for *in situ* and off-site observer logs do not overlap. Because data from both methods represent a total of 12-16 hours of logging for each measurement site (i.e., approximately 2.5 percent of the total duration of the measurements), it is hypothesized that both methods would yield similar representative audibility information for a particular site. As stated in Sections 3.1 and 3.2, *in situ* logging consists of continuous sessions of listening over several days at each site; off-site logging consists of post-measurement listening to periodic and threshold audio samples recorded over the course of the entire measurement period. In order to test this hypothesis, *in situ* logs for Great Smoky Mountains National Park Site GR4 over the course of 2 days were compared to off-site logs listening to periodic audio recordings collected over 6 days. Figure 27 and Table 5 present the total percent time audible for different types of acoustic events for the *in situ* and off-site observer logs analyzed (i.e., non-synchronous comparisons).

* Note: An R^2 value of 1 indicates perfect correlation.

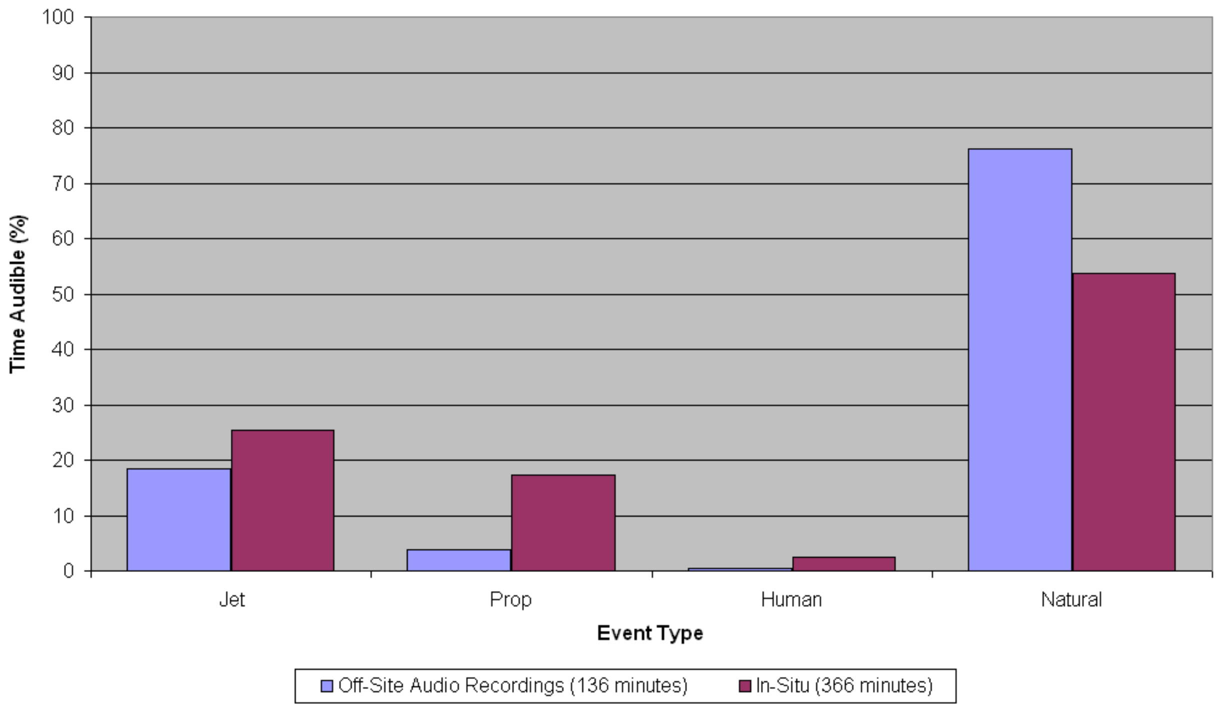


Figure 28. Time audible comparison of *in situ* and off-site log events for Site GR4.

Table 5. R^2 correlation of *in situ* and off-site (using audio wave files) observer logging for Site GR4.

Observer Type	Off-Site Listening	*In Situ* Observer
Off-Site Listening	1	0.92
***In Situ* Observer**		1

Note: An R^2 value of 1 indicates perfect correlation.

It can be seen that although there is moderately good agreement between time audible results for *in situ* and off-site observer logging, the degree of agreement is much less than when the logs are compared for the exact same time intervals. One possible cause for the difference between the two methods is that periodic and threshold recordings can truncate or entirely miss quiet non-natural events; whereas an *in situ* observer would be capable of hearing entire events with long onset and decay. Another possible cause for the difference might be the length of the observer logs. Temporal considerations in park visitation patterns are also recommended when determining representative days/times to perform *in situ* observer logging. Most parks experience heavier visitation on weekends than during the week. Therefore, *in situ* observer logging should be performed during different times/days for sites that experience large visitation fluctuations.

3.4 Conclusions

The analyses in the previous sections show there is good agreement between observer logging data obtained by experienced listeners both *in situ* and off-site using digital audio recordings. The following limitations of off-site observer logging should be noted:

1. When less experienced observers listen off-site to recorded audio wave files, visual cues, as well as source direction are lost, which can make source identification (such as specific aircraft types) more difficult, or impossible.
2. The quality of the recording will affect the ability of the observer to identify sounds.
3. If the purpose of logging is to simply document noise intrusions to the natural ambient, details of aircraft type becomes less critical. When such distinctions are important, then an expert observer is recommended when off-site logging is utilized.

Additionally, when determining representative days/times to perform *in situ* observer logging, temporal considerations in park visitation patterns and other activities are recommended.

4. COMPUTATION OF AMBIENT

Over the past decade, several definitions of ambient noise have been adopted by different organizations depending on their application.[35,27,11,12] The four types of "ambient" typically used are defined as follows (see Figure 29):

- *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 Air Tours:* 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.

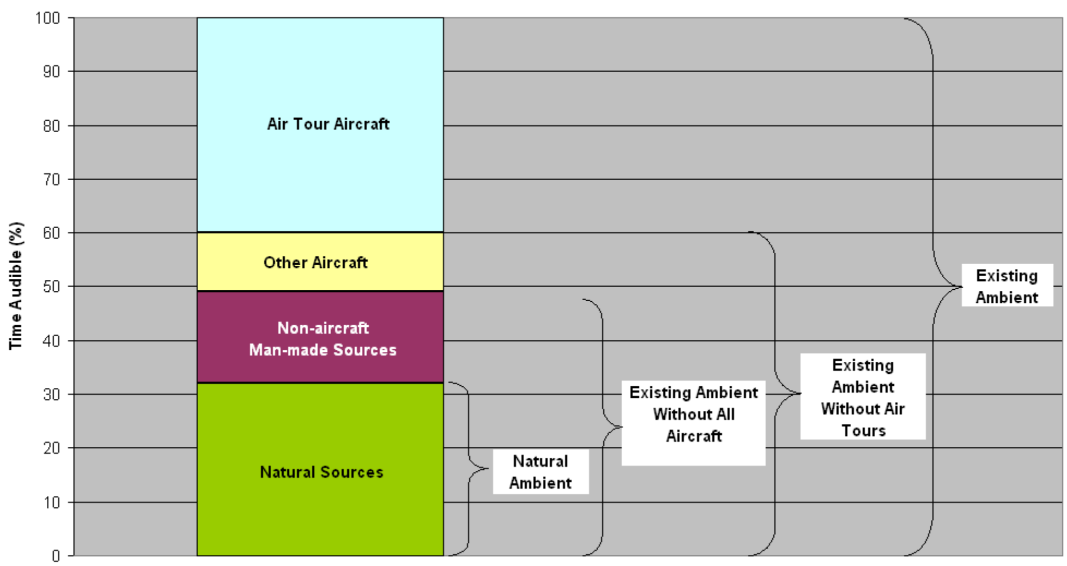


Figure 29. Graphical example of ambient definitions.

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

The FAA, NPS, and Volpe agree on the definitions of ambient; however, the FAA and NPS have different methods for assessing noise impacts. For National Environmental Policy Act (NEPA) analysis, the FAA seeks an estimate for the ambient without the sound source of interest (i.e., air tours for ATMPs), and the NPS seeks an estimate for the ambient if no human-caused sounds were present (i.e., natural ambient).

There are three basic approaches to calculating ambient sound levels that are currently available. The first approach involves using a priori, fixed exceedence (L_x) value. Historically, agencies have used different exceedence values (e.g., L_{50} and L_{90}). Prior analyses performed by the Volpe Center[13] on ambient sound-level data collected in fifteen National Parks showed that the use of L_{50} or L_{90} as a "one size fits all" statistical descriptor in establishing ambient has been shown to be inappropriate and may introduce errors as large as 10 decibels. The purpose of this previous study was to determine if there was an alternative exceedence value that could adequately represent the natural ambient sound level when no observations were available to denote intervals with human-caused sounds. The study concluded that while it is likely that the appropriate L_x for a park will fall between an L_{55} and L_{65}, some listening data are required in order to characterize the distribution of natural and human-caused sound levels. Idiosyncrasies of the natural sound level distributions were shown to significantly affect the natural ambient estimates for all exceedence measures. Thus, the use of a universal statistical descriptor often leads to large errors in ambient estimates.

The remaining two approaches utilize listener judgments about the presence of human-caused sounds to adjust the calculation of ambient background level. This requires characterizing natural and non-natural acoustic conditions in a park – that is, knowledge of the intensity, duration, and distribution of the sound sources is essential. Thus, during sound-level data collection, it has been agreed by the FAA and NPS that periods of observer logging and/or high-quality digital recordings with subsequent offline logging will be conducted in order to discern the type, timing, and duration of different sound sources. Performing *in situ* observer logging and/or offline logging of high-quality digital recordings is time-consuming, labor intensive, and thus often cost prohibitive. Hence, the calculation of ambient sound levels, such as natural ambient (sound levels without the influence of human-caused sounds), utilizing short-term knowledge (based on observer logging) of the intensity, duration, and distribution of the sound sources is difficult.

Additionally, because acoustic data in rural or park-like settings are rarely normally distributed, the FAA and NPS have also agreed that the use of the standard arithmetic mean calculation to characterize the central tendency of the data is inappropriate. When calculating central tendencies of hourly data that are not normally distributed, the median is the most appropriate measure, rather than the mean. Likewise, when computing central tendencies for data from many hours (such as 31 days of the 0800 hour), the median should be used (if, as is usually the case, those values are not normally distributed). When computing summary metrics for such values, calculations should be based on hourly summary data, not individual 1-second data of all the hours. This is necessary to ensure that hour-to-hour and day-to-day variation is addressed.[14]

All National Parks have both natural and human-caused sounds, which often overlap in both frequency and amplitude, and currently, there is no practical method to separate acoustic energy of human-caused sounds from that of natural sounds. Both agencies acknowledge that existing methods are imperfect. Additional research is on-going to develop better methods for these calculations. This section is focused on quantifying the difference in results between two methods used to compute natural ambient and ultimately recommend an enhanced method to compute different definitions of ambient.

4.1 Computing Natural Ambient (Method 1)

Working closely with the NPS in 2003,[15] a method was developed to utilize short-term measurement data, collected with detailed acoustic state logs, to develop short-term distributions of ambient data as a function of acoustic state, and apply these short-term distributions to the long-term dataset. The objectives of the method were:

- To obtain a percentile value from the short-term data (commonly referred to as L_x), which corresponds to the median level (L_{50}) of the natural ambient, and apply that statistical measure to the long-term data. The assumption is that the statistical measure (*not the level*) is representative of what would be obtained over the long term. Note: The actual ambient level would be based on the long-term data, and the short-term data would only be used to determine the statistical index; and

- To obtain a spectral shape from the short-term data, which corresponds to natural ambient, and adjust the shape (up or down in level) based on the L_x value derived from the long-term data.

The developed method, used for all ambient sound-level processing to date in support of ATMPs, was comprised of the following steps:

1. Using the A-weighted sound level data derived from the short-term, one-second, one-third octave-band data, in concert with the acoustic state observer logs, remove data during intervals when human-caused sounds were audible. The L_{50} computed from the remaining data is the A-weighted, short-term, natural ambient.
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 determine what L_x corresponds to the computed natural L_{50} ambient from Step 1 above.
3. Sort, high-to-low, the long-term data collected at a site and apply the L_x statistical measure, determined in Step 2 above, to the long-term data determine the corresponding level from the long-term data. For example, if from Step 2 above, it is determined that at a particular site, the natural L_{50} ambient corresponds to an L_{65} of all the short-term data, then determine the sound level which corresponds to an L_{65}, taking into account all of the long-term data. The result will be a long term, A-weighted ambient sound level representing the natural ambient.
4. The associated one-third octave-band un-weighted spectrum from 12.5 to 20,000 Hz is constructed by using the short-term, one-second, one-third octave-band data, in concert with the acoustic state observer logs, and removing data during intervals when human-caused sounds were audible. The L_{50} spectrum is a composite spectrum determined by 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.
5. Determine a spectrum adjustment factor for each ambient type by subtracting the L_x value from Step 3 from the energy-averaged spectrum (A-weighted and summed) derived in Step 1. Note the two values being subtracted would be overall, A-weighted values, not one-third

octave-band values. But the resultant factor is appropriate to apply to one-third octave-bands (see Step 6).

6. Apply the factor derived in Step 5 to the level in each one-third octave-band from Step 4 above to calibrate the spectrum based on the long-term sound levels. This will ensure the ambient A-weighted sound level from the long-term data is consistent with the spectrum, after A-weighting and summation.

The above method is conceptually straightforward; however, the difficulty with this approach is that it occasionally results in natural ambient sound levels being greater (generally less than 1 dB) than existing ambient sound levels, which is a logically impossible outcome, because existing ambient data represents the summed contributions of natural and human-caused ambient sounds. The explanation for this anomaly is simple: human caused sounds are more likely to be audible when the natural ambient levels are low rather than high. This results in a disproportionate fraction of quiet data being removed and an over-estimate of the natural ambient.

4.2 Computing Natural Ambient (Method 2)

Because the method developed by Volpe and NPS in 2003 can result in natural ambient sound levels being greater (generally less than 1 dB) than existing ambient sound levels, an alternative method for computing natural ambient that involves sub-sampling the measurement period to determine the percent time human-caused sounds are audible (from short-term *in situ* and off-site logging) has been developed.[14] Since these human-caused sounds are audible over natural sounds, these sounds are generally (but not always) the loudest sounds. With the assumption that human-caused sounds are louder than natural, the loudest percentage (determined from the percent time audible of human-caused sounds in the short-term observer logs) of sound-level data is removed. The median of the remainder of the dataset, and its associated L_x, is an approximation of the natural ambient sound level.

The method is comprised of the following steps:

1. From the short-term *in situ* and off-site logging, determine the percent time human-caused sounds are audible.

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 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: $\boldsymbol{X = \frac{100(1+\%TA)}{2}}$

Where: X is the percentile value for L_X, and

%TA = the percent of time human-caused sounds are audible in the short-term observer logs (between 0 and 1.0).

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.

2. The Lx value is computed similarly for each one-third octave-band from 12.5 to 20,000 Hz. As with the Volpe method, the result 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.

The above method is also 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 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.

4.3 Comparison of Ambient Computation Methods on Overall Ambient Sound Level Descriptors

It is important to note that both methods for computing natural ambient would produce the same result for situations when (1) human-caused sounds are louder than natural sounds, and (2) the distribution of the sound sources is almost entirely natural. The situations where the two methods diverge are when human-caused sounds are quiet, but audible (such as distant vehicular traffic or high-altitude aircraft overflights), and/or natural sounds are loud (such as areas with abundant bird or insect activity). In these situations, Method 1 may over-predict the natural ambient; whereas Method 2 may under-predict. Figure 30 illustrates an example of this situation, where louder wind-induced natural events and quiet non-natural events were audible during *in situ* observer logging at Great Smoky Mountains National Park (Site GR4).

