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Hawai`i Volcanoes National Park: Baseline Ambient Sound Levels 2003



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The Federal Aviation Administration (FAA), with the cooperation of the National Park Service (NPS) and assistance of the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is developing Air Tour Management Plans (ATMP) or Voluntary Agreements (VA) for all national parks with commercial air tours, with the exception of the Grand Canyon National Park (GCNP), tribal lands within or abutting the GCNP, Rocky Mountain National Park, exempt park units (50 or fewer annual tours) and national park units located in Alaska. An important area of technical support is the determination of representative baseline ambient sound levels for the study parks. The FAA, with the assistance of the Volpe Center's Environmental Measurement and Modeling Division, and the NPS, with assistance of Harris Miller Miller & Hanson, Inc., conducted baseline ambient sound level measurements during the period October 23, 2002, through June 1, 2003, in Hawai`i Volcanoes National Park. In total, over 900 days of acoustical and meteorological data were measured at 22 sites throughout the park. This document summarizes the results of the noise measurement study.

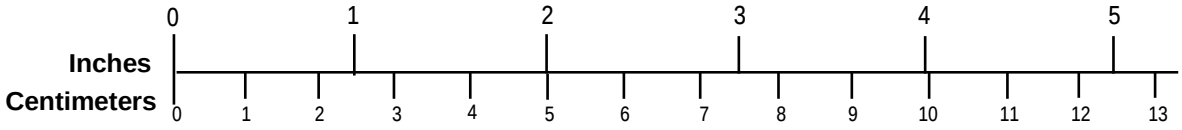
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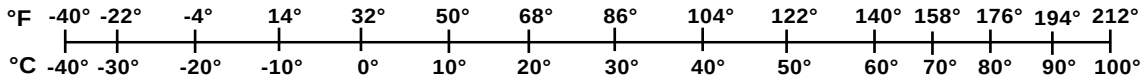
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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA), with the cooperation of the National Park Service (NPS) and assistance of the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is developing Air Tour Management Plans (ATMP) or Voluntary Agreement (VA) for all national parks with commercial air tours, with the exception of the Grand Canyon National Park (GCNP), tribal lands within or abutting the GCNP, air tour operations flying over or near the Lake Mead National Recreation Area solely as a transportation route to conduct an air tour over GCNP, Rocky Mountain National Park, exempt park units (50 of fewer annual tours) and national park units located in Alaska.

An important area of technical support is the determination of representative baseline ambient sound levels for the study parks. The baseline ambient data will be used to establish a foundation from which potential noise impacts can be assessed. Ambient sound level data collected in this study will be used for the primary purposes of:

- Establishing baseline ambient sound levels (both overall and frequency based) in key areas within Hawai`i Volcanoes;
- Establishing the different sound sources contributing to the baseline levels in key areas within Hawai`i Volcanoes;
- Modeling sound levels in other similar areas within Hawai`i Volcanoes for which resource constraints (or other issues) do not allow for direct measurements,
- Building a library of baseline ambient sound levels (both overall and frequency based), which may potentially be used in ATMPs and VAs to generalize baseline ambient sound levels within similar types of parks, or park areas; and
- Provide input into the FAA's Integrated Noise Model (INM)[*], to assess the complete acoustical environment within the entire park. INM is a computer program used by over 700 organizations in over 50 countries to assess changes in noise impact. The INM model was recommended by the Federal Interagency Committee on Aviation Noise (FICAN) as the best-practice modeling methodology currently available for evaluating aircraft noise in national parks.[1,2]

[*] As of May 2015, the Aviation Environmental Design Tool (AEDT) has replaced INM.

This document summarizes the noise measurement study undertaken to provide data for the baseline ambient noise environment in Hawai`i Volcanoes National Park, located in the state of Hawai`i (see Figure 1).

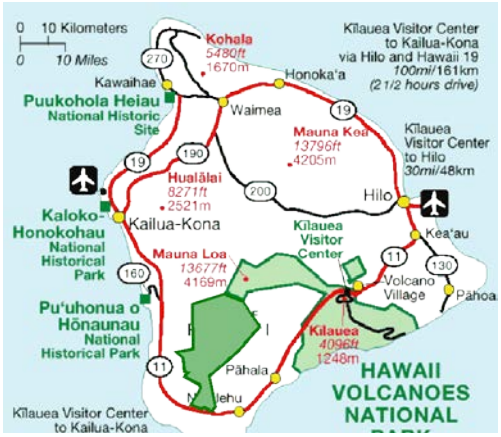


Figure 1. Location of Hawai`i Volcanoes.

The FAA, with assistance of the Volpe Center's Environmental Measurement and Modeling Division, and the NPS, with assistance of Harris Miller Miller & Hanson, Inc. (HMMH), conducted baseline ambient sound level measurements during the period October 23, 2002, through June 1, 2003, in Hawai`i Volcanoes National Park. In total, over 900 days of acoustical and meteorological data were measured at 22 sites throughout the park. These sites were selected during a meeting between the FAA, the NPS, the Volpe Center, HMMH, Hawai`i Flight Standards District Office (FSDO), and Hawai`i Volcanoes NPS personnel.

The primary goal of the site selection process was to identify the minimum number of field-measurement sites, which would allow for characterization of the baseline ambient sound levels throughout the entire park. This was accomplished by identifying acoustically representative regions for which data could be collected and stratified, i.e., "acoustic zones." These data could then be applied to other regions in the park possessing similar attributes, which will affect acoustics, such as land cover, wind conditions, and wildlife habitats.

The resultant nine acoustic zones mutually agreed to by FAA, NPS, the Volpe Center, and HMMH were as follows:

- Shoreline (Zone 1);
- Coastal Lowlands (Zone 2);
- Ka`ū Desert/Kīlauea Summit (Zone 3);
- `Ola`a Rain Forest (Zone 4);
- Mauna Loa Forest (Zone 5);
- Dry `Ohi`a Woodlands (Zone 6);

- Mauna Loa Alpine (Zone 7);
- Young Rain Forest (Zone 8); and
- New Lava Flows (Zone 9).

Note: Several attempts to deploy a measurement site within Zone 7 (Mauna Loa Alpine) during the study period failed due to difficult weather and accessibility issues. As such, since vegetative land cover is one of the key attributes, which drives the acoustics of how sound propagates from a source to a receiver, ambient data from a zone with the closest land cover and topography (Zone 3) was applied to this zone as the "best available data" for the purposes of this document. In addition, the 116,000-acre Kahuku Ranch on Hawai`i Island was purchased and added to Hawai`i Volcanoes National Park in July 2003. As the Kahuku Ranch was added to the park subsequent to the measurement study, no ambient data was able to be collected within this area in support of the data analysis. Similar to Zone 7 above, vegetative land cover was used to apply ambient data from a zone with the closest land cover and topography (Zone 3) to this zone (Zone 10) as the "best available data" for the purposes of this document.

In discussions with Hawai`i Volcanoes NPS personnel, because there is little climatic seasonal variation in Hawai`i as compared with other U.S. national parks, a minimum of one week of continuous, 24-hour measurements at each site was recommended, with up to two weeks being preferred. To validate this recommendation and provide guidance for adequate measurement duration for use in ATMP and VA parks, it was agreed that: (1) one site within each acoustic zone would include data collection on a long-term basis, i.e., longer than 2 weeks up to the entire measurement study duration of eight months (permanent sites, designated with the letter "A" in Figure 2); and (2) additional sites placed within each zone would include data collection on a short-term basis, i.e., one to three weeks (mobile sites designated with subsequent letters in Figure 2). For example, Sites 1A and 1B indicate a permanent system and a mobile system, respectively, in Zone 1 (Shoreline). Site 1C indicates a second mobile site in a similar coastal area. Figure 2 displays the locations of the acoustic zones and the final measurement sites selected.

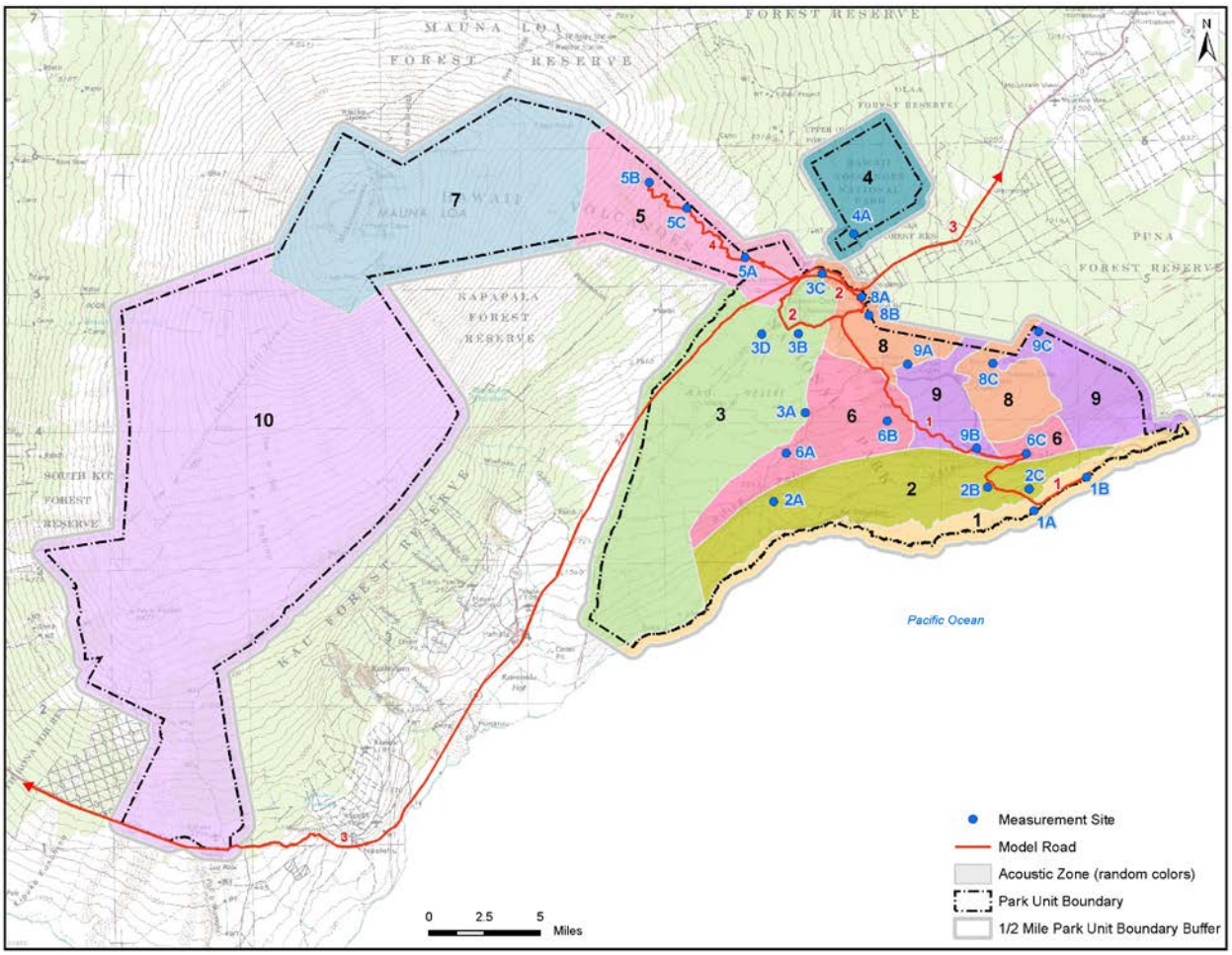


Figure 2. Acoustic zones and final measurement sites for Hawai`i Volcanoes.

As stated earlier, in total, over 900 days of acoustical and meteorological data were measured at 22 sites throughout Hawai`i Volcanoes during the period October 23, 2002, through June 1, 2003 (see Figure 3).

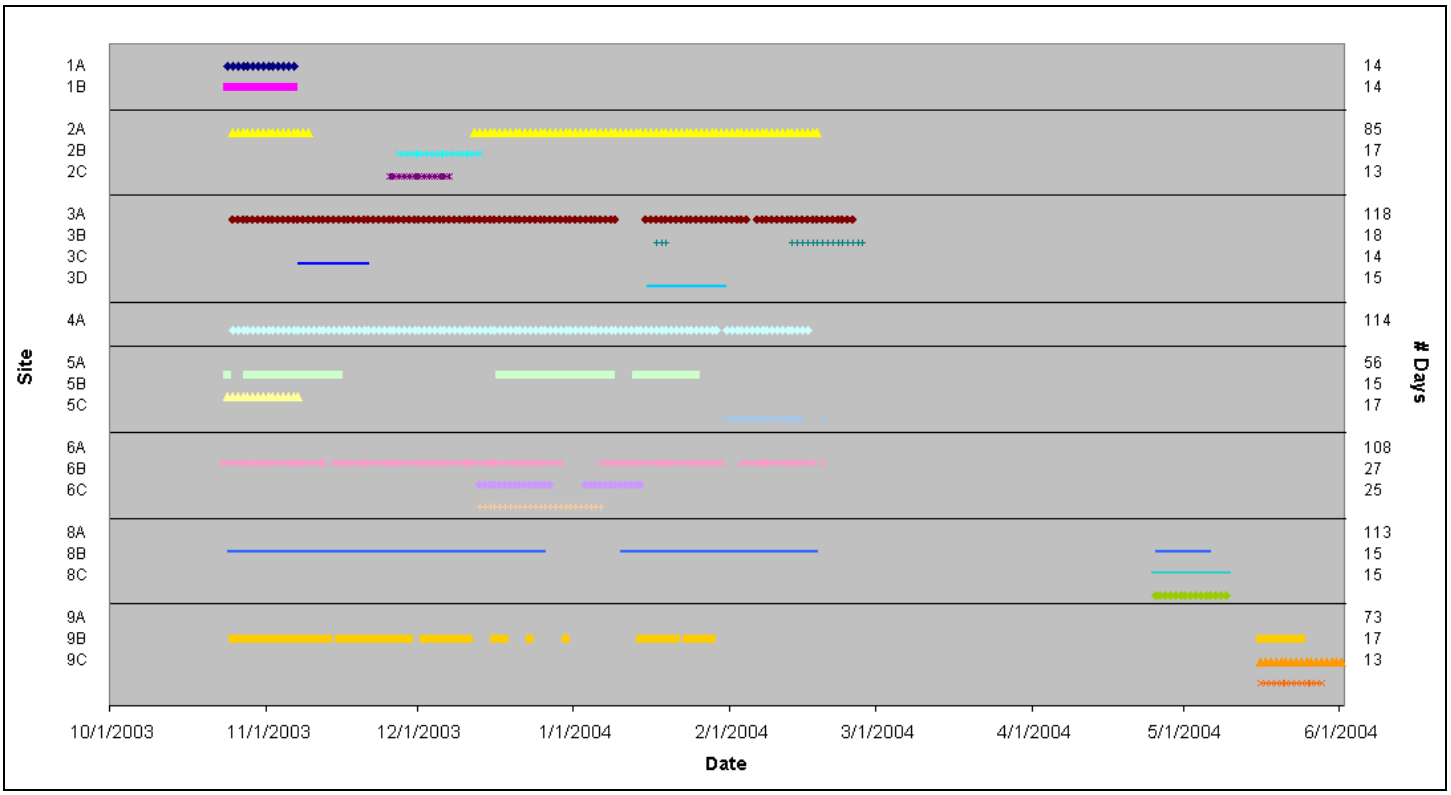


Figure 3. Baseline ambient data collection timeline for each site.

The following types of data were collected:

- *Acoustical*: Continuous, one-second, A-weighted sound levels and their associated one-third octave-band un-weighted spectrum from 12.5 to 20,000 Hz;
- *Meteorological*: Continuous, one-second wind speed and direction data; and
- *Observer Logs*: During site visits, a field observer would perform short-term documentation of the acoustic environment at the site. Events audible within the acoustic environment were categorized into 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. Examples of non-aircraft (human) intrusions include hikers, campers, talking, motor vehicles, etc. The natural category was documented when no aircraft or other human-made sounds could be heard.

All data analyses were performed in terms of three metrics:

- *The A-weighted equivalent sound level (L_{Aeq}) and its associated one-third octave-band spectrum (unweighted):* Ten times the base-10 logarithm of the time-mean-square, instantaneous A-weighted sound pressure, during a stated time interval, divided by the squared reference sound pressure of 20 μPa, the threshold of human hearing;
- *The 50-percentile exceeded sound level (L_{50}) and its associated one-third octave-band spectrum (unweighted):* A statistical descriptor describing the sound level exceeded 50 percent of a specific time period. For example, from a fifty-sample measurement period with the samples sorted from highest sound level to lowest sound level, the twenty-fifth sound level is the 50-percentile exceeded sound level; and
- *The 90-percentile exceeded sound level (L_{90}) and its associated one-third octave-band spectrum (unweighted):* A statistical descriptor describing the sound level exceeded 90 percent of a specific time period. For example, from a fifty-sample measurement period with the samples sorted from highest sound level to lowest sound level, the forty-fifth sound level is the 90-percentile exceeded sound level.

In addition, because for most parks, the majority of air tour operations occur during the day, the FAA and NPS have agreed that any subsequent impact assessment will be conducted using ambient sound levels during the time that the air tour operations occur. Accordingly, all ATMP and VA analyses will be based on daytime ambient data. For Hawai`i Volcanoes, only data measured during the time period of 6 am to 6 pm were used. This time period is the typical operating hours for air tour operators conducting air tours in Hawai`i according to Honolulu Flight Standard District Office personnel.

Using the data in the acoustic observer logs to group the individual, one-second, sound level values, four different types of ambient for each of the three above metrics were computed from the data. The four primary types of "ambient" used in this document are defined as follows (see Figure 4):

- *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.

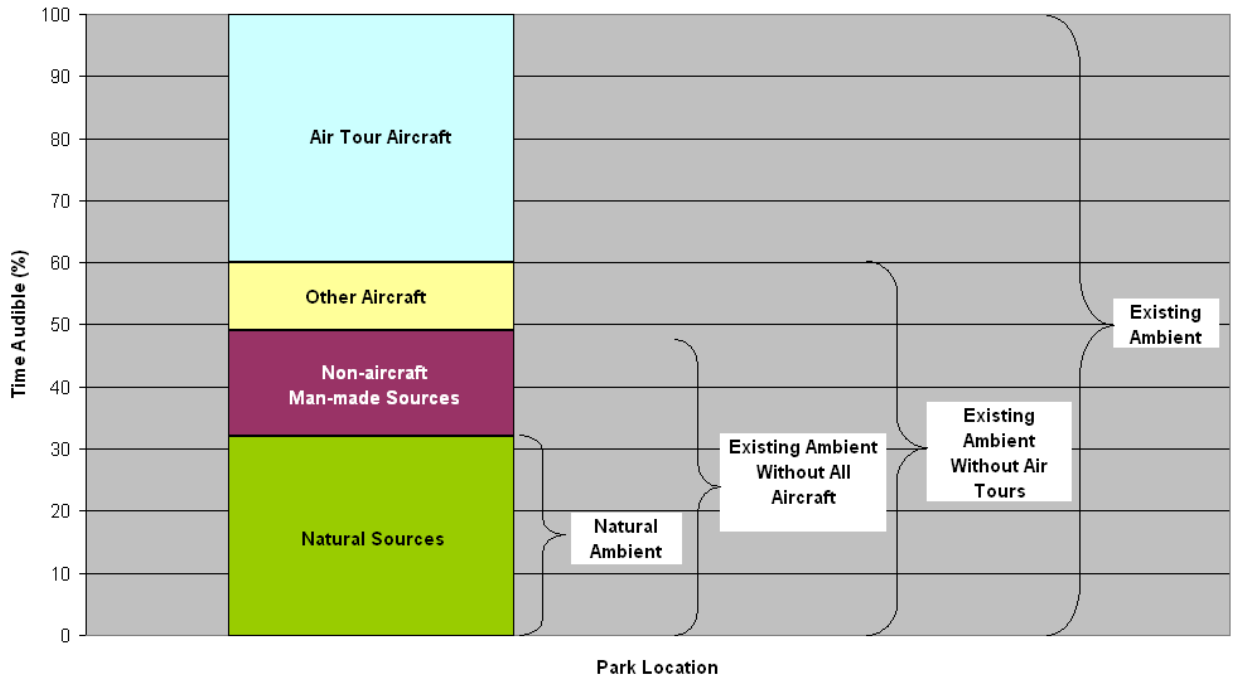


Figure 4. Graphical depiction of ambient definitions.

Table 1 contains a summary of the ambient, sound level data measured at each measurement site. The table is arranged by acoustic zone, followed by measurement site number. The first three columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was

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

located;

- *Site ID*: The unique two-character ID representing the site "number"; and
- *Total # Days*: The total number of days measured.

The next four primary columns define the additional types of ambient represented by the data: Existing, Existing Without Air Tours, Existing Without All Aircraft, and Natural, as defined above. Then for each type of ambient, the following data are presented: [*]

- L_{Aeq}: The equivalent, A-weighted sound level (in decibels). Presented is the energy-averaged value determined from daytime sound levels (6 am to 6 pm), taking into account the data from all days of measurements (Note: This metric was computed for the Existing Ambient only);
- L_{50}: The L_{50} sound level (in decibels) determined by the sound level exceeded 50 percent of the daytime hours (6 am to 6 pm), taking into account the data from all days of measurements;
- L_{90}: The L_{90} sound level (in decibels) determined by the sound level exceeded 90 percent of the daytime hours (6 am. to 6 pm), taking into account the data from all days of measurements; and
- *W/S*: The average wind speed (in mph). Presented is the algebraically averaged value determined from daytime sound levels (6 am to 6 pm), taking into account the data from all days of measurements.

Table 2 contains a summary of the acoustic observer data logged at each measurement site. The first six columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was located;
- *Site ID*: The unique two-character ID representing the site "number";

[*] As noted previously, because for most parks, the majority of air tour operations occur during the day, the FAA and NPS have agreed that any subsequent impact assessment will be conducted using ambient sound levels during the time that the air tour operations occur. Accordingly, all ATMP or VA analyses will be based on daytime ambient data. For Hawai`i Volcanoes, only data measured during the time period of 6 am to 6 pm were used. This time period is the typical operating hours for air tour operators conducting air tours in Hawai`i according to Honolulu Flight Standard District Office personnel.

- *Land Cover*: The land cover of the site in accordance with the National Land Cover Data 21-class land cover classification scheme;
- *Management Zone*: The NPS management zone that the site was located in;
- *Site Category*: A designator indicating expected visitor use (with "overlook" indicating high visitor use, "short hike" indicating moderate visitor use, and "wilderness/backcountry" indicating minimal or no visitor use) in the measurement site area;
- *Total Duration (s):* The duration in seconds of all acoustic observer logging performed at the measurement site.

The next six columns define the amount of time that different noise sources were audible to the acoustic observer:

- *Air Tour Aircraft*: The duration in seconds that air tour aircraft were audible;
- *Other Aircraft*: The duration in seconds that other aircraft (e.g., commercial, military, general aviation, and agricultural) were audible;
- *Human*: The duration in seconds that human noise sources (visitor- and mechanical-related) were audible;
- *Natural*: The duration in seconds that natural noise sources were audible;
- *% Air Tour*: The percentage of observer log time that air tour aircraft were audible; and
- *% All Aircraft*: The percentage of observer log time that all aircraft were audible (i.e., air tour and other aircraft).

In addition, Table 3 summarizes two additional metrics (per NPS request) determined using the acoustic observer logs taken during the ambient measurements:

- *Number of Events Per Hour (NEH):* The number of air tour operations audible within a specified time period, ideally each hour during the day (where sufficient operational data exists); and
- *Noise-Free Interval (NFI):* The length of time during which only natural sounds are audible.

The columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was located;
- *Site ID*: The unique two-character ID representing the site "number";
- *Noise-Free Periods*: Periods of time during which only natural sounds were audible;
- *Air Tour Aircraft Events*: Periods of time during which air tour aircraft sounds were audible; and
- *Other Aircraft Events*: Periods of time during which non-air tour aircraft sounds were audible.

Table 1. Summary of measured, daytime (6 am to 6 pm), ambient sound level data.

Acoustic Zone	Site ID	Total # Days	Existing L_{Aeq} (dBA)	Existing L_{50} (dBA)	Existing L_{90} (dBA)	Existing W/S (mph)	Existing Without Air Tours L_{50} (dBA)	Existing Without Air Tours L_{90} (dBA)	Existing Without Air Tours W/S (mph)	Existing Without All Aircraft L_{50} (dBA)	Existing Without All Aircraft L_{90} (dBA)	Existing Without All Aircraft W/S (mph)	Natural Ambient L_{50} (dBA)	Natural Ambient L_{90} (dBA)	Natural Ambient W/S (mph)
1: Shoreline*	1A	14	58.0	54.0	41.1	7.0	54.2	40.8	N/A	54.2	40.8	N/A	54.2	40.8	N/A
1: Shoreline	1B	14	51.7	46.8	42.3	9.0	46.7	43.1	33.0	46.7	43.1	33.0	46.6	43.1	33.1
2: Coastal Lowlands	2A	85	36.5	28.3	20.6	4.8	28.3	20.3	7.7	28.3	20.3	7.7	28.3	20.3	7.7
2: Coastal Lowlands	2B	17	45.0	32.4	22.2	6.1	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
2: Coastal Lowlands	2C	13	40.6	33.0	18.9	6.3	29.1	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9
3: Ka`ū Desert/ Kīlauea Summit	3A	118	42.1	28.2	17.2	4.7	30.3	18.0	6.1	31.4	18.0	5.9	31.4	18.0	5.9
3: Ka`ū Desert/ Kīlauea Summit	3B	18	44.2	29.6	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9
3: Ka`ū Desert/ Kīlauea Summit	3C	14	43.0	37.2	28.6	3.8	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
3: Ka`ū Desert/ Kīlauea Summit	3D	15	39.8	20.2	17.4	7.2	19.3	17.1	8.8	19.3	17.1	8.8	20.4	18.1	9.4
4: Ola`a Rain Forest	4A	114	39.7	33.1	25.6	0.4	33.0	25.0	0.0	33.5	27.3	0.0	33.5	27.3	0.0
5: Mauna Loa Forest	5A	56	42.5	34.9	26.5	1.7	35.0	26.3	2.3	35.0	26.7	2.3	35.0	26.7	2.3
5: Mauna Loa Forest	5B	15	33.3	23.4	17.4	1.8	23.3	17.2	2.0	22.1	17.1	1.9	22.1	17.1	1.9
5: Mauna Loa Forest	5C	17	36.7	27.6	20.3	4.7	27.7	20.2	4.4	27.7	20.2	4.4	27.5	19.9	4.4
6: Dry Ohi`a Woodlands	6A	108	39.4	28.9	23.7	4.9	28.0	23.8	7.8	28.0	23.8	7.7	28.0	23.8	7.7
6: Dry Ohi`a Woodlands	6B	27	42.5	30.8	23.8	6.4	28.0	23.8	7.8	28.0	23.8	7.7	28.0	23.8	7.7
6: Dry Ohi`a Woodlands	6C	25	53.3	33.1	23.2	5.6	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
8: Young Rain Forest	8A	113	46.6	43.0	36.9	0.7	42.8	36.6	1.1	42.8	36.6	1.1	42.6	36.6	1.1
8: Young Rain Forest	8B	15	46.1	38.3	32.7	0.7	38.2	32.7	0.2	38.2	32.2	0.2	38.2	32.2	0.2
8: Young Rain Forest	8C	15	42.0	31.4	24.4	0.9	31.3	24.4	1.6	29.7	23.3	1.7	29.7	23.3	1.7
9: New Lava Flows	9A	73	49.1	29.5	19.0	4.3	28.3	18.7	6.5	28.3	18.7	6.5	28.6	18.7	6.5
9: New Lava Flows	9B	17	39.7	33.0	20.2	7.0	28.3	18.7	6.5	28.3	18.7	6.5	28.6	18.7	6.5
9: New Lava Flows	9C	13	48.2	29.2	22.1	6.8	28.3	21.4	6.7	25.4	19.9	7.0	25.4	19.9	7.0

* Note that for sites with acoustic zone 1 (Shoreline), the 11 mph (5 m/s) wind speed threshold (see also Appendix E) was removed as the strong trade winds throughout the zone did not diminish during the data collection. As such, this data is contaminated with some wind noise and should be used with caution.

Table 2. Summary of acoustic observer log data.

Acoustic Zone	Site ID	Land Cover	Management Zone	Site Category	Total Duration (s)	Seconds Audible: Aircraft Sound Sources - Air Tours	Seconds Audible: Aircraft Sound Sources - Other	Seconds Audible: Human Sound Sources	Seconds Audible: Natural Sound Sources	% Time Audible: Air Tour	% Time Audible: All Aircraft
1: Shoreline*	1A	Bare Rock/Sand/Clay	Natural	Short Hike	3380	102	0	8	3270	**3.0%**	**3.0%**
1: Shoreline	1B	Bare Rock/Sand/Clay	Natural	Overlook	3171	738	0	260	2173	**23.3%**	**23.3%**
2: Coastal Lowlands	2A	Grasslands/Herbaceous	Wilderness (Natural subzone)	Wilderness	346	0	0	0	346	**0.0%**	**0.0%**
2: Coastal Lowlands	2B	Grasslands/Herbaceous	Natural	Short Hike	651	0	0	0	651	**0.0%**	**0.0%**
2: Coastal Lowlands	2C	Bare Rock/Sand/Clay	Natural	Short Hike	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
3: Ka`ū Desert/ Kīlauea Summit	3A	Bare Rock/Sand/Clay	Natural	Short Hike	1412	0	151	0	1261	**0.0%**	**10.7%**
3: Ka`ū Desert/ Kīlauea Summit	3B	Bare Rock/Sand/Clay	Natural	Overlook	1011	0	0	0	1011	**0.0%**	**0.0%**
3: Ka`ū Desert/ Kīlauea Summit	3C	Grasslands/Herbaceous	Natural	Overlook	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
3: Ka`ū Desert/ Kīlauea Summit	3D	Bare Rock/Sand/Clay	Natural	Short Hike	295	0	0	137	158	**0.0%**	**0.0%**
4: Ola`a Rain Forest	4A	Evergreen Forest	Wilderness (Natural Subzone)	Wilderness	4901	0	427	471	4003	**0.0%**	**8.7%**
5: Mauna Loa Forest	5A	Evergreen Forest	Natural	Overlook	7633	0	491	82	7060	**0.0%**	**6.4%**
5: Mauna Loa Forest	5B	Shrubland	Natural	Overlook	3637	0	745	65	2827	**0.0%**	**20.5%**
5: Mauna Loa Forest	5C	Shrubland	Natural	Short Hike	1059	0	0	30	1029	**0.0%**	**0.0%**
6: Dry Ohi`a Woodlands	6A	Grasslands/Herbaceous	Natural	Short Hike	3733	104	36	0	3593	**2.8%**	**3.8%**
6: Dry Ohi`a Woodlands	6B	Grasslands/Herbaceous	Natural	Backcountry	1073	0	531	0	542	**0.0%**	**49.5%**
6: Dry Ohi`a Woodlands	6C	Grasslands/Herbaceous	Natural	Short Hike	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
8: Young Rain Forest	8A	Evergreen Forest	Natural	Short Hike	7193	476	0	2166	4551	**6.6%**	**6.6%**

* Noted that for sites with acoustic zone 1 (Shoreline), the 11 mph (5 m/s) wind speed threshold (see also Appendix E) was removed as the strong trade winds throughout the zone did not diminish during the data collection and would have resulted in an unacceptable data loss. As such, this data is contaminated with some wind noise and should be used with caution.

Acoustic Zone	Site ID	Land Cover	Management Zone	Site Category	Total Duration (s)	Seconds Audible: Aircraft Sound Sources - Air Tours	Seconds Audible: Aircraft Sound Sources - Other	Seconds Audible: Human Sound Sources	Seconds Audible: Natural Sound Sources	% Time Audible: Air Tour	% Time Audible: All Aircraft
8: Young Rain Forest	8B	Evergreen Forest	Natural	Short Hike	3322	0	581	0	2741	**0.0%**	**17.5%**
8: Young Rain Forest	8C	Evergreen Forest	Natural	Backcountry	3528	0	2175	0	1353	**0.0%**	**61.6%**
9: New Lava Flows	9A	Transitional	Wilderness (Natural Subzone)	Backcountry	14964	690	4	129	14141	**4.6%**	**4.6%**
9: New Lava Flows	9B	Transitional	Natural	Overlook	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
9: New Lava Flows	9C	Transitional	Natural	Backcountry	4347	0	2272	0	1951	**0.0%**	**52.3%**

Table 3. Summary of acoustic observer log data: number of events per hour and noise-free interval.

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Number Periods/Events:	1: Shoreline	1A	4	2	0
Mean Time (minutes):	1: Shoreline	1A	0:13:37	0:00:51	0:00:00
Minimum Time (minutes):	1: Shoreline	1A	0:01:40	0:00:48	0:00:00
Maximum Time (minutes):	1: Shoreline	1A	0:28:00	0:00:54	0:00:00
Total Time (minutes):	1: Shoreline	1A	0:54:30	0:01:42	0:00:00
Number Periods/Events:	1: Shoreline	1B	9	11	0
Mean Time (minutes):	1: Shoreline	1B	0:02:01	0:01:07	0:00:00
Minimum Time (minutes):	1: Shoreline	1B	0:00:11	0:00:11	0:00:00
Maximum Time (minutes):	1: Shoreline	1B	0:07:49	0:03:19	0:00:00
Total Time (minutes):	1: Shoreline	1B	0:36:13	0:12:18	0:00:00
Number Periods/Events:	2: Coastal Lowlands	2A	7	0	0
Mean Time (minutes):	2: Coastal Lowlands	2A	0:02:12	0:00:00	0:00:00
Minimum Time (minutes):	2: Coastal Lowlands	2A	0:00:10	0:00:00	0:00:00
Maximum Time (minutes):	2: Coastal Lowlands	2A	0:08:32	0:00:00	0:00:00
Total Time (minutes):	2: Coastal Lowlands	2A	0:15:22	0:00:00	0:00:00
Number Periods/Events:	2: Coastal Lowlands	2B	1	0	0
Mean Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Minimum Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Maximum Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Total Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
(No logging performed here)	2: Coastal Lowlands	2C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3A	7	1	0
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:08:12	0:06:58	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:00:08	0:06:58	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:29:59	0:06:58	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:57:27	0:06:58	0:00:00
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3B	20	2	0
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:04:17	0:00:48	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:00:05	0:00:45	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:58:35	0:00:52	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	1:25:32	0:01:37	0:00:00
(No logging performed here)	3: Ka`ū Desert/ Kīlauea Summit	3C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3D	8	0	0

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:00:40	0:00:00	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:00:07	0:00:00	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:01:29	0:00:00	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:05:22	0:00:00	0:00:00
Number Periods/Events:	4: Ola`a Rain Forest	4A	53	7	0
Mean Time (minutes):	4: Ola`a Rain Forest	4A	0:01:44	0:01:18	0:00:00
Minimum Time (minutes):	4: Ola`a Rain Forest	4A	0:00:01	0:00:04	0:00:00
Maximum Time (minutes):	4: Ola`a Rain Forest	4A	0:17:48	0:02:25	0:00:00
Total Time (minutes):	4: Ola`a Rain Forest	4A	1:32:17	0:10:28	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5A	16	9	0
Mean Time (minutes):	5: Mauna Loa Forest	5A	0:06:57	0:01:02	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5A	0:00:03	0:00:08	0:00:00
Maximum Time (minutes):	5: Mauna Loa Forest	5A	0:34:24	0:02:12	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5A	1:58:14	0:08:14	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5B	126	9	0
Mean Time (minutes):	5: Mauna Loa Forest	5B	0:00:22	0:01:23	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5B	0:00:01	0:00:03	0:00:00
Maximum Time (minutes):	5: Mauna Loa Forest	5B	0:02:31	0:04:07	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5B	0:47:09	0:12:25	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5C	32	0	0
Mean Time (minutes):	5: Mauna Loa Forest	5C	0:00:32	0:00:00	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5C	0:00:01	0:00:00	0:00:00
Maximum Time (minutes):	5: Mauna Loa Forest	5C	0:02:46	0:00:00	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5C	0:17:20	0:00:00	0:00:00
Number Periods/Events:	6: Dry Ohi`a Woodlands	6A	29	3	0
Mean Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:03:17	0:01:13	0:00:00
Minimum Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:00:02	0:00:13	0:00:00
Maximum Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:35:54	0:02:30	0:00:00
Total Time (minutes):	6: Dry Ohi`a Woodlands	6A	1:31:55	0:03:40	0:00:00
Number Periods/Events:	6: Dry Ohi`a Woodlands	6B	6	4	0
Mean Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:01:31	0:02:58	0:00:00
Minimum Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:00:30	0:01:40	0:00:00
Maximum Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:02:59	0:04:39	0:00:00
Total Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:09:07	0:08:53	0:00:00

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
(No logging performed here)	8: Young Rain Forest	6C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	8: Young Rain Forest	8A	58	11	0
Mean Time (minutes):	8: Young Rain Forest	8A	0:01:49	0:01:19	0:00:00
Minimum Time (minutes):	8: Young Rain Forest	8A	0:00:02	0:00:22	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8A	0:18:09	0:03:52	0:00:00
Total Time (minutes):	8: Young Rain Forest	8A	1:45:02	0:14:24	0:00:00
Number Periods/Events:	8: Young Rain Forest	8B	34	9	0
Mean Time (minutes):	8: Young Rain Forest	8B	0:01:21	0:01:05	0:00:00
Minimum Time (minutes):	8: Young Rain Forest	8B	0:00:04	0:00:27	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8B	0:07:41	0:02:15	0:00:00
Total Time (minutes):	8: Young Rain Forest	8B	0:45:43	0:09:41	0:00:00
Number Periods/Events:	8: Young Rain Forest	8C	22	16	0
Mean Time (minutes):	8: Young Rain Forest	8C	0:01:01	0:01:54	0:00:00
Minimum Time (minutes):	8: Young Rain Forest	8C	0:00:05	0:00:40	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8C	0:03:28	0:06:10	0:00:00
Total Time (minutes):	8: Young Rain Forest	8C	0:22:33	0:36:15	0:00:00
Number Periods/Events:	9: New Lava Flows	9A	87	19	0
Mean Time (minutes):	9: New Lava Flows	9A	0:03:06	0:00:53	0:00:00
Minimum Time (minutes):	9: New Lava Flows	9A	0:00:08	0:00:01	0:00:00
Maximum Time (minutes):	9: New Lava Flows	9A	0:16:27	0:04:53	0:00:00
Total Time (minutes):	9: New Lava Flows	9A	4:32:11	0:20:15	0:00:00
(No logging performed here)	9: New Lava Flows	9B	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	9: New Lava Flows	9C	28	9	0
Mean Time (minutes):	9: New Lava Flows	9C	0:00:33	0:02:48	0:00:00
Minimum Time (minutes):	9: New Lava Flows	9C	0:00:03	0:00:11	0:00:00
Maximum Time (minutes):	9: New Lava Flows	9C	0:02:09	0:10:18	0:00:00
Total Time (minutes):	9: New Lava Flows	9C	0:05:35	0:42:00	0:00:00

As stated earlier, the primary goal of the site selection process was to identify the minimum number of field-measurement sites, which would allow for characterization of the baseline ambient sound levels in the park. Thus, the measured data establishes ambient sound levels in key areas within the park and is then generalized to larger areas with similar acoustical attributes, such as land cover, wind conditions, wildlife habitats, and visitor-use.

In addition to the measured ambient sound levels, the contributing effect of localized noise sources, such as waterfalls, river rapids, trains, and roads, are also considered in the development of the ambient maps. Because it is not feasible to carry out field data collection efforts in all

areas of a park, the contributions of these localized sound sources are typically modeled and combined with the measured sound levels to develop a composite, baseline, ambient "map" of a park. An ambient "map" is essentially a comprehensive grid of ambient sound levels throughout a study area. The composite, baseline, ambient map (along with representative one-third octave-band spectral data) is used as input to the INM or AEDT model to compute various noise-related descriptors and generate the sound-level contours that will be used in the assessment of potential noise impacts due to air tour operations.

For Hawai`i Volcanoes, there were four primary, and relatively busy, roads: Highway 11, Mauna Loa Strip Road, Crater Rim Drive, and Chain of Craters Road. Specifically, the estimated drop-off rate, reflecting a continuous decrease in sound level as a function of increasing distance from each road, was computed using the Federal Highway Administration's Traffic Noise Model® (TNM). Figure 5 presents the resultant roadway ambient map.

With four ambient types computed in terms of three metrics, nine composite ambient maps were developed (see Table 4).

Table 4. Nine composite ambient maps.

Metric	Existing Ambient	Existing Ambient Without Air Tours	Existing Ambient Without All Aircraft	Natural Ambient*
L_{Aeq}	Map 1: Measured + Roadway	N/A	N/A	N/A
L_{50}	Map 2: Measured + Roadway	Map 4: Measured + Roadway	Map 6: Measured + Roadway	Map 8: Measured
L_{90}	Map 3: Measured + Roadway	Map 5: Measured + Roadway	Map 7: Measured + Roadway	Map 9: Measured

Note: The combined (Measured + Roadway) ambient were computed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition. For a non-time-varying source, such as roadway noise, the TNM-computed L_{Aeq} sound level parameters were conservatively assumed to be equivalent to the L_{50} and L_{90} and, thus, used interchangeably as the "roadway" ambient.

The FAA and NPS agree on the definitions of ambient. However, because the FAA and NPS have different methodologies for assessing noise impacts, it is not clear which definition is the most appropriate. From the above nine, two ambient maps were agreed upon for use in ATMP or VA analyses:

* As defined in earlier, Natural Ambient includes the natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excludes all human and mechanical sounds.

- *Existing Ambient Without Air Tours* – Map 4 from the table above; and
- *Natural Ambient* – Map 8 from the table above.

Figure 6 and Figure 7 present the two ambient maps, respectively. Section 7 presents all nine maps.

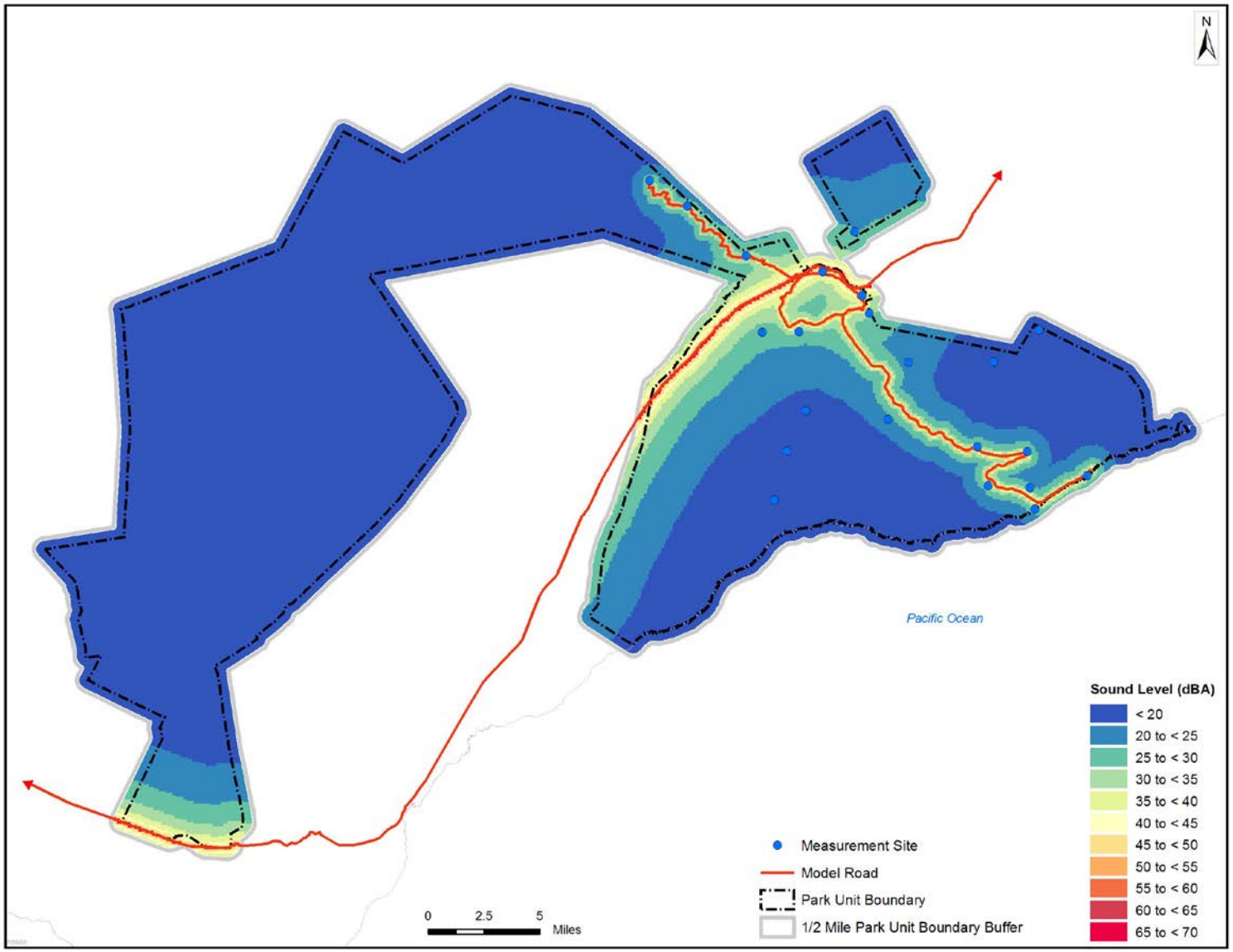


Figure 5. Roadway ambient map.

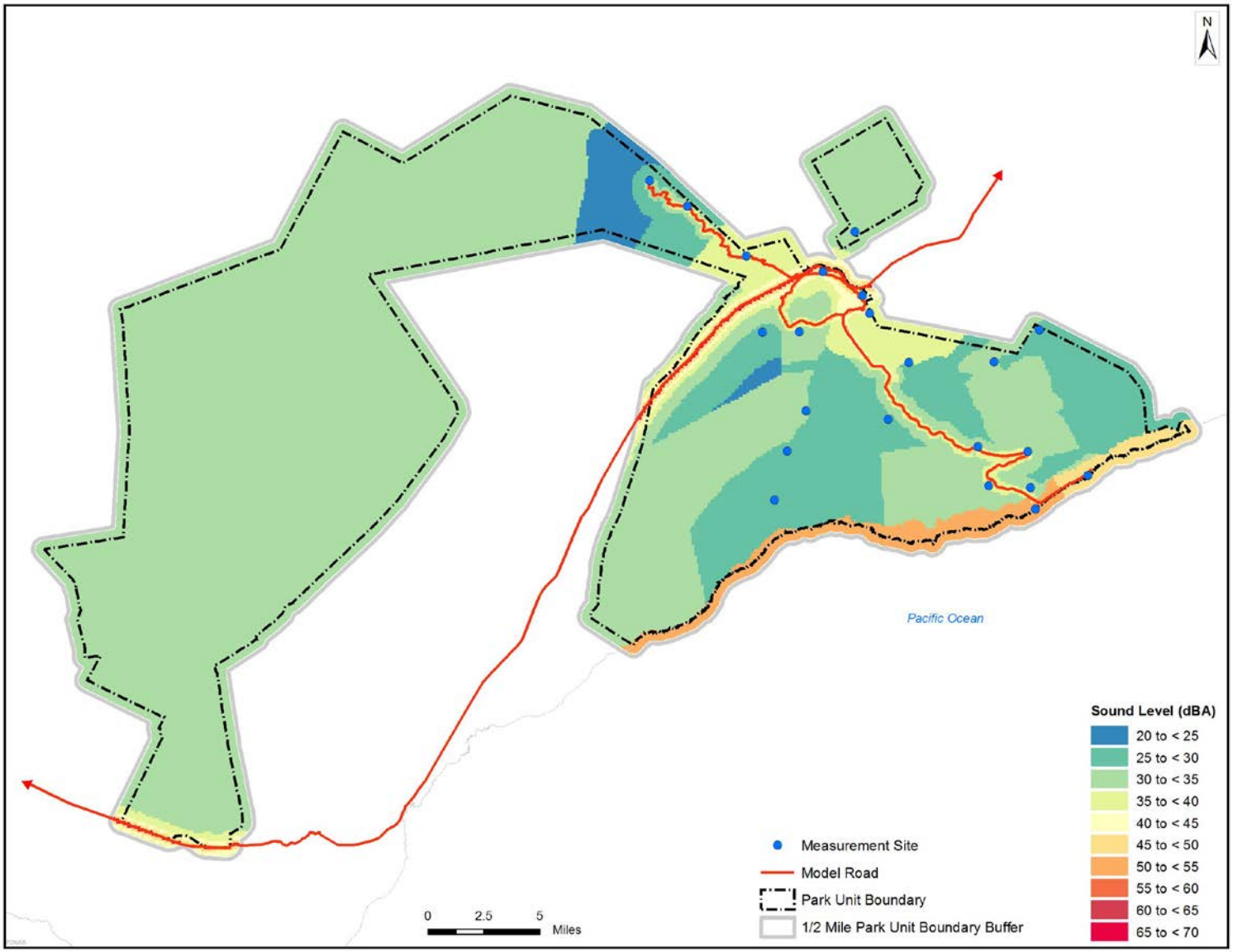


Figure 6. Baseline composite ambient map – Existing Ambient Without Air Tours: L_{50}.

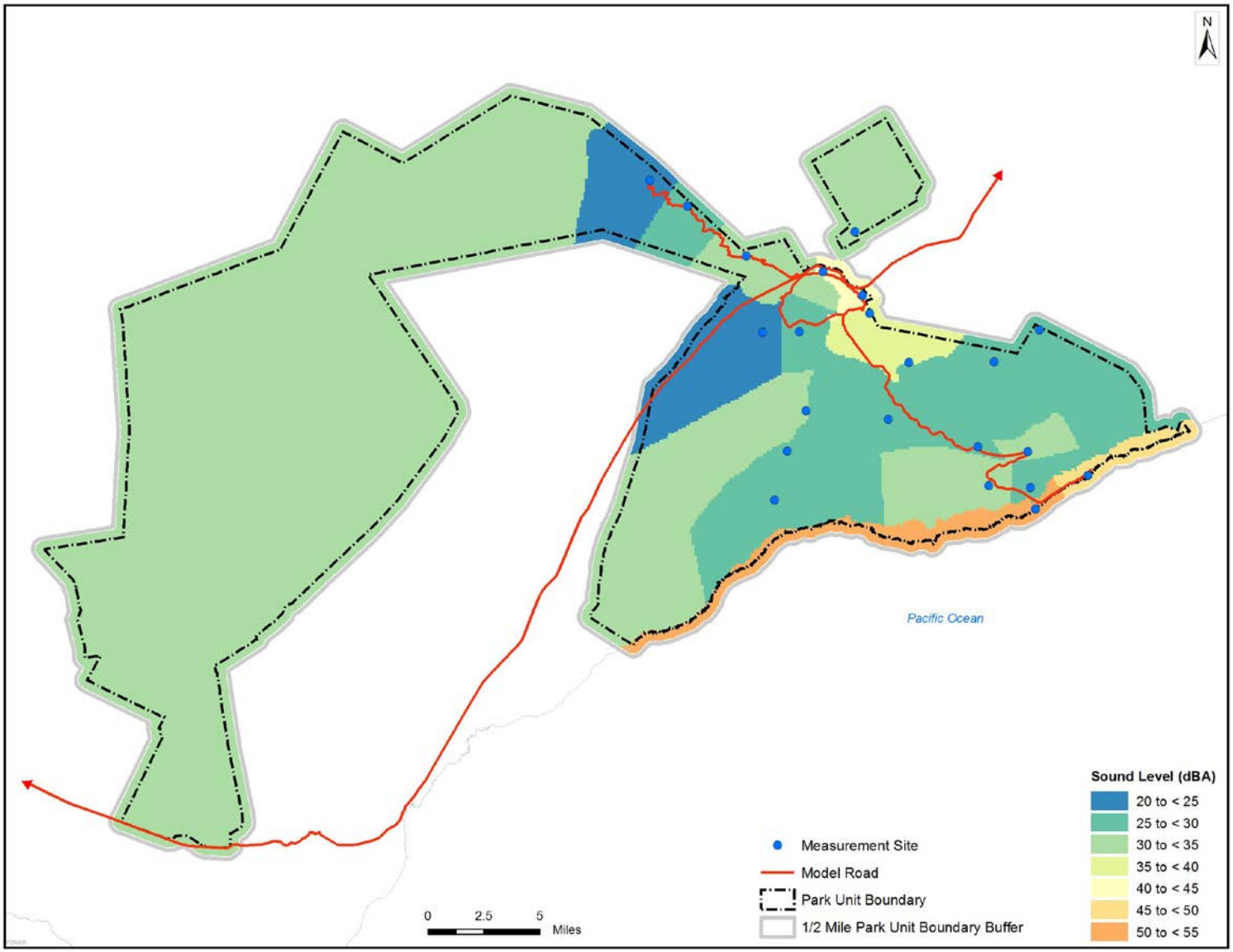


Figure 7. Baseline composite ambient map – Natural Ambient: L_{50}.

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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 3 through 7.

A'A FLOWS – Jagged and slow moving lava flows with dense surfaces. The lava contains cinder, bombs, and ryholite rocks, which hardened when it released from the vent of the lava's mouth.

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 kHz 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 the sound source 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., 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.

ANNOYANCE - Any bothersome or irritating occurrence.

BACKCOUNTRY - Any location in a study area subject to minimal human activity, such as designated wilderness areas or restricted, hiking and camping areas (destinations generally located 1 hour or more from frontcountry locations).

CALDERA - A large crater formed by volcanic explosion or by collapse of a volcanic cone.

C-WEIGHTING - A frequency-based methodology that is linear over the mid frequency range from 200 Hz to 1.6 kHz, and de-emphasizes the low (below 200 Hz) and high (above 1.6 kHz) frequencies.

DAY-NIGHT AVERAGE SOUND LEVEL (DNL, denoted by the symbol L_{dn}) - A 24-hour time-averaged sound exposure level (see definition below), adjusted for average-day sound source operations. In the case of aircraft noise, a single operation is equivalent to a single aircraft operation. The adjustment includes a 10-dB penalty for operations occurring between 2200 and 0700 hours, local time.

DECIBEL - (symbol dB) A unit of measure for defining a noise level or a noise exposure level. The number of decibels is calculated as 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.

DOSE RESPONSE - Quantitative dose data (in this case noise data measured in the field), correlated with qualitative response data (in this case visitors' responses to a questionnaire).

EQUIVALENT SOUND LEVEL (TEQ, denoted by the symbol L_{AeqT}) - 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:

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

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:

$$L_{AeqT2} = L_{AeqT1} - 10Lg(T2/T1) \quad \text{(dB)}$$

FRONTCOUNTRY - Any location in a study area subject to substantial human activity, such as scenic overlooks, visitor centers, recreation areas, or destinations reached by short hikes (1 hour or less).

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).

GRASSY KIPUKA - Oasis of undisturbed land within a lava field.

HARD GROUND - Any highly reflective surface in which the phase of the sound energy is essentially preserved upon reflection; examples include water, asphalt and concrete.

HERTZ - (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of 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 with the samples sorted from highest sound level to lowest sound level, the twenty-fifth 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 with the samples sorted from highest sound level to lowest sound level, the forty-fifth sound level is the 90-percentile exceeded sound level.

L_{AE} (see Sound Exposure Level)

L_{Aeq} (see Equivalent Sound Level)

L_{ASmx} (see Maximum Sound Level)

L_{dn} (see Day-Night Average 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}.

LINE SOURCE - Multiple point sources moving in one direction, radiating sound cylindrically. Note: Sound levels measured from a line source decrease at a rate of 3 dB per doubling of distance.

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.

MAXIMUM SOUND LEVEL - The maximum, A-weighted sound level associated with a given event (see figure with definition of sound exposure level). Fast exponential response (L_{AFmx}) and Slow exponential response (L_{ASmx}) characteristics effectively damp a signal as if it were to pass through a low-pass filter with a time constant (τ) of 125 and 1000 milliseconds, respectively.

MESIC - A moderately moist habitat.

NATURAL AMBIENT (see Ambient)

NATURAL QUIET - The natural sound conditions found in a study area. Natural quiet is a subset of ambient noise. Traditionally, it is characterized by the total absence of human or mechanical sounds, but includes all sounds of nature, such as wind, streams, and wildlife. In a park environment, the National Park Service (NPS) on Page 74 of its Report to Congress[7] defines natural quiet as the absence of mechanical noise, but containing the sounds of nature, such as wind, streams, and wildlife, as well as human-generated "self-noise" (e.g., talking, the tread of hiking boots on the trail, a creaking packframe, the rattle of pots or pans).

NATURAL SOUNDSCAPE - In accordance with National Park Service's Director's Order #47, the natural soundscape is 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. [8]

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

NOISE DOSE - A measure of the noise exposure to which a person is subjected.

NOISE-POWER DISTANCE (NPD) DATA – A set of noise levels representing a particular aircraft/engine combination in the FAA's model, expressed as a function of: (1) engine power, usually the corrected net thrust per engine; and (2) source-to-receptor distance.

OVERLOOK - Any frontcountry location in a study area subject to substantial human activity, or destinations reached by automobile or bus, and generally traversable within thirty minutes.

PAHOEHOE FLOWS – Smooth lava flows resembling ropes, which flows at a faster rate and cools at a slower rate than a'a flows.

PALI – Hawaiian word for tall fault escarpment, cliff, steep hill or slope.

PERCENT TIME-ABOVE – The percentage of time that a time-varying sound level is above a

given sound level threshold.

PHOTO-SCALING - The technique of photo-scaling relies on the geometric principle that the ratio of the lengths of the bases of two similar isosceles triangles is equal to the ratio of their heights. "Similar" in this context has the geometric meaning that the vertex angles of the isosceles triangles are equal. In photo-scaling, the first isosceles triangle has the distance from the observer to the object as the height of the triangle and the known length of the object as the triangle's base. The second isosceles triangle has the camera/lens combination's focal length as the height of the triangle and the length of the recorded image as the triangle's base. This study used SAE Aerospace Information Report AIR 902 as the basis for determining the Closest Point of Approach (CPA) of an object moving relative to an observer.[9]

POINT SOURCE - Source that radiates sound spherically. Note: Sound levels measured from a point source decrease at a rate of 6 dB per doubling of distance.

SHORT HIKE - Any frontcountry location in a study area subject to moderate to substantial human activity, or destinations generally reached within one hour of hiking.

SOFT GROUND - Any highly absorptive surface in which the phase of the sound energy is changed upon reflection; examples include terrain covered with dense vegetation or freshly fallen snow. (Note: At grazing angles greater than 20 degrees, which can commonly occur at short ranges, or in the case of elevated sources, soft ground becomes a good reflector and can be considered hard ground).

SOUND – Auditory sensation evoked by the oscillation in pressure, stress, particle displacement, particle velocity, etc., in a medium with internal forces (e.g., elastic or viscous), or the superposition of such propagated oscillations.

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 8 below).

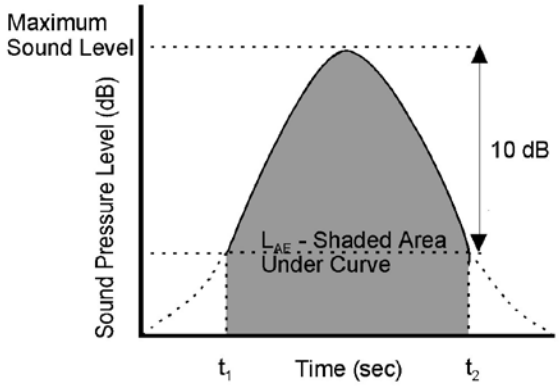


Figure 8. Graphical representation of L_{AE}.

The L_{AE} can be developed from 1-second, A-weighted sound levels (L_{Ak}) by the following equation:

$$L_{AE} = 10Lg\left[\sum_{k=t_1}^{t_s} 10^{L_{AK}/10}\right] \quad \text{(dB)}$$

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

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

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.

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

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

(http://www.nps.gov/policy/DOrders/DOrder47.html), 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 ⅓-octave bands.

TIME-ABOVE – The duration that a time-varying sound level is above a given sound level threshold in a given area during a given time period.

TIME-AUDIBLE – The percentage of time that a time-varying sound level can be heard by a receiver in a given area during a given time period.

Z-WEIGHTING – Indicates no frequency-based methodology was used (also referred to as flat or no weighting).

1. INTRODUCTION

Congress passed the National Parks Air Tour Management Act of 2000 (NPATMA), as amended, to regulate commercial air tour operations over units of the National Park System.[10] NPATMA directed the Federal Aviation Administration (FAA), with the cooperation of the National Park Service (NPS), to develop Air Tour Management Plans (ATMP) for all national parks with commercial air tours. The objective of the ATMPs is to develop acceptable and effective measures to mitigate or prevent significant adverse impacts from the air tours on the natural and cultural resources, visitor experiences, and tribal lands within the parks. Subsequent amendments exempted parks with 50 or fewer annual tours from NPATMA requirements and allowed for development of a Voluntary Agreement (VA) as an alternative to an ATMP.

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center (Volpe Center) is supporting the FAA, Western-Pacific Region (AWP), and working cooperatively with the NPS, Natural Sounds and Night Skies Division, in the development of ATMPs and VAs. Approximately 85 park units have authorized air tours. These parks will either be exempt due to low annual operations (50 or fewer) or will need ATMPs or VAs developed. Some of these parks will require noise analyses, and a major component of establishing noise impacts is the determination of representative baseline sound levels, or ambient levels for each park. As it is neither economically nor expeditiously feasible to manually collect noise data under all possible conditions throughout an entire park, only through computer modeling will it be possible to assess the complete acoustical environment.

1.1 Scope

This document summarizes the baseline ambient measurement study conducted by the FAA, with the assistance of the Volpe Center's Environmental Measurement and Modeling Division, and the NPS, with assistance of HMMH, during the period of October 23, 2002, through June 1, 2003, in Hawai`i Volcanoes.

Hawai`i Volcanoes is located on the big island of Hawai`i. A close-in view of the big island is shown in **Figure 9**. The park was established in 1916, encompasses 333,000 acres and ranges from sea level to the summit of the earth's most massive volcano, Mauna Loa at 13,677 feet. Also in Hawai`i Volcanoes is Kīlauea, currently, the world's most active volcano. Over half of

the park is designated wilderness and contains unique wildlife and cultural resources.



Figure 9. Location of Hawai`i Volcanoes.

A more detailed description of the park can be found in Section 2 of this document.

1.2 Objectives

The primary objective of this study is to quantify the baseline ambient sound levels within Hawai`i Volcanoes to establish a foundation from which potential noise impacts can be assessed, if necessary. Approximately eight months of acoustical and meteorological data were measured at 22 sites throughout the park. Ambient sound level data collected in this study will be used for the primary purposes of:

- Establishing baseline ambient sound levels (both overall and frequency based) in key areas (or "acoustic zones") within Hawai`i Volcanoes;
- Establishing the different sound sources contributing to the baseline levels in key areas within Hawai`i Volcanoes;
- Modeling sound levels in other similar areas within Hawai`i Volcanoes for which resource constraints (or other issues) do not allow for direct measurements; and
- Building a library of baseline ambient sound levels (both overall and frequency based), which may potentially be used in ATMPs and VAs to generalize baseline ambient sound levels within similar types of parks, or park areas to those encountered at Hawai`i Volcanoes.

The data will be used as input into the FAA's Integrated Noise Model (INM) [*],[11] which will be used to assess the complete acoustical environment within the entire park. INM is a computer program used by over 700 organizations in over 50 countries to assess changes in noise impact. The INM model was recommended by the Federal Interagency Committee on Aviation Noise (FICAN), as the best-practice modeling methodology currently available for evaluating aircraft noise in national parks, and agreed to by the NPS and FAA.[1,2]

In addition, an ancillary objective is to further refine an FAA- and NPS-accepted site selection and data collection protocol for use in any future ATMPs and VAs. The protocol is based upon the document, Draft Guidelines for the Measurement and Assessment of Low-Level Ambient Noise,[12] and discussions with the members of the FAA Western-Pacific Region, NPS Natural Sounds and Night Skies Division, Hawai`i Volcanoes park personnel, and Flight Standards District Office (FSDO) representatives.

1.3 Report Organization

The presentation of this document, entitled "Hawai`i Volcanoes National Park: Baseline Ambient Sound Levels 2003," begins with an executive summary and glossary. Section 1 presents an introduction and the objectives of this document. Section 2 overviews the process of measurement site selection with a brief description of the preliminary sites chosen. Section 3 discusses instrumentation. Section 4 presents the measurement procedures employed in the field. Section 5 discusses data reduction. Section 6 discusses data analysis. Section 7 presents the results of the study. Appendix A presents detailed measurement site information. Appendix B contains the User's Guides for the continuous monitoring systems. Appendix C presents the instrumentation frequency response adjustments. Appendix D describes the development of instrumentation noise floor adjustments. Appendix E describes the results of special wind analysis performed on the data. Appendix F discusses the acoustic zone analysis. All related references are presented at the end of this document.

[*] As of May 2015, the Aviation Environmental Design Tool (AEDT) has replaced INM.

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2. SITE SELECTION

Hawai`i Volcanoes, established in 1916, is the result of 70 million years of volcanism, migration, and evolution. Hawai`i Volcanoes encompasses 333,000 acres and an acoustical environment that changes from sea level to the summit of the earth's most massive volcano, 13,677-foot Mauna Loa, with arid, old lava fields existing within a few miles of lush forests. Human activity also varies substantially from the highly visited 11-mile drive circling Kīlauea Volcano's summit caldera to the bottom of Chain of Craters Road where as many as 4,000 visitors per day flock to view flowing lava up close.[13] Over half of the park is designated wilderness and there are approximately 150 miles of hiking trails. In 2003, more than one million people visited the park.[14] Figure 10 provides a general overview of the areas within Hawai`i Volcanoes.

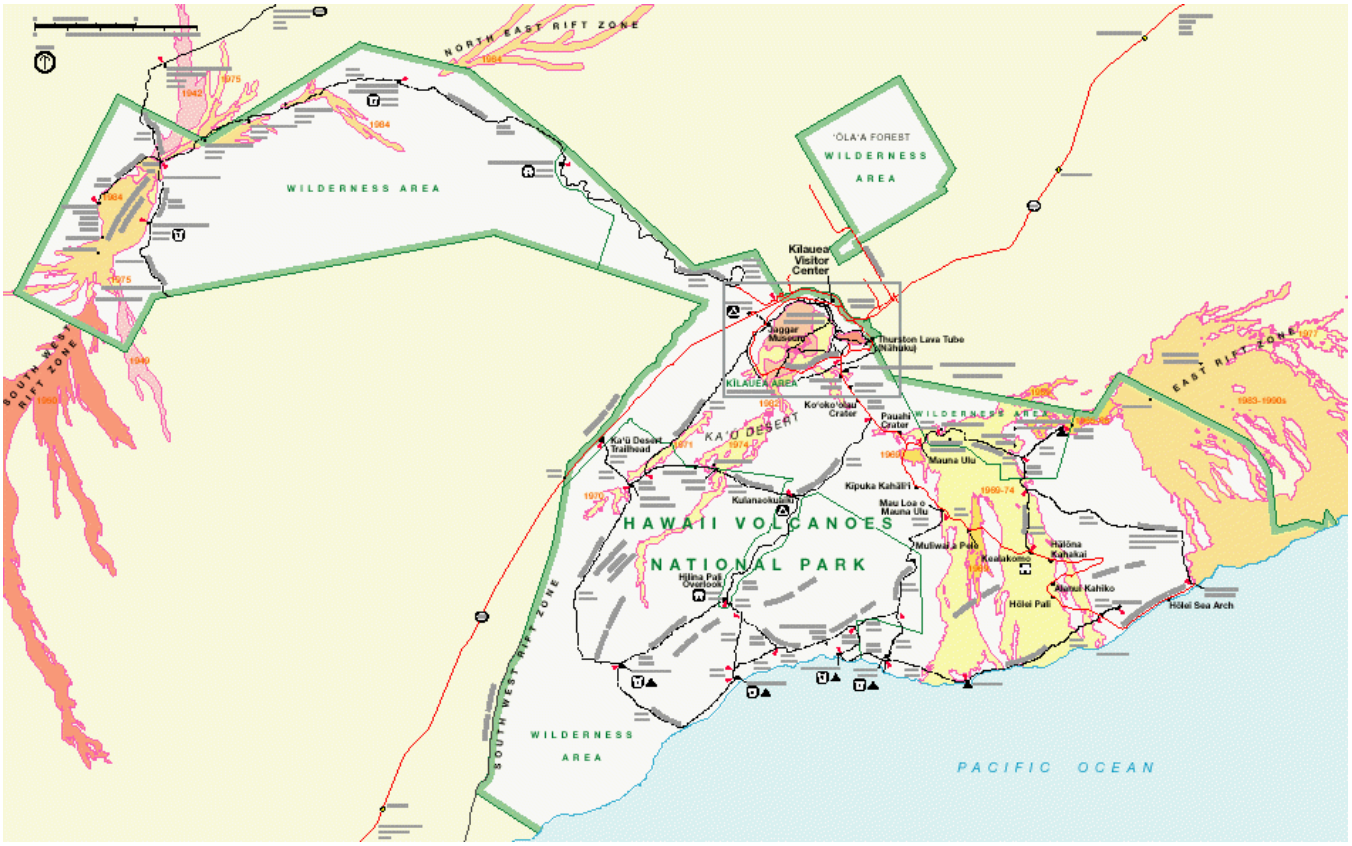


Figure 10. Overview map of Hawai`i Volcanoes.[13]

2.1 Site Selection Criteria

The primary goal of the site selection process was to identify the minimum number of field-measurement sites, which would allow for characterization of the baseline ambient sound levels throughout the entire park. This was accomplished by identifying acoustically representative regions for which data could be collected and stratified, i.e., "acoustic zones." These data could then be applied to other regions possessing similar attributes, which will affect acoustics, such as land cover, wind conditions, and wildlife habitats. In the site selection process, the following technical criteria were used in the determination of acoustic zones:

- *Vegetation/Land Cover (see Section 2.2):* Sound propagates differently over different types of ground cover and through different types of vegetation. For example, sound propagates more freely over barren environments as compared with grasslands, and less freely through forest type environments. In addition, vegetation is typically dependent upon time-of-year, with foliage being sparser in the winter than other times in the year. Land cover can also affect wildlife activity. Previous studies in national parks have established a strong correlation between land cover, wind speed, and ambient sound level.[15,16,17,18]
- *Climate Conditions (see Section 2.3):* Climate conditions include: temperature, humidity, precipitation, wind speed, wind direction, etc.; all of which can affect ambient sound levels as shown in previously referenced studies. For example, higher elevation areas typically exhibit higher wind speeds resulting in higher ambient sound levels. Climate is also dependent upon daily and seasonal variations, which can affect ambient sound levels. For example, under conditions of a temperature inversion (temperature increasing with increasing height as in winter and at sundown), sound waves may be heard over larger distances; and winds tend to increase later in the day, and, as such, may be expected to contribute to higher ambient noise levels in the afternoon as compared with the morning. In addition, biological activity is also affected by climate and seasonality. Natural biological sounds fluctuate with season and might contribute to lower ambient sound levels in the winter. Finally, visitors contribute to a wide variety of sounds, including hikers talking and walking, tour buses and other vehicular noises, as well as air tours. The influence of weather on visitor-use patterns is also important. For example, moderate climate areas of the park are much more popular for backcountry hiking and camping. Areas with more extreme climates are visited less often, for shorter periods of time and more likely only during the day.