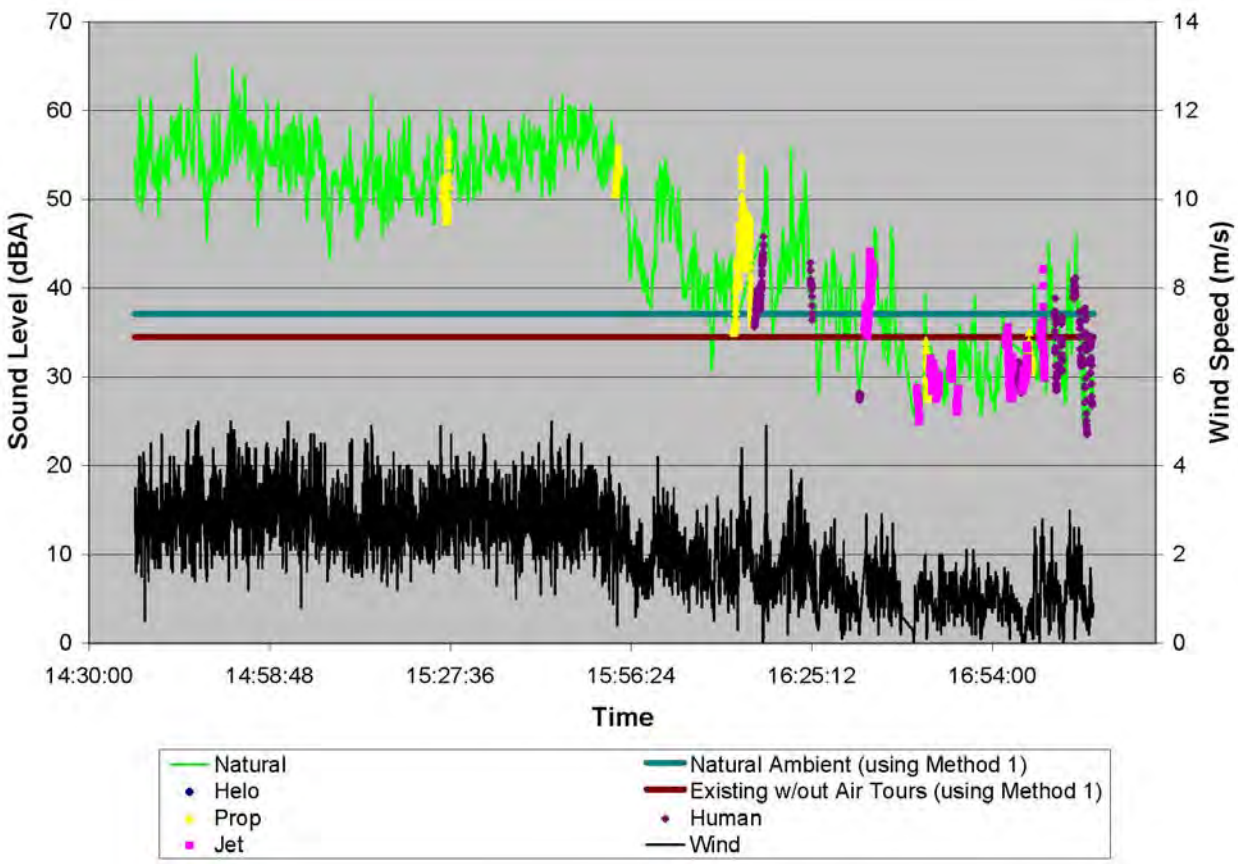


Figure 30. Time history of measured sound levels correlated with observer logging at Great Smoky Mountains National Park Site GR4.

To further examine how the two methods correlate, the following table presents the natural ambient computed by both methods. For comparison purposes, the existing ambient without air tours determined using Method 1 is also shown. It can be seen that for those sites where Method 1 results in a natural ambient being greater than the existing ambient without air tours (shown in red), the differences between Method 1 and Method 2 are also greater. Figure 31 plots the correlation between natural ambient computed by each method for the sites in Table 6.

Table 6. Comparison of ambients computed by two methods.

Site*	Method 1				Method 2		Delta (1-2)		% Time Audible (Human Events)	Average Wind Speed (m/s)
	Natural (Short Term)	Natural (Long Term)	Existing Without Air Tours (Long Term)	Delta Longterm (Natural-Existing)	Natural (Short Term)	Natural (Long Term)	Natural (Short Term)	Natural (Long Term)		
GR6	33	37.3	35.5	1.8	28.8	32.7	4.2	4.6	95%	0.55
A01	36.4	37.7	36.1	1.6	31.8	30.4	4.6	7.3	86%	0.52
G04	25.8	30.2	28.6	1.6	20.4	24.2	5.4	6	55%	0.51
P02	24.5	27.7	26.8	0.9	23.9	25.9	0.6	1.8	18%	2.8
A03	29.4	30.3	30	0.3	25.6	24.6	3.8	5.7	75%	2.2
A02	30.7	27	26.7	0.3	24.7	23.3	6	3.7	49%	1.1
ST6	23.2	21.4	21.4	0	21.2	19.7	2	1.7	67%	2.5
ST4	35.9	22.6	22.7	-0.1	35.1	21.6	0.8	1	18%	4
G06	19.4	22.1	22.3	-0.2	19	22.3	0.4	-0.2	11%	0.28
G02	29.9	30.3	30.6	-0.3	29.6	29.9	0.3	0.4	25%	1.9
GR3	30	32.9	33.4	-0.5	28.7	31.9	1.3	1	13%	0.71
NV2	22.4	22.4	23.5	-1.1	20.7	20.6	1.7	1.8	60%	1.3
GR4	46.5	32.7	34.5	-1.8	41.8	28	4.7	4.7	16%	1.8
B02	15.5	24.1	26.2	-2.1	14.9	22.9	0.6	1.2	33%	1.2
ST7	24.1	23.6	26.6	-3	25.9	25.9	-1.8	-2.3	30%	3.5
GR2	24.1	25.5	32.9	-7.4	22.6	21.7	1.5	3.8	74%	0.9
PF2	23.6	18.8	29.2	-10.4	24	19.6	-0.4	-0.8	83%	2.1

* Note: Sites A01, A02, and A03 are from Acadia National Park.
Site B02 is from Badlands National Park.
Sites G02, G04, and G06 are from Glacier National Park.
Sites GR2, GR3, GR4, and GR6 are from Great Smoky Mountains National Park.
Sites P02, ST4, ST6, and ST7 are from Haleakala National Park.
Site NV2 is from Navajo National Monument.
Site PF2 is from Petrified Forest National Park.

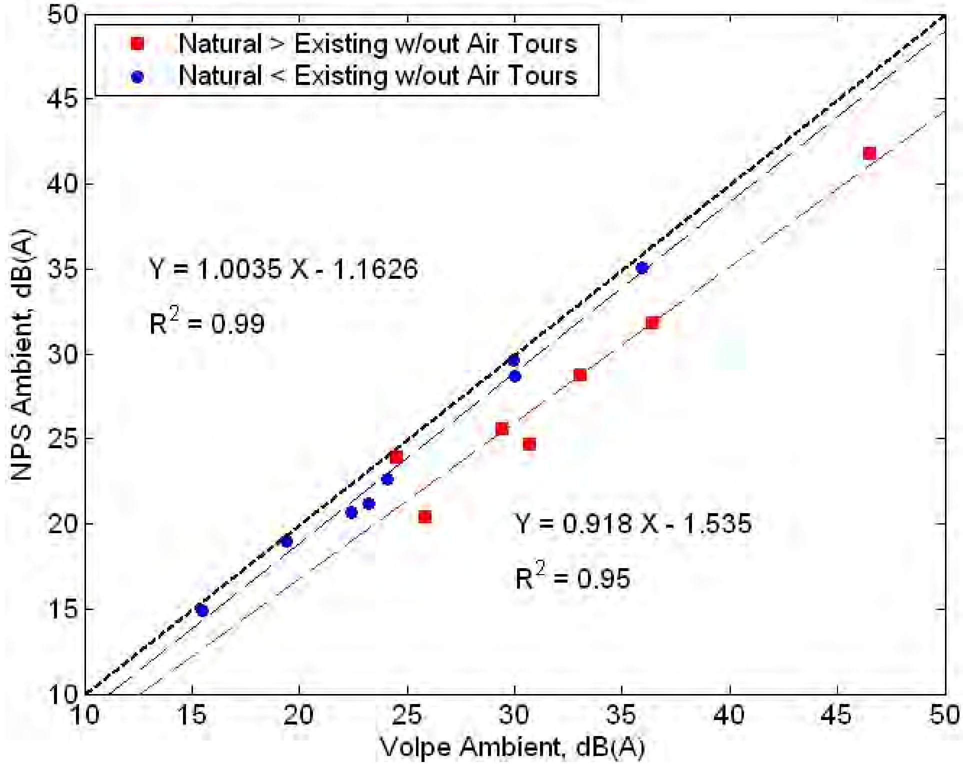


Figure 31. Correlation between ambient computation methods.

As shown, the methods are highly correlated, with the Method 2 ambient almost always lower than the Method 1 natural ambient. The average difference for natural ambient computed by each method (1-2) is 4.2 dBA when the Method 1 natural ambient is greater than existing without air tours; the average is 1.1 dB when the Method 1 natural ambient is less than existing without air tours.

To determine if those sites, where Method 1 results in a natural ambient being slightly greater than the existing ambient without air tours, is statistically significant, the confidence interval was computed for Sites P02, G04, A01, A02, A03, and GR6 (see Figure 32). From Figure 32, overlapping confidence intervals show that they are not statistically different.

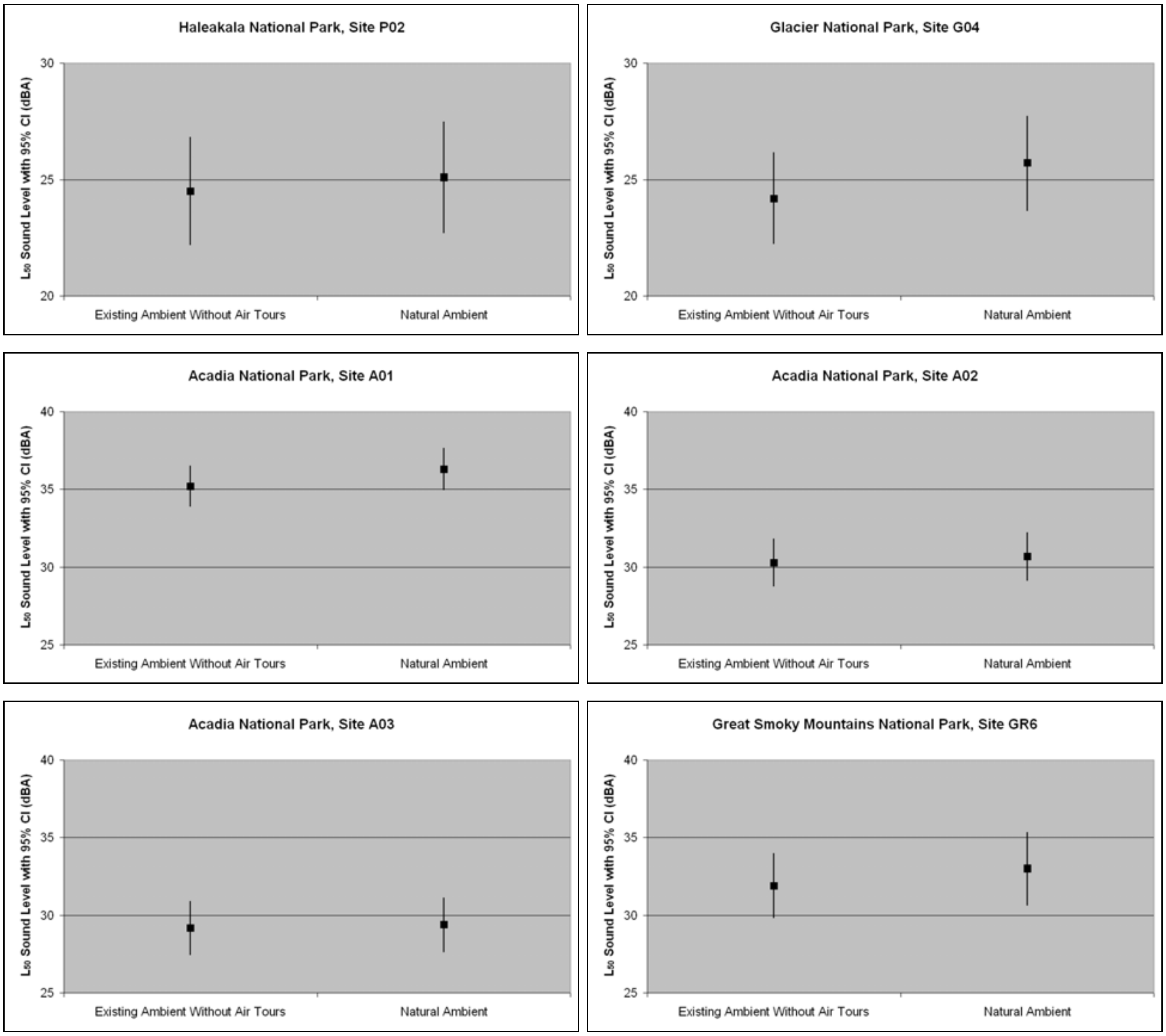


Figure 32. Comparison of 95% confidence intervals for sites where natural ambient is greater than existing ambient without air tours.

4.4 Comparison of Ambient Computation Methods on Ambient Spectra

This section is focused on quantifying the spectral differences between the two methods used to compute natural ambient. Figure 33 through Figure 35 compare the natural ambient spectra computed by each method for several sites. 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.[16] As with the narrowband natural ambient sound level results, it can be seen that results computed using Method 2 are generally lower for all frequencies.

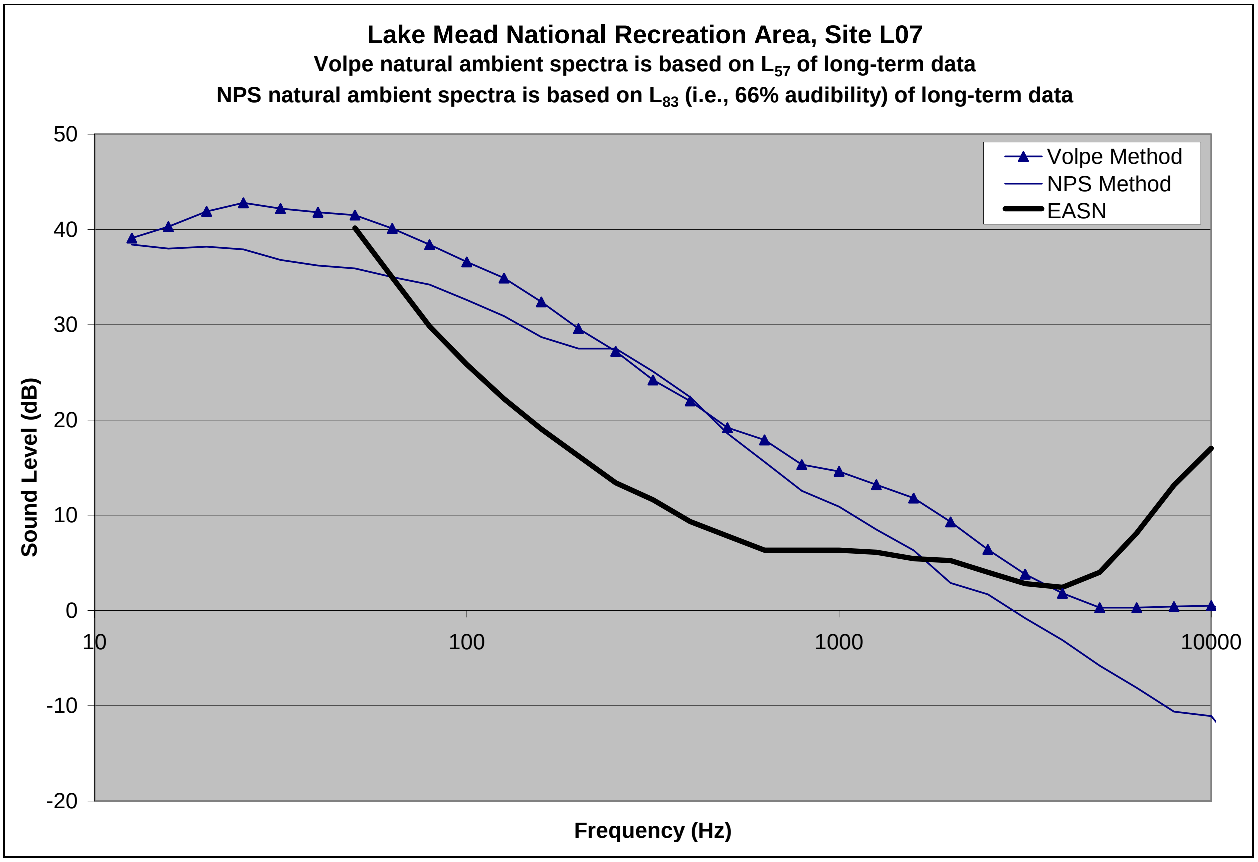


Figure 33. Lake Mead NRA, Site L07: Comparison of natural ambient spectra computed using Volpe and NPS methods

Figure 33 shows that using ambient computation Method 1(see Section 4.1), the percentile statistical value equivalent to the natural L_{50} of the short-term data was determined to be the existing L_{57}. As such, the L_{57} of each one-third octave-band frequency was used to develop the composite natural ambient spectra. Using the ambient computation Method 2 (see Section 4.2), the percent time human-caused sounds are audible during the short-term observer logging was determined to be 66 percent. Thus, the L_{83} of each one-third octave-band frequency was used to develop the composite natural ambient spectra.