The above technical criteria were used to determine the acoustic zones in Hawai`i Volcanoes (see Section 2.6), and then combined with the following secondary criteria to determine the final sites selected (see Section 2.7):

- *Park Resources/Management Zones (see Section 2.4):* As the objective of the ATMPs and VAs is to develop acceptable and effective measures to mitigate or prevent significant adverse impacts from the air tours on the natural and cultural resources, visitor experiences, and tribal lands within the parks, it is important to examine these resources and their locations/habitats during site selection. Park resources contribute, not only, to the multitude of sounds produced in certain areas of the park, but also to the serenity of other areas in the park. The way in which a park manages its resources can affect how potential impacts may be later assessed. It may also help identify where greater resource protection may be needed.
- *Commercial Air Tour Flight Routes (see Section 2.5):* Commercial air tours provide not only a unique experience for visitors of the National parks, but also a different way for visitors to enjoy certain areas of parks. However, these tours also have the potential to disrupt visitors' enjoyment of a park, its wilderness environment, and its native wildlife. As NPATMA directs the development of ATMPs and VAs to reduce or eliminate impacts, if any, caused by commercial air tours, the consideration of existing air tour routes during site selection is very important. Sites in the vicinity of air tour routes provide the unique opportunity to gather in-situ information during ambient data collection regarding the noise source of interest, i.e., air tour aircraft.
- *Logistics/Access (see Section 2.7):* Overarching the above criteria, and in many cases the definitive criterion in the final-decision-making process, is site accessibility. As important as a given site is to satisfy any of the above criteria, if it is inaccessible, measurements cannot be conducted.

2.2 Vegetation/Land Cover

With an annual rainfall ranging from 15 to as much as 100 inches depending upon location, Hawai`i Volcanoes exhibits a wide range of vegetative types - from the tropical rain forest of Ola`a Forest to the nearly barren Ka`ū Desert to the alpine tundra of Mauna Loa Summit.[19] Figure 11 provides an overview of the general land cover in Hawai`i Volcanoes. Measurement sites were selected to encompass as many of these vegetative types as possible.

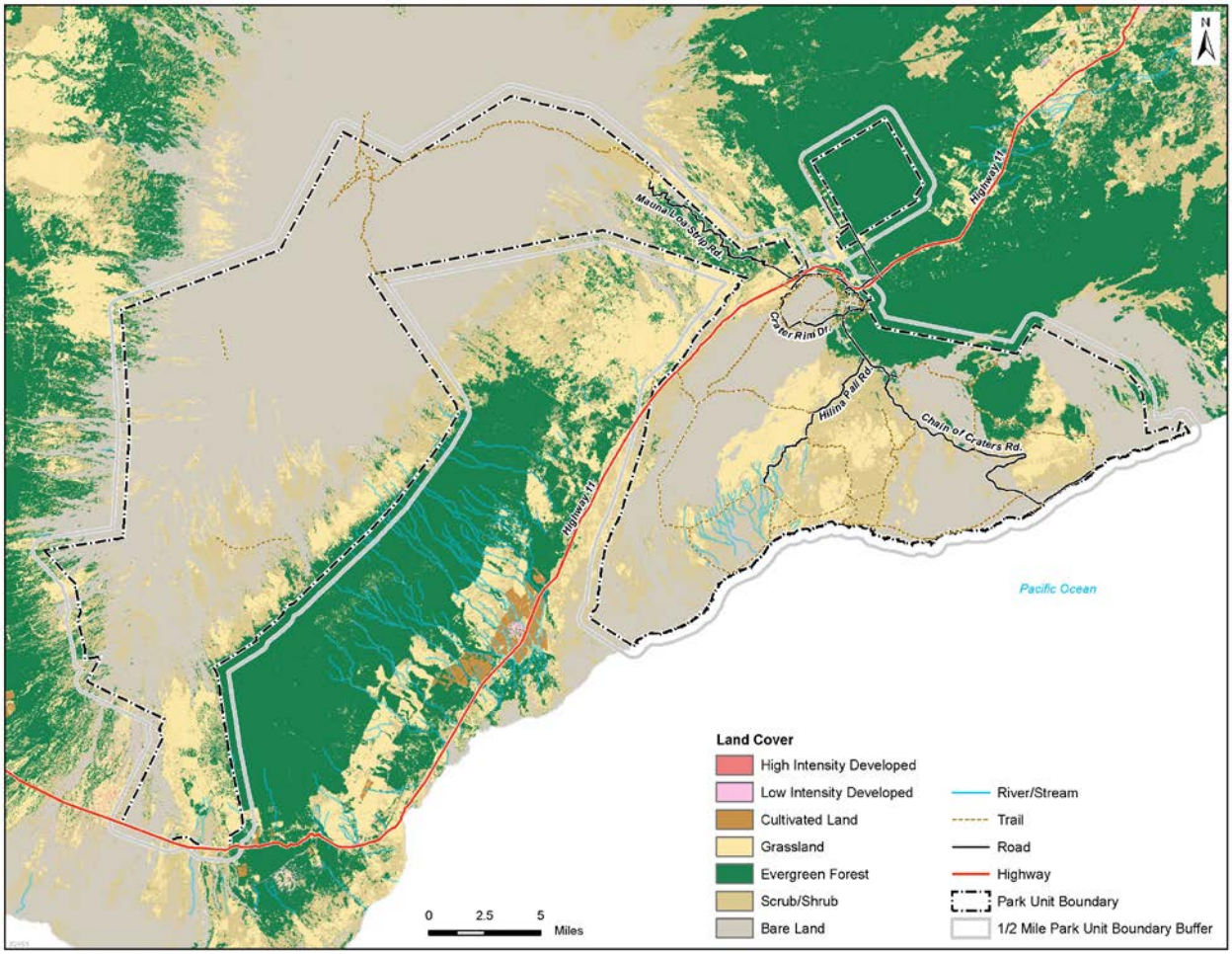


Figure 11. Land cover in Hawai`i Volcanoes.

2.2.1 Lava Flow

Sites were also selected to take into account current and anticipated future lava flow locations. As mentioned earlier, Kīlauea Volcano in Hawai`i Volcanoes is currently the world's most active volcano. The Pu`u `O`o-Kupaianaha eruption of Kīlauea,* now in its 19th year and 55th eruptive episode, ranks as the most voluminous outpouring of lava on the volcano's east rift zone in the past five centuries (see Figure 12). By September 2002, lava from this eruption had covered 42 mi^2 (110 km^2) of Kīlauea's southern shore. In the

* Pu`u` O`o is a massive cinder-cone created by a series of short-lived lava fountains erupting from Kīlauea in 1983. In 1986, the eruption migrated 3 km down the east rift zone to build a broad shield, Kupaianaha, which fed lava to the coast for the next 5.5 years. When the eruption shifted back to Pu`u `O`o in 1992, a series of flank-vent eruptions formed a shield banked against the uprift side of the cone. Continuous eruption from these vents undermined the west and south flanks of the cone, resulting in large collapses of the west flank.

process, 189 structures were destroyed and 8 mi (13 km) of highway resurfaced.[20] Thus, roads and vegetation that once existed or currently exist in one area may no longer exist or will soon no longer exist due to more recent lava activity. Lava flows also affect visitor-related noise. For example, in the summer of 2002, as many as 4000 visitors per day flocked to the end of Chain of Craters Road to view the lava flow into the ocean. This resulted in increases in not only vehicular noise on relevant roadways, but also noise due to loitering aircraft in the immediate eruption viewing areas.

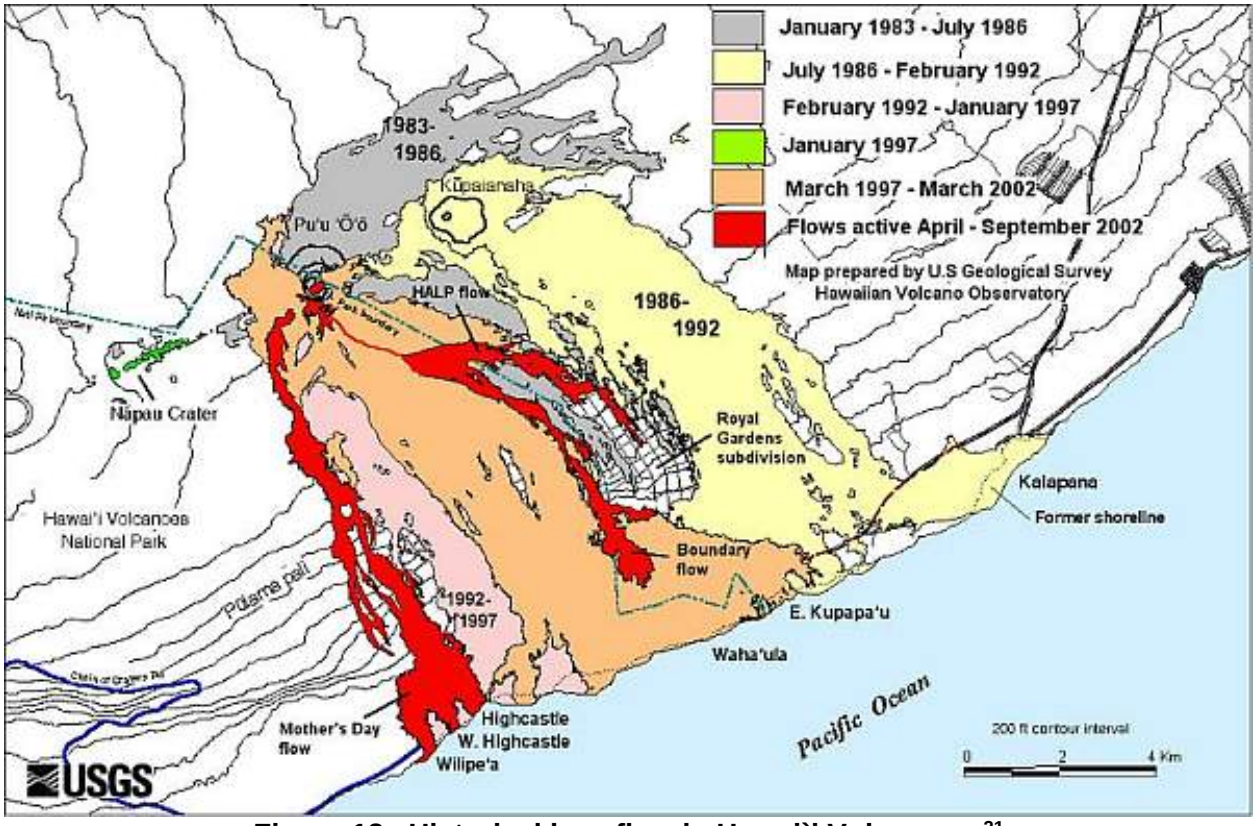


Figure 12. Historical lava flow in Hawai`i Volcanoes.[21]

Figure 13 shown below depicts the current U.S. Geological Survey (USGS) hazard zones from lava flows, based chiefly on the location and frequency of historical eruptions. The map shows the approximate boundary of Hawai`i Volcanoes in white outline and divides the island into zones that are ranked from 1 through 9, with 1 being the areas of greatest hazard. The USGS hazard assessment is based on the assumption that future eruptions will be similar to those in the

past. As air tour loitering areas historically follow active lava flows to accommodate visitor demand, the locations of future eruptions are important to the site selection process.

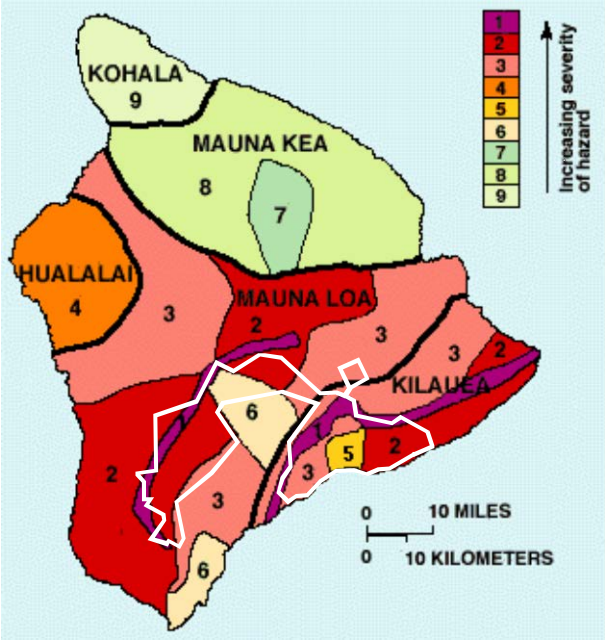


Figure 13. Hawai`i Island hazard zones.[22]

2.3 Climate Conditions

The contrast in elevation within Hawai`i Volcanoes, from sea level to 13,677 ft, has resulted in a wide range of weather conditions (temperature, humidity, precipitation, wind speed, wind direction, etc.), all of which can affect ambient sound levels (see Figure 14). The Mauna Loa summit area, located at the higher elevations, is subject to greater seasonal variations, with periods of cold winds occurring from December to February. The coastal sections of the park are also subject to high winds and exhibit a mild and even climate throughout most of the year. Precipitation varies greatly throughout the park according to elevation. Maximum rainfall occurs at moderate elevations of about 3,000 to 5,000 feet; less precipitation occurs at the higher elevations.[23]

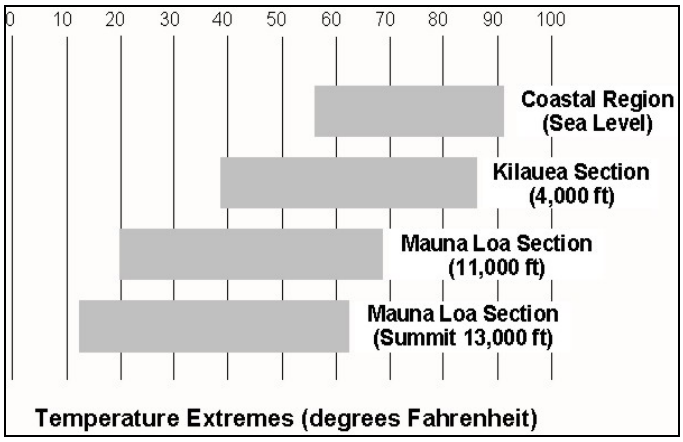


Figure 14. Temperature extremes in Hawai`i Volcanoes (from Hawai`i Volcanoes Statement for Management).[23]

Table 5 provides the monthly climate summary (averaged from 1949 through September 2004) recorded by a meteorological station located at Hawai`i Volcanoes Park Headquarters, The months of October through May during which this study occurred are shaded.

Table 5. Monthly climate summary for Hawai`i Volcanoes.[24]

Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Max Temp (F)	67	66.8	66.6	67	68.6	70.1	71.2	72.3	72.3	71.5	68.9	66.9
Average Min Temp (F)	49.6	49.6	50.3	51.6	52.6	53.8	55	55.4	54.9	54.6	53.2	51.1
Average Total Precipitation (in)	13.33	10.21	12.53	10.67	7.26	4.85	6.25	7.01	5.37	6.75	13.26	11.59
Average Total Snow Fall (in)	0	0	0	0	0	0	0	0	0	0	0	0

2.4 Park Resources/Management Zones

The NPS' Hawai`i Volcanoes Statement for Management identifies different zones by which park areas are designated for different management purposes and the protection of different park resources. Four zones are used as the framework for the manner and intensity of visitor use, as well as management of resources.[23]

- *Natural Zone (212,530 acres):* This zone encompasses over ninety percent of Hawai`i Volcanoes, including the 123,100 acres of designated wilderness. It includes areas managed by the park for all types of visitor-use (e.g., busy overlooks and trails for short and long backcountry hikes), wildlife habitats (e.g., protected Nene goose breeding grounds), and

cultural resources (e.g., sacred Native Hawaiian sites). The other zones discussed below exist as "islands" within the Natural Zone.

- *Development Zone (80 acres):* This zone is composed of the two NPS administrative-residential sites at Kīlauea and Wahaula, and the Hawaiian Volcano Observatory of the U.S. Geological Survey on the rim of the Kīlauea Caldera.
- *Historic Zone (4,640 acres):* This zone includes areas along the Puna-Ka`ū coast where the relics of early human habitation are found. Also included in this zone is the Mauna Loa trails, the pulu factory ruins, the Volcano House, and several other structures of historical architectural importance.
- *Special Use Zone (50 acres):* This zone consists of the Kīlauea Military Camp operating under a ten-year special use permit.

Figure 15 was provided to the Volpe Center as noise-sensitive areas in Hawai`i Volcanoes, including visitor resources, cultural and historic sites, wildlife habitats, etc.[24] Sections 2.4.1 through 2.4.3 discuss these areas in more detail.

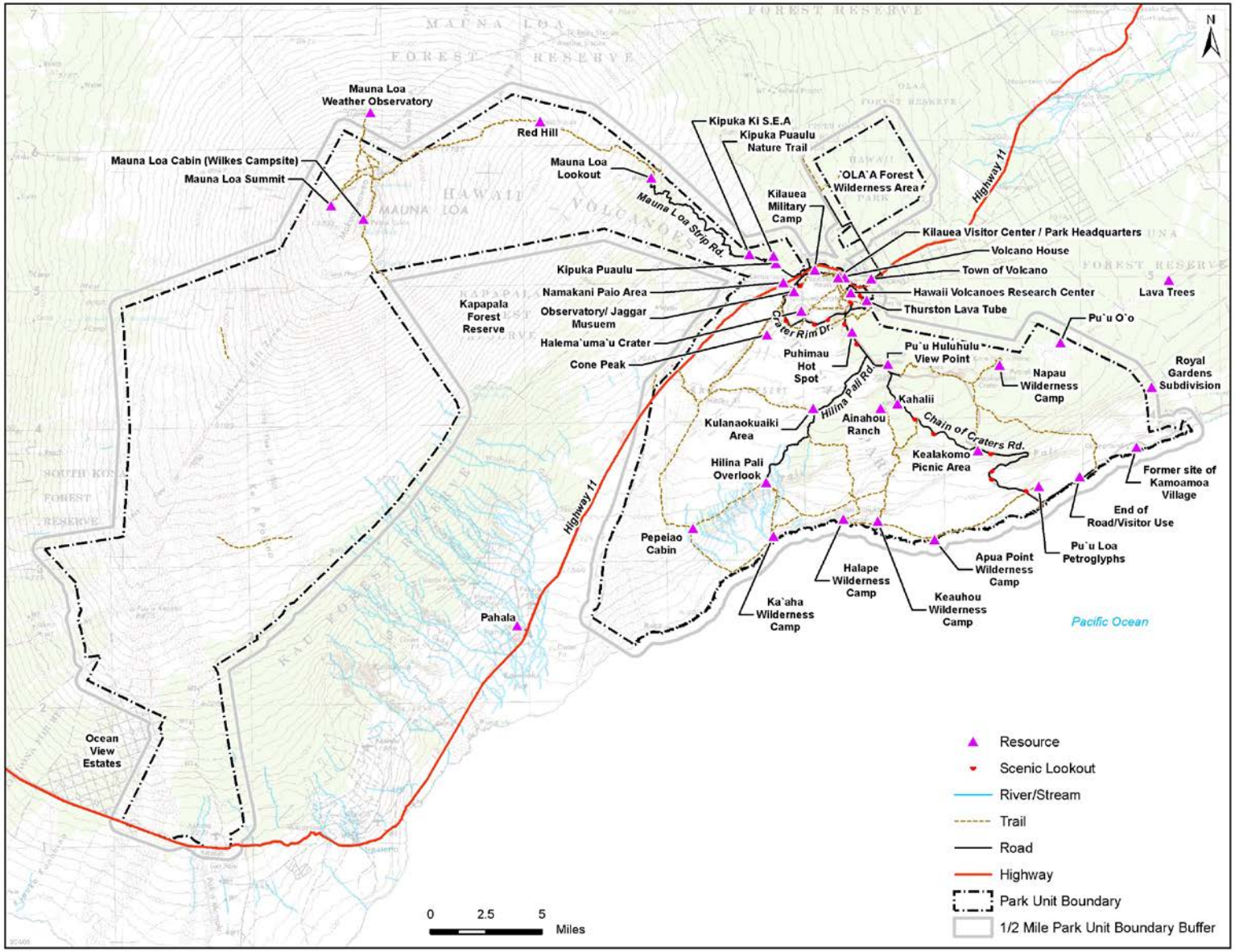


Figure 15. Noise-sensitive areas in Hawai`i Volcanoes.

2.4.1 Visitor Use Areas

Park use at Hawai`i Volcanoes is year-round and 90-percent day use. In 2003, the total recreational visits were approximately 1.2 million, with an average of 105,000 per month.[14] Visitors contribute a wide variety of sounds, from hikers talking and walking, to tour buses and other vehicular noises, to air tours, etc. Sites were chosen to cover three levels of visitor-use:

- *Overlook Sites (high visitor-use):* Any frontcountry location in a study area subject to substantial human activity, or destinations reached by automobile or bus, and generally traversable within thirty minutes (e.g., Steam Vents and lava viewing area at end of Chain of Craters Road).
- *Short-Hike Sites (medium visitor-use):* Any frontcountry location in a study area subject to moderate to substantial human activity, or destinations generally reached within one hour of hiking (e.g., Mauna Loa Trail and Hilina Pali Overlook).
- *Backcountry Sites (low visitor-use):* Any location in a study area subject to minimal human activity, such as designated wilderness areas or restricted, hiking and camping areas - these destinations are generally located 1 hour or more from frontcountry locations (e.g., Napau Trail and Ola`a Forest Wilderness Area).

2.4.2 Wildlife Resource Areas

Wildlife activity can directly affect the daily and seasonal characteristics of the Natural Ambient (e.g., the Hawaiian Nene goose nests in the winter, breeds during spring and summer, and fledges their chicks by early fall). The native fauna within Hawai`i Volcanoes contains several important endangered wildlife species, such as the Hawaiian Honeycreeper, the Nene goose, the Hoary bat, and several migrant sea birds.[23] Because protection of these endangered, wildlife-habitat areas is a particular concern, some of these areas have restricted/limited visitor access. Because of their importance, sites were chosen within these "noise sensitive" areas (e.g., `Āinahou Education Center, a restricted-access sanctuary for the Hawaiian Nene goose).

2.4.3 Cultural and Historic Resource Areas

Discussions with Hawai`i Volcanoes NPS personnel have indicated that cultural or historical sites exist throughout the entire park. For example, native Hawaiians leave "offerings" of leis and other items to the Goddess of Volcanoes, Pele, at the Kīlauea Caldera (considered sacred) and at many other different areas within the park. As such, sites were chosen within these important cultural/historical areas (e.g., Halema`uma`u Crater within Kīlauea Caldera).

2.5 Commercial Air Tour Flight Routes

In working with individuals, communities, private and public associations and agencies, and others to resolve issues of concern relating to sound abatement and air safety of air tours throughout Hawai`i, the FAA Flight Standards District Office (FSDO) in Honolulu, the Hawai`i Volcanoes NPS, and local air tour operators established Special Federal Aviation Regulation (SFAR) 71 Procedures Manual.[25] SFAR 71 prescribes visual flight rules for fixed-wing airplane and helicopter air tour flights conducted in the State of Hawai`i. The general air tour routes shown in Figure 16 below were provided by the Hawai`i FSDO, with routes being altered primarily only for weather or for changes in the active lava flow. Flights departing from Kona on the west side of Hawai`i Island pass from west to east, roughly through the center to northern portion of the park. Flights departing from Hilo typically affect only the eastern portion of the park. As air tour routes do alter with changes in active lava flow, it is important that data be collected in areas that will allow evaluation of the potential future impacts of alternative air tour routes on park resources and visitors, taking into account current and anticipated future lava flow locations (see also Section 2.2.1).

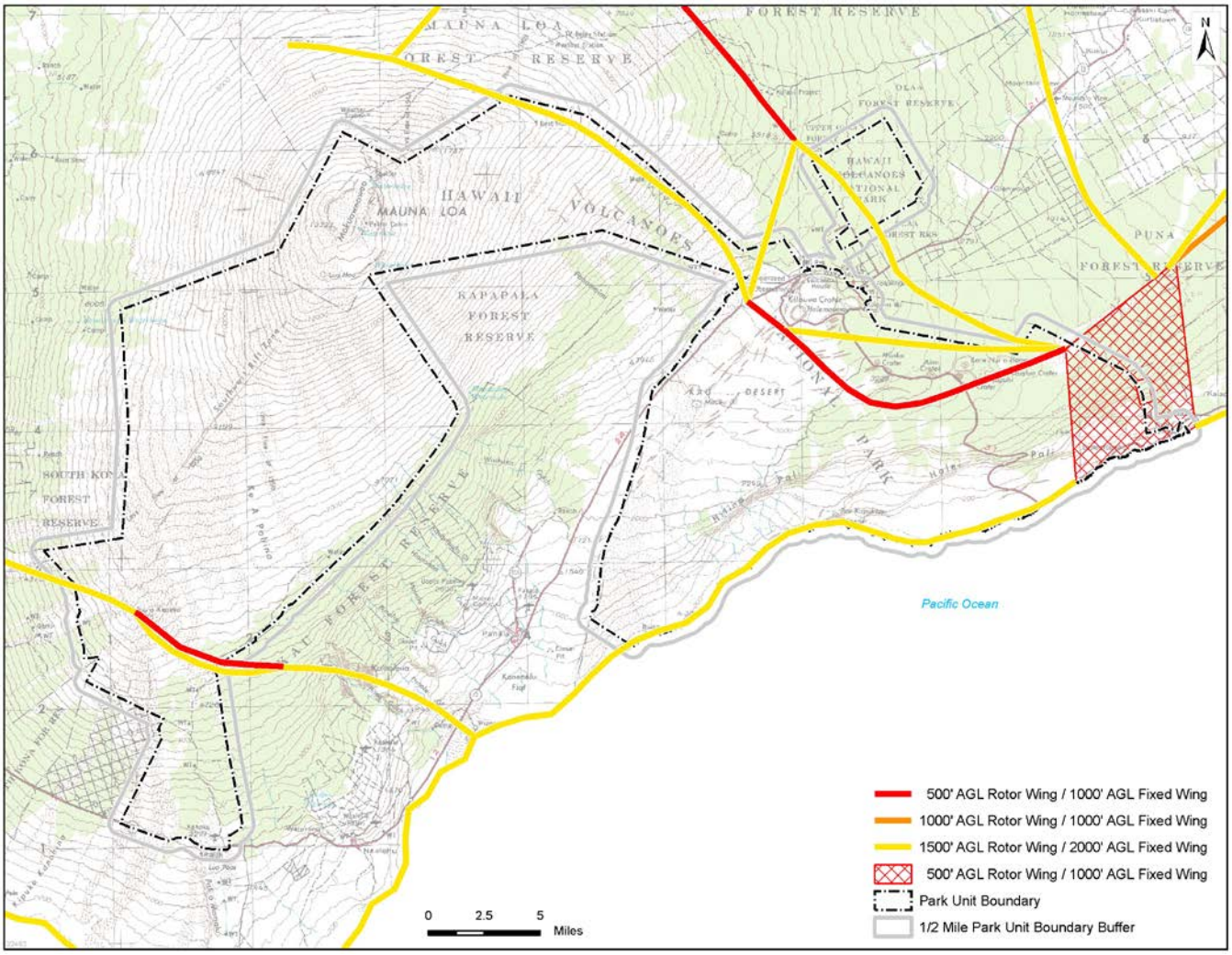


Figure 16. Air tour routes in the vicinity of Hawai`i Volcanoes.*

2.6 Hawai`i Volcanoes Acoustic Zones

Using the above site selection considerations, the FAA, the NPS, the Volpe Center, and HMMH met with the Hawai`i FSDO and Hawai`i Volcanoes NPS personnel on October 23, 2002, to discuss the park's unique acoustic environs, or "acoustic zones," within which measurement sites would be selected. As stated earlier, it is anticipated that the use of acoustic zones as representative units, within which data can be collected and grouped (by vegetation, management zone, etc.) may be extrapolated to similar areas in Hawai`i Volcanoes. The agreed-upon nine acoustic zones and their dominant, distinguishing natural sounds are as follows (see Figure 17):[26]

* Note: The large red box in the graphic denotes a loitering area, where aircraft linger to allow visitor viewing of the current eruption lava flows.

- *Shoreline (Zone 1):* This is a very narrow band along the immediate shoreline of the park from sea level to approximately 100 ft (0 to 30.5 m) elevation. Surf and wave action and bird vocalizations dominate the sound of this zone. It is a zone of strong trade winds blowing across tall coastal bluffs and low shoreline vegetation.
- *Coastal Lowlands (Zone 2):* This zone extends from the shoreline zone to the tops of the coastal palis (tall fault escarpments) 1.5 to 3 miles inland from approximately 100 to 1,500 ft (30 to 457 m) elevation. It is an area of largely barren lava flows or low grass or scrub vegetation and characterized by strong trade winds, especially with orographic (due to the presence of mountains) uplift at the tops of the palis. Unlike the shoreline zone, natural animal sounds (as compared with domesticated animals brought by visitors) are negligible.
- *Ka`ū Desert/Kīlauea Summit (Zone 3):* This zone includes recent lava flows and low vegetation in the southwest portion of the park (including Kīlauea Caldera) from approximately 700 to 3,800 ft (213 to 1,158 m) elevation. The dominant sounds are strong trade winds blowing over the rough volcanic landscape.
- *`Ola`a Rain Forest (Zone 4):* This is a 10,000 acre parcel of tree-fern-dominated rain forest on the slopes of Mauna Loa from 3,300 to 4,400 ft (1,005 to 1,341 m) elevation. The dominant natural sounds are rain on the tree fern canopy and crickets, with localized occurrences of bird vocalizations.
- *Mauna Loa Forest (Zone 5):* This zone extends between 4,000 to 8,500 ft (1,219 to 2,591 m) elevation on the slopes of Mauna Loa. It is a complex zone of forest, shrublands, grasslands, and lava flows. It lies in and above the trade wind inversion, where wind speeds are generally lower than along the coast. Bird vocalizations in forested areas are prominent.
- *Dry `Ohi`a Woodlands (Zone 6):* These are the forests, woodlands, and savannas above the large inland palis and Chain of Craters Road in the drier, leeward part of the park from approximately 1,000 to 3,300 ft (305 to 1,006 m) elevation. The dominant sounds are strong trade winds in the forest canopy.
- *Mauna Loa Alpine (Zone 7):* This is the barren "moonscape" on Mauna Loa from approximately 8,500 to 13,677 ft (2,591 to 4,170 m) elevation. Lying above the inversion layer, it is a dry environment without strong winds. The dominant sounds are winds flowing over rough-textured lava fields, with occasional bird vocalizations heard in the lower reaches

of the zone. Note: Several attempts to deploy a measurement site within Zone 7 (Mauna Loa Alpine) during the study period failed due to difficult weather and accessibility issues. As such, since vegetative land cover is one of the key attributes, which drives the acoustics of how sound propagates from a source to a receiver, ambient data from a zone with the closest land cover and topography (Zone 3) was applied to this zone as the "best available data" for the purposes of this document.

- *Young Rain Forest (Zone 8):* This zone occurs on the eastern edge of the park along the perimeter of Kīlauea Caldera and the East Rift Zone from approximately 2,000 to 4,000 ft (610 to 1,220 m) elevation. Rain on vegetation is a dominant sound along with high densities of birds in closed canopy forest, especially at higher elevations.
- *New Lava Flows (Zone 9):* These include recent flows of the last 40 years on the East Rift Zone of Kīlauea from approximately 8,500 to 13,677 ft (2,591 to 4,170 m) elevation. Sounds on the newest flows include bench collapses, rock fall from cinder cones and pit crater edges, crackling of cooling pahoehoe flows, and sound of clinkers falling in moving a`a flows, gas venting, methane explosions and falling trees on the edge of lava flows.

In addition, subsequent to the baseline ambient measurements, the 116,000-acre Kahuku Ranch on Hawai`i Island was purchased and added to Hawai`i Volcanoes National Park in July 2003:

- Kahuku Ranch (Zone 10): This zone is the recent 116,000 acre addition to Hawai`i Volcanoes and contains woodlands and rainforests, lava flows, and ancient archeological sites. The addition encompasses Mauna Loa's southwest rift zone and extends from 2,000 to 13,000 ft (610 to 3,962 m) elevation. As this area is home to rare and endangered plant, bird, and insect species, it is expected that the dominant sounds would include bird and insect vocalizations in the forest canopy and strong trade winds blowing over the rough volcanic landscape. It should be noted, however, that because the Kahuku Ranch was added to the park subsequent to the measurement study, no ambient data was able to be collected within this zone in support of the data analysis. Similar to Zone 7 above, vegetative land cover was used to apply ambient data from a zone with the closest land cover and topography (Zone 3) to this zone as the "best available data" for the purposes of this document.

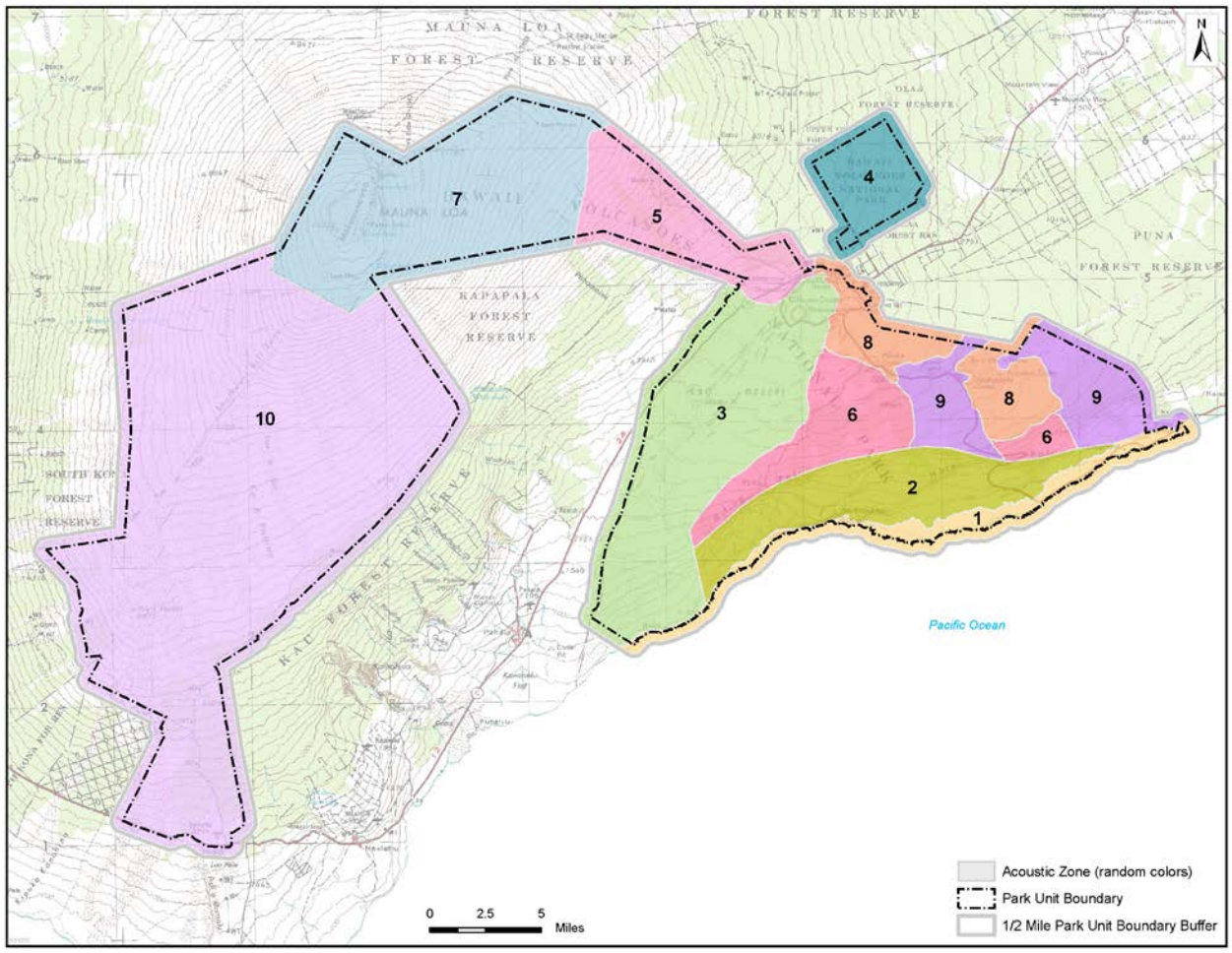


Figure 17. Acoustic zones for Hawai`i Volcanoes.

2.7 Logistics/Access

To validate the use of acoustic zones, it was agreed during the October 23, 2002 meeting that data would be collected at multiple sites within each zone and later analyzed to determine if the data collected at one site within a particular zone is statistically similar to data collected at a different site within the same zone.

2.7.1 Access

In identifying potential measurement site locations within each zone, the final, overarching consideration was site accessibility. As important as a given site is to satisfy any of the technical criteria discussed in previous sections, if it is inaccessible, measurements cannot be conducted. There are several entry points into Hawai`i Volcanoes: the Kīlauea Visitor Center, the Ka`ū Desert Trailhead, Mauna Loa Road, and

the Mauna Loa Weather Observatory Trail. Access to current lava viewing areas requires driving down Chain of Craters Road from the Visitor Center to the shore. Most visitor-use areas are accessible driving and/or hiking - however, as a precautionary move, the local NPS routinely close portions of Chain of Craters Road and other hiking trails to all visitors depending on lava activity and related safety concerns. The majority of the final measurement site locations were accessible by motor vehicle and/or up to 1-hour hikes. For those sites that were either: (1) not easily accessible, but deemed important to the baseline, ambient data collection effort; or (2) initially accessible, but no longer accessible due to lava movement, Hawai`i Volcanoes NPS provided personnel and/or transportation assistance (e.g., helicopter transport). The access considerations associated with each measurement site are discussed in Appendix A.

2.7.2 Duration of Measurements

Measurement duration is a very difficult technical issue on which to reach consensus. It is likely that there will be substantial day-to-day, and for that matter, week-to-week, and possibly season-to-season variability, for many parks. For example, insect activity, which generally increases at night, may cause higher ambient sound levels than during the daytime. As another example, some wildlife activities (e.g., breeding) increase during certain months of the year, and, as such, may be expected to contribute to different ambient noise levels. However, it is typically not practical to measure at sites continuously for periods of many months, or several years. The choice of how long to measure must balance technical considerations and available resources. Measurements at a particular site should not only be of sufficient duration to ensure statistical confidence in the data, but also be reasonable in light of practical and other resource considerations.

In discussions with Hawai`i Volcanoes NPS personnel, because there is little climatic seasonal variation in Hawai`i as compared with other U.S. national parks, a minimum of one week of continuous, 24-hour measurements at each site was recommended, with up to two weeks being preferred. To validate this recommendation and provide *guidance* for adequate measurement duration for use in future parks, it was agreed that: (1) several sites would include data collection on a long-term basis, i.e., longer than 2 weeks up to

the entire measurement study duration of eight months (permanent sites); and (2) the remaining sites would include data collection on a short-term basis, i.e., one to three weeks (mobile sites). With regard to Agreement (1), Hawai`i Volcanoes effectively served as a "test bed" to assess the needed measurement duration of future park ambient studies.

As such, one site within each zone was designated the long-term "permanent" site. At that site, data were collected continuously for up to eight months. Additional sites placed within each zone were designated as short-term, "mobile" sites. At these sites, data were collected continuously for approximately one to three weeks. Permanent sites were designated with the letter "A"; and mobile sites with a "B" or "C." For example, Sites 1A and 1B indicate a permanent system and a mobile system, respectively, in Zone 1 (Shoreline). Site 1C indicates a second mobile site in a similar coastal area. Figure 18 and Table 6 below summarize the final measurement sites selected. Appendix A contains individual descriptions and photographs of each measurement site location.

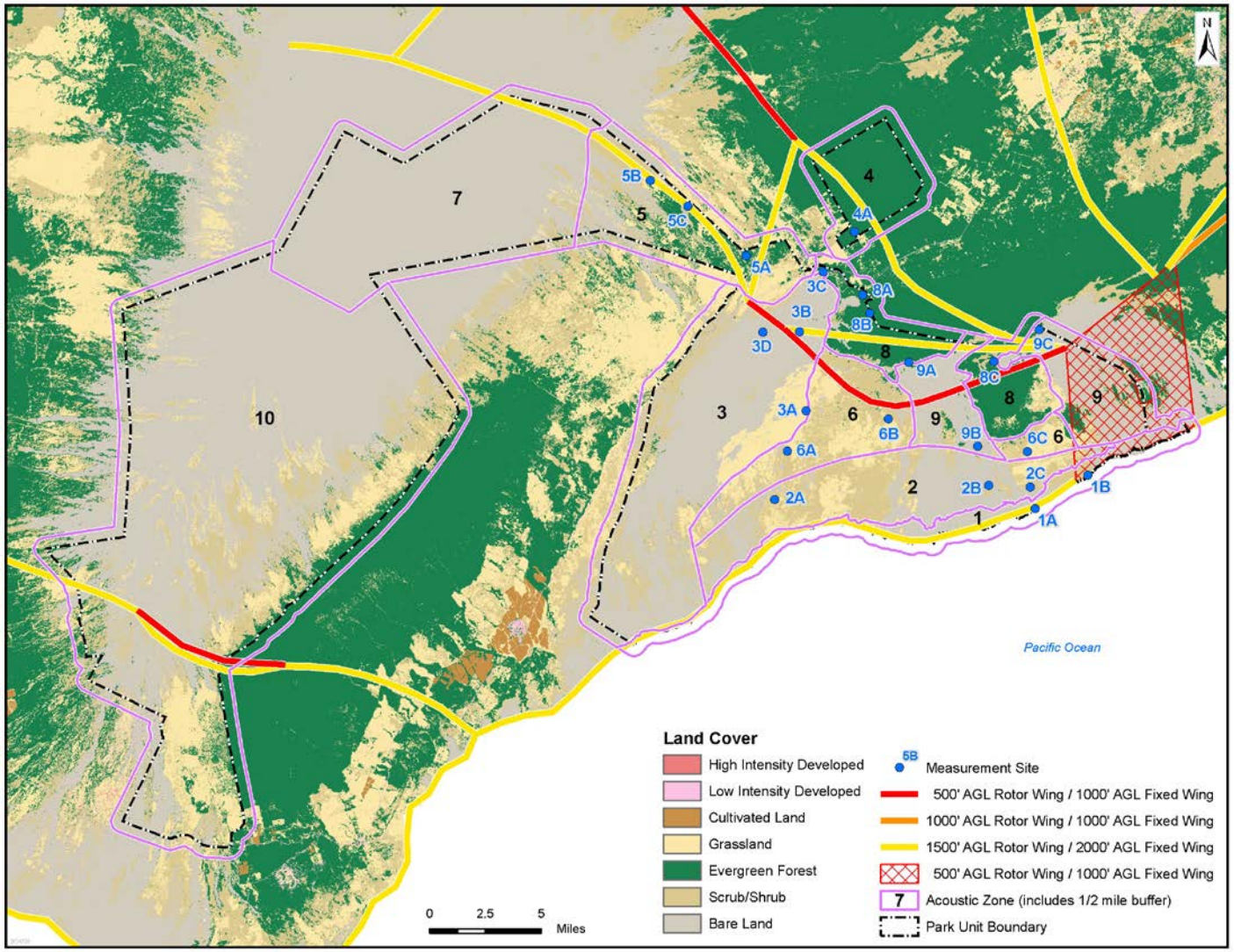


Figure 18. Final measurement sites for Hawai`i Volcanoes.*

* Note: The large red box in the graphic denotes a loitering area, where aircraft linger to allow visitor viewing of the current eruption lava flows.

Table 6. Summary of measurement sites selected for Hawai`i Volcanoes.[26]

Acoustic Zone	Site #	Site Name	Vegetation/ Land Cover Description	Lat/Lon (decimal degrees)	Approx. Elevation	Site Type	Site Category	Management Zone	Potential Sound Sources
1: Shoreline	1A	20-Minute Trail	Black sand beach with bare lava fields just above coastal bluffs	155.1219 19.2787	40 ft.	Permanent	Short Hike	Natural	Aircraft Vehicles Hikers Birds Wind Surf
1: Shoreline	1B	Current Eruption Viewing	Newest black sand beach with bare lava fields just above coastal bluffs	155.0857 19.3004	10 ft.	Mobile	Overlook	Natural	Aircraft Hikers Birds Wind Surf
2: Coastal Lowlands	2A	Base of Hilina Pali	Grassland	155.3004 19.2847	800 ft.	Permanent	Wilderness	Wilderness (Natural subzone)	Aircraft Wind
2: Coastal Lowlands	2B	Kealakomo Waena	Grassy Kipuka (oasis of undisturbed land within a lava field)	155.1537 19.2938	450 ft.	Mobile	Short Hike	Natural	Aircraft Vehicles Wind
2: Coastal Lowlands	2C	Pu`u Loa	Lava plain with sparse grass and shrubs	155.1252 19.2927	170 ft.	Mobile	Short Hike	Natural	Aircraft Wind
3: Ka`ū Desert/ Kīlauea Summit	3A	Mauna Iki Trail	Mostly bare lava deserts with scattered shrubs	155.2788 19.3426	2700 ft.	Permanent	Short Hike	Natural	Aircraft Wind
3: Ka`ū Desert/ Kīlauea Summit	3B	Halema`um a`u	Bare lava and ash	155.2835 19.3941	3600 ft.	Mobile	Overlook	Natural	Vehicles Hikers Wind
3: Ka`ū Desert/ Kīlauea Summit	3C	Steam Vents	Grassy field with trees and shrubs in steam vents area	155.2672 19.4332	4000 ft.	Mobile	Overlook	Natural	Aircraft Vehicles Wind
3: Ka`ū Desert/ Kīlauea Summit	3D	Cone Peak	Bare lava and ash	155.3086 19.3937	3600 ft.	Mobile	Short Hike	Natural	Vehicles Hikers Wind
4: Ola`a Rain Forest	4A	Ola`a Transect 19	Dense rainforest with tree ferns	155.2454 19.4592	3800 ft.	Permanent	Wilderness	Wilderness (Natural Subzone)	Aircraft Insects Rain

Acoustic Zone	Site #	Site Name	Vegetation/ Land Cover Description	Lat/Lon (decimal degrees)	Approx. Elevation	Site Type	Site Category	Management Zone	Potential Sound Sources
5: Mauna Loa Forest	5A	Kīpuka Kī	Mesic (a moderately moist habitat) forest	155.3199 19.4436	4200 ft.	Permanent	Overlook	Natural	Aircraft Vehicles Birds Wind
5: Mauna Loa Forest	5B	Top of Strip Road	Mesic forest, verging on shrubland	155.3859 19.4925	6700 ft.	Mobile	Overlook	Natural	Aircraft Vehicles Birds Wind
5: Mauna Loa Forest	5C	Strip Road Weather	Mesic forest, verging on shrubland	155.3601 19.4759	5500 ft.	Mobile	Short Hike	Natural	Aircraft Vehicles Birds Wind
6: Dry Ohi`a Woodlands	6A	Hilina Pali Road/ Weather Station	Grassy savanna with scattered shrubs	155.2918 19.3163	2700 ft.	Permanent	Short Hike	Natural	Aircraft Wind
6: Dry Ohi`a Woodlands	6B	`Āinahou Education Center (restricted access)	Tall thick grass and shrubs with scattered trees	155.2225 19.3371	2800 ft.	Mobile	Backcountry	Natural	Aircraft Birds Wind
6: Dry Ohi`a Woodlands	6C	Hairpin Turn	Thick grass with scattered shrubs and trees and old lava Ohi`a outcrops	155.1271 19.3159	1300 ft.	Mobile	Short Hike	Natural	Aircraft Wind
8: Young Rain Forest	8A	Escape Road/ Orchid Farm	Dense tree fern and Ohi`a tree forest	155.2401 19.4178	3900 ft.	Permanent	Short Hike	Natural	Aircraft Vehicles Hikers Insects Rain
8: Young Rain Forest	8B	Escape Road/ Thurston	Dense tree fern and Ohi`a tree forest	155.2351 19.406	3800 ft.	Mobile	Short Hike	Natural	Aircraft Vehicles
8: Young Rain Forest	8C	Nāpau Crater	Tree fern and Ohi`a tree forest	155.1499 19.3745	2700 ft.	Mobile	Backcountry	Natural	Aircraft Hikers

Acoustic Zone	Site #	Site Name	Vegetation/ Land Cover Description	Lat/Lon (decimal degrees)	Approx. Elevation	Site Type	Site Category	Management Zone	Potential Sound Sources
9: New Lava Flows	9A	Pu`u Huluhulu/ Lava Trees	Recent lava with young Ohi`a trees and shrubs	155.2083 19.3742	3300 ft.	Permanent	Backcountry	Wilderness (Natural Subzone)	Aircraft Wind
9: New Lava Flows	9B	Kealakomo	Bare, recent lava flows	155.1611 19.3193	2100 ft.	Mobile	Overlook	Natural	Aircraft Vehicles Wind
9: New Lava Flows	9C	Pu`u Ō`ō	Bare, recent lava flows	155.1187 19.3951	2400 ft.	Mobile	Backcountry	Natural	Aircraft Wind

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3. INSTRUMENTATION

Ambient sound levels measured in remote areas of the country under low wind conditions often approach the threshold of human hearing. As a result, specialized low-level instrumentation is required to accurately measure these sounds. This section discusses the three types of specialized low-level ambient measurement systems used for this study:

- NoiseLogger™ Continuous Monitoring System (Section 3.1);
- NoiseLogger Plus™ Continuous Monitoring System (Section 3.2); and
- Volpe Low-Amplitude Recording Equipment (VoLARE) System (Section 3.3).

3.1 NoiseLogger™ Continuous Monitoring System

This system is a specialized measurement system used to conduct unattended, long-term (30+ days), continuous one-third octave-band noise measurements in outdoor environments. It is compact, light, rugged, and can run with external battery power, or solar panels, thus, enabling the system to store uninterrupted acoustic and wind data. Appendix B contains a more detailed description of the system.[27] Eight NoiseLogger™ systems were used in collecting data in this study.

The system uses a large diameter windscreen and a ½-inch electret condenser microphone, interfaced with a sound level meter and a Personal Digital Assistant (PDA) device for storing measured data using the NoiseLogger™ software. The system includes an ultrasonic anemometer to measure wind speed and direction. The output of the anemometer is also stored by the PDA via the NoiseLogger™ software. Figure 19 illustrates the basic components of the system.

3.1.1 Microphone System

The G.R.A.S.™ Model 40AQ and Model 40AE ½-inch, prepolarized microphones used in this study are electret condenser microphones. The random-incidence, frequency response of each microphone utilized in this study is shown in Appendix C. Being pre-polarized, these models of microphone function as a closed system with regard to humidity, thus eliminating the potential for condensation in high humidity situations. Additionally, LD Model PRM902 preamplifiers were employed at each site.

A 12-in (30 cm) diameter foam windscreen (400 pores/sq. in. porosity) custom designed by Musashi Kasei Co., Ltd. for outdoor monitoring applications was placed atop each microphone to reduce the effects of wind-generated noise at the microphone diaphragm. Such reduction can effectively improve the signal-to-noise ratio of sound measurements. The attenuation of this windscreen is shown in Appendix C.

3.1.2 Sound Level Meter (SLM)

The microphone system was connected to a Larson Davis™ (LD) Model 824 sound level meter (SLM). The Model 824 SLM was set up with slow exponential time-weighting to continuously measure the overall A-weighted equivalent sound level for each 1-second sample, as well as the Z-weighted equivalent sound level in each one-third octave-band from 12.5 Hz to 20 kHz.

3.1.3 Handheld Personal Computer

The AC output of the LD Model 824 SLM was connected directly to the input of a Handheld Systems Husky™ Model Fex-21 handheld personal computer (H/PC) for data storage. With a 128-MB CompactFlash™ card, the Husky™ H/PC can provide approximately 2-weeks of continuous data storage.

3.1.4 Ultrasonic Anemometer

Two types of ultrasonic anemometers were used in this study: the Gill™ Instruments Model WindObserver II and the FT Technologies™ Model 702. The WindObserver II samples wind speed and direction at a rate of 40 samples per second and provides a 1-second averaged output that was stored in the Husky™ H/PC. The FT 702 samples wind speed and direction at a rate of 5 samples per second and also provides a 1-second averaged output that was stored in the Husky™ H/PC. Due to the low ambient sound levels anticipated at many of the measurement sites, the use of these ultrasonic anemometers over a conventional wind cup/vane anemometer provides the advantages of: (1) the elimination of moving parts, which could potentially contaminate the acoustic data collected; and (2) a rugged, stainless steel construction, which means they are well suited for outdoor environments.

3.1.5 Solar Panel Array

Power to the instrumentation was provided by one of two means: (1) in areas with sun exposure during the day, a portable solar panel array was used; and (2) in areas with little or no sun exposure, two marine batteries were used. The two marine batteries provided enough power to support collection of data for approximately two weeks between charges; whereas systems using a solar panel array allowed for continuous data collection, as long as a modest amount of direct sunlight was available during daylight hours.

3.2 NoiseLogger Plus™ Continuous Monitoring System

This is similar to the NoiseLogger™ system, but with the capability to record live audio samples using a Fujitsu™ Lifebook P1110 computer, which effectively replaced the Husky™ Fex-21 H/PC. The NoiseLogger Plus™ system is powered by two solar panel arrays or four marine batteries. Figure 20 illustrates the basic components to the system. This system can record sounds on both a periodic basis, e.g., a 5-second recording every five minutes, and on a threshold basis, e.g., a recording is triggered when a sound level exceeds a user-defined threshold. Appendix B contains a more detailed description of these systems.[28] Two NoiseLogger Plus™ systems were used in collecting data in this study.[*]

[*] These systems were placed at Sites 3A and 5A for the following reasons: (1) they were permanent sites; (2) they were located under the current air tour routes; and (3) they were expected to record a diversity of natural, visitor, and mechanical sounds.

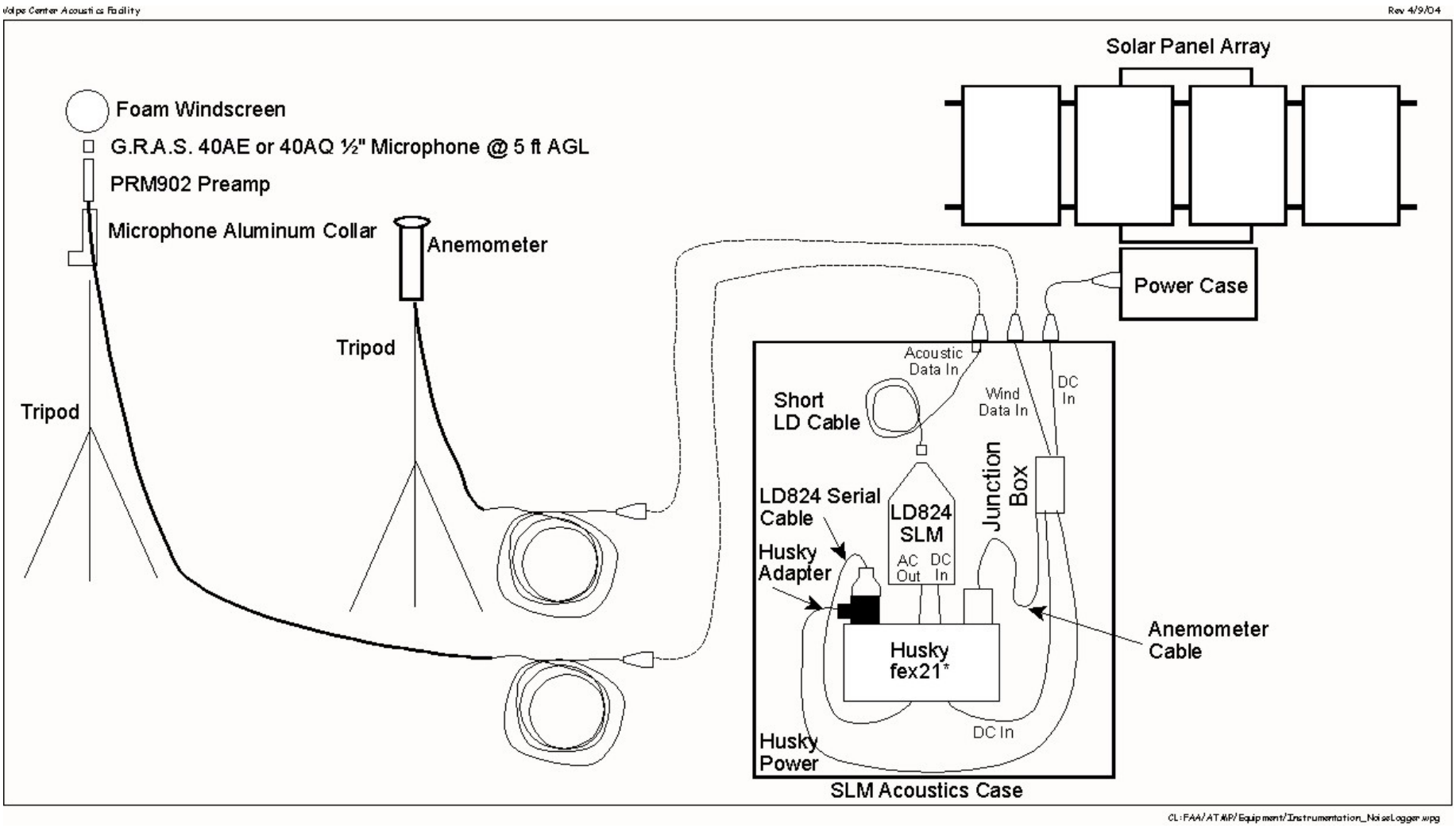


Figure 19. NoiseLogger™ continuous monitoring system.

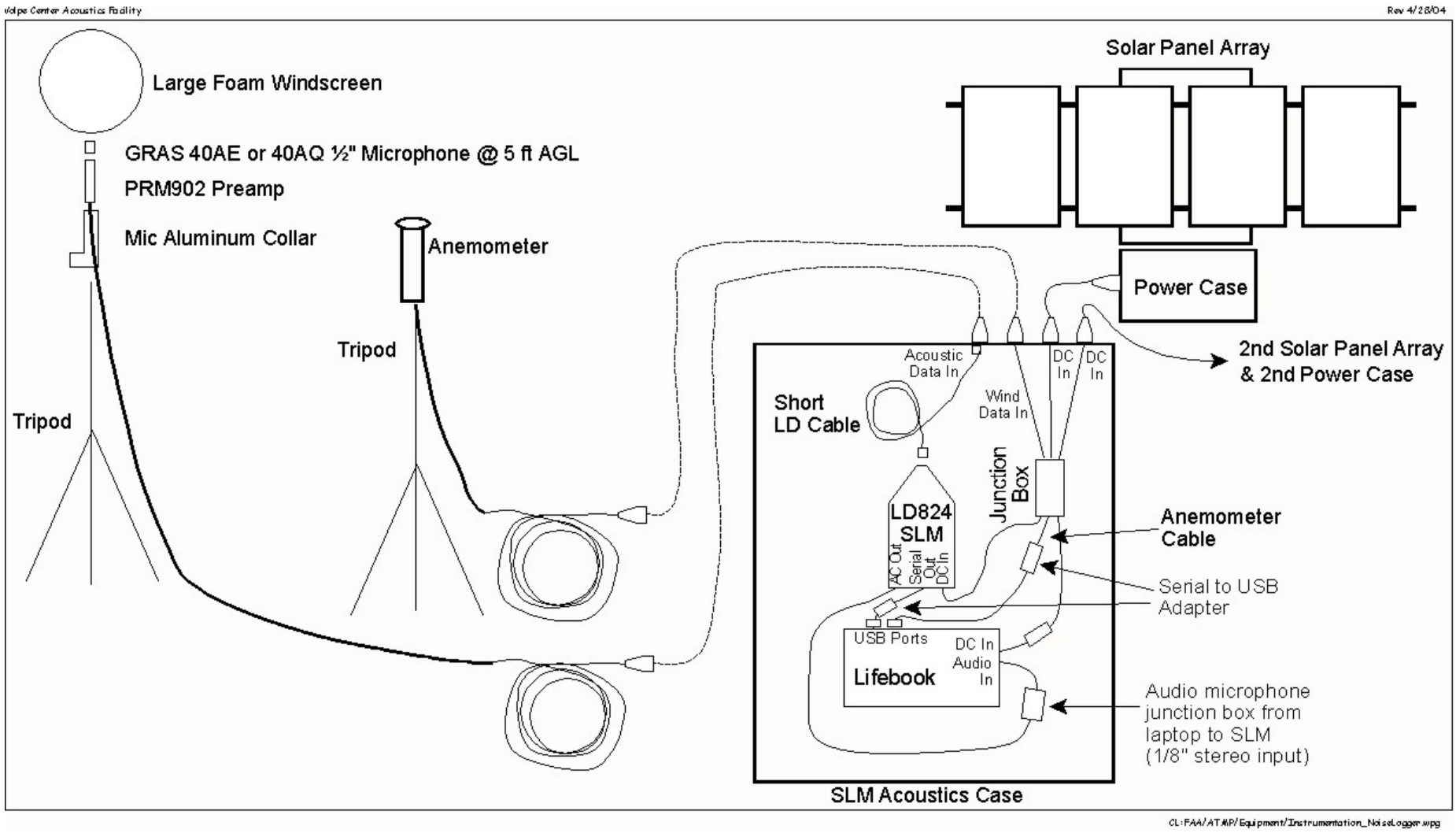


Figure 20. NoiseLogger Plus™ continuous monitoring system.

3.3 Volpe Low-Amplitude Recording Equipment (VoLARE) System

This is a specialized "turn-key" system, developed by the Volpe Center for low-level ambient noise measurements. It facilitates direct recording or on-site one-third octave-band analysis of measured low-level ambient sound level data. More detailed discussion on this system can be found in Reference 16. Figure 21 illustrates its basic components. VoLARE has been extensively tested and successfully used in previous FAA and NPS studies.[15,16,17]

3.3.1 Microphone System

The microphones used in most conventional acoustic systems, including the NoiseLogger™ and NoiseLogger Plus™ systems, are capable of measuring sound levels down to about 15 to 20 dBA. For measuring sound level data near the threshold of human hearing (approximately 0 dBA), which is common in some of the remote areas within national parks, the microphone is the limiting component in a conventional measurement system. The Brűel & Kjær™ (B&K) Model 4179 microphone is a highly sensitive, 1-inch condenser microphone specially designed for very low-level sound measurements and capable of measuring down to the threshold of human hearing.* Additionally, the B&K Model 2660 preamplifier and Model 2804 power supply were employed in this system. As per manufacturer's specifications, the Model 2804 power supply was modified for use with the Model 4179 and 2660.

The VoLARE system utilizes a tripod-mounted, two-stage windscreen, which is documented extensively in Reference 16, consists of a 20-in (51 cm) diameter, fabric-covered, outer stage, and a conventional, B&K Model UA0207 3.5-in (9 cm) diameter, foam windscreen making up the inner stage.

3.3.2 Sound Level Meter (SLM)

The microphone system was connected to a Larson Davis™ (LD) Model 824 sound level meter (SLM). The Model 824 SLM was set up with slow exponential time-weighting to

* Because the B&K 4179 microphone is a condenser microphone, it is extremely sensitive to humidity, which can result in electrical arcing in high humidity environments. Arcing will contaminate the measured signal, and can, in extreme situations, cause damage to the microphone. It is for this reason that the B&K 4179 microphone is only used in the VoLARE system with an acoustic observer present and not used in the unmanned, long-term NoiseLogger™ and NoiseLogger Plus™ systems.

continuously measure the overall A-weighted equivalent sound level for each 1-second sample, as well, as the Z-weighted equivalent sound level in each one-third octave-band from 12.5 Hz to 20 kHz.

To successfully utilize the 824 SLM for measurements down to the threshold of human hearing, it was necessary to bypass the unit's built-in firmware parameters, which limit the minimum levels that can be measured and stored (about 20 dBA). To circumvent this limitation, an offset calibration technique was employed. Specifically, the SLM requires that the output level of the sound calibrator be specified. In this case, the B&K Model 4231's 94-dB nominal output level was used. By means of setting the SLM so that the 94-dB level indicated a level of 119 dB, an effective 25-dB-offset calibration was applied. The result was that all of the sound level data measured and stored by the SLM was artificially high by an offset of 25 dB. This 25-dB factor was accounted for, as if it were system gain, in the data reduction process (see Section 5).* This technique allowed the SLM to accurately measure sound levels down to below 0 dBA.

3.3.3 Digital Audio Tape (DAT) Recorder

The AC output of the LD 824 SLM was connected directly to the input of a Sony™ Model TCD-D100 digital audio tape (DAT) recorder. The DAT recorder was set up to operate at single speed in a two-channel recording mode. At single speed, the 295-ft. (90-meter) tapes used were capable of providing slightly more than 3 hours of recording time. The use of a DAT recorder allowed for later repeated playback and analysis, including the option for narrow-band analysis if deemed necessary.

* This 25-dB offset factor was used for VoLARE measurements at all Hawai`i Volcanoes sites except Sites 1A and 1B where a LD Model 820 SLM and a 20-dB offset factor were used.

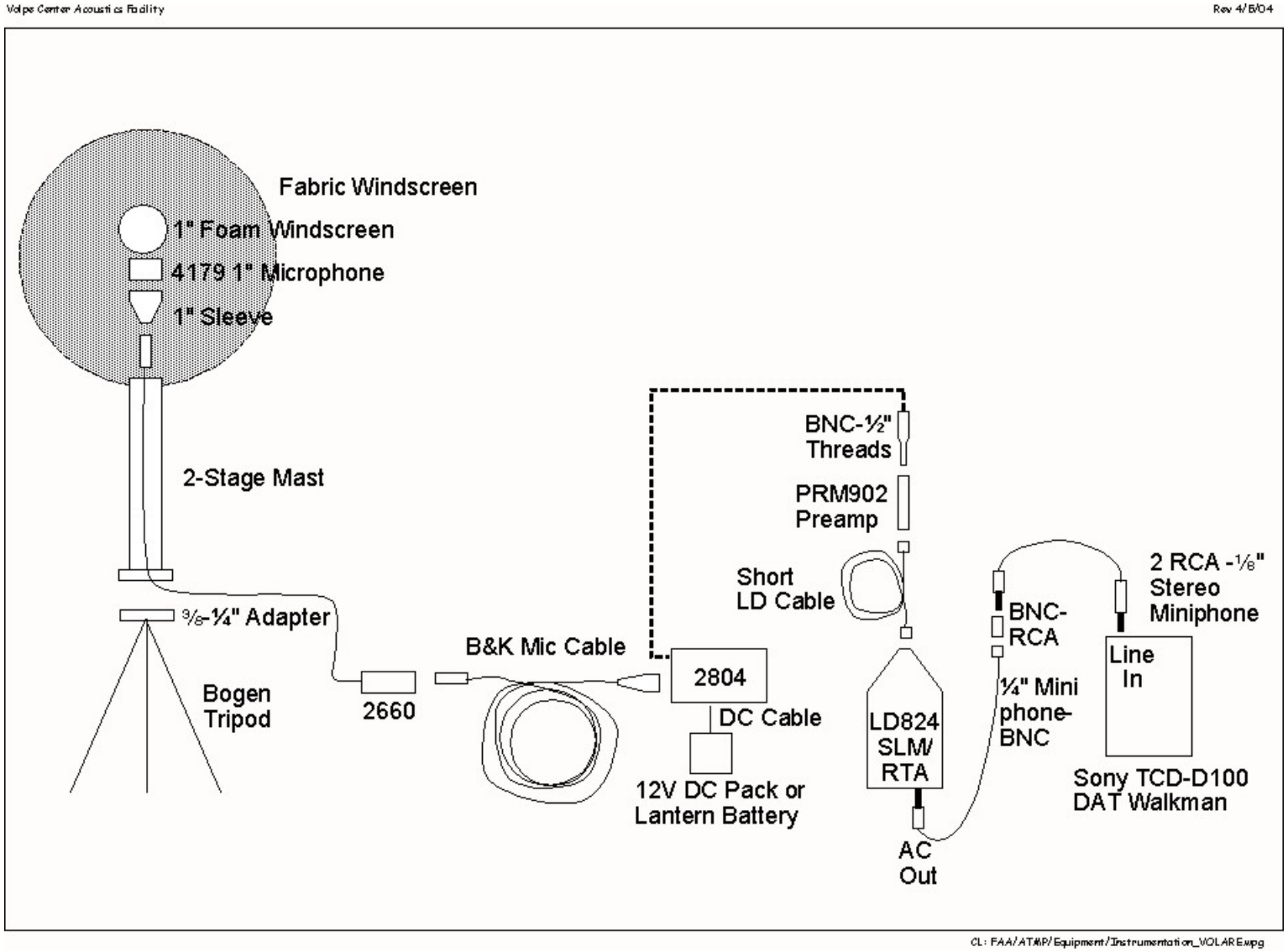


Figure 21. Volpe Low-Amplitude Recording Equipment (VoLARE) system.