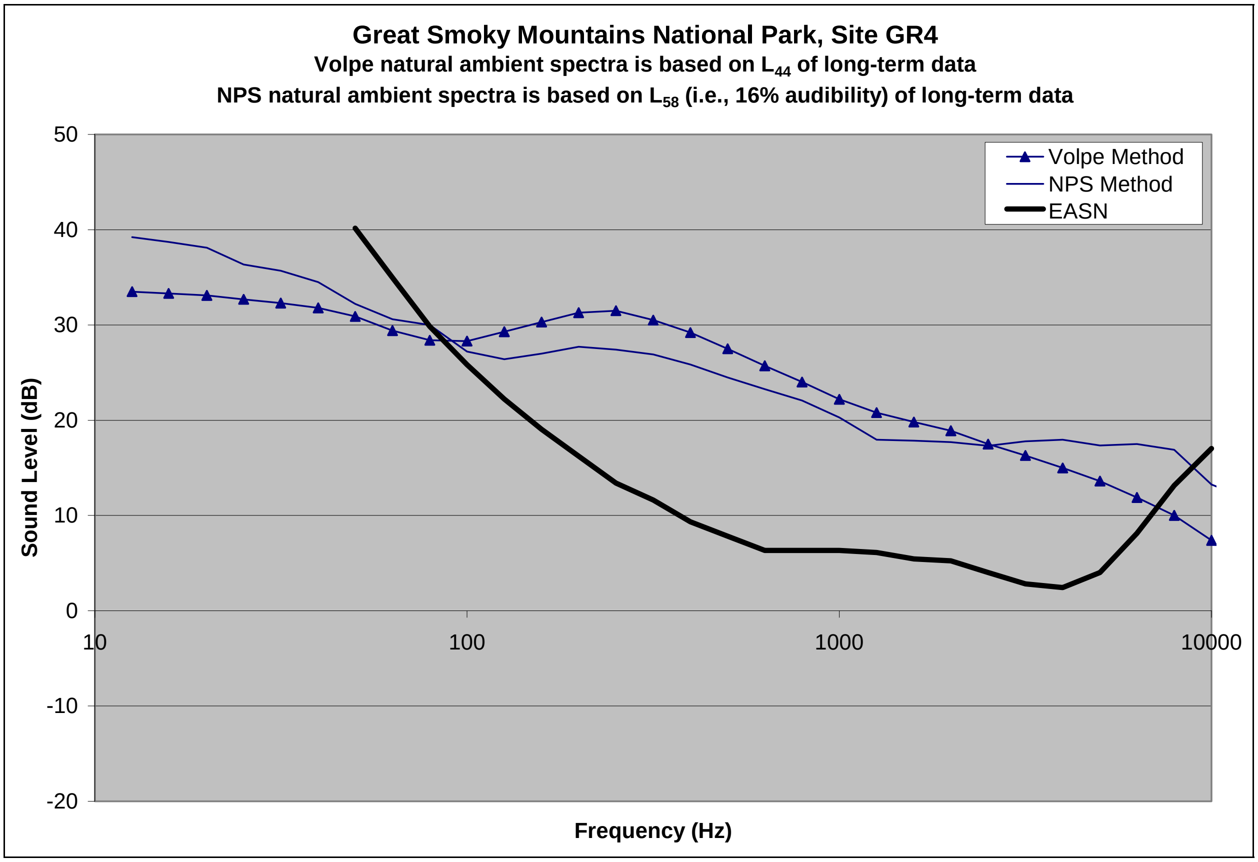


Figure 34. Great Smoky Mountains NP, Site GR4: Comparison of natural ambient spectra computed using Volpe and NPS methods

Figure 34 shows that using ambient computation Method 1 (see Section 4.1), the percentile statistical value equivalent to the natural L_{50} of the short-term data was determined to be the existing L_{44}. As such, the L_{44} of each one-third octave-band frequency was used to develop the composite natural ambient spectra. Using ambient computation Method 2 (see Section 4.2), the percent time human-caused sounds are audible during the short-term observer logging was determined to be 16 percent. Thus, the L_{58} of each one-third octave-band frequency was used to develop the composite natural ambient spectra.

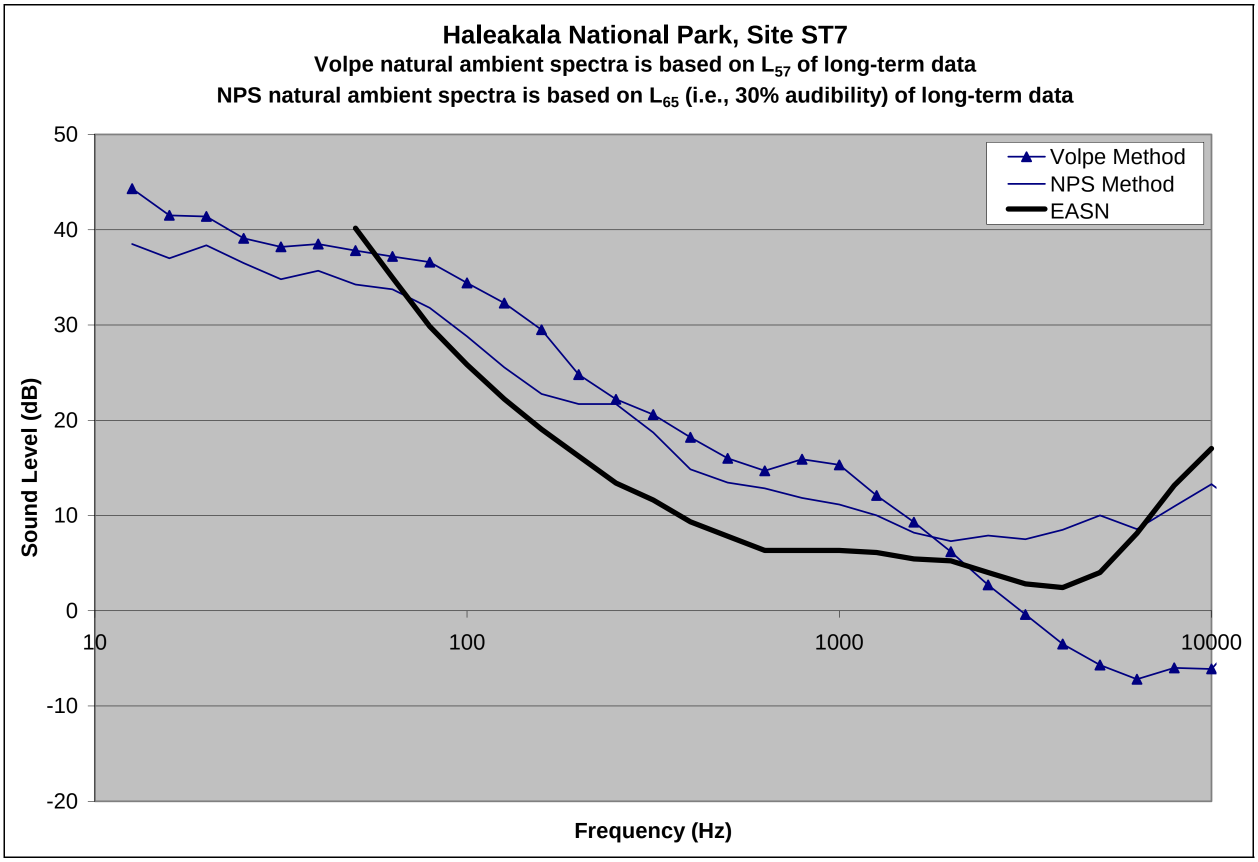


Figure 35. Haleakala NP, Site ST7: Comparison of natural ambient spectra computed using Volpe and NPS methods

Figure 35 shows that using ambient computation Method 1 (see Section 4.1), the percentile statistical value equivalent to the natural L_{50} of the short-term data was determined to be the existing L_{57}. As such, the L_{57} of each one-third octave-band frequency was used to develop the composite natural ambient spectra. Using ambient computation Method 2 (see Section 4.2), the percent time human-caused sounds are audible during the short-term observer logging was determined to be 30 percent. Thus, the L_{65} of each one-third octave-band frequency was used to develop the composite natural ambient spectra.

4.5 Conclusions

The analysis has shown that the two methods are highly correlated, with the natural ambient computed using the Method 2 almost always slightly lower than that computed by the Method 1. For the following reasons, it is recommended that Method 2 for computing ambient be used until additional research on the masking effects of different sound sources can be performed:

- The differences between the two methods are generally less than 1 dB.
- Method 2 is conceptually straightforward.
- Method 2 produces intuitive results.
- Method 2 requires less time (and therefore money) for data processing.

Note: Ambient data collected in support of ATMPs through May 2004 (i.e., 6 Hawaii parks, Mount Rushmore National Memorial, Badlands National Park, and Lake Mead) were analyzed using the Method 1, i.e., the best-available scientific methodology at the time. Pending FAA and NPS agreement on the above recommendation to utilize Method, ambient data collected since Lake Mead and for future ATMPs will be analyzed accordingly.

Future research on the masking effects of different sound sources may reveal potential improvements to the approach.

APPENDIX A: SITE DESCIPTIONS

This appendix provides site photographs for each site used the analyses.

A.1 Hawaii Volcanoes National Park (Hawaii Island, Hawaii)

Refer to Reference 7 for additional information about the measurements performed in Hawaii Volcanoes National Park.

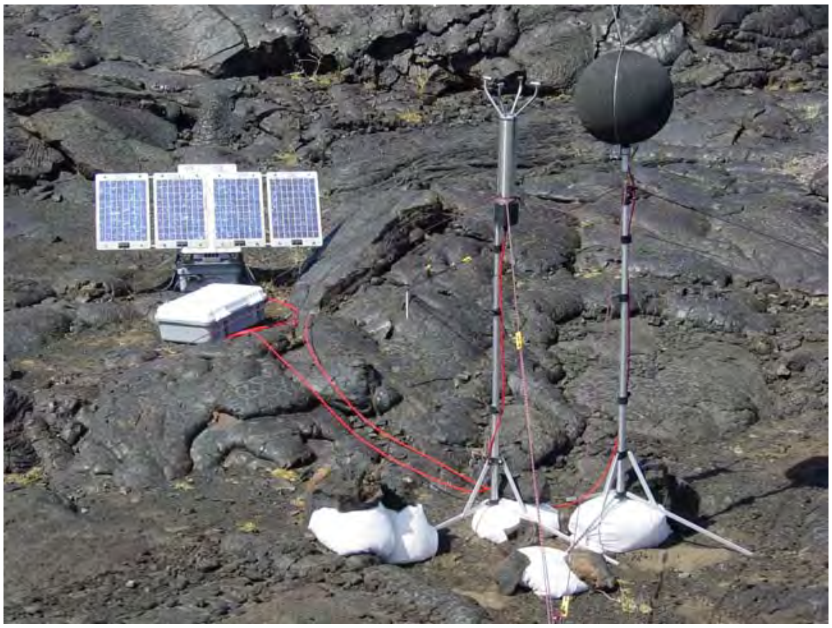


Figure 36. Hawaii Volcanoes National Park Site 1A - (14 days - October 24, 2002 to November 6, 2002)

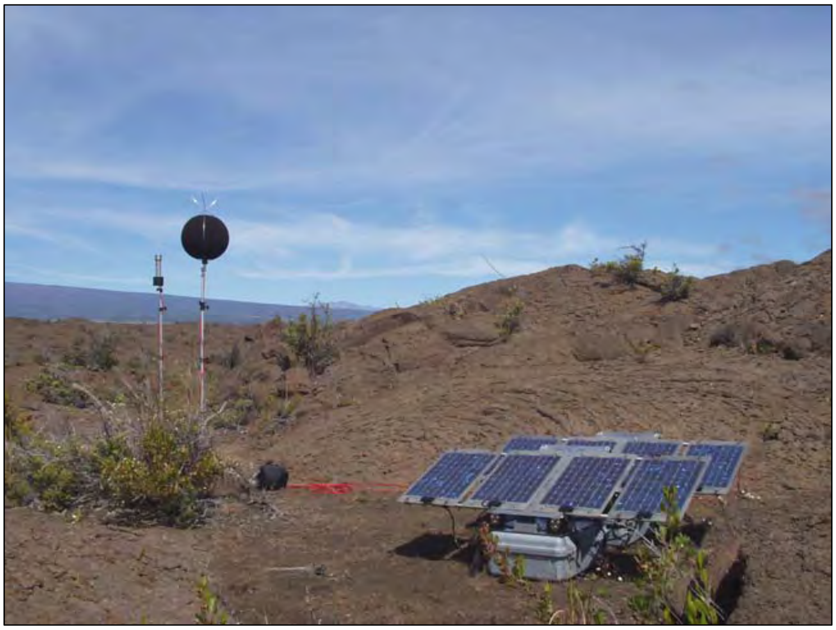
This site was used for the following analyses:

- Development of Processing Methods to Incorporate High-Wind Data (see Section 2.2)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

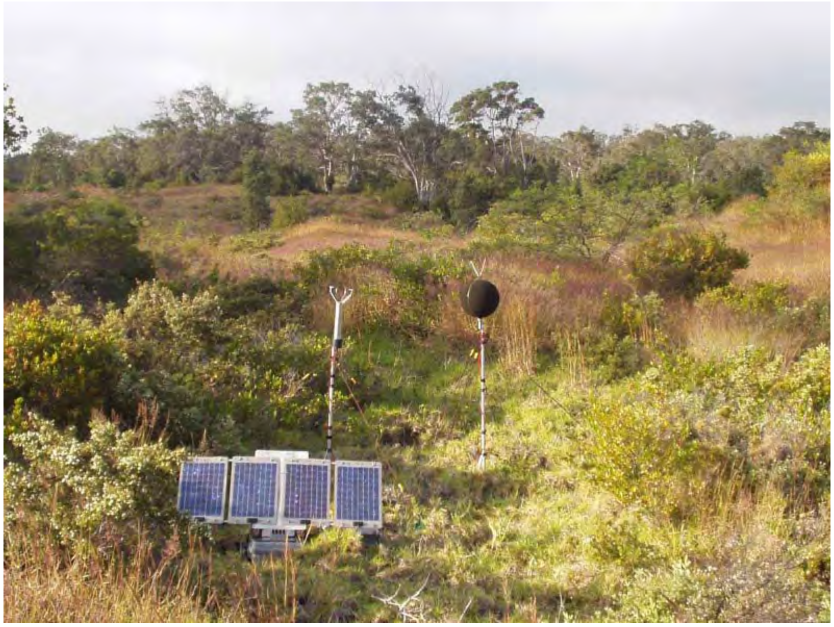
Figure 37. Hawaii Volcanoes National Park Site 1B - Current Eruption Viewing (14 days - October 24, 2002 to November 6, 2002)



This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 38. Hawaii Volcanoes National Park Site 3A - Mauna Iki Trail (118 days - October 25, 2002 to February 25, 2003)



This site was used for the following analyses:

- Development of Processing Methods to Incorporate High-Wind Data (see Section 2.2)

Figure 39. Hawaii Volcanoes National Park Site 6B (73 days - October 25, 2002 to January 28, 2003 and May 16 to May 24, 2003)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 40. Hawaii Volcanoes National Park Site 9A - Pu`u Huluhulu/Lava Trees (73 days - October 25, 2002 to January 28, 2003 and May 16 to May 24, 2003)

A.2 Haleakala National Park (Maui Island, Hawaii)

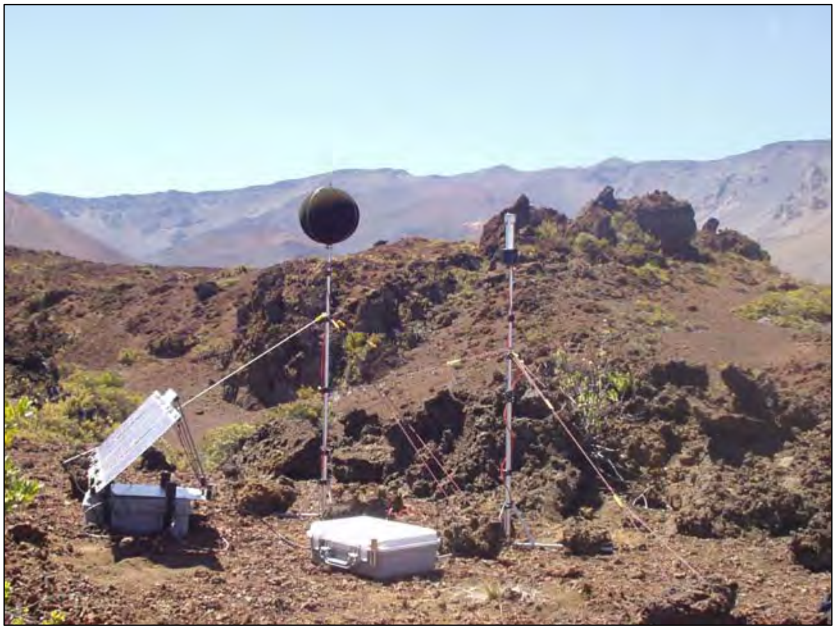
Refer to Reference 17 for additional information about the measurements performed in Haleakala National Park.[17]

This site was used for the following analyses:
- Computation of Ambient (see Section 4)

Figure 41. Haleakala National Park Site P02 - Supply Trail (30 days - February 27, 2003 to March 28, 2003)

This site was used for the following analyses:
- Computation of Ambient (see Section 4)

Figure 42. Haleakala National Park Site ST4 - Paliku Kaupo Gap (15 days – February 28, 2003 to March 14, 2003)



This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)
- Computation of Ambient (see Section 4)

Figure 43. Haleakala National Park Site ST6 - Silversword Loop (15 days – March 14, 2003 to March 28, 2003)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)
- Development of Processing Methods to Incorporate High-Wind Data (see Section 2.2)
- Computation of Ambient (see Section 4)

Figure 44. Haleakala National Park Site ST7 - Kalahaku Overlook (13 days – March 1, 2003 to March 13, 2003)

A.3 Badlands National Park (South Dakota)

Refer to Reference 18 for additional information about the measurements performed in Badlands National Park.[18]

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 45. Badlands National Park Site B02 - Sage Creek Campground (10 days – September 14, 2003 to September 26, 2003)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 46. Badlands National Park Site B03 - Cedar Butte (12 days – September 14, 2003 to September 25, 2003)

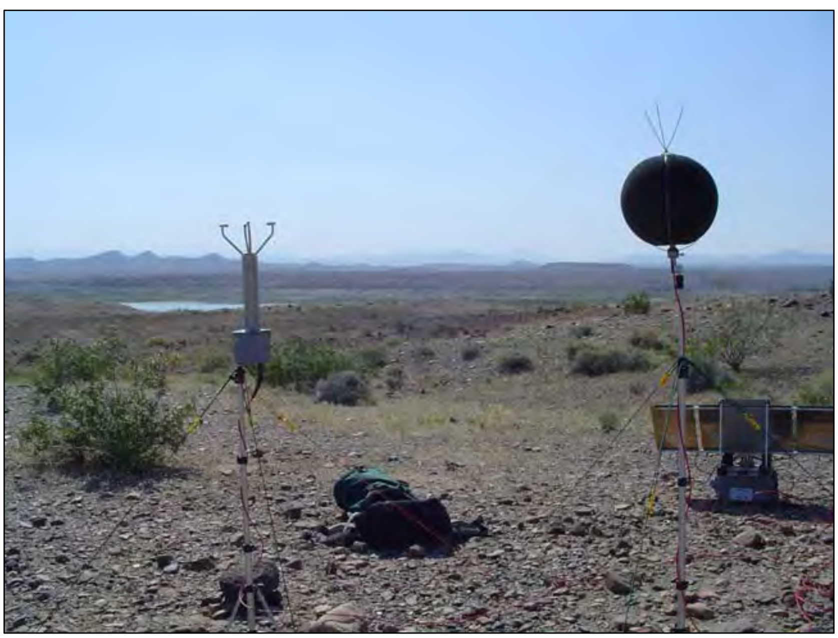
A.4 Lake Mead National Recreation Area (Arizona and Nevada)

Refer to Reference 19 for additional information about the measurements performed in Lake Mead National Recreation Area.[19]

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 47. Lake Mead National Recreation Area Site L02 - Pinto Valley (17 days – May 4 to 20, 2004)



This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 48. Lake Mead National Recreation Area Site L03 - Bonelli Bay Landing (8 days – May 8 to 12, 2004)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)
- Development of Processing Methods to Incorporate High-Wind Data (see Section 2.2)

Figure 49. Lake Mead National Recreation Area Site L07 - Indian Pass (17 days – May 5 to 21, 2004)

This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 50. Lake Mead National Recreation Area Site L08 - Katherine Landing (17 days – May 6 to 22, 2004)

A.5 Glacier National Park (Montana)

Refer to Reference 20 for additional information about the measurements performed in Glacier National Park.[20]

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 51. Glacier National Park Site G02 - Logan Pass (18 days - August 6 to August 22, 2004)

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 52. Glacier National Park Site G04 - Two Medicine Lake (16 days - August 6 to August 22, 2004)

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 53. Glacier National Park Site G06 - Bowman Lake (12 days - August 7 to August 21, 2004)

A.6 Canyon de Chelly National Monument (Arizona)

Refer to Reference 21 for additional information about the measurements performed in Canyon de Chelly National Monument.[21]

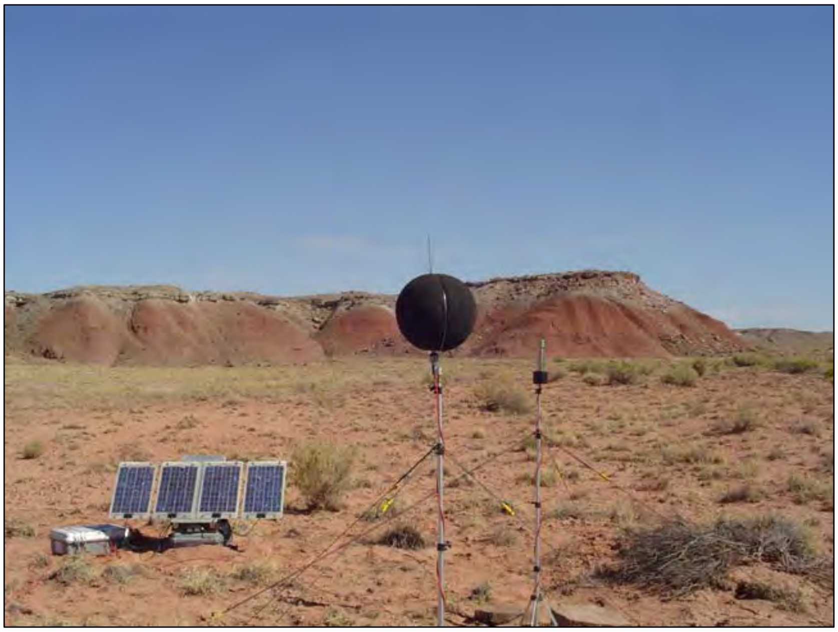
This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 54. Canyon de Chelly National Monument Site CC1 - First Ruin (15 days – September 11 to September 25, 2004)

A.7 Petrified Forest National Park (Arizona)

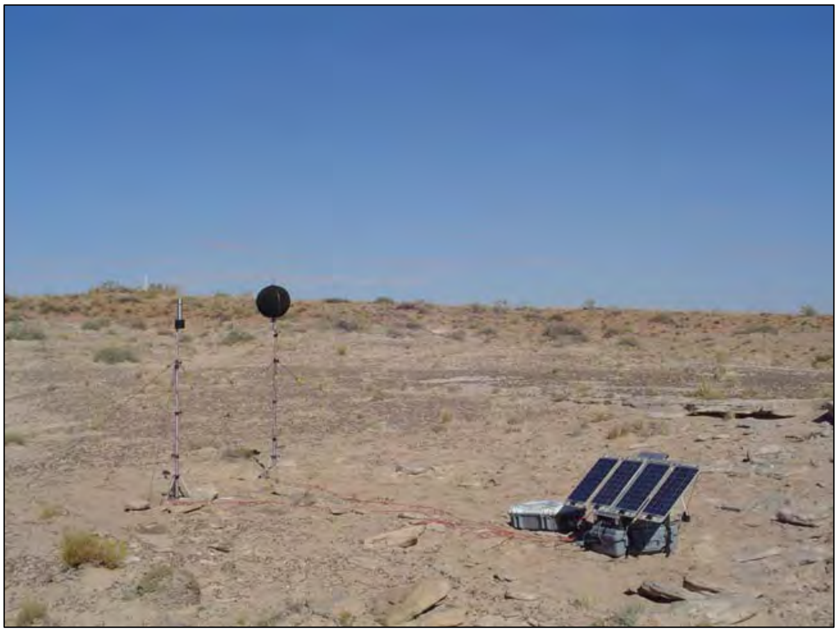
Refer to Reference 21 for additional information about the measurements performed in Petrified Forest National Park.



This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)

Figure 55. Petrified Forest National Park Site PF1 - Painted Desert (15 days – September 9 to September 23, 2004)



This site was used for the following analyses:

- Detailed Analyses of Measured High-Wind Data (see Section 2.1)
- Development of Processing Methods to Incorporate High-Wind Data (see Section 2.2)
- Computation of Ambient (see Section 4)

Figure 56. Petrified Forest National Park Site PF2 - Agate Bridge (16 days- September 8 to September 23, 2004)

A.8 Acadia National Park (Maine)

Refer to Reference 22 for additional information about the measurements performed in Acadia National Park. [22]

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 57. Acadia National Park Site A01 – Northeast Creek (23 days - August 2 to 29, 2005)

This site was used for the following analyses:

- In Situ and Wave-File Observer Logging (see Section 3)
- Computation of Ambient (see Section 4)

Figure 58. Acadia National Park Site A02 – Bernard Mountain (29 days - August 2 to 30, 2005)

This site was used for the following analyses:
- Detailed Analyses of Measured High-Wind Data (see Section 2.1)
- Computation of Ambient (see Section 4)

Figure 59. Acadia National Park Site A03 – Cadillac Mountain (27 days - August 3 to 29, 2005)

A.9 Great Smoky Mountains National Park (Tennessee)

Refer to Reference 23 for additional information about the measurements performed in Great Smoky Mountains National Park.[23]

This site was used for the following analyses:
- Computation of Ambient (see Section 4)

Figure 60. Great Smoky Mountains National Park Site GR2 – Parsons Branch (28 days – November 9 to December 6, 2005)

This site was used for the following analyses:

- Computation of Ambient (see Section 4)

Figure 61. Great Smoky Mountains National Park Site GR3 – Porters Creek (26 days – November 10 to December 5, 2005)

This site was used for the following analyses:

- In Situ and Wave-File Observer Logging (see Section 3)
- Computation of Ambient (see Section 4)

Figure 62. Great Smoky Mountains National Park Site GR4 – Purchase Knob (26 days – November 10 to December 5, 2005)

This site was used for the following analyses:
- Computation of Ambient (see Section 4)

Figure 63. Great Smoky Mountains National Park Site GR6 – Cades Cove (25 days – November 12 to December 6, 2005)

A.10 Navajo National Monument (Arizona)

Refer to Reference 21 for additional information about the measurements performed in Navajo National Monument.

This site was used for the following analyses:
- Computation of Ambient (see Section 4)

Figure 64. Navajo National Monument Site NV2 – Betatakin Sandal Trail (1 day – September 15, 2004)

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APPENDIX B: DETERMINATION OF UPPER WIND LIMIT

Documented ambient noise levels measured in remote areas of the country under low wind conditions (such as in national parks) often approach the threshold of human hearing. As a result, specialized low-level instrumentation is required to accurately measure these sounds. Measurements in support of ATMPs are performed with two primary types of systems: the robust, long-term, NoiseLogger™ system; and the ultra-sensitive, short-term, VoLARE system.[24,25] The NoiseLogger™ system has the capability of measuring sound levels down to about 15 to 20 dBA;[*] and the VoLARE system has the capability of measuring sound levels down to below 0 dBA.

One of the primary purposes for collecting simultaneous data using both systems is the development of adjustments for NoiseLogger™ data for contamination effects of the system noise floor. When measured sound levels are well above the NoiseLogger™ system's noise floor, both systems were expected to measure similar sound levels. However, this was not always the case. In some instances, significant differences were observed between data measured with each system. This prompted additional investigations of data collected during three ATMP baseline ambient studies: Hawaii Volcanoes, Haleakala, and Badlands National Parks. As shown in Figure 65, there is a noticeable correlation between the observed sound-level differences of the NoiseLogger™ and VoLARE systems and wind speed. That is, there is a tendency for the delta between the two datasets to increase with increasing wind speed. This can be attributed to the difference in performance between the two systems' respective windscreens. The NoiseLogger™ system uses a 30-cm (12-in) diameter foam windscreen (400 pores/in^2) custom designed by Musashi Kasei Co., Ltd. for outdoor monitoring applications; whereas, the VoLARE system utilizes a two-stage windscreen, which consists of a 51 cm (20-in) diameter, fabric-covered, outer stage, with a conventional, Brüel & Kjær Model UA0207 9-cm (3.5-in) diameter, foam windscreen making up the inner stage. The dual-stage windscreen of the VoLARE system is expected to outperform the single-stage windscreen used by the NoiseLogger™ system.

[*] "NoiseLogger" is trademarked by Harris Miller Miller & Hanson, Inc.

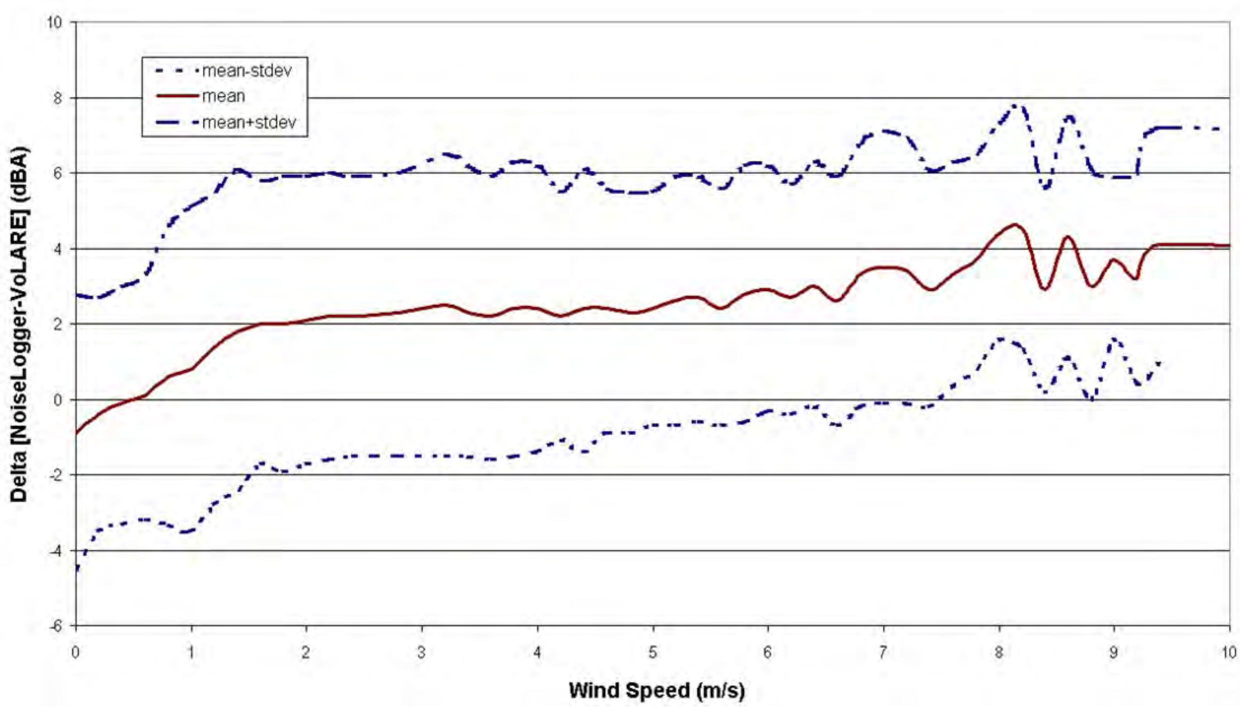

Figure 65. Average deltas between NoiseLogger™ and VoLARE data versus wind speed for 3 parks: Hawaii Volcanoes, Haleakala and Badlands.

From Figure 65, the following conclusions were drawn:

- For wind speeds up to approximately 1.5 m/s (3.4 mph), a small, steady increase in the deltas between NoiseLogger™ and VoLARE data can be seen with increasing wind speed;
- For wind speeds between 1.5 m/s (3.4 mph) and 5.4 m/s (12 mph), the effects of wind on the sound level delta are relatively independent of wind speed; and
- For wind speeds greater than 5.4 m/s (12 mph), the trend between the two datasets becomes unacceptably complex, as the mean value starts to fluctuate. At those higher wind speeds, predictions of delta versus wind speed are not useful.