3.4 Acoustic Observer Log

During staffed measurements, a field observer continuously documented the acoustic environment at the site. In performing this activity, the acoustic environment was documented as a timed record of audible sounds using an automated spreadsheet programmed onto a Hewlett-Packard™ Model 200LX palmtop or Jornada hand-held computer. Using pre-programmed macros, the spreadsheet allows the observer to place an immediate time stamp for an event and categorize that event into 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, talking, motor vehicles, etc. The natural category is documented when no aircraft or other human-made sounds can be heard. If more than one event within the same state category could be heard, the louder one (based on the observer's judgment) is logged with a notation of the other sounds that were present. An acoustic state would prevail until the current intrusion is no longer audible, or a new intrusion higher in the hierarchal order becomes audible to the observer.

3.5 Aircraft Photo-scaling System

The Volpe Center's photo-scaling system,[29] developed in accordance with the SAE Aerospace Information Report (AIR) 902,[9] enables the determination of the minimum distance from an observer at the measurement site to an object - in this case, air tour aircraft.[*] The system uses:

1. Canon Model D60 digital camera to record an image of the object;
2. Canon "RAW image converter2" software to convert the raw image files to JPEG format;
3. Adobe Photoshop® to convert the image to its pixel equivalent; and
4. Fotoscale (a Volpe-developed program) to convert the pixel dimensions to slant range distance from the observer to the object.

Detailed logs, including camera settings site, data, time, aircraft type, aircraft model, operator, tail number, and direction (when identifiable), were kept for later correlation with the recorded

[*] As a backup to the photo-scale system, a Bushnell Laser Range Finder, Yardage Pro Model 800 was brought to all sites, but not used. This was because most observed aircraft were more than 800 yd. away, the instrument's maximum distance capability.

images. Slant range data can be used to correlate aircraft altitude with computer-modeled sound level data. As stated in Section 1, computer modeling will be used to compute the sound levels in areas within Hawai`i Volcanoes for which resource constraints (or other issues) did not allow for direct measurements. Slant range data will be used to correlate actual data with computer-predicted data during the modeling task to be performed at a later time.

3.5 Other Instrumentation

Four additional pieces of acoustic-support instrumentation are worthy of mentioning:

1. *Sound level calibrator* - A B&K Model 4231 sound level calibrator was used in the field for establishing and checking the sensitivity of the entire acoustic instrumentation system (i.e., microphone, preamplifier, cables, and SLM). The Model 4231 produces a user-selectable 94-dB sound pressure level at a frequency of 1 kHz.
2. *Pink-noise generator* - A small, portable, signal generator was used to establish the frequency response characteristics of the entire electrical system absent of the microphone.[*] The signal generator produces pink noise, a random signal for which the spectrum density, i.e., narrow-band signal, varies as the inverse of frequency.
3. *Microphone simulator* - A microphone simulator was used to establish the electronic noise floor of the entire electrical system absent of the microphone.
4. *GPS unit* - A Garmin™ GPS Plus III unit was used to perform time synchronization of all pertinent instrumentation and documentation of the exact site location.

[*] Note: Frequency-response calibration was not performed on the NoiseLogger™ system, as the Husky™ Fex-21 H/PC running the NoiseLogger™ software did not display sound levels in one-third octave-band frequencies.

4. FIELD MEASUREMENT PROCEDURES

This section presents the field measurement procedures utilized in the study. Two 2-person teams (one Volpe team and one HMMH team) performed the initial deployment during October 23 through November 11, 2002, of the ten NoiseLogger™ and NoiseLogger Plus™ systems. During this time frame, data collection, using the VoLARE system at each site, also took place.* At the end of this initial deployment period, the Volpe and HMMH teams departed. From then on, NPS personnel continued downloading data every two weeks, and were responsible for maintaining and relocating the ™ and NoiseLogger Plus™ systems to subsequent site locations throughout the remainder of the eight-month measurement period, November 12, 2002 through June 1, 2003. Sections 4.1 through 4.5 present a step-by-step description of the field measurement procedure, including deployment and dismantling.

4.1 NoiseLogger™ and NoiseLogger Plus™ System Deployment

Figure 22 and Figure 23 show the NoiseLogger™ and NoiseLogger Plus™ systems as deployed in the field at Sites 1A and 3A, respectively.

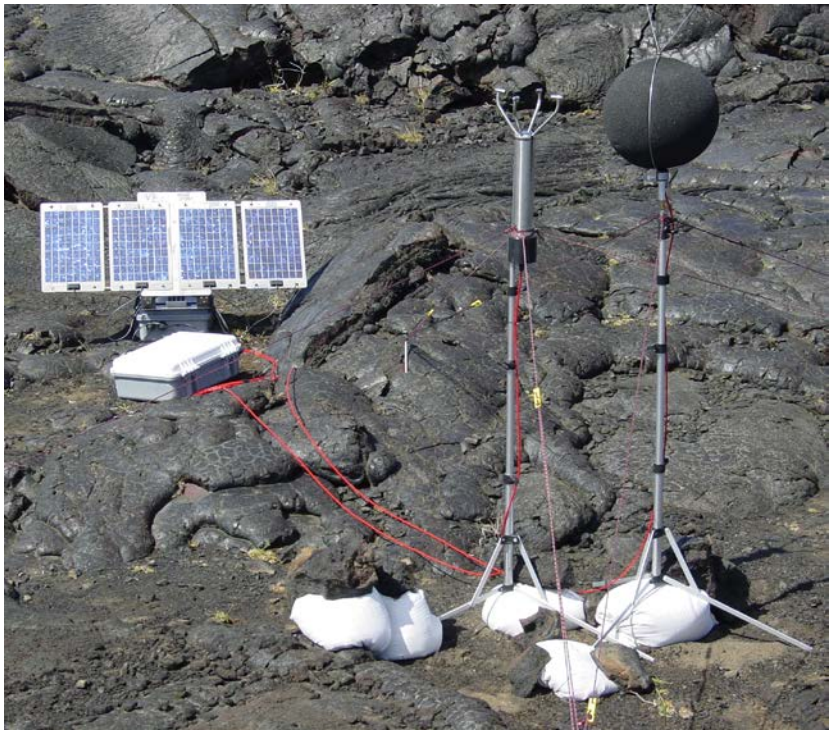


Figure 22. NoiseLogger™ system deployment; Site 1A.

* The VoLARE system (see Section 3.3) was used by the Volpe Center. A comparable "low noise" system was used by HMMH to perform similar data collection.

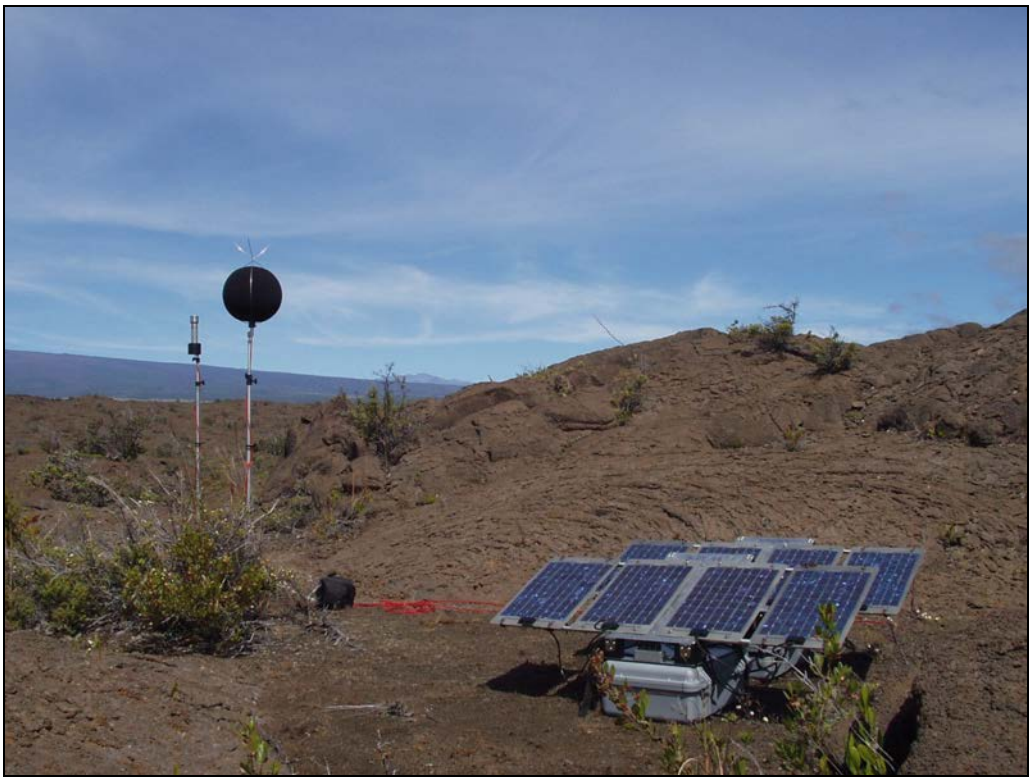


Figure 23. NoiseLogger Plus™ system deployment; Site 3A.

Following is a general step-by-step description of the system setup, which took place at all measurement sites:

1. The microphone, preamplifier, and windscreen were attached to a tripod, which was positioned in a location considered typical of the surrounding ambient environment. Care was taken to ensure that this location was not near any known localized noise sources and/or reflective surfaces. The tripod was adjusted to locate the microphone diaphragm at a height of 5 ft (1.5 m) above the local ground surface and oriented vertically (microphone grid facing the sky). To ensure physical stability, the tripod legs were secured using nylon rope with tension adjusters and/or sandbags.
2. The ultrasonic anemometer was attached to a second tripod, which was positioned at least 1 ft (0.3 m), but within 5 ft (1.5 m) of the microphone location. The tripod was adjusted to locate the anemometer sensor at a height of 5 ft (1.5 m) above the local ground surface and oriented north using a compass. To ensure physical stability, the tripod legs were secured using nylon rope with tension adjusters and/or sandbags.
3. The microphone and anemometer system cables were connected to the SLM acoustic case.

4. The solar panel array was deployed facing due south to ensure maximum exposure to daytime sunlight. Note: For the NoiseLogger Plus™ system, two solar panel arrays were deployed.
5. Power to the solar array and SLM case was verified.
6. The solar panel array was secured by strapping it to the power case after power was verified and the vent knob on the front of the power case was removed and placed inside the case.
7. All connections in the SLM system case were checked and a new CompactFlash™ card, which was used to store measured data, was inserted into the Husky™ H/PC prior to turning on the H/PC. Note: For the NoiseLogger Plus™ system, CompactFlash™ cards were not necessary as this system utilized the Fujitsu laptop computer and measured data were stored in its internal hard drive (see also Section 3.2).
8. The NoiseLogger™ program was retrieved from the CompactFlash™ card, then invoked. Note: Because CompactFlash™ cards were not necessary for the NoiseLogger Plus™ system, the NoiseLogger Plus™ program, stored in its internal hard drive, was invoked from the computer desktop.
9. Per the program instructions, the following information/action was entered/performed:
    a. *Site information:* The unique two-character ID representing the site "number" (e.g., 1B for Site 1B), and the site's name (e.g., Current Eruption Viewing) were entered;
    b. *Synchronization with the GPS unit:* Two minutes of one-second latitude and longitude data from the GPS unit were collected by the Husky™ H/PC;
    c. *Equipment information:* System component model and serial numbers (Note: Table 7 provides a summary of the system numbering convention and each system's equipment information), and support equipment model and serial numbers (e.g., calibrator) were entered;

Table 7. Summary of NoiseLogger™ and NoiseLogger Plus™ system equipment information

System #	System Type	LD824 Serial #	Microphone Type and Serial #	Preamplifier Serial #	Anemometer Type and Serial #	Windscreen #	Used at Site
1	NoiseLogger™	A0842R	40AQ #20729	1243	FT702 #2080-77	1	4A, 8C, 9C
2	NoiseLogger™	A0843S	40AQ #25837	1276	FT702 #2080-56	2	2B, 3B, 3C, 5B, 6C, 8B, 9A (from 5/16-5/24)
3	NoiseLogger™ Plus	A0844T	40AQ #19879	1268	FT702 #2080-88	3	5A, 8A (from 4/25-5/5), 9B
4	NoiseLogger™ Plus	A0845U	40AQ #19905	1282	FT702 #2080-68	4	3A
5	NoiseLogger™	A1148R	40AE #24020	1643	Gill WindObserver #000528	5	1B
6	NoiseLogger™	A1149S	40AE #24021	1647	FT702 #2080-87	6	9A (from 10/25-1/28)
7	NoiseLogger™	A1150K	40AE #24038	1678	Gill WindObserver #000524	7	1A, 2C
8*	NoiseLogger™	A1150K	40AQ #19909	2133	Gill WindObserver #000524	7	3D, 5C, 6B
9	NoiseLogger™	A1151L	40AE #24017	1650	FT702 #2080-58	8	2A
10	NoiseLogger™	A1155P	40AE #24040	1630	Gill WindObserver #000525	9	6A
11	NoiseLogger™	A1156Q	40AE #24034	1634	FT702 #2080-86	10	8A (from 10/24-2/17)

* Note: Systems 7 and 8 were identical except for the microphone, which was replaced due to a small amount of corrosion that developed from extended exposure to the sulphuric atmosphere present at the Hawai`i Volcanoes shoreline Site 1A. No similar corrosion was visible on the microphone used at the other Hawai`i Volcanoes shoreline site, Site 1B.

d. *System calibration:* Approximately 30 seconds of calibration signal are collected by the Husky™ H/PC;

e. *Sound Level Range:* The maximum sound level anticipated to be measured at the site. Given this user-selected "maximum," the NoiseLogger™ program automatically sets both a designated amount of gain and an absolute sound level limit ("ceiling") for the LD Model 824 SLM (see Table 8 below). For example, for sites where a wide range of natural and mechanical sound sources were expected, this range was set to 90 dB. At this setting, the NoiseLogger™ program would apply 20 dB of gain to the LD Model 824 SLM, and the loudest sound level that could be measured would be 108 dB. For quieter sites, the "Sound Level Range" was set to lower levels, as appropriate.

Table 8. LD Model 824 SLM sound level range and associated gain setting and ceiling level.

Sound Level Range (dB)	LD824 Gain Setting (dB)	Ceiling Level (dB)
110	0	128
100	+10	118
90	+20	108
80	+30	98
70	+40	88
60	+50	78

10. For the NoiseLogger Plus™ system, digital audio recording settings were also selected:
    a. *Sampling Rate:* Set to 20 kHz to collect most audible sounds. Equal to twice the highest frequency that is recorded by the wave file;
    b. *Sound Quality:* Set to 16 Bits to collect the widest range of sounds. This determines the dynamic range of the sound that is recorded by the wave file;
    c. *Periodic Wave Collection:* Box was "checked" to enable automatic wave file collection, then the option to record a 30-second wave file every 30 minutes was selected;
    d. *Event Triggered:* Box was "checked" to enable automatic wave file collection when certain threshold parameters (see Item e) are met in order to try and capture certain noise events;
    e. *Threshold:* Typically set to 50 dBA for quiet sites, and 60 dBA for other sites. This was the sound level that must be exceeded in order for an event-triggered, automatic wave file to begin collection;
    f. *Trigger Arming Duration:* Set to 5 seconds. This was equal to the number of seconds that either the broadband or tonal triggering conditions must be met in order for wave file collection to begin (e.g., if events were selected with a threshold of 55 dBA and an arming duration of 5 seconds, then the sound level must have been equal to or greater than 55 dBA for 5 seconds for a wave file to begin collection). This helped to avoid collection of impulsive bird chirping events;
    g. *Trigger Reset Duration:* Set to 10 seconds. In order to avoid constant wave file collection, this was equal to the number of seconds that the threshold triggering

condition must NOT be met in order for another wave file to be collected (e.g., if events were selected with a threshold of 55 dBA, a reset duration of 10 seconds, then after a wave file was collected, it was necessary for the sound level to be below 55 dBA for 10 seconds in a row before another wave file could be collected);

h. *Number of Wave Files Per Day:* Set to 200. This was the total number of event wave files (Note: Periodic wave files were not counted) that could be collected in each day. This quantity was set to avoid collecting too many wave files within a short period of time and expending all of the laptop's internal hard drive space.

11. Following calibration, the large windscreen was replaced onto the microphone and all external system cables were "dressed" to allow for easy visual inspection, and to prevent disturbance by site activity.
12. Sections 4.2 and 4.3 next present the step-by-step description of the deployment of the VoLARE system and the field data collection procedure, respectively.

4.2 VoLARE System Deployment

Figure 24 and Figure 25 show the microphone and recording instrumentation of the VoLARE system as deployed in the field at Site 9A.



Figure 24. VoLARE microphone system deployment; Site 9A.



Figure 25. VoLARE recording system deployment; Site 9A.

Following is a step-by-step description of the VoLARE system setup, which took place at measurements sites during October 23 through November 11, 2002:

1. The microphone, preamplifier, and windscreen were attached to a tripod. The tripod was adjusted to locate the microphone diaphragm at a height of 5 ft (1.5 m) directly above the local ground surface, oriented vertically (microphone grid facing the sky).
2. The SLM, DAT, and acoustic data recording instrumentation were positioned in full view of the microphone location, but at a distance approximately 50 to 100 ft (15-30 m) away from it, to avoid noise intrusions by the acoustic observers.
3. A total of 100 ft (30 m) of cable was connected between the instrumentation at the microphone system and the recording system; and all instrumentation was then powered up.
4. The next step was to establish that the internal clocks of all pertinent instrumentation (namely the SLM, DAT, meteorological system and palmtop) were set to the time of the nearby NoiseLogger™ or NoiseLogger Plus™ system.
5. With all electrical components of the acoustic measurement system connected and given adequate time to warm up (typically 10 to 15 minutes), a preliminary sound level calibration of the system was performed. The purpose of the preliminary calibration was to ensure that all equipment was operating properly. A frequency-response calibration of the entire electrical system, absent of the microphone was then performed with the pink noise generator.
6. The electronic noise floor of the entire electrical system absent of the microphone was established, using a non-transducive (i.e., mechanically passive) capacitive load.
7. After re-installation of the microphone and given adequate time to stabilize, a pre-measurement sound level calibration of the system was performed.
8. The two-stage windscreen was then deployed and the preamplifier cable secured to a leg of the tripod, to prevent possible vibration. All other cables were “dressed” to allow for easy visual inspection, and to prevent disturbance by site activity.
9. Section 4.3 next presents the step-by-step description of the field data collection procedure.

4.3 Measurements

The following is the step-by-step description of the field data collection procedure:

1. One field observer continuously documented the acoustic environment at the site, i.e.,

acoustic observer logging. In performing acoustic observer logging, the observer used pre-programmed macros in an automated spreadsheet to place an immediate time stamp and identify each event as 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, talking, 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. In addition to the three primary acoustic states, there were several sub-states as shown in Table 9.

2. The second field observer periodically checked the equipment and took photographs of any visible aircraft for later determination of slant range. Detailed logs, including site, data, time, aircraft type, aircraft model, operator, tail number, and direction (when identifiable), were kept for later correlation with the recorded images. Note: Slant range data collection occurred only during the initial systems deployment, and not during remaining measurement period (June 1, 2003), when only one NPS employee performed all site visits, acoustic observer logging, and system maintenance/relocation.
3. At the end of the site visit, all data were downloaded and transferred onto a central computer, located at Hawai`i Volcanoes park headquarters. For NoiseLogger™ systems, data were downloaded by removing the CompactFlash™ card from the Husky™ H/PC. For NoiseLogger Plus™ systems, data were downloaded by moving the data onto a portable, external hard drive. Copies of the data were then placed on DVD and sent to both the Volpe Center and HMMH for periodic review, quality control (QC) checks, processing, and analysis, approximately once every month during the eight-month measurement study. For the VoLARE system, data were downloaded by removing the DAT tape from the recorder and using Larson Davis software to transfer data from the LD824 sound level meter to a laptop.
4. A post-measurement sound level calibration of the VoLARE's acoustical system was

performed and any drift from the initial calibration was documented. The internal clocks of the SLM and DAT were compared with the master clock and any time drift was documented.

5. All VoLARE instrumentation was powered down, disconnected, and stored.
6. If the site was designated as a "permanent" site, the NoiseLogger™ system was recalibrated and ambient sound level data collection then re-initiated.
7. If the site was designated as a "mobile" site, then the NoiseLogger™ system was dismantled and moved to the next location.
    a. A post-measurement sound level calibration of the acoustical system was performed and any drift from the initial calibration was documented.
    b. All instrumentation was powered down and the entire system was disconnected and stored.

Table 9. Acoustic state identifiers.

Aircraft Intrusion Sub-States	Description	Human Intrusion Sub-States	Description	Natural Sounds Sub-States	Description
Helicopter Aircraft	Designates noise produced by rotor-type aircraft	Human	Designates noise produced by park visitors, e.g., voices	Wildlife Animal	Designates noise produced by wildlife, e.g., birds
Propeller Aircraft	Designates noise produced by propeller-type aircraft	Vehicle	Designates noise produced by vehicles, e.g., automobiles	"Wind in the Foliage"	Designates noise produced the wind in foliage, e.g., trees
Jet Aircraft	Designates noise produced by jet-type aircraft	Domesticated Animal	Designates noise produced by pets, e.g., dog barking	"Wind in the Ear"	Designates noise produced the wind in the observer's ear, including silence
Unknown	Designates noise produced by unknown-type aircraft (invoked primarily for aircraft, which are heard, but not seen)	Other	Designates noise produced by other human-induced sources	Water	Designates noise produced the water sources, e.g., waterfall
Tour Operator	Designates tour operator	Measurement Team	Designates noise produced by the field measurement team	Other	Designates noise produced by other natural sources
Commercial Operator	Designates commercial operator				
General Aviation Operator	Designates general aviation operator				
Military Operator	Designates military operator				
Unknown Operator	Designates unknown operator (invoked primarily for aircraft, which are heard, but not seen)				
High Altitude	Designates high altitude aircraft				
Medium Altitude	Designates medium altitude aircraft				
Low Altitude	Designates low altitude aircraft				

Note: All sound level data measured during acoustic states identified with "Human Intrusion - Measurement Team" designations are not included in the data analysis.

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5. DATA REDUCTION AND PROCESSING

Figure 26 presents a diagram of the data reduction process. Essentially, there were three types of data: (1) acoustical; (2) meteorological; and (3) other, e.g., slant range photographs. The acoustical and meteorological data were used by the Volpe Center as input to its data processing program, entitled NLcrunch (see Section 5.4). NLcrunch is a program developed by the Volpe Center to reduce, analyze, and archive the large volume of data that will be collected at the national parks.

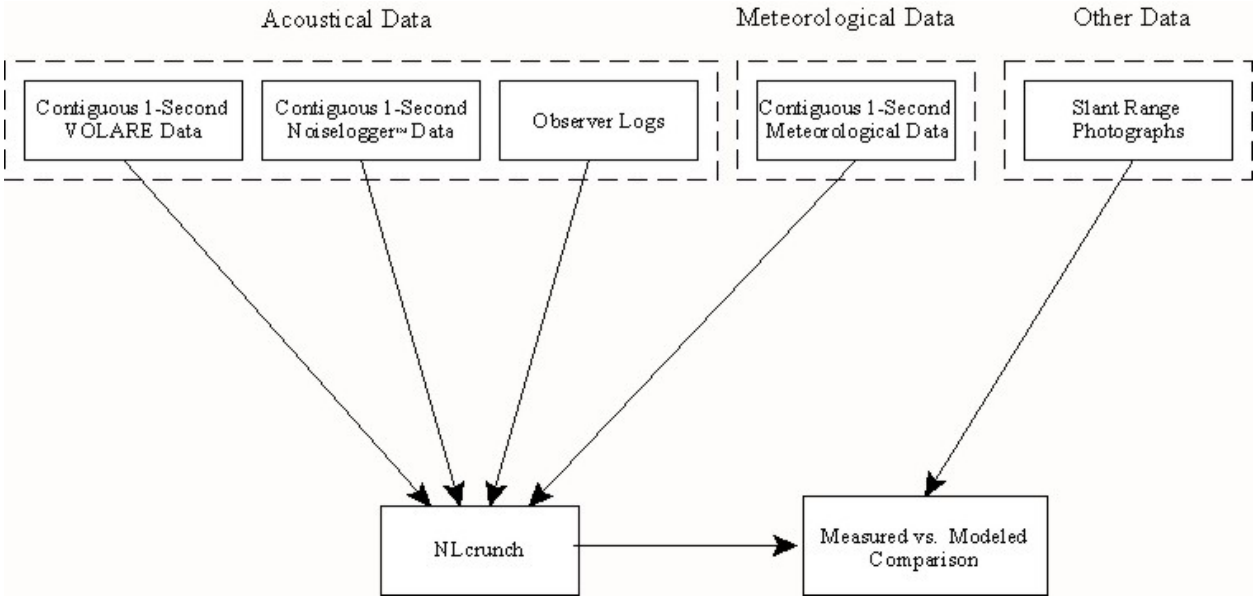


Figure 26. Flow diagram of data reduction process.

Data from the field measurement sites were transferred to a central computer located at Hawai`i Volcanoes Park Headquarters. Copies of the data were then placed on DVD and sent to both the Volpe Center and HMMH approximately once every month during the eight-month measurement study.

5.1 Raw NoiseLogger™ and NoiseLogger Plus™ Acoustic and Meteorological Data Reduction

No editing was required for NoiseLogger™, which contained both acoustic and meteorological data. The filename format of the raw, binary files was as follows:

"TH13OB_Sxx1_YYYYMMDD.000,"

where "TH13OB_" is the default NoiseLogger™ header label, "Sxx1" is a unique four-character ID representing the site number (e.g., "S6B1" represents Site 6B), "YYYY" is the four-digit representation for the year, "MM" is the two-digit representation for the month, and "DD" is the two-digit representation for the day of the month. The ".000" extension identifies these files as binary formatted.

Raw, binary NoiseLogger™ files were then translated into ASCII text files by the NLcrunch program. Each line of the text file represented a 1-second data sample containing the date, time, equipment ID, battery voltage, internal temperature, 1-second averaged wind speed, 1-second averaged wind direction, 1-second Z-weighted (flat or no weighting) L_{eq}, 1-second C-weighted L_{eq}, 1-second A-weighted L_{eq}, and Z-weighted spectral data (12.5-20,000 Hz).

In addition to the binary files, the NoiseLogger Plus™ system also recorded live audio samples. These files were used for later repeated playback whenever there was a question on the noise source of the sound levels from the binary files.

5.2 Raw VoLARE Acoustic Data Reduction

No editing was required for the VoLARE acoustic data. The filename format of the raw, binary files was as follows:

"MMDDYYxx.slmdl"

where "MM" is the two-digit representation for the month, "DD" is the two-digit representation for the day of the month, "YY" is the two-digit representation for the year, and "xx" is a unique two-character character ID representing the site (e.g., "6B" represents Site 6B). The ".slmdl" extension identifies these files as binary formatted Larson Davis (LD) Model 824 sound level meter (SLM) files. It should be noted that the LD 824 was used for VoLARE measurements at all Hawai`i Volcanoes sites except Sites 1A and 1B, where a LD Model 820 SLM was used. The filename format of the raw, binary LD 820 files was "MMDDYYxx.bin." A filename size of 8 characters, not including the filename extension, is a limitation set by the LD820 utility software and, as such, was the convention used for all VoLARE acoustic files for consistency.

Prior to processing, the raw, binary VoLARE files were translated into comma-delimited ASCII files using the LD 824 Utility Software (or LD 820 Utility Software, as appropriate). The text file contained the SLM settings and the 1-second data samples, which included the date, time, battery voltage, internal temperature, 1-second A-weighted L_{eq}, and Z-weighted spectral data (12.5-20,000 Hz).

5.3 Acoustic Observer Log Data Reduction

The acoustic observer log data files were checked by the actual field observer for accuracy, and edited as necessary to complete incomplete entries, clarify ambiguous comments, fix typos, and remove blank rows. The files were then translated to Microsoft™ Excel format for input into NLcrunch.

5.4 Slant Range Data Reduction

The filename format of the raw, digital-photograph files was as follows:

"CRW_xxx..CRW"

where "CRW" identifies these files as raw Canon camera digital photograph files, and "xxx" is a sequential three-digit number assigned to the file by Canon's internal counter.

The digital photograph files were reviewed using Canon's "RAW image converter2" software to convert the raw files to a format that the image processing software can use (such as Joint Photographic Experts Group, or JPG, format), and compared with the detailed logs, which the field observer kept, noting site, data, time, aircraft type, aircraft model, operator, tail number, and direction of flight (when identifiable). No editing was required for the slant range photos. All photos were individually reviewed to determine if they were properly taken, i.e., the image must represent a perpendicular side or frontal view of the aircraft. If the aircraft was shown at an angle other than perpendicular, that photo is discarded. Remaining "good" photos were then processed using a Volpe-developed program, Fotoscal,[29] which computes the slant range distance of the aircraft to the camera, based on a triangular comparison of the length of the aircraft in pixels in the photograph with the actual length of the aircraft as documented by the manufacturer.

As stated in Section 1, computer modeling, will be used to compute aircraft sound levels in areas within Hawai`i Volcanoes for which resource constraints (or other issues) did not allow for direct measurements.

5.5 Data Processing

As stated earlier, the acoustical, meteorological data, and observer log data were used as input to the data processing program, NLcrunch Version 3.13 (dated 8/12/2005). The NLcrunch program applies several quality assurance filters and checks (Section 5.5.1), and then several adjustments (Section 5.5.2) to the acoustic data prior to detailed data reduction and analysis.

5.5.1 Data Filters

The NLcrunch program applies several quality assurance filters and checks to the acoustic data to ensure that any questionable data is identified and that only "good" data is reduced and analyzed. Following is the list of NLcrunch filters used to identify "bad" or questionable data:

- Data whose associated battery readings were less than 11.0 volts, the minimum voltage required to properly run the NoiseLogger™ or NoiseLogger Plus™ system;
- Data whose associated internal temperature readings were greater than 122 degrees Fahrenheit, the LD Model 824 SLM's maximum operating temperature limit;
- Data whose associated 1-second average wind speeds were less than zero m/s, indicating an anemometer error;
- Data whose associated 1-second average wind speeds were greater than 11 mph (5 m/s), the predetermined, acceptable, wind speed threshold (Note: Appendix E discusses the development of this wind criterion in greater detail);[*]
- Data whose associated 1-second Z-weighted sound levels exceeded the LD Model 824 SLM's instrumentation noise "ceiling level" for the gain setting of the instrument (see Section 4.1 for more information);
- Data whose associated ⅓-octave frequency band data do not deviate by at least one

[*] Available data suggests that there is a high probability of microphone-induced distortion above the wind speed threshold; however, unless such wind conditions occur more than 50 percent of the hour, exceedence metrics (L_{50}, L_{90}, and L_x) will not likely be influenced. Both the FAA and NPS acknowledge that additional research is needed to determine if a more refined approach is necessary to account for data collected during high wind conditions.

standard deviation (dB) across all 33 bands, typically represented by no variations in sound levels within the bands, which indicates a problem with the LD824 sample;

- Data that were measured within twenty minutes of performing calibration (to remove data potentially contaminated by field personnel handling instrumentation during the calibration process);
- Data that were measured during NPS helicopter transportation of field personnel and/or equipment to/from sites; and
- Data that were potentially contaminated by field personnel during the observer logging.

5.5.2 Data Adjustments

The following is the list of adjustments applied to the acoustic data by the NLcrunch program:

- Gain adjustments were applied to VoLARE acoustic data (Note: No gain adjustments were required for NoiseLogger™ or NoiseLogger Plus™ data). As mentioned previously in Section 3.3.2, to successfully utilize the VoLARE system down to the threshold of human hearing, an offset calibration technique was employed.
- Calibration adjustments were applied. These adjustments accounted for calibration drift as determined by measuring a calibration signal at the start and end of each data collection period.
- Microphone frequency response adjustments were applied. These adjustments accounted for frequency response biases of the microphone and were provided by a microphone calibration facility. Appendix C presents these adjustments in detail.
- Windscreen frequency response adjustments were applied. These adjustments accounted for frequency response biases of the windscreen and were measured by HMMH. Appendix C presents these adjustments in detail.
- Noise floor adjustments were applied to NoiseLogger™ and NoiseLogger Plus™ data, as appropriate. These adjustments were developed to determine a more accurate representation of the true ambient sound levels in Hawai`i Volcanoes' low-level ambient environment. Appendix D discusses these adjustments in detail.

5.5.3 Sound Level Descriptors

All ambient, sound-level data will be analyzed (see Section 6.0) in terms of the following metrics (refer to the Terminology section for definitions):

- L_{Aeq}: The A-weighted equivalent sound level and its associated ⅓-octave band un-weighted spectrum from 12.5 to 20,000 Hz.
- L_{50}: A statistical descriptor describing the sound level exceeded 50 percent of a specific time period and its associated ⅓-octave band un-weighted spectrum from 12.5 to 20,000 Hz. Note: This spectrum is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.*
- L_{90}: A statistical descriptor describing the sound level exceeded 90 percent of a specific time period and its associated ⅓-octave band un-weighted spectrum from 12.5 to 20,000 Hz. Note: This spectrum is constructed by determining the L_{90} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

* This method for constructing spectra has precedent as this approach has been agreed to by the FAA and NPS for noise analyses in Grand Canyon National Park.[2]

6. DATA ANALYSIS

In support of this study, over 20,000 hours (900+ days) of acoustic and wind data were measured at 22 sites from October 23, 2002 through June 1, 2003. Figure 27 below shows the specific periods of time that data were collected at each site. It should be noted that there was a hiatus in data collection between late February and late April. During this period, the systems were removed for use in the baseline ambient data collection effort in Haleakala. Three systems were returned in late April to complete data collection in Hawai`i Volcanoes at Sites 8A, 8B, 8C, 9A, 9B, and 9C.

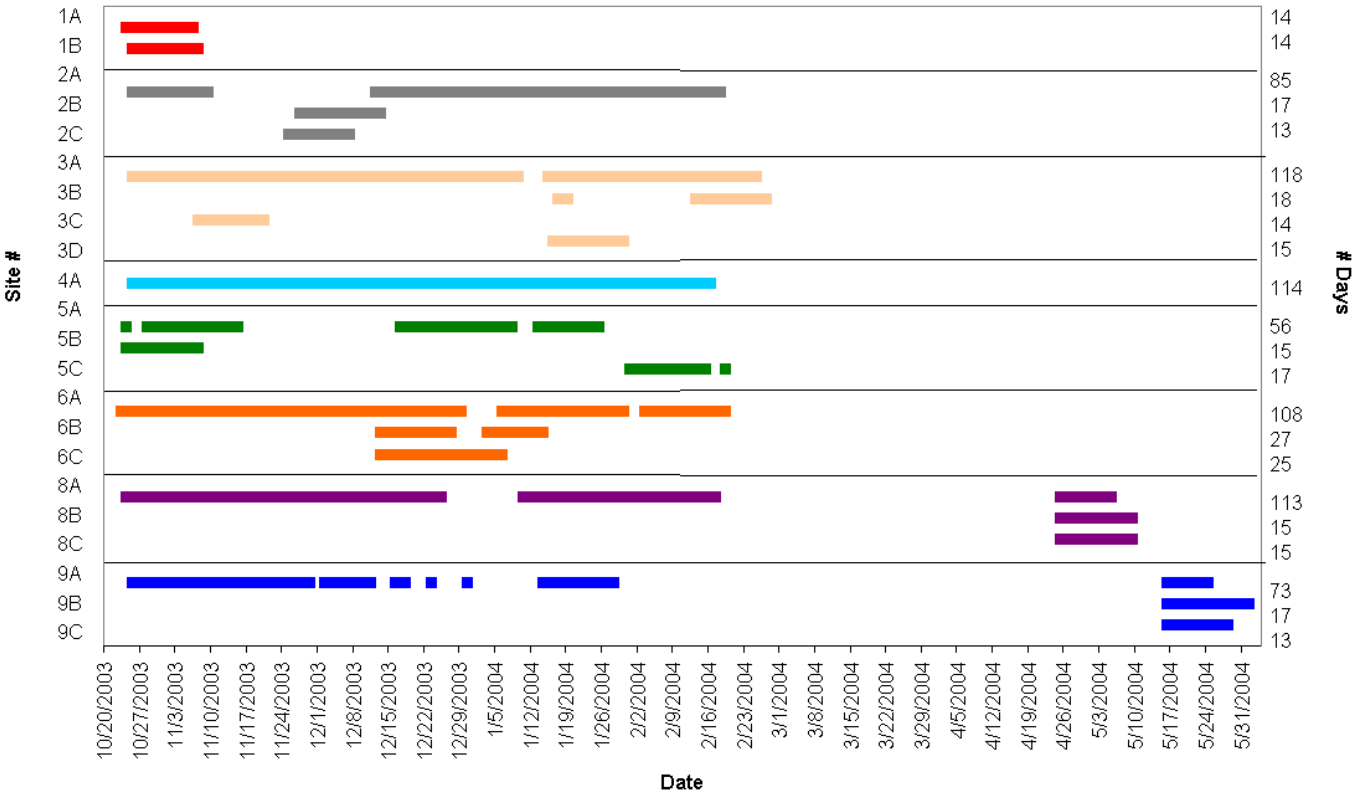


Figure 27. Baseline ambient data collection timeline for each site.

As stated in Section 1.1, the primary objective of this study was to quantify the baseline ambient sound levels within Hawai`i Volcanoes to establish a foundation from which potential noise impacts due to air tour operations can be assessed. This was accomplished by developing a comprehensive grid of ambient sound levels (i.e., ambient *maps*) throughout the park.[12] These ambient maps (along with representative one-third octave-band spectral data) will be used as

input to the FAA's Integrated Noise Model (INM) or Aviation Environmental Design Tool (AEDT)[30]. The models will be used to compute various noise-related descriptors and generate the sound-level contours that will be used in the assessment of potential noise impacts due to air tour operations.

This section discusses in detail the data analyses performed, and the process used in the development of the Hawai`i Volcanoes ambient maps. All data analyses were performed in terms of three metrics: (1) the A-weighted equivalent sound level (L_{Aeq}) and its associated one-third octave-band spectrum (unweighted); (2) the 50-percentile exceeded sound level (L_{50}) and its associated one-third octave-band spectrum (unweighted); and (3) the 90-percentile exceeded sound level (L_{90}) and its associated one-third octave-band spectrum (unweighted).[*] These data were then used in the conductance of a series of analyses. Specific analyses consisted of the following:

- *Time-based Analysis (Section 6.1)* – Determine the diurnal and seasonal trends of the data.
- *Acoustic Zone Analysis (Section 6.2)* – Determine the feasibility of the use of "acoustic zones" to allow for the transferability of baseline ambient data within large, homogeneous regions of Hawai`i Volcanoes and possibly between similar regions in other parks.
- *Measurement Duration (Section 6.3)* – Determine the potential errors associated with shorter versus longer duration data sets with the goal of potentially minimize data collection/analysis costs in future parks.
- *Development of Ambient Maps (Section 6.4)* – Because the specific "ambient" to be used in the modeling and any subsequent impact assessment is the subject of on-going discussions between the FAA and NPS, four different ambient maps for each of the three metrics were developed from the data.

[*] Note: As discussed in Section 5.5.3, the one-third octave-band spectra associated with the L_{50} and L_{90} are constructed by determining the L_{50} and L_{90}, respectively, from each ⅓-octave band; therefore, they are not actual measured one-third octave-band spectra associated with a measurement sample. This method for constructing spectra has precedent as this approach has been agreed to by the FAA and NPS for noise analyses in Grand Canyon National Park.

6.1 Daily and Seasonal Variability

It is likely that there will be substantial day-to-day, and for that matter week-to-week, and season-to-season variability, for many parks. For example, in some areas, insect activity increases at night and can result in higher ambient sound levels than during the day. As another example, some wildlife activities (e.g., breeding) increase during certain months of the year, and, as such, may be expected to contribute to different ambient noise levels. These trends may affect how the baseline ambient will be characterized during any subsequent impact assessment. Should the ambient of a site be defined differently during the day then during the night (Section 6.1.1)? Can seasonal variations be seen in the data as well (Section 6.1.2)?

6.1.1 Diurnal Temporal Trends

For the purpose of assessing trends in the diurnal data, average, hourly, sound levels for each site were computed by grouping the individual sound-level values from all measurement days by hour. For each hourly grouping, L_{Aeq} sound level values were weighted by the duration in seconds that hour represented,[*] and then energy-averaged over all measurement days to compute a single, average, ambient, sound-level value; L_{50} and L_{90} sound level values were algebraically averaged over all measurement days to compute a single, average, ambient, sound-level value. Table 10 through Table 12 present the results for each site computed using each of the three noise metrics (L_{Aeq}, L_{50}, and L_{90}). These data are presented graphically for each individual site in Appendix A. Note: As stated in Section 5.5 and discussed in Appendix E, several quality assurance filters and checks (e.g., high wind filter) and then several adjustments (e.g., noise floor adjustments) were applied to the acoustic data prior to data analysis.

In addition, because the majority of Hawai`i air tours operate on a daily basis between the hours of 6 am and 6 pm, the data measured during this time period (hereafter referred to as "daytime" hours) were compared to data measured outside this time period (6 pm to 6 am, hereafter referred to as "nighttime" hours). A daytime and nighttime sound level for each site was computed by grouping the individual sound-level values from all

[*] Because the NLcrunch program applies several quality assurance filters and checks to the acoustic data prior to detailed data reduction and analysis, sound level values were weighted by the duration in seconds that hour represented since an hour may not necessarily be 3600 seconds.

measurement days by "daytime" hours and "nighttime" hours, and then re-computing the L_{Aeq}, L_{50}, and L_{90} over all measurement days. Note: FAA and NPS have agreed that any subsequent impact assessment will be conducted using ambient sound levels during the time that the aircraft operations occur. Because the majority of Hawai`i air tours operate during the daytime, all final ambient maps (see Section 7) will be developed using daytime data. The specific hours to be defined as daytime will be park dependent. For example, a time period of 6 am to 6 pm will be used for the analyses of national parks in Hawai`i. This time period is the typical operating hours for air tour operators conducting air tours in Hawai`i according to Flight Standard District Office personnel.

As summarized in Table 13, the magnitudes of the differences between daytime and nighttime average, hourly, sound levels as compared to the overall average, hourly, sound levels were small – on average, generally less than 3 dBA. Sites in or near dense vegetation exhibited stronger diurnal differences between daytime and nighttime sound levels due to bird and/or insect activity. These data are presented graphically for each individual site in Appendix A.

Table 10. Average hourly sound levels - L_{Aeq}.

Site #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1A	53.0	45.2	44.1	42.5	43.6	45.3	43.6	45.9	49.7	53.1	56.0	59.6	60.9	62.5	57.3	55.3	54.2	52.1	52.9	51.1	47.3	46.1	47.7	45.4
1B	48.0	49.3	48.1	47.2	46.9	46.8	47.4	51.7	49.3	53.4	52.1	53.3	51.3	52.2	55.9	56.6	54.6	50.3	49.2	49.9	50.5	50.2	48.3	48.8
2A	42.5	40.4	42.4	40.6	39.5	42.9	34.2	34.2	33.6	34.2	35.2	37.0	37.7	37.5	36.7	38.7	39.4	35.5	53.7	52.0	46.9	44.0	43.9	41.5
2B	48.9	51.6	47.7	42.6	45.9	38.6	37.7	39.2	36.5	38.5	39.6	40.3	42.8	44.3	46.0	47.7	48.7	51.2	62.3	56.8	49.2	48.4	52.8	51.1
2C	44.3	35.7	38.5	36.3	36.3	35.0	34.0	38.3	37.3	39.9	41.3	44.0	42.0	43.8	44.8	42.0	41.5	32.2	53.7	58.7	41.3	44.5	39.9	43.4
3A	37.0	35.8	35.9	35.7	38.1	36.7	37.4	39.9	39.1	42.0	40.8	44.6	44.2	43.4	43.3	42.7	42.4	40.9	39.5	39.0	37.8	39.3	43.0	38.0
3B	36.2	35.4	34.6	34.2	34.0	33.8	34.2	46.8	45.6	46.0	45.0	42.9	47.3	43.9	45.8	40.9	36.8	37.8	35.2	36.1	36.3	36.9	36.6	35.6
3C	40.5	40.4	39.9	39.0	36.9	36.6	38.8	45.7	44.4	42.8	44.0	41.5	43.3	40.8	43.0	42.9	44.5	38.6	43.8	45.9	40.6	40.7	41.1	41.0
3D	23.6	24.7	29.0	29.5	24.8	31.7	33.6	45.3	25.3	44.8	28.8	30.5	28.3	23.6	27.3	35.1	26.9	35.6	35.0	27.0	25.8	26.7	27.3	25.7
4A	48.2	48.0	47.6	46.8	43.5	37.5	36.8	40.7	39.8	40.8	40.1	39.8	41.3	40.2	39.4	39.2	38.8	37.3	41.6	46.5	47.9	48.4	48.3	48.1
5A	32.7	33.7	31.4	33.7	35.6	35.7	39.4	43.1	41.1	43.6	43.1	43.5	44.2	43.1	43.7	43.0	39.2	39.3	36.3	37.5	34.4	37.7	34.6	35.2
5B	22.2	21.5	20.3	22.3	24.3	21.6	26.9	30.8	32.7	30.4	29.9	36.8	31.7	30.7	38.2	34.0	32.9	33.7	25.5	20.8	20.1	23.9	22.5	22.6
5C	30.6	26.7	27.7	26.0	29.0	28.7	35.9	38.0	36.0	40.6	38.3	35.1	37.4	36.0	35.4	35.5	33.9	32.8	32.1	26.6	27.7	33.1	30.1	28.2
6A	40.4	42.7	34.0	41.5	39.7	34.3	32.4	35.1	36.0	38.7	37.5	36.9	38.5	38.7	42.6	44.7	41.8	39.0	54.5	51.6	45.0	46.8	49.2	41.6
6B	31.8	30.9	31.9	39.2	32.6	26.8	46.3	46.1	43.6	41.5	39.7	40.0	41.0	39.1	41.0	41.5	39.6	39.6	53.7	45.2	47.2	41.0	32.6	38.4
6C	42.0	42.1	41.7	43.2	42.3	42.5	41.5	44.0	40.9	42.7	53.9	58.0	57.0	53.6	57.7	55.7	43.4	43.4	51.1	49.2	45.5	44.7	45.9	43.9
8A	55.0	55.1	55.2	54.8	52.4	45.5	45.9	44.8	46.1	46.6	47.2	47.3	47.7	47.1	47.6	46.9	46.1	44.9	42.6	48.0	51.4	53.1	54.1	54.7
8B	47.0	47.6	48.0	47.8	45.6	42.7	42.1	42.4	42.2	43.1	42.5	54.3	44.2	43.2	43.0	42.5	43.0	42.7	41.4	38.7	42.1	43.9	45.1	46.2
8C	51.0	51.1	51.0	50.2	45.0	45.0	37.2	44.9	42.7	47.2	44.9	37.6	40.5	38.5	40.6	37.3	37.2	36.4	38.7	39.8	45.8	48.2	49.2	50.3
9A	40.2	38.2	37.0	36.4	35.6	34.1	34.0	45.6	47.8	51.8	51.2	49.0	48.0	48.4	47.9	48.3	52.0	49.5	41.5	41.8	40.9	39.5	40.2	39.9
9B	38.7	36.0	36.6	37.9	36.3	35.6	33.5	38.5	41.0	37.3	40.6	40.5	41.1	40.9	41.7	38.1	37.5	41.5	35.7	38.4	40.2	38.1	40.4	41.5
9C	38.3	38.5	38.7	38.5	35.3	31.3	30.2	47.6	43.8	48.6	55.1	47.4	46.9	48.1	47.3	47.6	46.4	40.9	31.1	27.6	33.2	35.9	36.9	37.0

Table 11. Average hourly sound levels - L_{50}.

Site #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1A	43.6	42.6	41.0	40.2	41.3	41.6	41.2	43.9	46.2	50.6	51.5	56.7	56.1	56.3	55.1	53.3	53.4	51.2	50.1	49.8	45.8	43.0	44.8	43.2
1B	46.4	47.2	46.5	45.8	45.7	45.5	46.0	47.2	45.2	46.2	47.4	48.2	48.5	50.2	49.8	50.5	49.9	49.0	46.2	46.5	48.0	48.4	46.9	47.5
2A	36.0	34.3	33.9	32.3	31.6	31.2	29.9	27.0	24.8	26.3	29.7	31.6	31.7	31.5	30.3	29.4	28.7	27.4	38.2	40.5	39.4	38.5	38.8	37.7
2B	33.7	31.1	30.9	30.8	30.3	29.9	29.0	29.9	29.4	30.0	32.4	33.5	35.3	35.2	36.0	34.9	34.8	33.0	52.8	41.9	37.2	38.0	36.4	34.2
2C	35.1	33.7	34.2	33.7	33.6	31.4	27.7	27.6	29.8	32.3	36.8	37.1	35.4	33.6	38.3	36.7	32.6	27.2	42.6	40.7	35.2	35.6	35.9	34.9
3A	24.9	23.6	23.9	23.5	23.3	23.6	23.2	24.6	26.5	27.7	29.1	30.5	32.3	33.3	33.7	32.0	29.5	27.2	27.1	26.9	25.9	26.0	25.5	25.1
3B	29.4	27.9	28.2	27.3	27.3	28.0	27.6	27.4	28.7	29.4	30.1	31.5	33.1	32.4	29.0	28.7	27.0	27.6	27.7	28.2	28.3	28.3	26.9	28.3
3C	39.3	38.7	37.3	36.2	32.1	30.0	35.4	36.5	35.9	36.1	36.4	36.8	36.8	36.6	36.7	36.8	36.8	35.9	36.4	38.5	39.4	39.8	40.0	40.1
3D	19.2	18.9	21.0	20.6	20.0	23.0	23.9	24.9	20.5	21.2	19.7	20.3	23.8	21.4	20.2	23.5	23.1	22.4	23.2	21.1	20.5	20.6	20.7	20.8
4A	45.0	44.3	43.3	41.4	36.2	28.6	27.8	30.3	32.3	34.5	35.0	35.1	35.3	34.8	33.2	32.0	31.8	30.2	38.8	45.5	46.7	46.9	46.3	45.5
5A	24.3	24.1	23.7	24.9	25.1	25.8	33.7	34.8	35.1	34.2	34.2	34.6	35.1	35.8	35.9	35.1	35.1	35.0	27.0	25.5	24.8	24.9	25.0	24.5
5B	18.9	18.4	18.2	18.5	18.9	17.1	19.8	20.3	22.1	23.5	24.0	25.0	27.3	27.2	26.1	24.7	23.1	20.3	17.5	17.4	17.6	19.1	18.8	18.6
5C	21.8	20.5	21.1	20.5	22.0	21.9	25.0	25.9	26.4	28.3	28.5	29.7	29.9	30.2	28.9	28.3	26.0	23.9	21.4	19.3	20.2	21.4	22.4	21.5
6A	27.7	27.2	26.7	26.9	26.4	26.5	26.7	27.0	28.1	28.6	29.4	29.9	31.3	31.9	32.0	32.4	33.1	32.8	39.8	35.7	31.2	30.6	29.4	28.1
6B	26.8	26.6	26.9	26.2	25.2	23.0	27.5	30.9	30.2	29.5	30.1	32.9	32.5	31.2	32.2	32.7	31.2	30.6	38.3	32.1	31.1	28.8	27.7	28.1
6C	31.6	31.5	30.9	30.9	30.9	30.5	29.7	31.2	31.4	31.5	33.1	34.1	34.9	35.5	36.1	35.9	34.9	33.1	38.0	35.4	35.0	34.1	33.0	33.0
8A	52.6	52.4	52.0	51.0	47.0	39.4	42.4	41.8	42.5	43.1	43.3	43.6	43.8	43.5	43.2	43.1	42.6	41.1	38.9	45.5	49.4	51.2	52.2	52.5
8B	44.6	44.8	44.9	43.6	40.4	40.5	37.6	37.6	37.5	37.2	36.9	37.0	39.5	38.7	38.0	38.6	39.3	39.1	37.5	36.3	40.4	42.3	43.3	44.2
8C	50.6	50.6	50.3	49.3	41.6	33.3	26.7	29.5	30.1	32.4	32.1	32.0	32.7	33.1	32.8	31.8	31.0	30.0	28.3	37.4	45.3	47.7	48.6	49.7
9A	35.9	35.5	35.0	34.3	30.9	24.2	24.9	26.6	28.0	29.9	30.7	30.8	31.9	32.2	31.4	30.8	29.5	27.2	26.5	30.6	32.8	34.2	34.9	35.2
9B	30.4	29.0	28.7	27.5	27.2	27.9	27.3	26.9	26.4	30.5	32.7	34.6	35.2	34.9	35.7	34.4	31.9	32.1	30.1	31.6	33.0	31.4	32.1	32.6
9C	37.4	37.3	37.5	37.3	33.4	26.1	25.1	26.1	27.3	30.5	31.9	31.4	29.8	32.5	32.6	30.9	30.4	27.3	24.6	25.3	32.1	35.6	36.4	36.1

Table 12. Average hourly sound levels - L_{90}.

Site #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1A	41.4	40.5	38.9	38.4	39.2	39.8	39.2	41.4	43.0	48.3	47.3	52.0	52.3	53.9	52.1	49.8	50.4	49.0	46.9	47.0	43.0	40.6	42.7	41.7
1B	43.3	44.5	43.3	42.4	42.3	42.2	42.6	43.0	41.7	42.1	42.5	44.8	46.0	46.9	46.6	47.1	46.9	46.2	43.0	43.9	46.1	46.2	44.1	44.9
2A	32.6	31.1	29.9	28.7	27.9	27.8	26.1	23.4	21.3	22.1	24.7	26.8	26.8	26.8	25.9	25.3	24.4	23.5	26.7	33.4	33.9	34.9	35.2	33.8
2B	27.8	27.0	27.2	27.2	26.6	25.8	25.2	25.7	24.6	24.4	27.0	28.8	30.5	30.6	31.0	30.5	30.3	29.0	40.0	33.3	31.5	31.4	29.6	28.8
2C	32.5	32.0	32.3	32.1	31.4	28.6	26.3	25.5	27.2	29.9	31.4	35.1	26.1	29.7	34.0	31.1	29.4	24.9	28.9	33.5	32.9	33.5	33.6	33.2
3A	21.4	20.4	20.6	20.4	20.2	20.5	20.1	20.8	22.4	23.3	24.2	24.7	26.2	27.1	27.6	26.4	24.9	23.1	22.6	22.5	21.8	21.9	22.2	21.8
3B	25.9	23.9	24.7	23.5	24.1	24.1	23.8	23.5	24.8	25.6	26.1	25.7	27.8	27.5	24.9	23.6	23.4	24.1	24.3	24.9	25.0	25.3	23.5	23.7
3C	38.4	37.2	36.4	34.3	28.6	25.6	30.5	32.5	31.9	32.4	32.8	33.2	33.2	33.2	33.3	33.3	33.1	31.9	32.4	36.2	38.2	38.8	39.2	39.1
3D	18.8	18.4	20.5	19.4	19.6	22.2	23.1	23.4	18.9	19.6	18.9	19.4	22.8	20.5	19.2	21.9	21.6	19.9	22.2	20.4	19.9	20.1	19.9	19.9
4A	43.6	42.7	41.8	39.2	32.1	25.8	25.1	26.5	29.4	32.2	33.0	32.9	33.0	32.2	30.1	28.6	28.2	27.0	31.8	43.4	45.5	45.6	45.0	44.0
5A	21.3	20.9	20.7	21.5	22.1	22.3	25.3	29.6	30.5	29.7	30.0	30.9	30.8	31.4	31.4	30.6	30.0	29.0	21.5	21.6	21.3	22.0	22.0	21.6
5B	16.2	16.9	16.2	17.5	18.1	16.0	17.3	17.3	19.0	19.9	20.1	20.3	22.0	22.0	21.3	20.1	18.4	17.1	16.7	16.5	16.5	17.0	17.3	17.0
5C	19.7	18.9	18.5	19.0	20.0	20.1	20.7	21.7	22.6	24.6	25.1	26.2	26.0	26.3	25.2	24.3	21.8	20.2	19.0	18.2	18.4	19.2	20.2	20.0
6A	25.7	25.0	25.0	25.0	24.8	25.1	25.0	25.2	25.9	26.4	26.8	27.0	28.0	28.7	28.9	29.2	30.4	30.2	33.6	30.8	27.8	27.4	27.1	25.9
6B	25.2	25.2	25.3	24.7	23.5	21.1	21.2	25.6	25.5	25.5	26.1	29.1	28.0	27.8	28.1	28.0	27.6	27.1	28.3	26.8	26.4	26.7	25.6	25.7
6C	27.6	27.7	26.6	26.4	26.8	26.8	25.0	26.1	27.1	27.0	28.1	28.9	29.9	30.9	31.9	32.0	31.5	29.6	30.1	30.7	30.5	29.8	28.8	29.2
8A	51.6	51.4	50.9	49.5	43.2	33.6	35.2	37.3	37.9	38.4	38.6	38.7	39.0	38.8	38.9	39.2	38.5	36.1	34.1	42.2	47.9	50.1	51.1	51.5
8B	43.5	43.8	43.7	41.8	36.1	32.0	33.6	33.1	33.2	33.2	32.5	32.5	34.5	34.8	34.5	34.7	35.1	35.1	33.4	33.1	38.4	40.7	42.1	42.7
8C	49.0	49.3	49.0	46.9	32.9	25.4	23.0	24.9	26.0	27.1	26.9	26.8	27.6	28.1	27.8	27.2	26.5	25.8	24.7	28.4	41.8	46.0	47.1	47.6
9A	34.6	34.2	33.9	32.6	27.0	21.1	21.2	22.5	24.0	25.5	26.0	26.2	27.0	27.7	27.2	26.4	25.2	23.2	22.6	27.4	30.3	32.4	33.4	34.0
9B	26.4	25.6	25.1	24.1	24.1	24.7	23.9	23.2	23.0	24.9	27.6	29.6	30.3	30.3	31.1	29.7	27.1	27.6	26.4	27.6	28.4	27.8	27.9	27.4
9C	36.3	36.4	36.8	36.4	25.0	21.0	22.0	22.8	22.7	23.8	24.2	24.9	24.5	25.6	25.5	24.5	24.4	23.3	21.2	21.9	29.3	34.0	35.1	34.5

Table 13. Summary of day versus night diurnal trends.

Site #	Overall Average L_{Aeq} (dBA)	Overall Average L_{50} (dBA)	Overall Average L_{90} (dBA)	Daytime Hourly 7am to 7pm L_{Aeq} (dBA)	Daytime Hourly 7am to 7pm L_{50} (dBA)	Daytime Hourly 7am to 7pm L_{90} (dBA)	Nighttime Hourly 7pm to 7am L_{Aeq} (dBA)	Nighttime Hourly 7pm to 7am L_{50} (dBA)	Nighttime Hourly 7pm to 7am L_{90} (dBA)	Delta (Overall – Day) L_{Aeq} (dBA)	Delta (Overall – Day) L_{50} (dBA)	Delta (Overall – Day) L_{90} (dBA)	Delta (Overall – Night) L_{Aeq} (dBA)	Delta (Overall – Night) L_{50} (dBA)	Delta (Overall – Night) L_{90} (dBA)
1A	56.5	51.3	38.6	58.0	54.0	41.1	48.7	41.3	37.4	-1.5	-2.7	-2.5	7.8	10.0	1.2
1B	50.3	46.4	42.3	51.7	46.8	42.3	47.7	46.0	42.3	-1.4	-0.4	0.0	2.6	0.4	0.0
2A	44.3	32.3	22.5	36.5	28.3	20.6	46.8	35.7	27.1	7.8	4.0	1.9	-2.5	-3.4	-4.6
2B	51.4	33.2	22.9	45.0	32.4	22.2	53.8	33.8	23.8	6.4	0.8	0.7	-2.4	-0.6	-0.9
2C	47.7	35.1	22.9	40.6	33.0	18.9	49.5	35.7	28.3	7.1	2.1	4.0	-1.8	-0.6	-5.4
3A	40.6	25.2	16.4	42.1	28.2	17.2	38.5	22.7	16.2	-1.5	-3.0	-0.8	2.1	2.5	0.2
3B	41.5	29.4	16.1	44.2	29.6	17.7	35.5	29.2	15.6	-2.7	-0.2	-1.6	6.0	0.2	0.5
3C	42.2	38.2	28.9	43.0	37.2	28.6	41.3	38.9	29.5	-0.8	1.0	0.3	0.9	-0.7	-0.6
3D	35.5	18.4	17.0	39.8	20.2	17.4	28.4	17.8	17.0	-4.3	-1.8	-0.4	7.1	0.6	0.0
4A	44.6	37.3	25.9	39.7	33.1	25.6	46.9	45.4	26.7	4.9	4.2	0.3	-2.3	-8.1	-0.8
5A	40.1	30.2	17.6	42.5	34.9	26.5	35.2	23.3	16.5	-2.4	-4.7	-8.9	4.9	6.9	1.1
5B	30.6	19.5	15.7	33.3	23.4	17.4	22.6	16.3	15.6	-2.7	-3.9	-1.7	8.0	3.2	0.1
5C	34.2	23.7	16.9	36.7	27.6	20.3	29.5	17.9	16.7	-2.5	-3.9	-3.4	4.7	5.8	0.2
6A	45.0	27.9	23.3	39.4	28.9	23.7	47.2	26.5	22.7	5.6	-1.0	-0.4	-2.2	1.4	0.6
6B	43.7	28.6	22.1	42.5	30.8	23.8	44.6	27.1	20.4	1.2	-2.2	-1.7	-0.9	1.5	1.7
6C	50.9	32.7	22.5	53.3	33.1	23.2	45.6	32.4	22.0	-2.4	-0.4	-0.7	5.3	0.3	0.5
8A	51.0	45.7	36.7	46.6	43.0	36.9	53.1	51.1	36.1	4.4	2.7	-0.2	-2.1	-5.4	0.6
8B	45.8	40.5	32.5	46.1	38.3	32.7	45.5	42.9	32.0	-0.3	2.2	-0.2	0.3	-2.4	0.5
8C	46.4	37.5	25.3	42.0	31.4	24.4	48.5	47.5	30.0	4.4	6.1	0.9	-2.1	-10.0	-4.7
9A	46.5	32.4	20.0	49.1	29.5	19.0	39.4	33.7	23.1	-2.6	2.9	1.0	7.1	-1.3	-3.1
9B	39.0	32.1	19.2	39.7	33.0	20.2	38.3	31.3	18.6	-0.7	-0.9	-1.0	0.7	0.8	0.6
9C	45.2	32.4	22.7	48.2	29.2	22.1	36.2	35.4	23.8	-3.0	3.2	0.6	9.0	-3.0	-1.1
Average										*0.6*	*0.2*	*-0.6*	*2.3*	*-0.1*	*-0.6*

6.1.2 Seasonal Temporal Trends

As discussed in Section 2.7.2, one site within each acoustic zone was designated the long-term "permanent" site. At that site, data were collected on a long-term basis, i.e., longer than 2 weeks up to the entire measurement study duration of eight months. The average, daily, sound levels for each site were computed and analyzed by month and by season.

As shown in Table 14, the magnitudes of the monthly differences were small – on average, generally within 3 dBA for all three noise metrics (L_{Aeq}, L_{50}, and L_{90}). This supports qualitative observations made by Hawai`i Volcanoes NPS personnel that there is little climatic seasonal variation in Hawai`i and, therefore, little variability in the ambient would be expected month-to-month. As such, a seasonal adjustment was not implemented for Hawai`i Volcanoes. It should be noted that while some large differences can be seen in a few sites for particular months, these large differences were attributed to the comparatively small amounts of data collected during that specific month/season.

Figure 28 through Figure 34 provide more detailed plots of the average, daily sound level data for each long-term measurement site. The average wind speed for each hour is also plotted. As shown, wind had a large effect on daily sound levels. Note: As stated in Section 5.5.1 and discussed in Appendix E, data whose associated 1-second average wind speeds were larger than 11 mph (5 m/s), the predetermined, acceptable, wind speed threshold were removed from the analysis.

Table 14. Summary of seasonal trends.

Metric/ Site #	Overall (dBA)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Delta: Overall - Oct	Delta: Overall - Nov	Delta: Overall - Dec	Delta: Overall - Jan	Delta: Overall - Feb	Delta: Overall - Mar	Delta: Overall - Apr	Delta: Overall - May	Delta: Overall - Fall Oct-Nov	Delta: Overall - Winter Dec-Feb	Delta: Overall - Spring Mar-May
L_{Aeq} 2A	44.3	39.7	42.4	46.8	45.3	40.2	N/A	N/A	N/A	4.6	1.9	-2.5	-1.0	4.1	N/A	N/A	N/A	3.3	0.2	N/A
L_{Aeq} 3A	40.6	36.1	37.6	41.9	30.3	42.8	N/A	N/A	N/A	4.5	3.0	-1.3	10.3	-2.2	N/A	N/A	N/A	3.8	2.3	N/A
L_{Aeq} 4A	44.6	46.5	45.9	44.3	43.4	41.5	N/A	N/A	N/A	N/A	N/A	0.3	1.2	3.1	N/A	N/A	N/A	N/A	1.5	N/A
L_{Aeq} 5A	40.1	39.1	41.2	40.4	38.4	N/A	N/A	N/A	N/A	1.0	-1.1	-0.3	1.7	N/A	N/A	N/A	N/A	-0.1	0.7	N/A
L_{Aeq} 6A	45.0	40.2	43.3	70.2	46.8	46.8	N/A	N/A	N/A	4.8	1.7	-25.2	-1.8	-1.8	N/A	N/A	N/A	3.3	-9.6	N/A
L_{Aeq} 8A	51.0	50.1	52.6	51.3	50.8	47.7	N/A	42.8	43.6	0.9	-1.6	-0.3	0.2	3.3	N/A	8.2	7.4	-0.4	1.1	7.8
L_{Aeq} 9A	46.5	44.1	45.6	47.2	48.5	N/A	N/A	N/A	44.7	2.4	0.9	-0.7	-2.0	N/A	N/A	N/A	1.8	1.7	-1.4	N/A
Average										*3.0*	*0.8*	*-4.3*	*1.2*	*1.3*	*N/A*	*8.2*	*4.6*	*1.9*	*-0.7*	*7.8*
L_{50} 2A	32.3	35.7	31.7	34.2	32.0	31.7	N/A	N/A	N/A	-3.4	0.6	-1.9	0.3	0.6	N/A	N/A	N/A	-1.4	-0.3	N/A
L_{50} 3A	25.2	27.3	23.0	25.6	18.4	30.2	N/A	N/A	N/A	-2.1	8.2	-0.4	6.8	-5.0	N/A	N/A	N/A	0.1	0.5	N/A
L_{50} 4A	37.3	38.7	37.6	38.1	36.6	35.8	N/A	N/A	N/A	N/A	N/A	-0.8	0.7	1.5	N/A	N/A	N/A	N/A	0.5	N/A
L_{50} 5A	30.2	32.8	28.7	31.5	27.8	N/A	N/A	N/A	N/A	-2.6	1.5	-1.3	2.4	N/A	N/A	N/A	N/A	-0.6	0.6	N/A
L_{50} 6A	27.9	31.9	27.0	28.1	26.1	29.5	N/A	N/A	N/A	-4.0	0.9	-0.2	1.8	-1.6	N/A	N/A	N/A	-1.6	0.0	N/A
L_{50} 8A	45.7	44.4	46.9	46.7	47.2	44.7	N/A	39.9	40.7	1.3	-1.2	-1.0	-1.5	1.0	N/A	5.8	5.0	0.1	-0.5	5.4
L_{50} 9A	32.4	34.9	31.9	33.6	33.1	N/A	N/A	N/A	37.4	-2.5	0.5	-1.2	-0.7	N/A	N/A	N/A	-5.0	-1.0	-1.0	N/A
Average										*-2.2*	*1.8*	*-1.0*	*1.4*	*-0.7*	N/A	*5.8*	*0.0*	*-0.7*	*0.0*	*5.4*
L_{90} 2A	22.5	24.0	21.8	23.2	23.3	21.7	N/A	N/A	N/A	-1.5	0.7	-0.7	-0.8	0.8	N/A	N/A	N/A	-0.4	-0.2	N/A
L_{90} 3A	16.4	17.0	15.9	16.3	16.0	16.6	N/A	N/A	N/A	-0.6	0.5	0.1	0.4	-0.2	N/A	N/A	N/A	-0.1	0.1	N/A
L_{90} 4A	25.9	29.3	27.2	25.8	23.8	24.5	N/A	N/A	N/A	N/A	N/A	0.1	2.1	1.4	N/A	N/A	N/A	N/A	1.2	N/A
L_{90} 5A	17.6	22.4	18.8	17.8	16.4	N/A	N/A	N/A	N/A	-4.8	-1.2	-0.2	1.2	N/A	N/A	N/A	N/A	-3.0	0.5	N/A
L_{90} 6A	23.3	22.9	22.0	22.2	23.6	23.8	N/A	N/A	N/A	0.4	1.3	1.1	-0.3	-0.5	N/A	N/A	N/A	0.9	0.1	N/A
L_{90} 8A	36.7	37.0	37.9	37.3	37.1	35.9	N/A	29.5	34.0	-0.3	-1.2	-0.6	-0.4	0.8	N/A	7.2	2.7	-0.8	-0.1	5.0
L_{90} 9A	20.0	24.6	21.5	21.6	21.2	N/A	N/A	N/A	27.3	-4.6	-1.5	-1.6	-1.2	N/A	N/A	N/A	-7.3	-3.1	-1.4	N/A
Average										*-1.9*	*-0.2*	*-0.3*	*0.1*	*0.5*	N/A	*7.2*	*-2.3*	*-1.1*	*0.0*	*5.0*

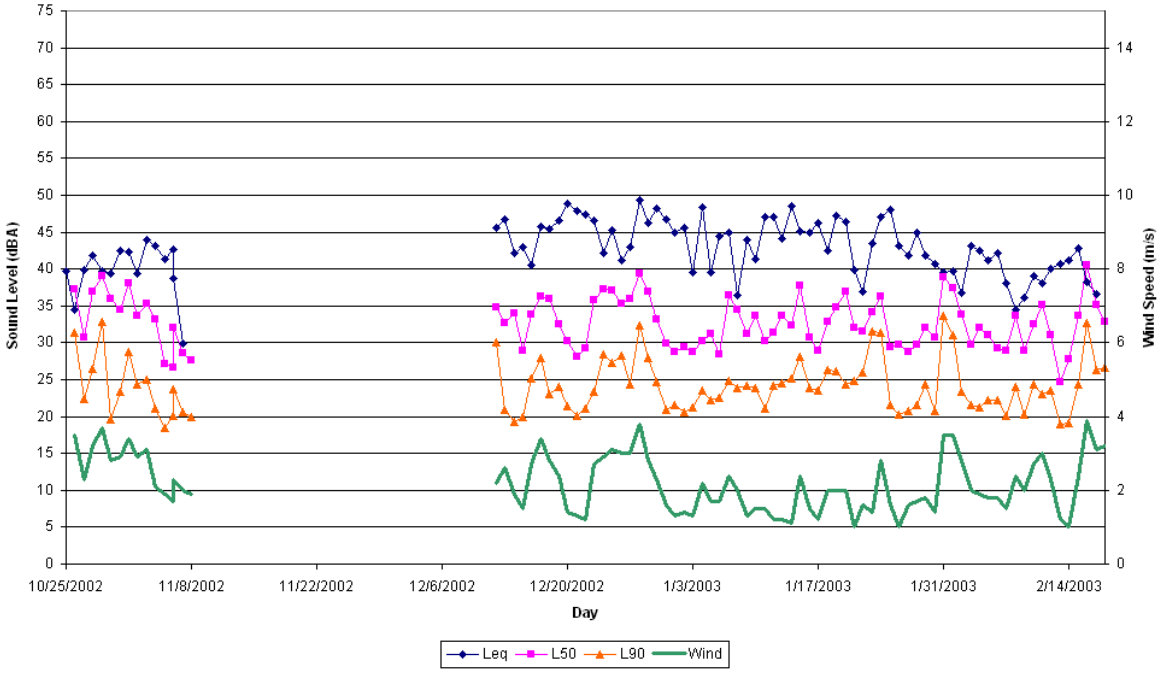


Figure 28. Long-term daily sound levels and wind speeds: Permanent Site 2A.