Additional analysis examining the spectral L_{eq} for NoiseLogger™ and VoLARE datasets from 0-10 m/s (0-22 mph) in wind-speed bins of 1-m/s intervals to determine where they begin to diverge showed a clear divergence in the spectra, starting at about 7 m/s (15.6 mph). These analyses indicated that an upper limit for wind speeds would be highly beneficial to the analysis and would effectively help offset the lower performance of the NoiseLogger™ windscreen relative to the VoLARE two-stage windscreen. Subsequently, a conservative 5 m/s (11 mph) wind-speed upper limit has traditionally been observed for the ATMP project.[26] This upper limit criterion is consistent with wind-speed limits used in other environmental sound-level monitoring.[27,28,29,30] However, as discussed in Section 2.2, the benefits of including contributions from sounds which may naturally occur under high-wind conditions may outweigh the risk of potentially introducing measurement system contamination. As stated earlier, because the intent of baseline ambient sound-level collection in support of the ATMP project is to characterize the *entire* ambient sound level environment (natural and non-natural), increases in the ambient due to wind should be represented by the measurements. The development of a method to process and incorporate high-wind data into ambient sound level estimates is further discussed in Section 2.2.

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APPENDIX C: SPECTRA ANALYSIS EXAMINING OTHER WIND-INDUCED MEASUREMENT SYSTEM CONTAMINATION

This Appendix presents the un-weighted, energy-average L_{eq} spectra of the measured data for wind speeds in 1 m/s increments (or bins) from 0 to 20 m/s (0 to 45 mph) as discussed in Section 2.1.2. Figures 24 through 36 present the data for each site. Additionally, in order to further examine the phenomena, the site-by-site data were re-plotted in Figures 37 through 43 for select one-third octave bands (12.5, 50, 100, 500, 1000, 5000, and 10000 Hz).

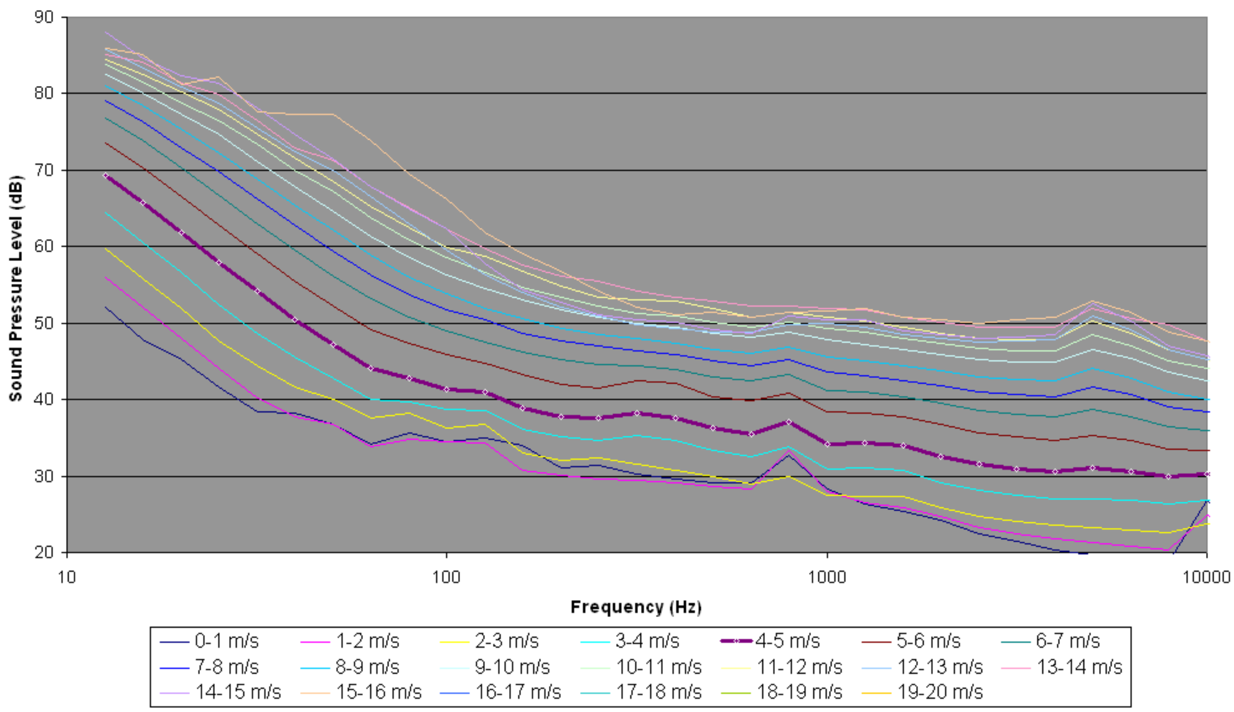

Figure 66. L_{eq} Spectra for Hawaii Volcanoes Site 3A in 1-m/s wind speed bins.

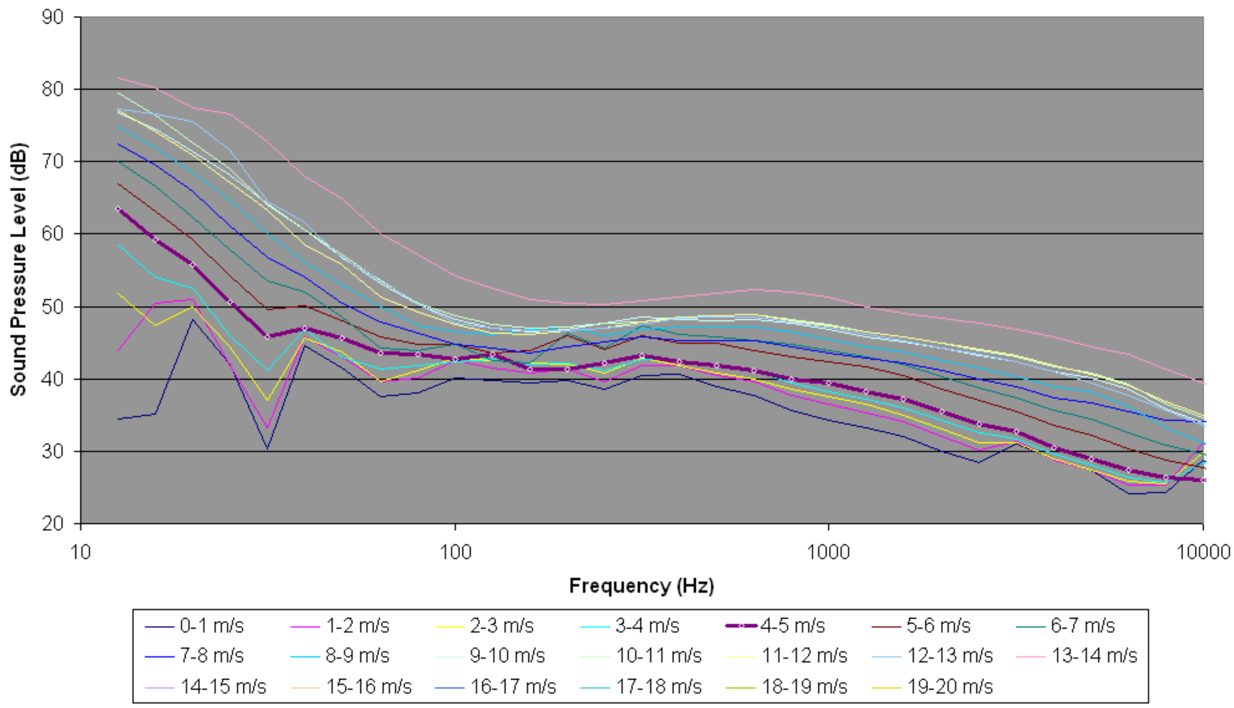

Figure 67. L_{eq} Spectra for Hawaii Volcanoes Site 9A in 1-m/s wind speed bins.

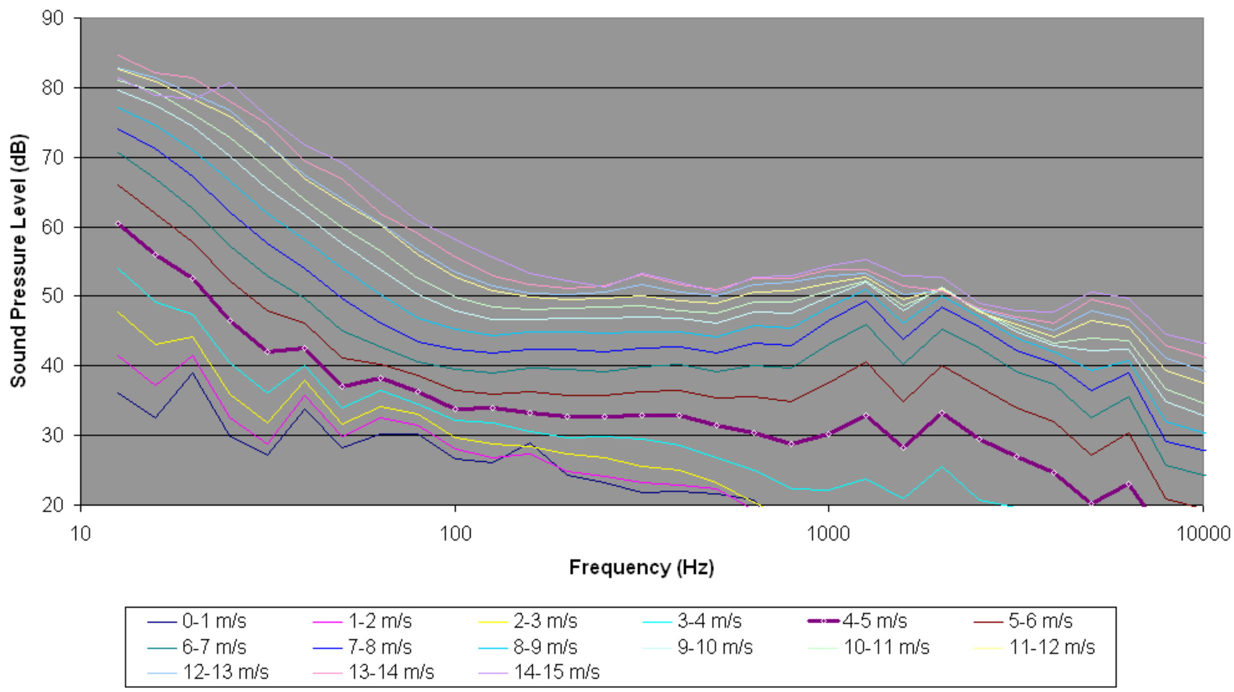

Figure 68. L_{eq} Spectra for Haleakala Site ST6 in 1-m/s wind speed bins.

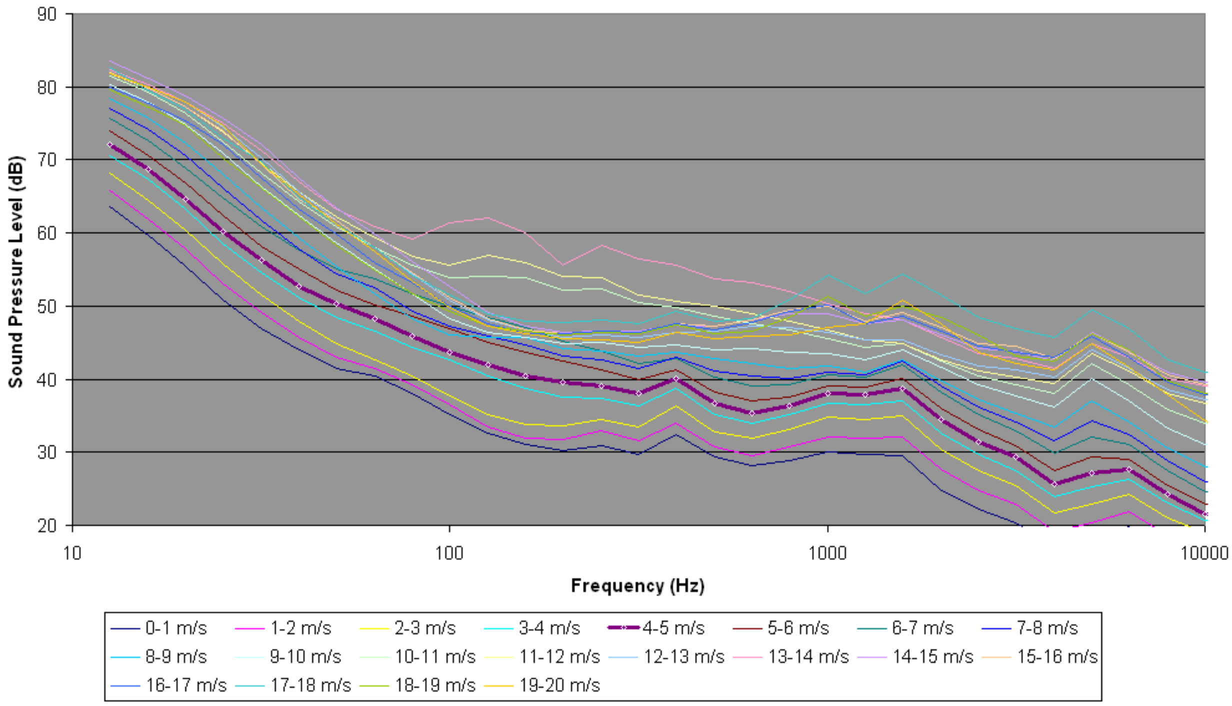

Figure 69. L_{eq} Spectra for Haleakala Site ST7 in 1-m/s wind speed bins.

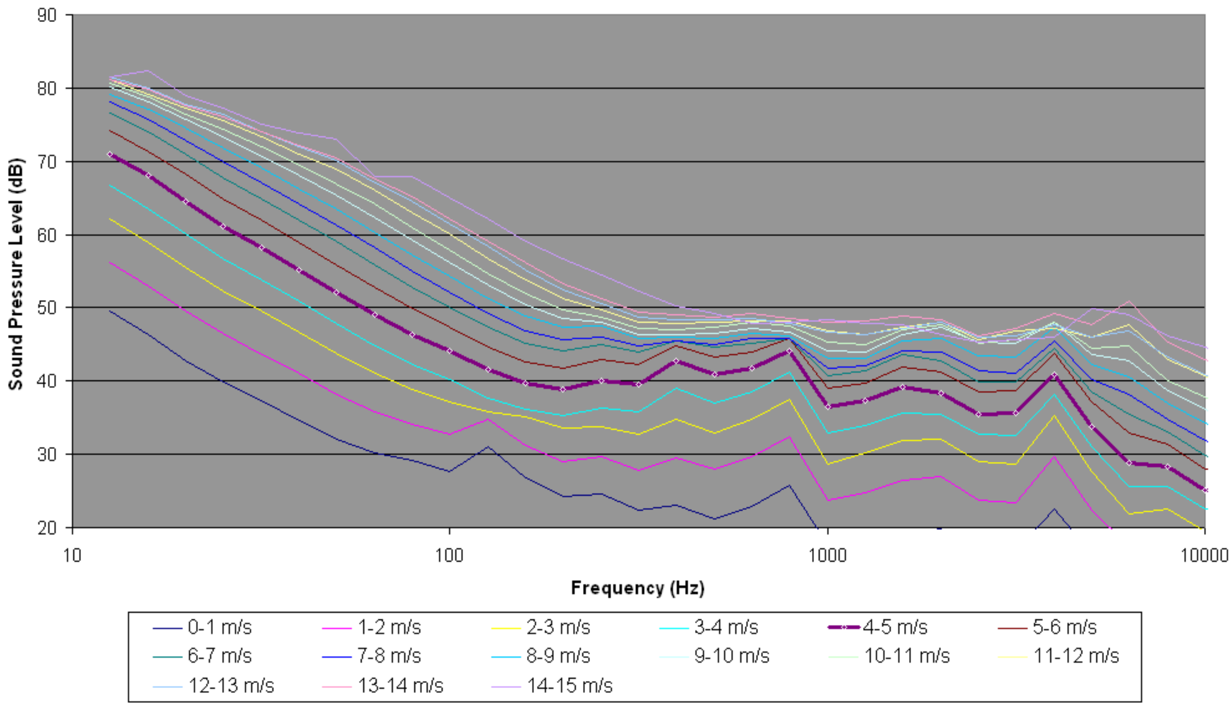

Figure 70. L_{eq} Spectra for Badlands Site B03 in 1-m/s wind speed bins.