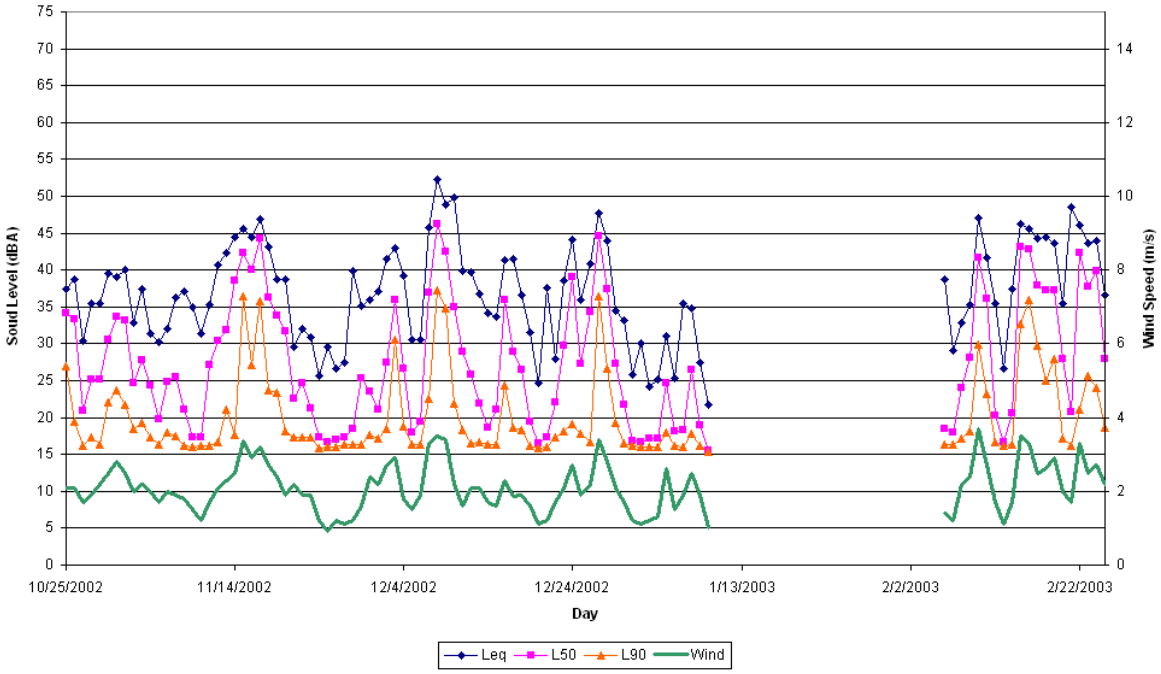


Figure 29. Long-term daily sound levels and wind speeds: Permanent Site 3A.

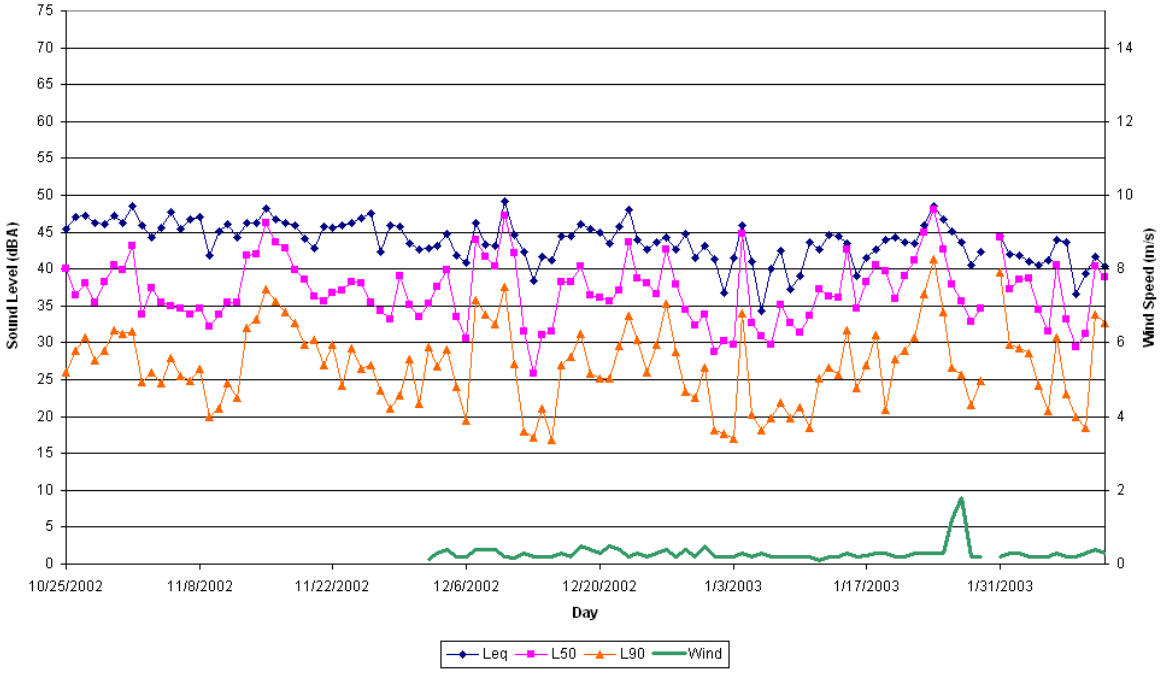


Figure 30. Long-term daily sound levels and wind speeds: Permanent Site 4A.

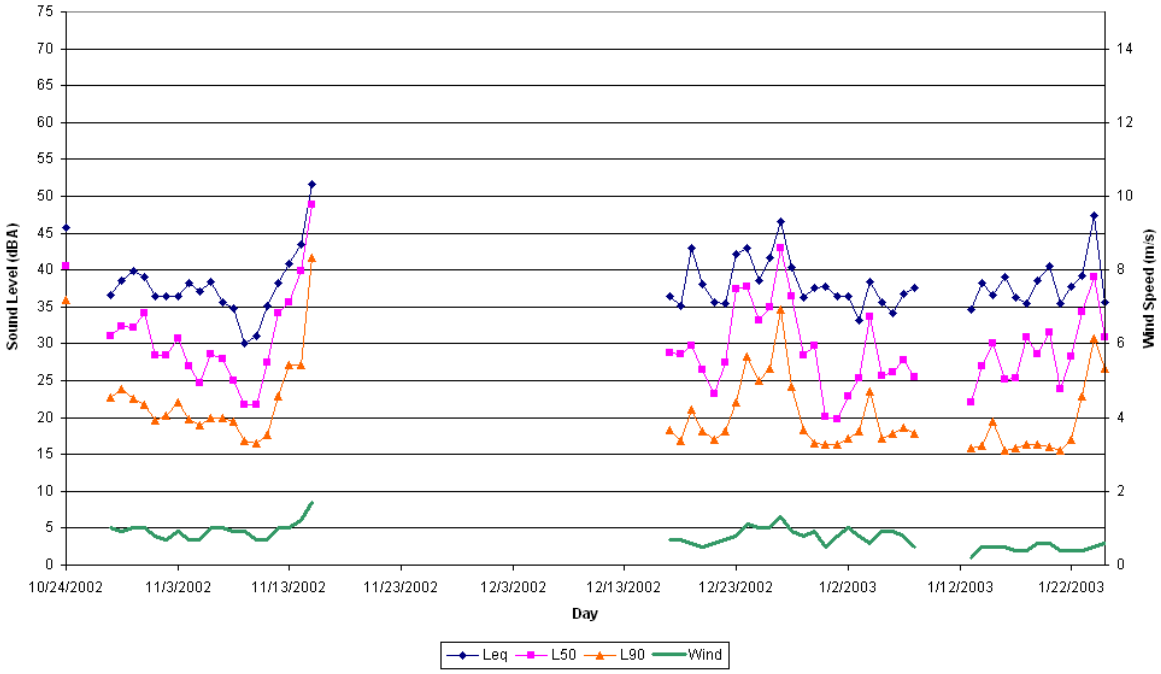


Figure 31. Long-term daily sound levels and wind speeds: Permanent Site 5A.

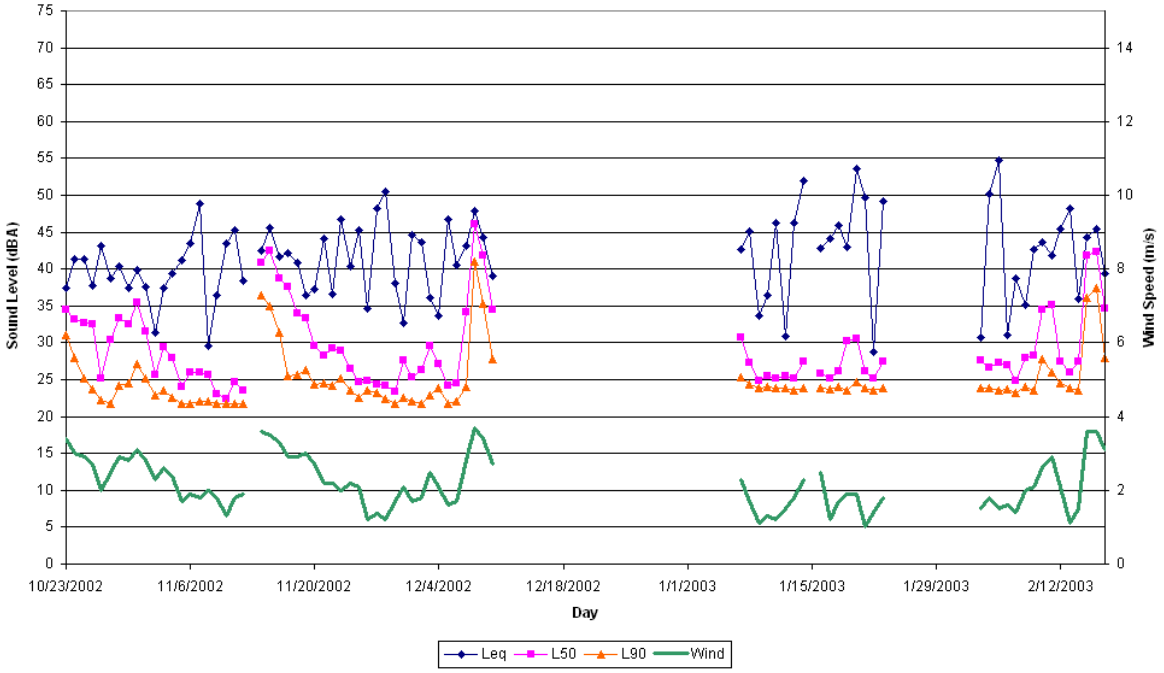


Figure 32. Long-term daily sound levels and wind speeds: Permanent Site 6A.

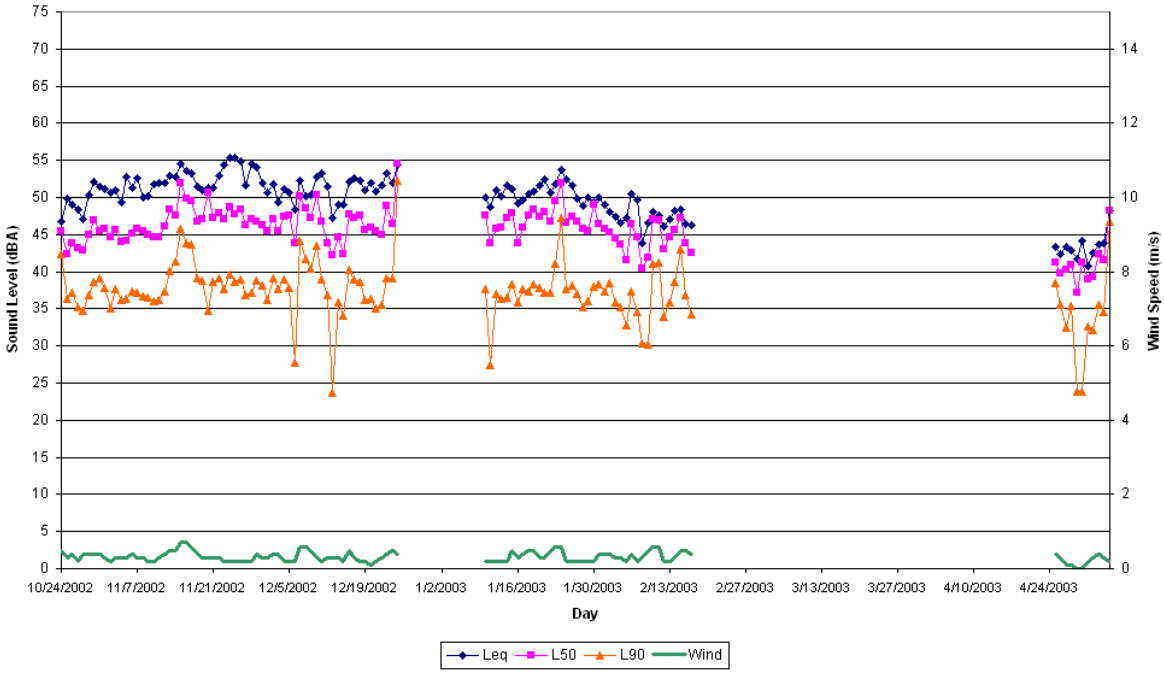


Figure 33. Long-term daily sound levels and wind speeds: Permanent Site 8A.

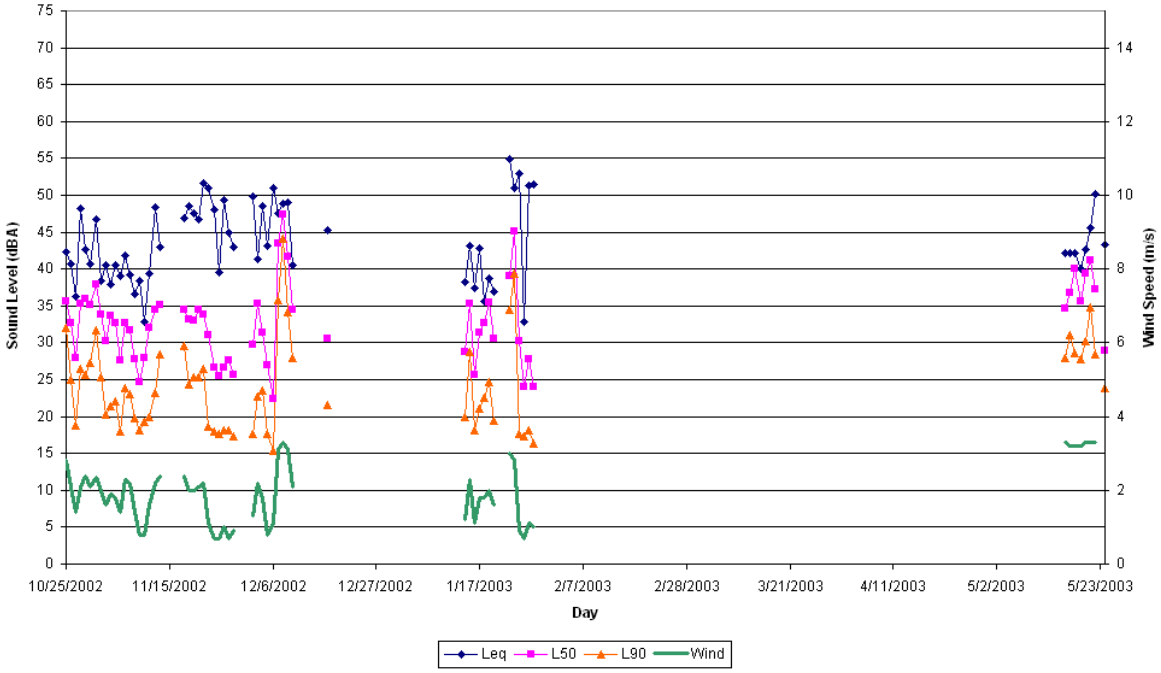


Figure 34. Long-term daily sound levels and wind speeds: Permanent Site 9A.

6.2 Acoustic Zones

As stated earlier in Section 2.6, it is anticipated that the use of acoustic zones as representative units, within which data can be collected and grouped (by land cover, wildlife activity, visitor-use, wind and seasonality, etc.) may be scientifically justified within large, homogeneous regions of a particular park, to similar areas within a park, and possibly between similar regions in other parks. In developing acoustic zones, land cover and climate/ecological domain appear to be the two most important technical factors influencing ambient sound levels in a national park since these factors are 1) related to the natural sources present in the area and 2) affect how sound waves propagate from source to receiver (Note: Appendix F discusses the analysis methodology in greater detail). In addition, human activity has been found to play a significant role in the acoustic characteristics of some park locations and, in some cases, overrides the land cover/ecological factors. Figure 35 displays the ten acoustic zones for Hawai`i Volcanoes as discussed in Section 2.6.

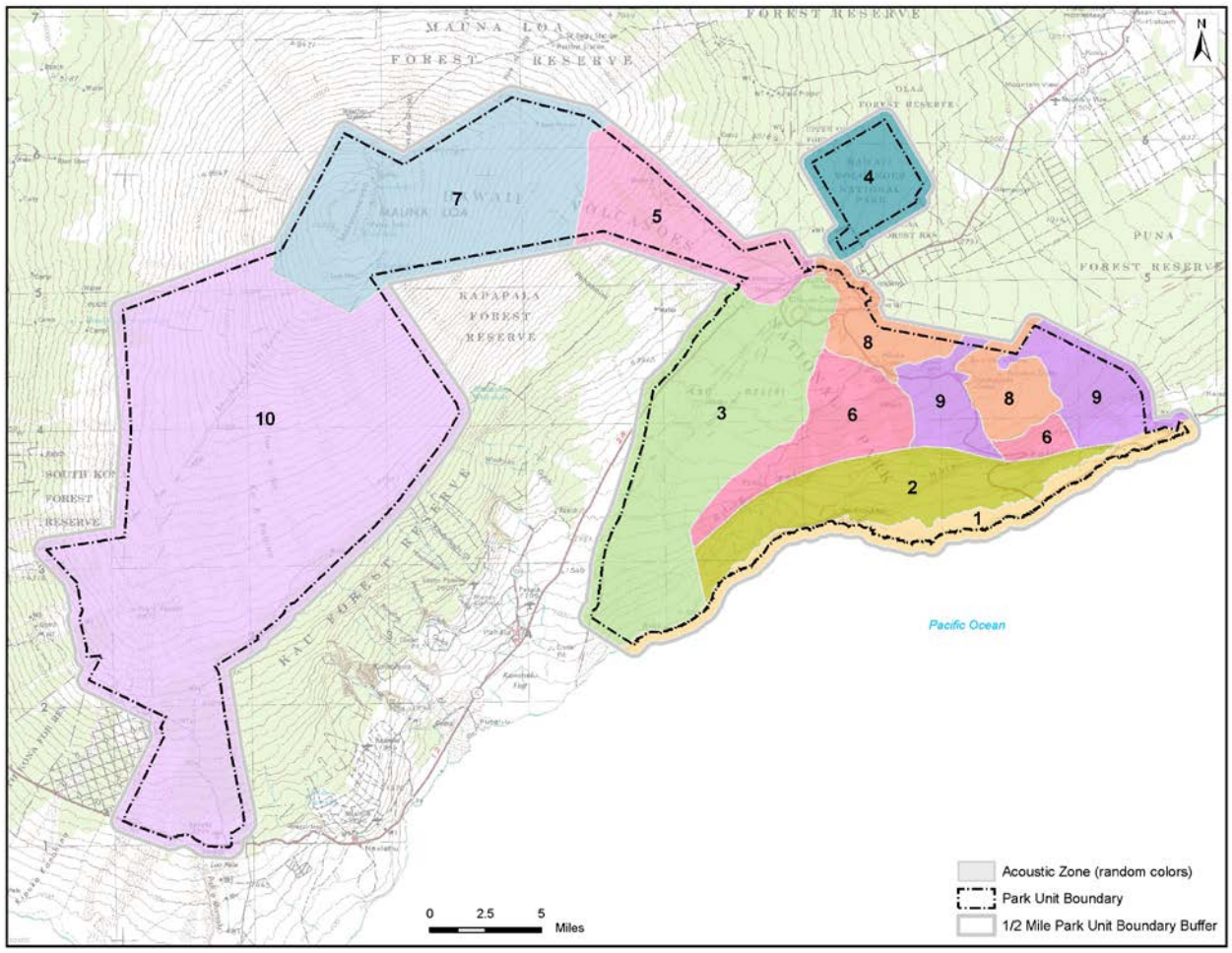


Figure 35. Acoustic zones for Hawai`i Volcanoes.

The following comparisons were performed to statistically assess ambient data collected at a pair of sites within Hawai`i Volcanoes that were: (1) located in the same acoustic zone, (2) had the same land cover class/subclass (per NLCD), or (3) experienced similar levels of visitor-use. As new ambient data are collected in parks with additional land cover types and within other ecological divisions, it is anticipated that the analysis of acoustic zones may be expanded to a larger scale, possibly nationwide.

Figure 36 presents the results of comparing ambient data collected at a pair of sites within Hawai`i Volcanoes, located in the same acoustic zone. From this analysis, there is statistical evidence to support the transferability of ambient data hypothesis. The following observations were made:

Acoustic Zone	Site ID	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	5A	5B	5C	6A	6B	6C	8A	8B	8C	9A	9B	9C
Shoreline	**1A**		S	F	F	F	F	F	S	F	F	S	F	F	F	F	F	S	F	S	F	F	F
Shoreline	**1B**			F	S	S	S	S	S	F	S	F	S	S	S	S	S	F	S	S	S	F	F
Coastal Lowlands	**2A**				F	S	F	S	F	F	F	F	SS	SS	S	S	F	F	F	F	F	S	S
Coastal Lowlands	**2B**					SS	S	S	S	F	S	S	S	S	S	SS	SS	F	S	SS	SS	S	S
Coastal Lowlands	**2C**						S	SS	SS	F	S	S	S	SS	F	SS	S	F	S	SS	S	SS	SS
Ka`u Desert/Kilauea Summit	**3A**							S	F	F	F	F	F	S	F	F	S	F	F	F	SS	F	S
Ka`u Desert/Kilauea Summit	**3B**								F	F	F	F	F	S	F	S	S	F	F	S	S	SS	SS
Ka`u Desert/Kilauea Summit	**3C**									F	S	S	F	F	F	F	S	F	SS	S	F	S	F
Ka`u Desert/Kilauea Summit	**3D**										S	F	SS	S	F	F	F	F	F	S	F	F	F
Ola`a Rain Forest	**4A**											S	F	F	F	SS	F	F	F	S	F	F	S
Mauna Loa Forest	**5A**												F	F	F	F	S	F	F	S	F	S	S
Mauna Loa Forest	**5B**													S	SS	S	S	F	F	F	S	F	S
Mauna Loa Forest	**5C**														SS	S	F	F	F	F	S	S	SS
Dry Ohi`a Woodlands	**6A**															S	F	F	F	S	S	F	S
Dry Ohi`a Woodlands	**6B**																S	F	F	SS	S	S	S
Dry Ohi`a Woodlands	**6C**																	F	F	S	SS	S	S
Young Rain Forest	**8A**																		F	F	F	F	F
Young Rain Forest	**8B**																			F	F	F	F
Young Rain Forest	**8C**																				S	S	SS
New Lava Flows	**9A**																					S	S
New Lava Flows	**9B**																						SS
New Lava Flows	**9C**																						

Figure 36. Data transferability within acoustic zones.

Note 1: SS = Both tests passed, i.e., data showed strong similarity.
F = Both tests failed, i.e., data were not similar.
S = One test passed, i.e., data showed some similarity.

Note 2: Cells highlighted in yellow indicate pairs of sites within the same acoustic zone.

- For acoustic zone 1 (Shoreline), this zone experienced significant wind and surf noise, and demonstrated reasonable similarity. The differences were attributed to visitor activity.
- For acoustic zone 2 (Coastal Lowlands), this zone consisted of primarily grassy vegetation (without significant bird or insect presence) and demonstrated reasonable similarity, with differences attributed to visitor activity.
- For acoustic zone 3 (Ka`ū Desert/Kīlauea Summit), Sites 3A and 3B showed similarity but other site comparisons within this zone not. Differences seen at Sites 3C and 3D when compared with Sites 3A and 3B were attributed to differences in visitor activity as the latter two sites were located in the more desolate Ka`ū Desert and exhibited higher wind speeds.
- For acoustic zone 5 (Mauna Loa Forest), this zone was initially expected to show similarity; however, differences in tour activity played a significant role as the spectral data for Site 5A showed more helicopter activity than Sites 5B and 5C.
- For acoustic zone 6 (Dry Ohi`a Woodlands), the analysis showed some similarity within the zone.
- For acoustic zone 8 (Young Rain Forest), the analysis did not show similarity within this zone. Differences were attributed to human activity upon review of the spectral data (vehicular traffic sounds at Site 8A; aircraft sounds at Sites 8B and 8C).
- For acoustic zone 9 (New Lava Flows), some similarity for all site comparisons was seen in this zone.

Figure 37 presents the results of comparing ambient data collected at pairs of sites within Hawai`i Volcanoes, located in the same land cover class/subclass (per National Land Cover Database, or NLCD, as discussed in Appendix F). From this analysis, data similarities were seen for grassland (Zones 2 and 6), bare rock/sand/clay (Zone 3 and Site 2C), evergreen forest (Sites 5A and 8C), shrubland (Sites 5B, 5C, 6B, and 6C). Interestingly, data similarities were not present for the evergreen forest sites in acoustic zones 4 and 8 (largely due to the remoteness of zone 4 and the variability in the bird and insect populations between the two zones).

NLCD Land Cover Classification	Site ID	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	5A	5B	5C	6A	6B	6C	8A	8B	8C	9A	9B	9C
31 Bare Rock/Sand/Clay	**1A**		S	F	F	F	F	F	S	F	F	S	F	F	F	F	F	S	F	S	F	F	F
31 Bare Rock/Sand/Clay	**1B**			F	S	S	S	S	S	F	S	F	S	S	S	S	S	F	S	S	S	F	F
71 Grasslands/Herbaceous	**2A**				F	S	F	S	F	F	F	F	SS	SS	S	S	F	F	F	F	F	S	S
71 Grasslands/Herbaceous	**2B**					SS	S	S	S	F	S	S	S	S	S	SS	SS	F	S	SS	SS	S	S
31 Bare Rock/Sand/Clay	**2C**						S	SS	SS	F	S	S	S	SS	F	SS	S	F	S	SS	S	SS	SS
31 Bare Rock/Sand/Clay	**3A**							S	F	F	F	F	F	S	F	F	S	F	F	F	SS	F	S
31 Bare Rock/Sand/Clay	**3B**								F	F	F	F	F	S	F	S	S	F	F	S	S	SS	SS
71 Grasslands/Herbaceous	**3C**									F	S	S	F	F	F	F	S	F	SS	S	F	S	F
31 Bare Rock/Sand/Clay	**3D**										S	F	SS	S	F	F	F	F	F	S	F	F	F
42 Evergreen Forest	**4A**											S	F	F	F	SS	F	F	F	S	F	F	S
42 Evergreen Forest	**5A**												F	F	F	F	S	F	F	S	F	S	S
51 Shrubland	**5B**													S	SS	S	S	F	F	F	S	F	S
51 Shrubland	**5C**														SS	S	F	F	F	F	S	S	SS
71 Grasslands/Herbaceous	**6A**															S	F	F	F	S	S	F	S
71 Grasslands/Herbaceous	**6B**																S	F	F	SS	S	S	S
71 Grasslands/Herbaceous	**6C**																	F	F	S	SS	S	S
42 Evergreen Forest	**8A**																		F	F	F	F	F
42 Evergreen Forest	**8B**																			F	F	F	F
42 Evergreen Forest	**8C**																				S	S	SS
33 Transitional	**9A**																					S	S
33 Transitional	**9B**																						SS
33 Transitional	**9C**																						

Figure 37. Data comparisons for land cover.

Note 1: SS = Both tests passed, i.e., data showed strong similarity.
F = Both tests failed, i.e., data were not similar.
S = One test passed, i.e., data showed some similarity.

Note 2: Cells highlighted in yellow indicate pairs of sites with the same land cover classification.

Figure 38 presents the results of comparing ambient data collected at pairs of sites within Hawai`i Volcanoes, with similar levels of estimated visitor activity (see Section 2.5.1). From this analysis, high and medium visitor-use sites showed data similarity, while low visitor-use sites did not. This leads to a conclusion that human influence can override natural features, which normally are significant in the definition of the ambient acoustics. It was further noted that the shorter monitoring periods at the short-term sites tended to be more sensitive to aircraft activity than the long-term sites.

In addition, a subsequent review of specific similar site combinations led to the observation that several site groupings exhibited regional similarity that was not anticipated by the original zone designations. For example, Sites 2A, 2B, 2C, 6A, 6C, and 9B were located within three different acoustic zones, according to the original zone delineation; however, the actual locations of these sites were in general proximity to each other (hereto referred as, "pali sites"). Statistical similarity was observed at all but the more remote "pali sites" (Sites 2A and 6A), indicating that human activity to be a significant factor (sound-level distributions at these two sites were quieter than other "pali sites"). These results are very interesting since these sites cut across predetermined intuition regarding eco-similarity and shows data similarity due to a mix of similar land cover and human exposure rather than one or the other.

In conclusion, the results of the acoustic zone analysis can be summarized as follows:

- Sites with low to medium human activity (hikers, roadway traffic, aircraft sounds), in general, showed statistical similarity when the land cover and ecological conditions were similar. For example, Sites 2A and 6A were remote and grassy sites and showed similarity; Sites 3A and 9A were vegetatively barren with some human activity and showed similarity.
- High and medium visitor-use sites showed data similarity, while low visitor-use sites did not.
- An interesting group of sites emerged ("pali sites") that were found to be statistically similar (Sites 2B, 2C, 6C, 9B, and 9C) despite differences in land cover.

Visitor-Use	Site ID	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	5A	5B	5C	6A	6B	6C	8A	8B	8C	9A	9B	9C
Short Hike	1A		S	F	F	F	F	F	S	F	F	S	F	F	F	F	F	S	F	S	F	F	F
Overlook	1B			F	S	S	S	S	S	F	S	F	S	S	S	S	S	F	S	S	S	F	F
Backcountry	2A				F	S	F	S	F	F	F	F	SS	SS	S	S	F	F	F	F	F	S	S
Short Hike	2B					SS	S	S	S	F	S	S	S	S	S	SS	SS	F	S	SS	SS	S	S
Short Hike	2C						S	SS	SS	F	S	S	S	SS	F	SS	S	F	S	SS	S	SS	SS
Short Hike	3A							S	F	F	F	F	F	S	F	F	S	F	F	F	SS	F	S
Overlook	3B								F	F	F	F	F	S	F	S	S	F	F	S	S	SS	SS
Overlook	3C									F	S	S	F	F	F	F	S	F	SS	S	F	S	F
Short Hike	3D										S	F	SS	S	F	F	F	F	F	S	F	F	F
Wilderness	4A											S	F	F	F	SS	F	F	F	S	F	F	S
Overlook	5A												F	F	F	F	S	F	F	S	F	S	S
Short Hike	5B													S	SS	S	S	F	F	F	S	F	S
Short Hike	5C														SS	S	F	F	F	F	S	S	SS
Short Hike	6A															S	F	F	F	S	S	F	S
Backcountry	6B																S	F	F	SS	S	S	S
Short Hike	6C																	F	F	S	SS	S	S
Short Hike	8A																		F	F	F	F	F
Short Hike	8B																			F	F	F	F
Backcountry	8C																				S	S	SS
Backcountry	9A																					S	S
Overlook	9B																						SS
Backcountry	9C																						

Figure 38. Data comparisons for visitor-use.

Note 1: SS = Both tests passed, i.e., data showed strong similarity.
F = Both tests failed, i.e., data were not similar.
S = One test passed, i.e., data showed some similarity.

Note 2: Cells highlighted in yellow indicate pairs of sites with the same visitor-use classification.

6.3 Measurement Duration

As discussed earlier in Section 2.7.2, measurement duration is a very difficult technical issue on which to reach consensus. Because many parks experience not only daily, but also seasonal, variability, the choice of how long to measure must balance technical considerations and available resources. It is simply not practical to measure at sites for many months, or over the course of several years. However, measurements at a particular site should not only be of sufficient duration to ensure statistical confidence in the data, but also be reasonable in light of practical and other resource considerations.

With the extensive amount of data collected (over 900 days spanning 3 seasons) during this study, a unique opportunity is provided, however, to test the magnitude of data variability as a function sample size (measurement duration). The data measured in this study provide a scientific basis to optimize future data collection durations and, thus, potentially minimize data collection/analysis costs in future parks. The assessment presented herein includes determining the potential errors associated with shorter versus longer duration data sets.