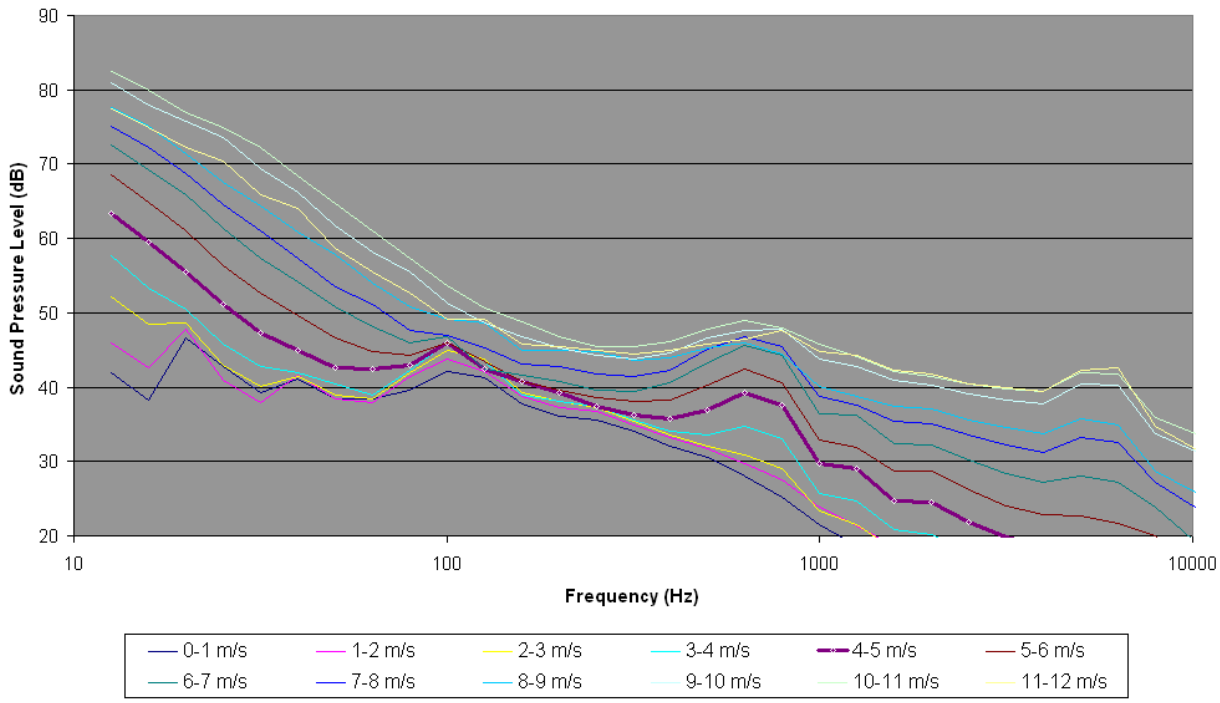

Figure 71. L_{eq} Spectra for Lake Mead Site L02 in 1-m/s wind speed bins.

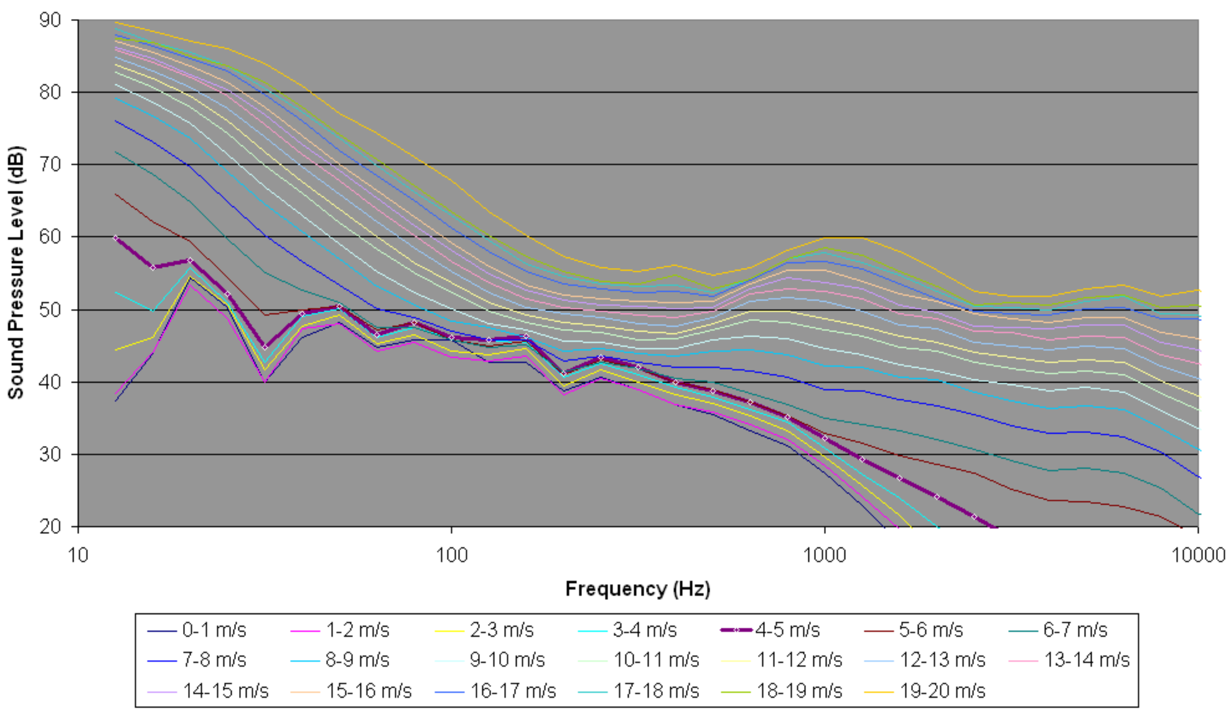

Figure 72. L_{eq} Spectra for Lake Mead Site L03 in 1-m/s wind speed bins.

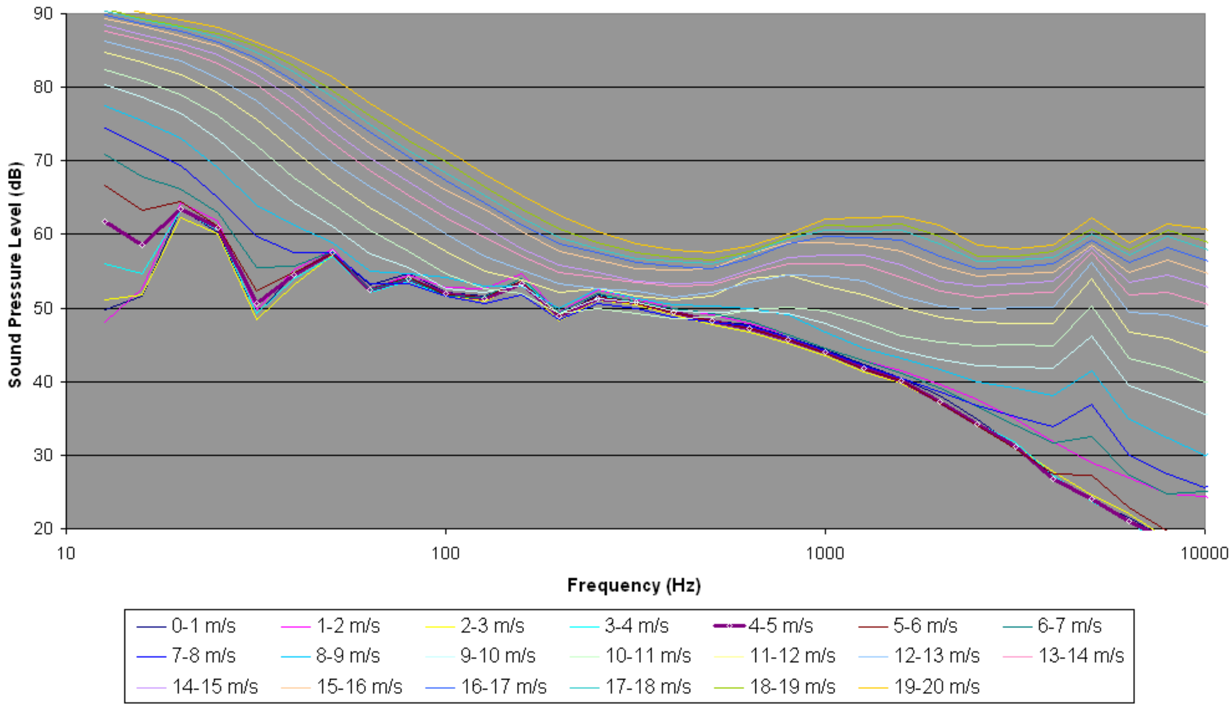

Figure 73. L_{eq} Spectra for Lake Mead Site L07 in 1-m/s wind speed bins.

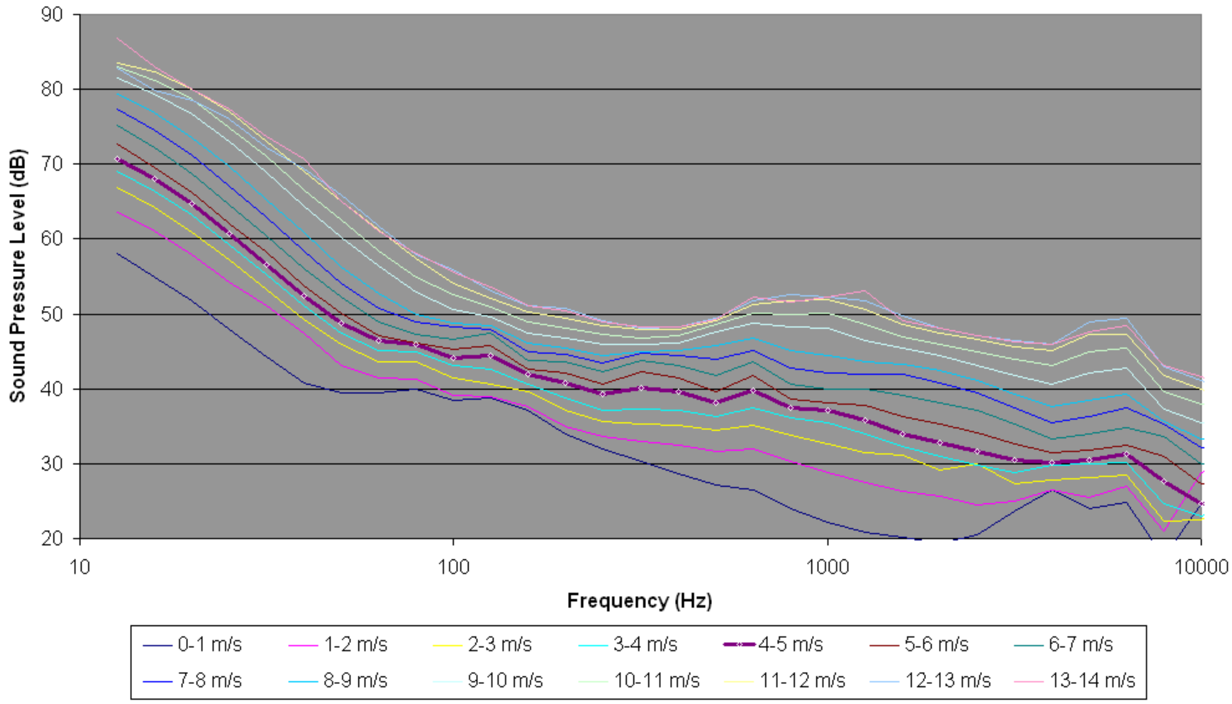

Figure 74. L_{eq} Spectra for Lake Mead Site L08 in 1-m/s wind speed bins.

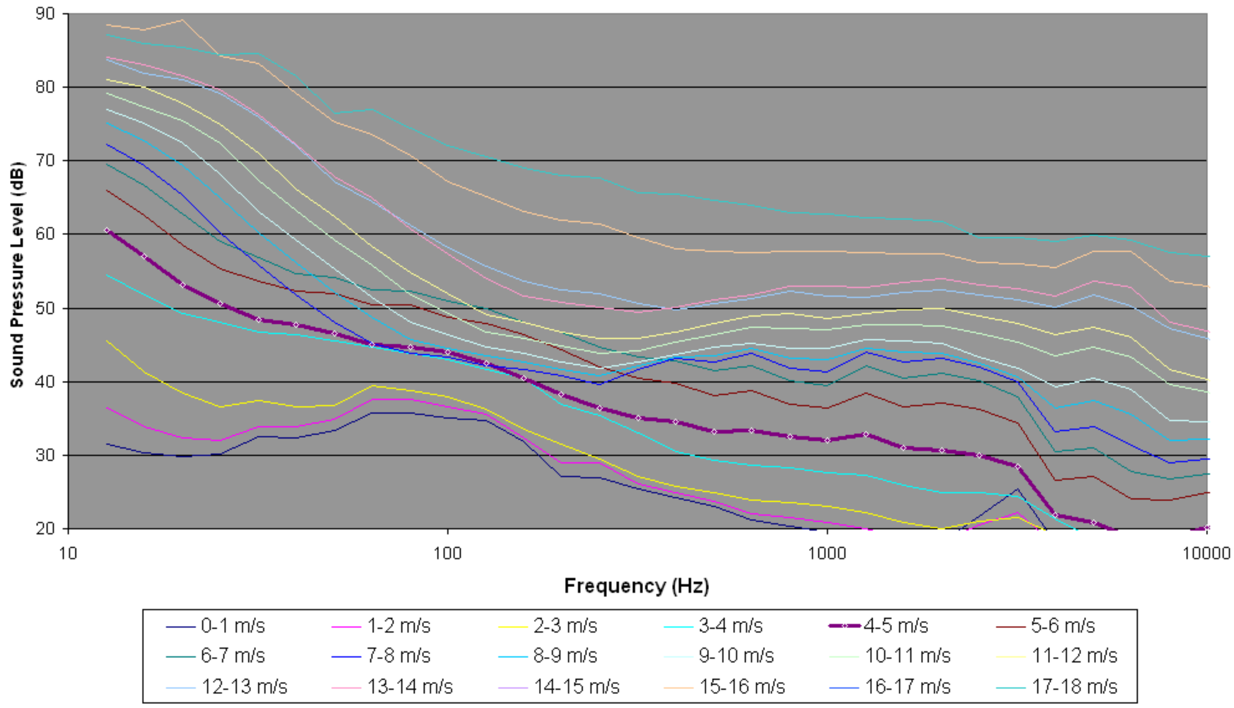

Figure 75. L_{eq} Spectra for Canyon de Chelly Site CC1 in 1-m/s wind speed bins.

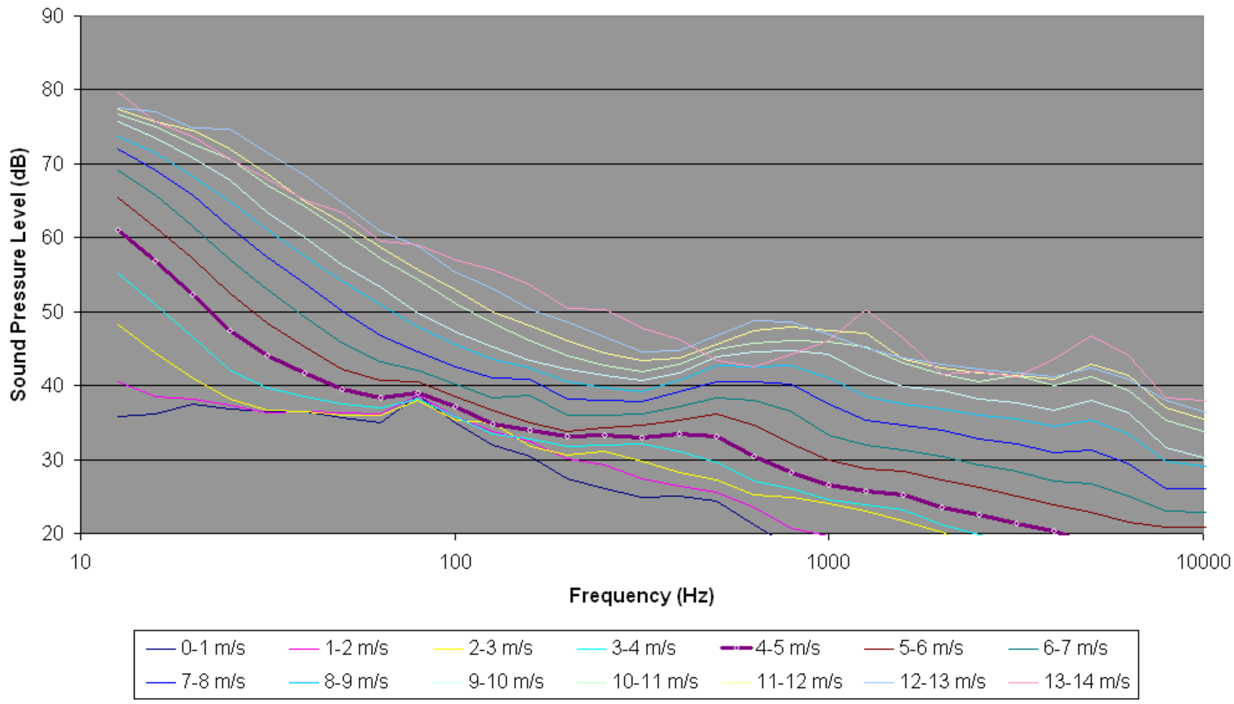

Figure 76. L_{eq} Spectra for Petrified Forest Site PF1 in 1-m/s wind speed bins.

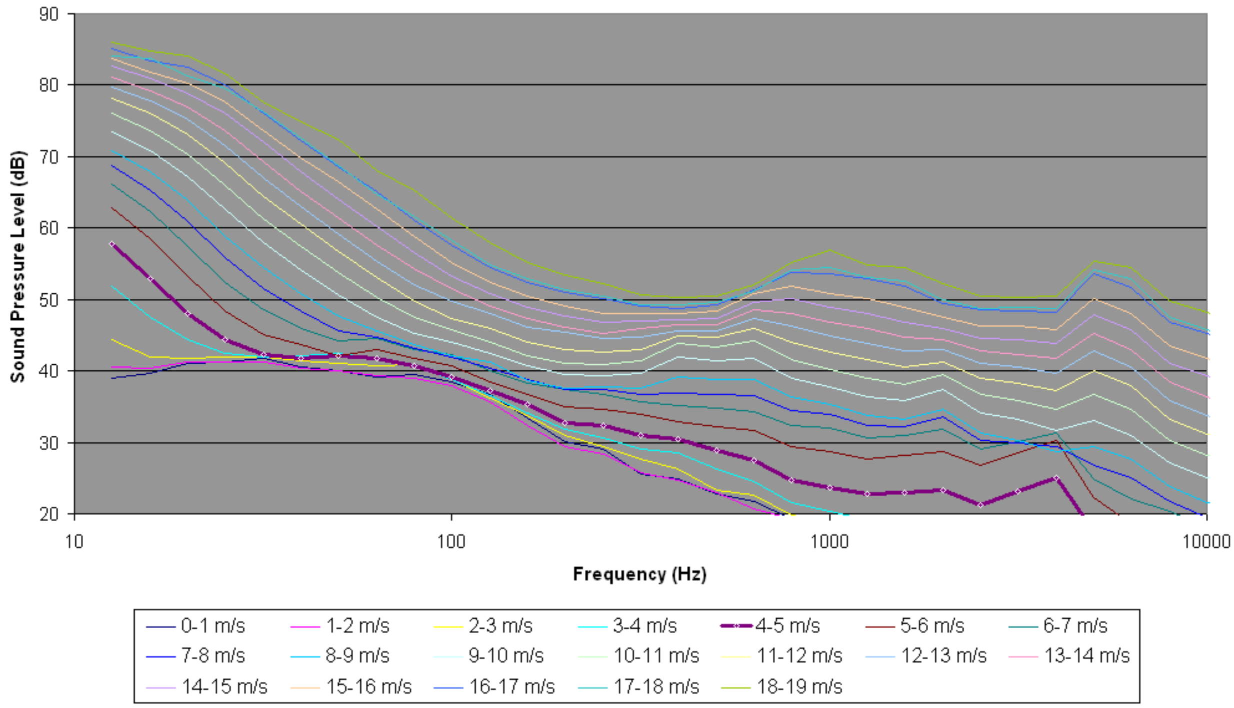

Figure 77. L_{eq} Spectra for Petrified Forest Site PF2 in 1-m/s wind speed bins.

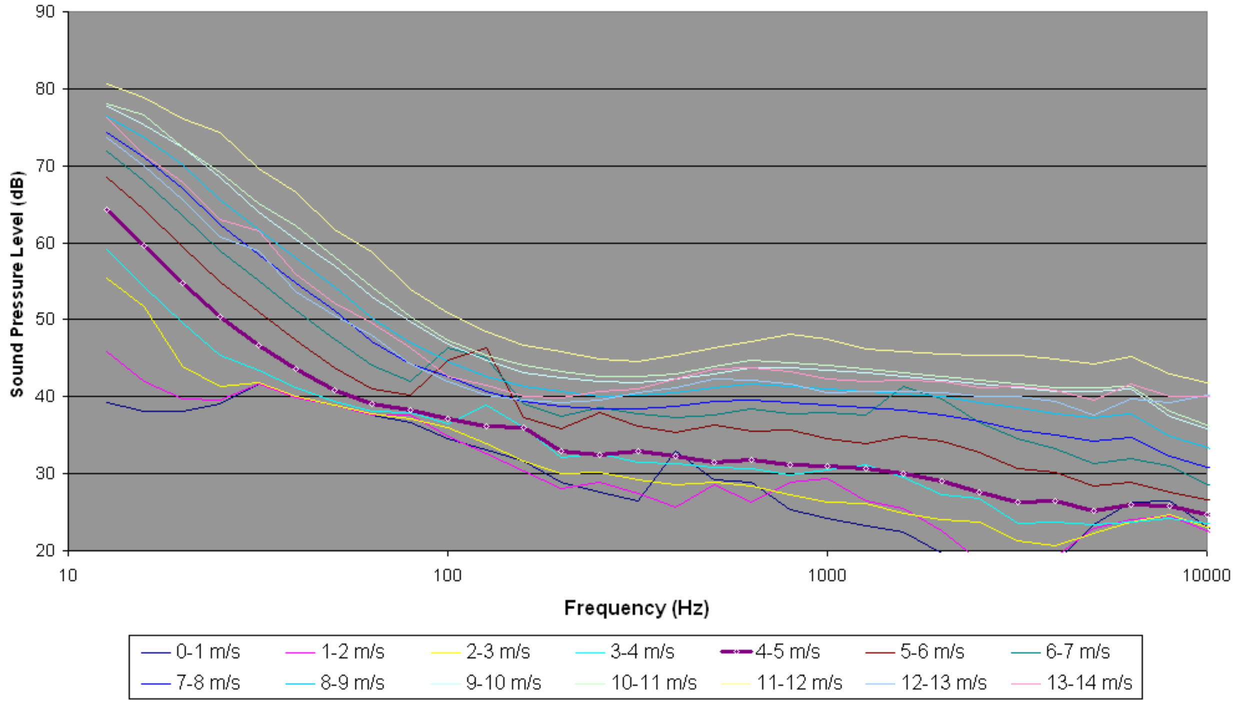

Figure 78. L_{eq} Spectra for Acadia Site A03 in 1-m/s wind speed bins.

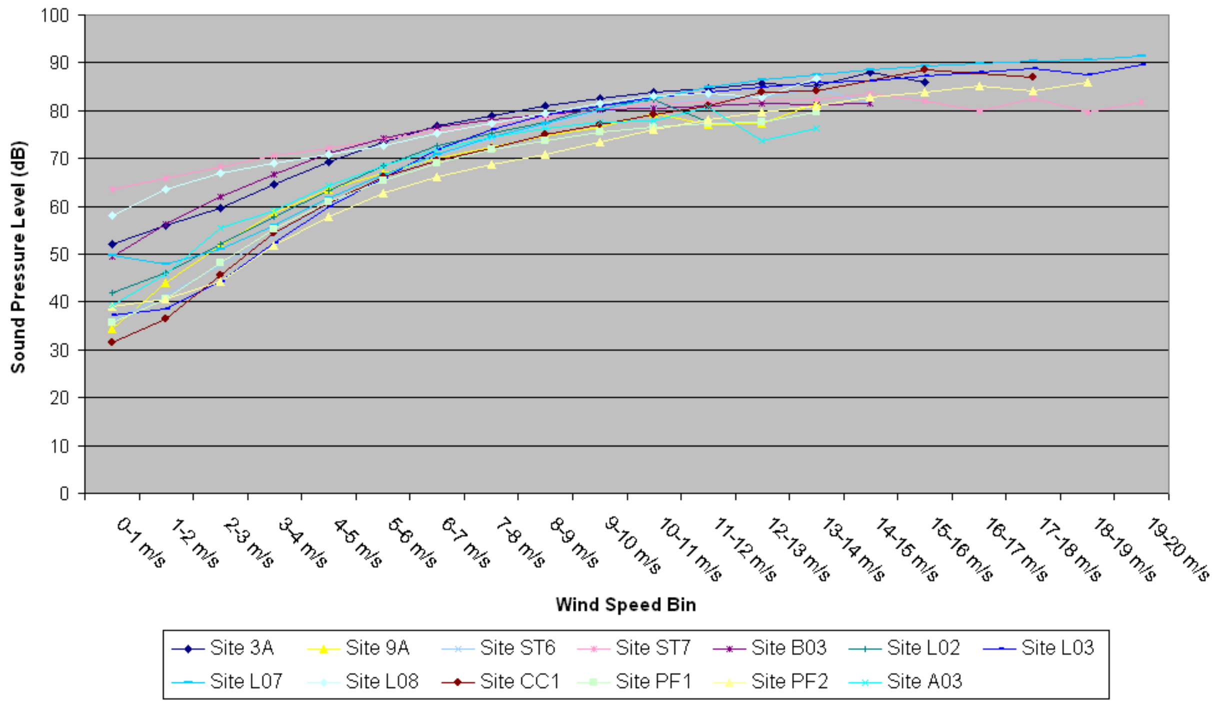

Figure 79. 12.5 Hz $L_{eq,1s}$ in 1-m/s wind speed bins by site.

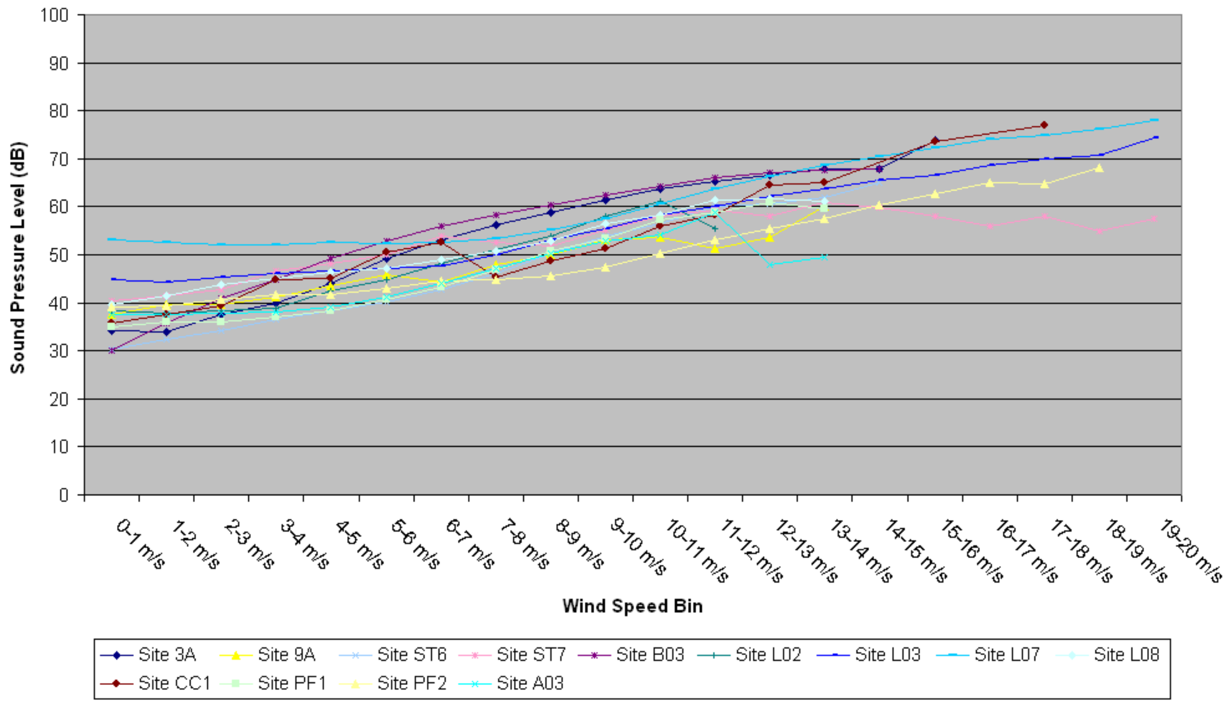

Figure 80. 50 Hz $L_{eq,1s}$ in 1-m/s wind speed bins by site.

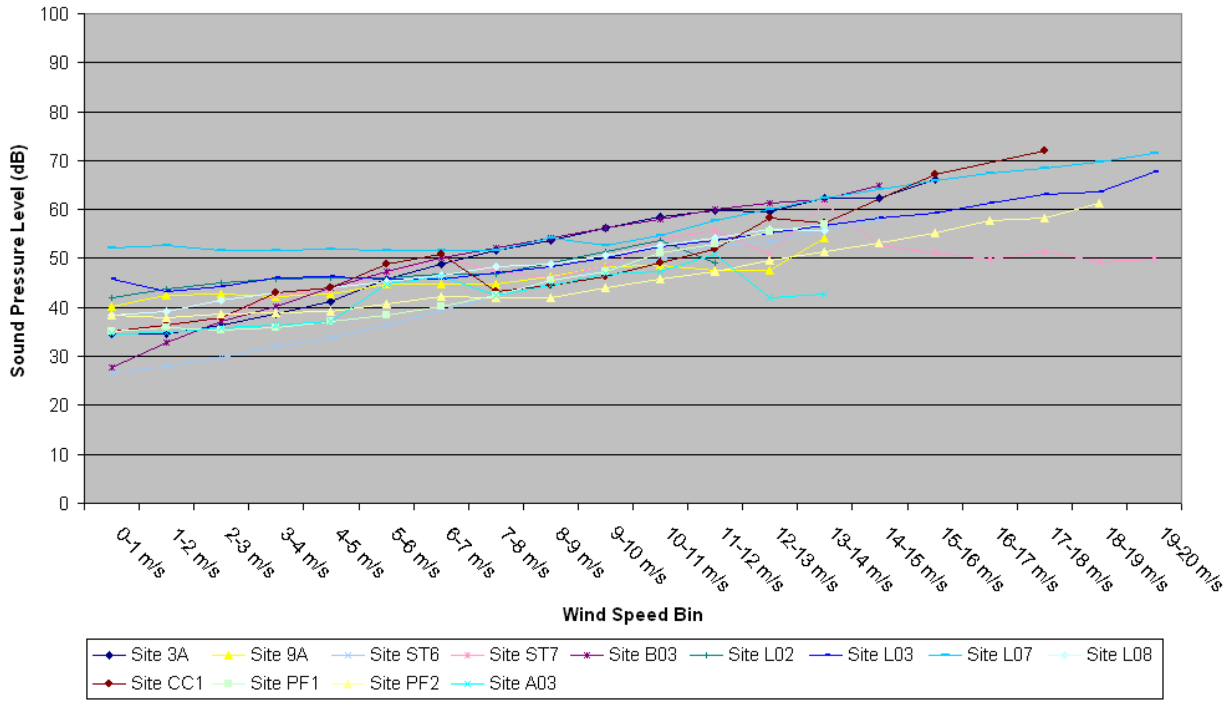

Figure 81. 100 Hz L_{eq} in 1-m/s wind speed bins by site.

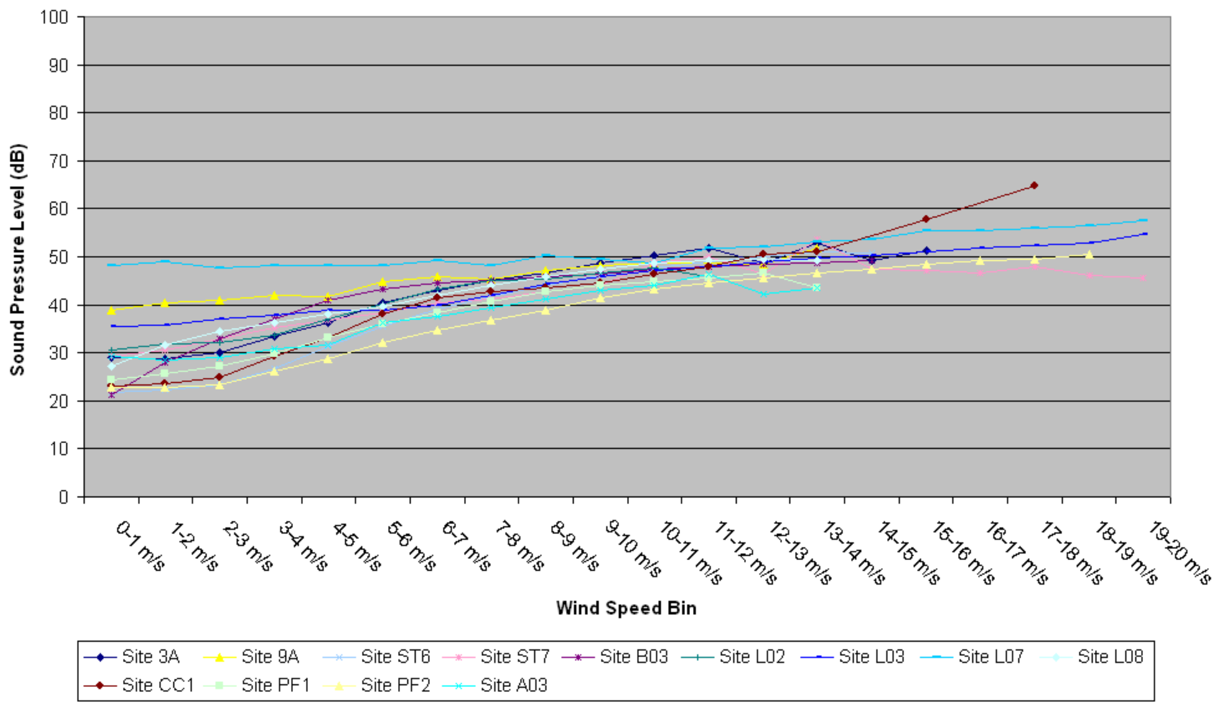

Figure 82. 500 Hz L_{eq} in 1-m/s wind speed bins by site.

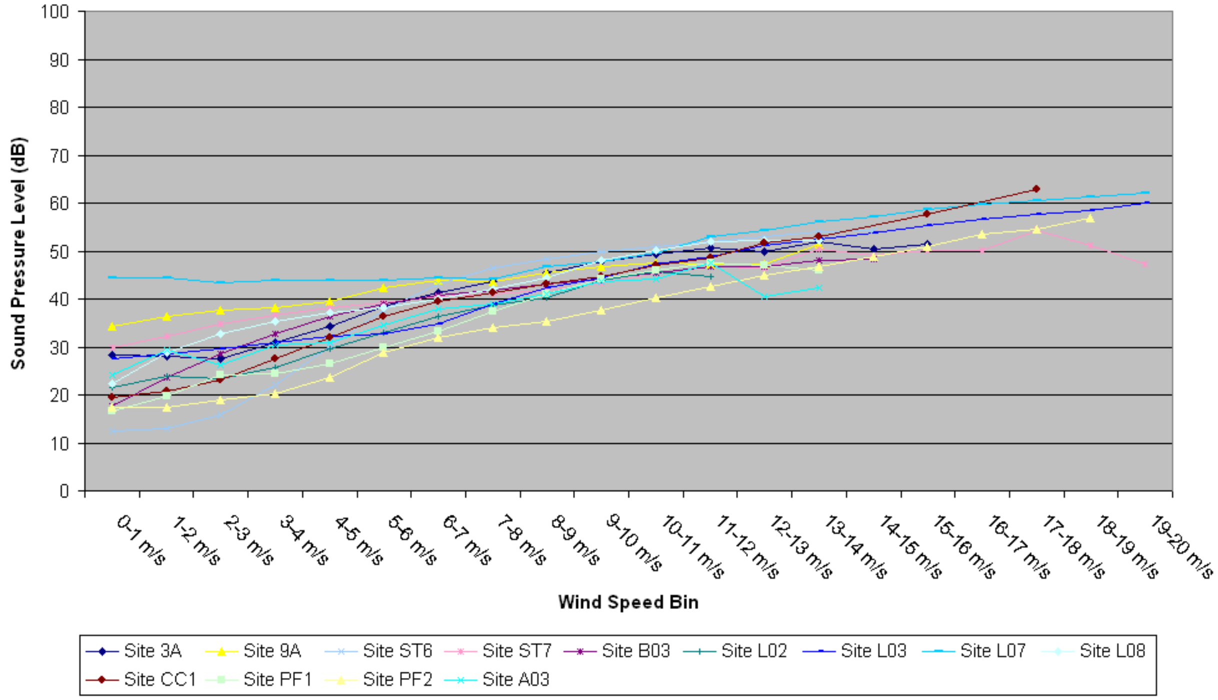

Figure 83. 1,000 Hz L_{eq} in 1-m/s wind speed bins by site.

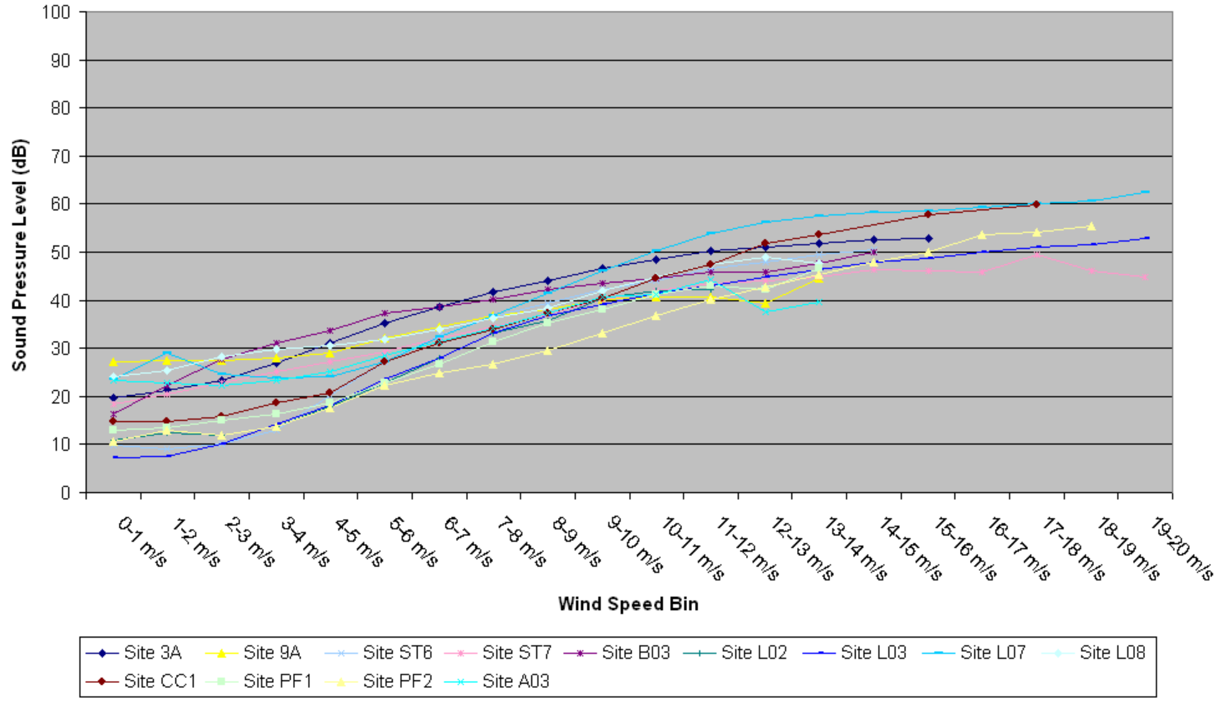

Figure 84. 5,000 Hz L_{eq} in 1-m/s wind speed bins by site.

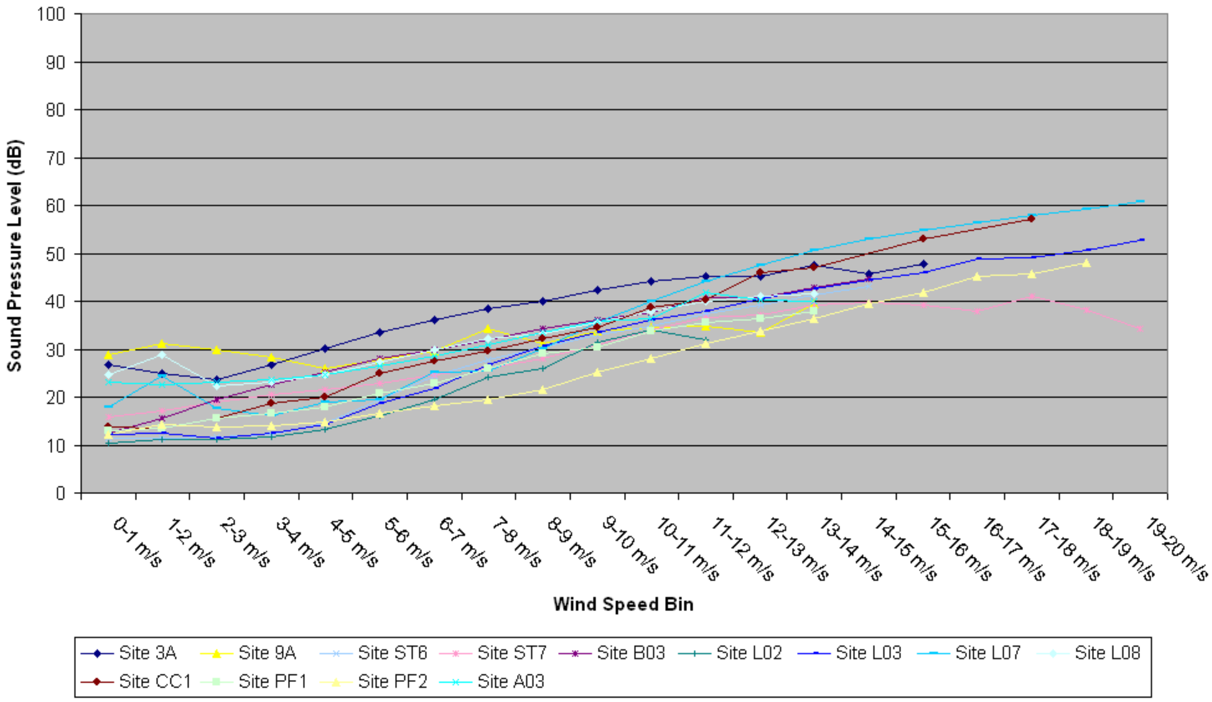

Figure 85. 10,000 Hz L_{eq} in 1-m/s wind speed bins by site.

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APPENDIX D: TERMINOLOGY

This section presents pertinent terminology used throughout the document. Note: Definitions are generally consistent with those of the American National Standards Institute (ANSI) and References 31 through 35.

A-WEIGHTING - A frequency-based methodology used to account for changes in human hearing sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 and 6.3 kHz, in an effort to simulate the relative response of human hearing.

ACOUSTIC ENERGY - Commonly referred to as the mean-square sound-pressure ratio, sound energy, or just plain energy, acoustic energy is the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing. It is arithmetically equivalent to $10^{(LEV/10)}$, where LEV is the sound level, expressed in decibels.

AMBIENT - The composite, all-inclusive sound associated with a given environment, excluding the analysis system’s electrical noise and sound sources of interest. Several definitions of ambient noise have been adopted by different organizations depending on their application.

- *Existing Ambient*: The composite, all-inclusive sound associated with a given environment, excluding only the analysis system’s electrical noise (i.e., human and mechanical sounds are included);
- *Existing Ambient Without Air Tours*: 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, air tour aircraft;
- *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.

AUDIBILITY - Refers to the capacity of a human with normal hearing to detect the presence of sound. Additionally, the sound pressure levels and frequency content of ambient sounds influence the ability of a human to hear a given sound.

DECIBEL - (symbol dB) A unit of level which denotes the ratio between two quantities that are proportional to power; the number of decibels is ten times the base-10 logarithm of the squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing.

EQUIVALENT SOUND LEVEL (TEQ, denoted by the symbol LAeqT) - Ten times the base-10 logarithm of the time-mean-square, instantaneous A-weighted sound pressure, during a stated time interval, T (where $T=t_2-t_1$, in seconds), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing. L_{AeqT} is related to L_{AE} by the following equation:

$$L_{AeqT} = L_{AE} - 10\mathrm{Log}_{10}(t_2-t_1) \qquad \text{(dB)}$$

Where L_{AE} = Sound exposure level (see definition below).
The L_{Aeq} for a specific time interval, T1 (expressed in seconds), can be normalized to a longer time interval, T2, via the following equation:

$$L_{AeqT2} = L_{AeqT1} - 10\mathrm{Log}10(T2/T1) \qquad \text{(dB)}$$

FAIRING – An auxiliary structure or an external surface that serves to reduce drag.

FREQUENCY – For a function periodic in time, the reciprocal of the period (the smallest increment of an independent variable for which a function repeats itself).

HERTZ - (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of time.

IN SITU - On site and in real-time.

L_{50} - A statistical descriptor describing the sound level exceeded 50 percent of a specific time period. For example, from a fifty-sample measurement period, the twenty-fifth (50% of 50 samples) highest sound level is the 50-percentile exceeded sound level.

L_{90} - A statistical descriptor describing the sound level exceeded 90 percent of a specific time period. For example, from a fifty-sample measurement period, the forty-fifth (90% of 50 samples) highest sound level is the 90-percentile exceeded sound level.

L_{AE} (see Sound Exposure Level)

L_{Aeq} (see Equivalent Sound Level)

L_x - A statistical descriptor describing the sound level exceeded "x" percent of a specific time period, e.g., L_{50} and L_{90}.

LOW-LEVEL NOISE ENVIRONMENT - An outdoor sound environment typical of a remote suburban setting, or a rural or public lands setting. Characteristic day-night average sound levels (DNL, represented by the symbol, L_{dn}) would generally be less than 45 dB, and the everyday sounds of nature, e.g., wind blowing in trees and birds chirping would be a prominent contributor to the DNL.

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.

NATURAL SOUNDSCAPE - The natural ambient sound level of a park. It is comprised of the natural sound conditions in a park, which exist in the absence of any human-produced noises. These conditions are actually composed of many natural sounds, near and far, which often are heard as a composite, not individually.

NOISE - Any unwanted sound. "Noise" and "sound" are used interchangeably in this document.

SOUND EXPOSURE LEVEL (SEL, denoted by the symbol L_{AE}) - Over a stated time interval, T (where $T=t_2-t_1$, in seconds), ten times the base-10 logarithm of a given time integral of squared instantaneous A-weighted sound pressure, divided by the product of the squared reference sound pressure of 20 µPa, the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10 dB down points (see Figure 1). The L_{AE} can be developed from 1-second, A-weighted sound levels (L_{Ak}) by the following equation:

$$L_{AE} = 10 Log_{10}\left[\sum_{k=t_1}^{t_2} 10^{L_{Ak}/10}\right] \quad \text{(dB)}$$

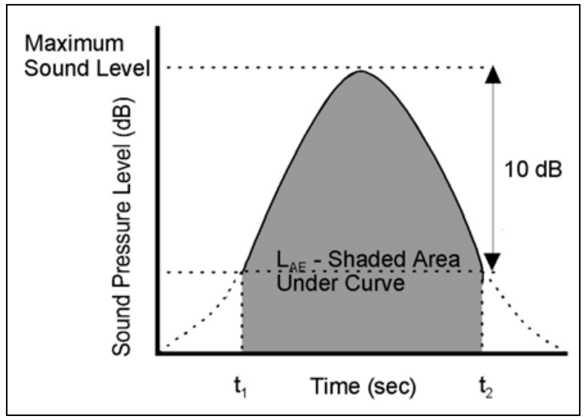

Figure 86. Graphical representation of L_{AE}.

In addition, L_{AE} is related to L_{AeqT} by the following equation:

$$L_{AE} = L_{AeqT} + 10Log_{10}(t_2 - t_1) \quad \text{(dB)}$$

Where L_{AeqT} = Equivalent sound level in dB (see definition above).

SOUND PRESSURE LEVEL (SPL) - Ten times the base-10 logarithm of the time-mean-square sound pressure, in a stated frequency band (often frequency-weighted), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing.

$$SPL = 10Log_{10}[p^2/p_{ref}^2]$$

Where p^2 = time-mean-square sound pressure; and p_{ref}^2 = squared reference sound pressure of 20 µPa.

SOUNDSCAPE - In accordance with National Park Service's Director's Order #47, soundscape is defined as "the total ambient acoustic environment associated with a given environment in an area such as a national park. In a national park setting, this soundscape is usually composed of both natural ambient sounds and a variety of human-made sounds."

SPECTRUM – A set of sound pressure levels in component frequency bands, usually one-third octave-bands.

WHISTLING – A tonal sound, a series of such sounds, or a high-pitched warbling.

WHOOSHING – A soft sibilant sound.

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