Figure 39 plots the average minimum and maximum differences in L_{50} and sound levels associated with various sample sizes, from 4 to 21 days (the orange and magenta lines, respectively) when compared to the overall L_{50} sound level for the entire measurement duration ***for all long-term measurement sites***. For example, the maximum L_{50} for a 4-day sample size represents the maximum L_{50} that would be obtained should the measurement team had visited and performed data collection at a permanent site for *any* 4 days within the full measurement period. As can be seen, the maximum and minimum L_{50} values can be many decibels different than the overall L_{50}. That indicates that a 4-day sample could result in a substantial overstatement/ understatement of the L_{50}. This "error" steadily decreases with increasing sample size and begins to approach reasonable (within about 5 dB) levels of uncertainty between about 10- and 14-day sample period. Also, at about this sample size, the rate of change in the variability begins to level out, i.e., longer sample periods increase the confidence in the measured data to a much lesser degree. As shown, the greater the sample size, the more the data converges with the overall level presenting a more accurate characterization of the ambient at that site. Figure 40 plots the results of this analysis performed using L_{90} sound levels.

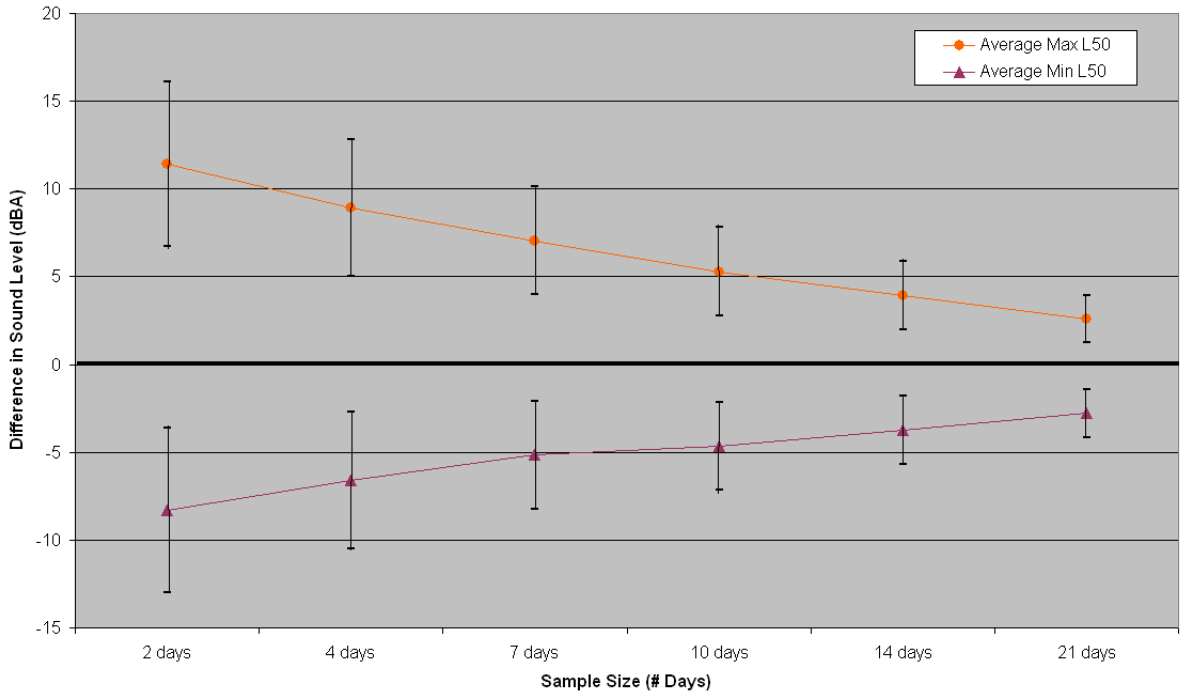


Figure 39. Summary of L_{50} results for all permanent measurement sites.

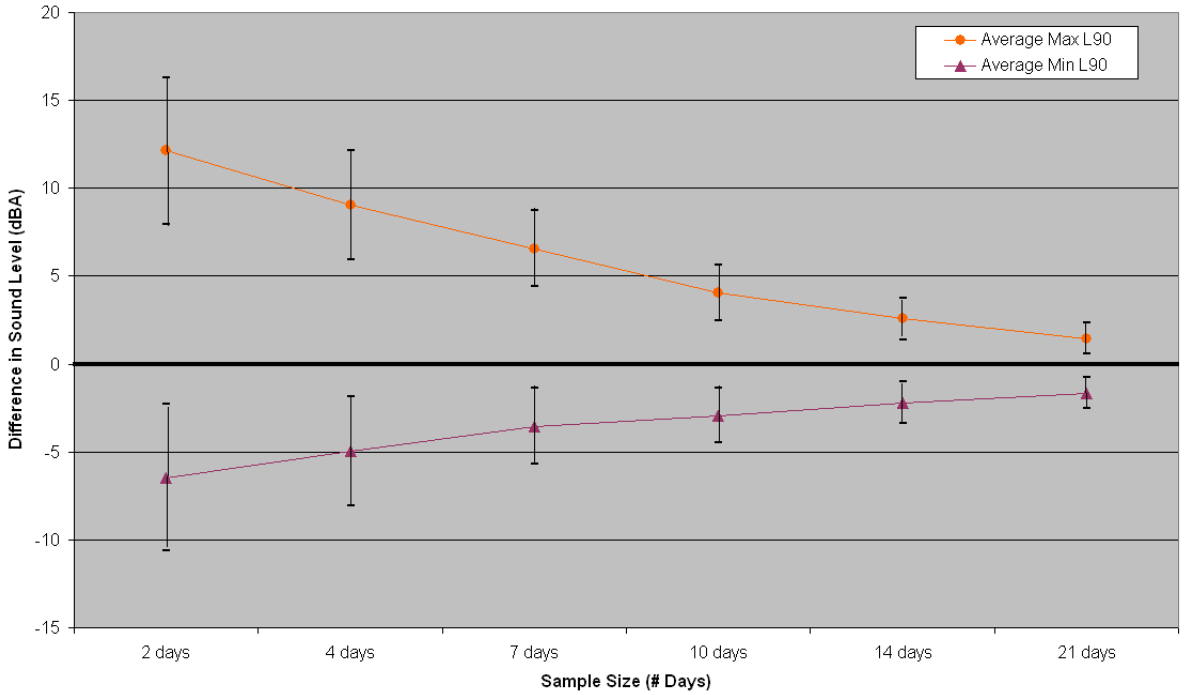


Figure 40. Summary of L_{90} results for all permanent measurement sites.

Figure 41 through Figure 47 plot the results of this analysis performed using L_{50} sound levels for each individual long-term site.

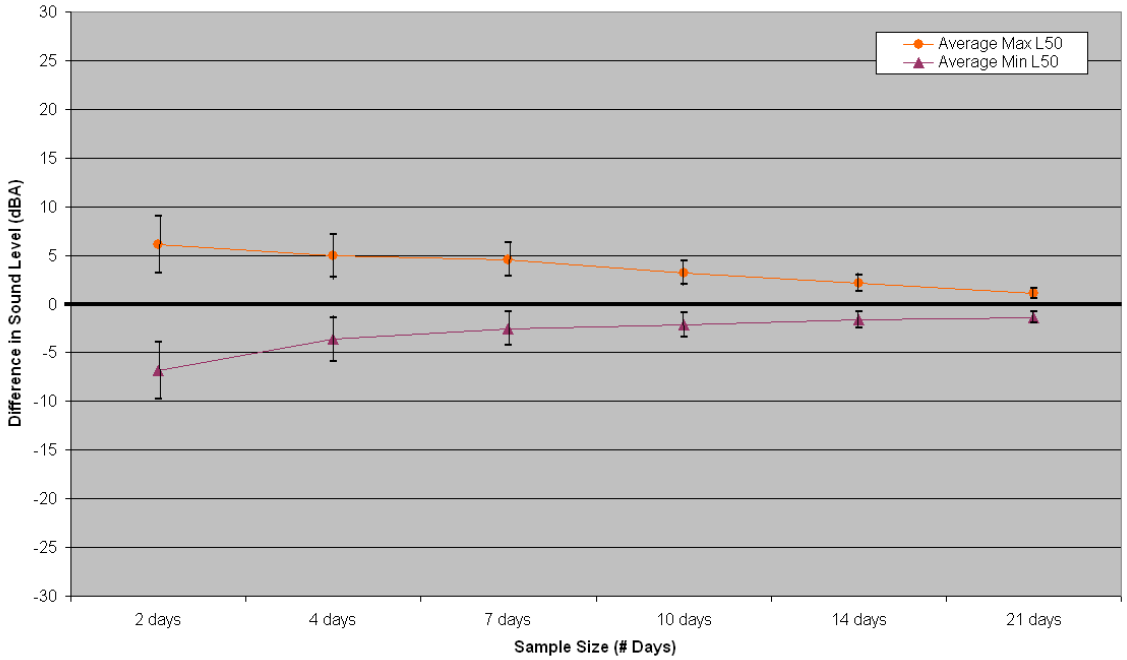


Figure 41. Summary of L_{50} results for Site 2A (86 days of data).

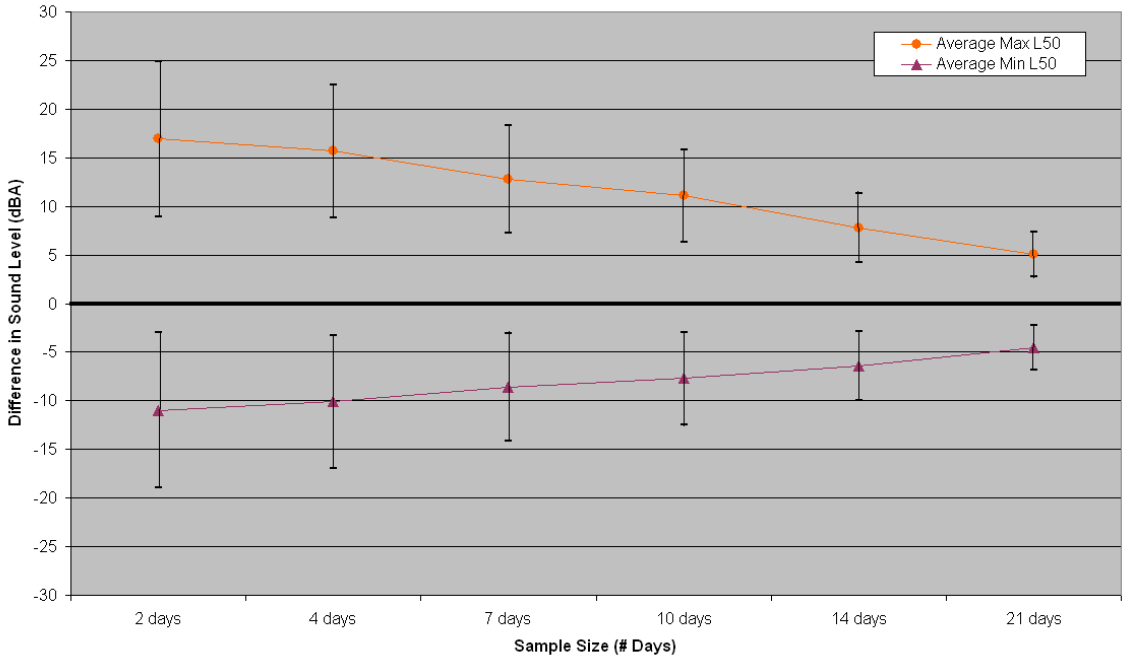


Figure 42. Summary of L_{50} results for Site 3A (99 days of data).

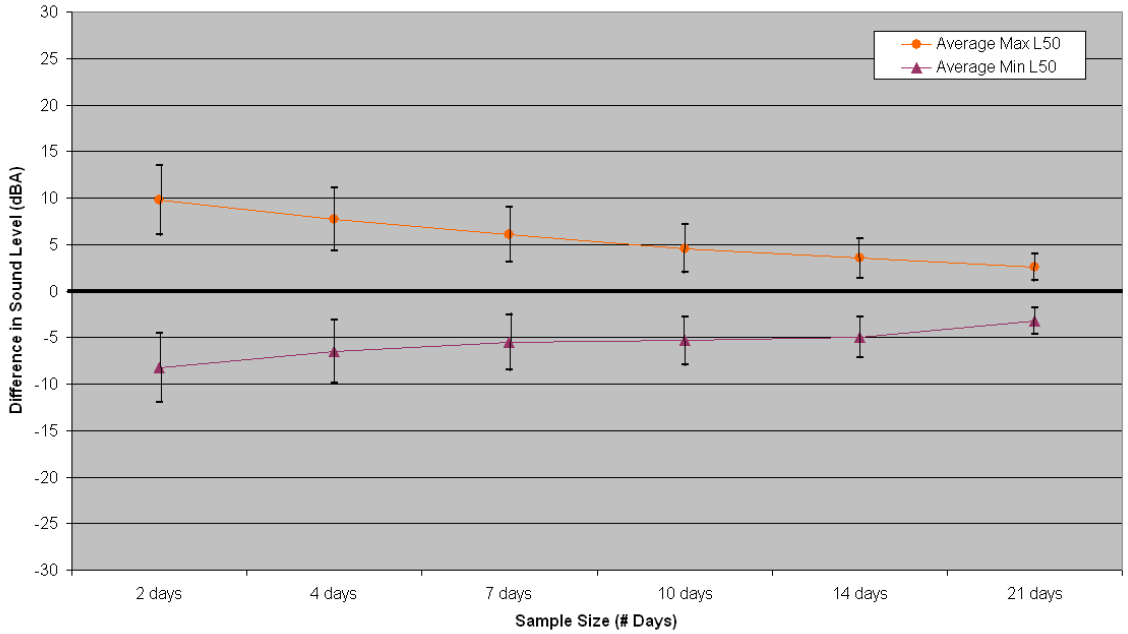


Figure 43. Summary of L_{50} results for Site 4A (118 days of data).

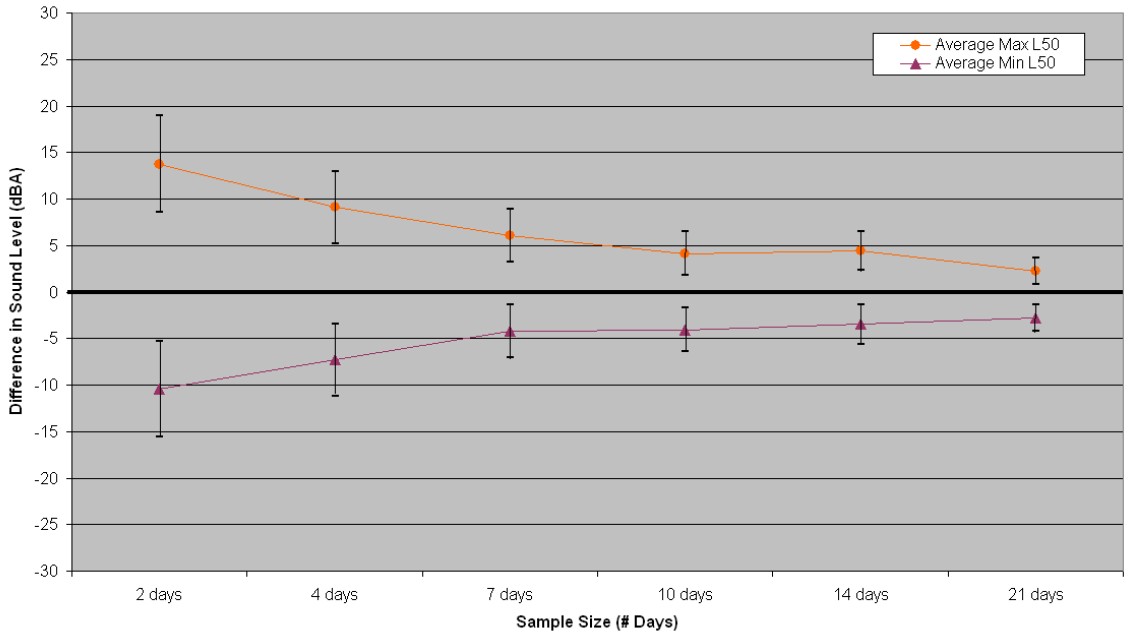


Figure 44. Summary of L_{50} results for Site 5A (57 days of data).

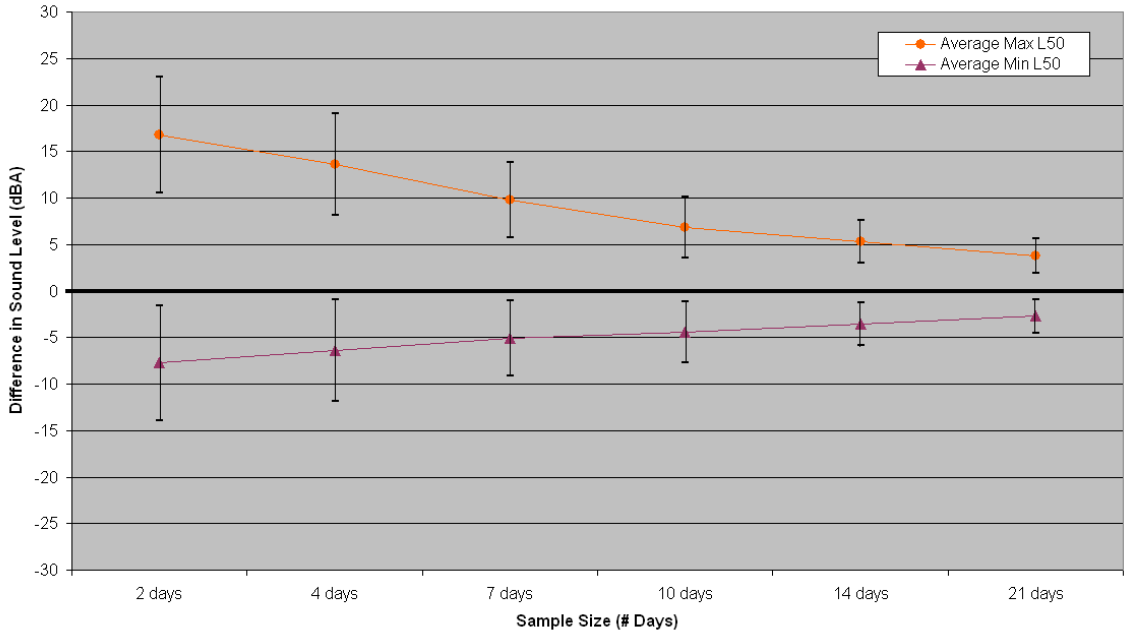


Figure 45. Summary of L_{50} results for Site 6A (84 days of data).

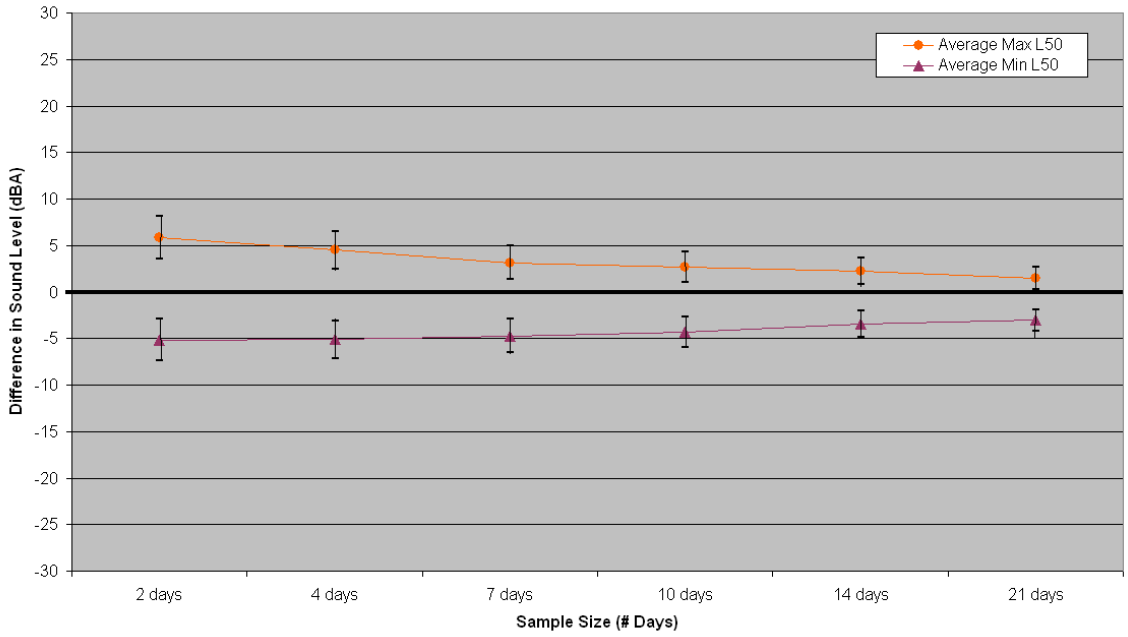


Figure 46. Summary of L_{50} results for Site 8A (120 days of data).

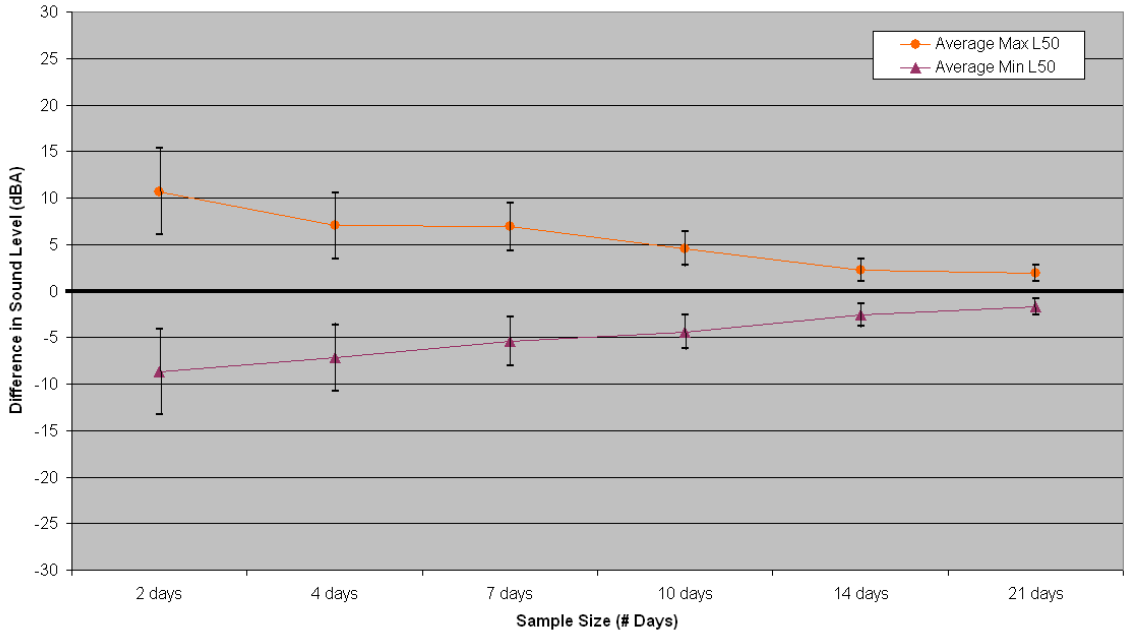


Figure 47. Summary of L_{50} results for Site 9A (68 days of data).

The FAA and NPS have jointly agreed that selecting a sample size, which limited measurement uncertainty to 3 decibels, was desirable. Based on this analysis, as well as a joint review of acoustic literature and other recent long-term NPS ambient studies in Bryce Canyon National Park and Arches National Park,[31] the 3-dB variability was achieved between 10, 25, and 40 days, depending on individual site variables/characteristics. As a result, the FAA and NPS have agreed upon a minimum 25-day measurement period for all future acoustic monitoring.

An exception to the 25-day requirement would be for measurements in close proximity to localized sound sources, which don't vary substantially in level, such as waterfalls, river rapids, train tracks, and busy visitor centers. The measurement period for such situations will be situation dependent, but generally, for visitor centers and travel corridors, a 10-day measurement period will be adequate. As discussed in Section 2.1, for the purpose of characterizing sound sources such as waterfalls and river rapids, acoustic data should be measured at a minimum of two distinct distances from the source, so as to characterize a reference level and the rate at which sound level decreases with increasing distance from the source. For roadways, traffic sounds may be modeled using the Federal Highway Administration's Traffic Noise Model® (TNM).[32] Note: To support TNM modeling, the following input data are required: traffic

volume, traffic speed, vehicle mix, and ground surface characteristics, e.g., grass, water, rock, etc. Section 6.4.2 discusses the localized sound sources for Hawai`i Volcanoes.

6.4 Development of Ambient Maps

Over the past decade, several definitions of ambient noise have been adopted by different organizations depending on their application.[7,15,16,33] In fact, a review of the acoustical issues regarding the measurement of ambient data has been the subject of on-going discussions between the FAA and NPS.[34,35] This includes which metric will be used to describe ambient (e.g., L_{Aeq}, L_{50}, or L_{90}). The FAA and NPS agree on the definitions of ambient. However, because the FAA and NPS have different methodologies for assessing noise impacts, it is not clear which definition is the most appropriate. The four types of "ambient" used in this report are defined as follows (see Figure 48):

- *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.

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

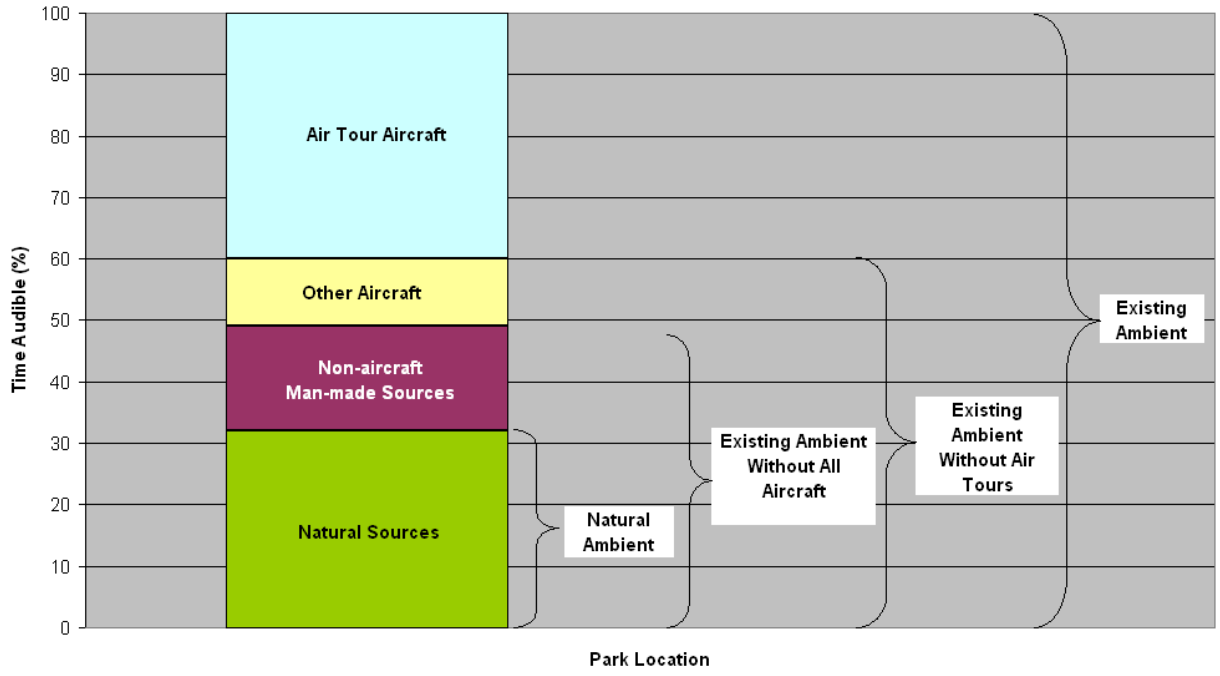


Figure 48. Graphical depiction of ambient definitions.

Nine ambient sound level values were initially computed for every measurement site as listed in Table 15 (Note: The L_{Aeq} metric was computed for the Existing Ambient only).*

Table 15. Matrix of ambient maps.

Metric	Existing Ambient	Existing Ambient Without Air Tours	Existing Ambient Without All Aircraft	Natural Ambient
L_{Aeq}	Map 1	N/A	N/A	N/A
L_{50}	Map 2	Map 4	Map 6	Map 8
L_{90}	Map 3	Map 5	Map 7	Map 9

6.4.1 Computation of Existing, Traditional, Cumulative Traditional, and Natural Ambients

The FAA/Volpe/NPS are developing standards for computing ambient sound levels in National Parks. Because different sound sources often overlap in both frequency and amplitude, there is currently no practical method to separate acoustic energy of human-caused sounds from that of natural sounds. Working closely with the NPS, [36] a

* If the need for a diurnal or seasonal adjustment had been determined during the data analysis, the number of resultant ambient sound level values would have increased by the number of adjustments to be applied.

methodology was developed to utilize short-term VoLARE 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 NoiseLogger™ data. The objectives of the methodology were:

- To obtain a percentile statistical value from VoLARE data (commonly referred to as L_x), which corresponds to each of the ambient types, 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 VoLARE would only be used to determine the statistical index; and
- To obtain a spectral shape from VoLARE, which corresponds to each of the ambient types, and adjust the shape (up or down in level) based on the L_x value derived from the long-term data.

The developed methodology was comprised of the following steps:

1. Using the A-weighted sound level data derived from the VoLARE one-second, one-third octave-band data, in concert with the acoustic state observer logs, compute the L_{50} for each of the four primary ambients, based on the definitions presented in Section 6.0.
2. Sort, high-to-low, the A-weighted level data, derived from the VoLARE one-second, one-third octave-band data (regardless of acoustic state), and determine what L_x corresponds to the L_{50} for each of the three ambients from Step 1 above.
3. Sort, high-to-low, the long-term NoiseLogger™ data collected at a site and based on the L_x values determined in Step 2 above for each ambient type, 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 L_{50} Natural Ambient corresponds to an L_{65} of all the VoLARE 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 for each of the four ambients.
4. 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 ⅓-octave bands (see Step 5).

5. Apply the factor derived in Step 4 to the level in each one-third octave-band from Step 1 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.

It should be noted that the above approach can result in some quiet Natural Ambient data being removed from the sub-sample and thus potentially over-estimating the resultant ambient. This results in ambient sound levels for the sub-sample occasionally being greater (generally less than 1 dB) than Existing Ambient sound levels, which is a logically impossible outcome, because the uncensored data represents the summed contributions of natural and human-caused ambient sounds. Such small differences will have a negligible effect on the computer modeling results. Both agencies acknowledge that the methods are imperfect, and additional research is on-going to develop better methodology for these calculations.

The final ambient maps are a composite of one-third octave-band spectral data, including contributions from ambient measurements, as well as contributions from modeled roadways and other localized sound sources (see Section 6.4.2). The ambient maps, along with aircraft source and schedule data, provide the input parameters utilized by the INM or AEDT to compute various noise-related descriptors and generate the sound-level contours that will be used in the assessment of potential noise impacts due to air tour operations.

6.4.2 Other Considerations

In addition to the measured ambient sound levels, the contributing effect of localized noise sources, such as waterfalls, river rapids, train tracks, and roads, should be considered in the development of the ambient maps. For Hawai`i Volcanoes, there were no localized water sources or train tracks, but there were four primary, and relatively

busy, roads: Highway 11, Mauna Loa Strip Road, Crater Rim Drive, and Chain of Craters Road. Specifically, the estimated drop-off rate, reflecting a continuous decrease in sound level as a function of increasing distance from each road, was computed using the Federal Highway Administration's Traffic Noise Model® (TNM).[32] The following assumptions were made in using TNM:

- *Traffic Volumes* – For Highway 11, an hourly traffic volume was determined based on data extrapolated from a three-day transportation study performed in 2002 and provided by Hawai`i Volcanoes NPS personnel (see Table 16). For the other three roads, an hourly traffic volume was determined from data provided by the NPS Public Use Statistics Office (http://www2.nature.nps.gov/stats/).

Table 16. TNM traffic volume input.

Vehicle Type	NPS Study: Highway 11 Annual Volume = 2,111,890	NPS Study: Highway 11 Estimated Hourly Volume	NPS Public Summary, Total Annual Volume [3]	NPS Public Summary, Estimated Hourly Volume [4]	NPS Public Summary, Estimated Hourly Volume on Mauna Loa Strip Road [5]	NPS Public Summary, Estimated Hourly Volume on Crater Rim Drive [6]	NPS Public Summary, Estimated Hourly Volume on Chain of Craters Road [6]
Autos		462	1,035,900	237	99	138	138
Buses		5	11,263	3	0	3	3
Heavy Trucks		14	N/A	0	0	0	0

* Note 1: Total annual automobile volume is based on total annual recreational and non-recreational vehicles in NPS Public Use Summary report.

** Note 2: Estimated hourly volume is computed by dividing the annual volume by 365 days and 12 hours per day, which assumes the majority of traffic in Hawai`i Volcanoes occurs between 6 am and 6 pm – an assumption consistent with the typical operational hours that the majority of Hawai`i air tours conduct air tours.

*** Note 3: Estimated hourly volume on Mauna Loa Strip Road is assumed to be proportional to the ratio of backcountry visits to Mauna Loa as compared to the rest of Hawai`i Volcanoes.

**** Note 4: As Crater Rim Drive and Chain of Craters Road is accessed via Hawai`i Volcanoes' main entrance, and Mauna Loa Strip Road is accessed via an outside entrance of Highway Route 11, it was assumed traffic on Mauna Loa would be separate from the other 2 roadways. It was further assumed that all traffic entering the main entrance would use both Crater Rim Drive and Chain of Craters Road.

- *Traffic Speeds* – According to Hawai`i Volcanoes NPS personnel, the posted speed limit ranges from 45 to 55 mph (72.4 to 88.5 kph) on Highway 11, and 15 to 45 mph (24.1 to 72.4 kph) on the other three roads. A conservatively high average speed of 50 mph (80.5 kph) was used for Highway 11; and 30 mph (48.3 kph) for the other three roads.

- *Ground Impedance* – Because of the amount of lava rock of various types (from a'a versus pahoehoe lava flows), a moderately hard acoustical ground impedance was assumed using an effective flow resistivity of 1000 cgs/rayls.

6.4.3 Assignment of Ambient Sound Levels

As stated in the previous section, a comprehensive grid was created in the development of a composite map of ambient sound levels throughout the park (including contributions from ambient measurements, as well as contributions from modeled roadways). The process of assigning ambient noise to each grid point location was a time-consuming, but relatively straightforward process, using Geographical Information System (GIS) in concert with software developed by the Volpe Center. The program performs the following actions:

- Define the input "objects":
  - Define the park boundary in Universal Transverse Mercator (UTM)* coordinates to set the initial grid area boundary.†
  - Divide the park into a regular grid of points at a desired spacing using a Digital Elevation Model (DEM), which is a digital representation of a topographic surface typically used in GIS applications. Each point is assigned an elevation value and UTM coordinates from the DEM. Note: For Hawai`i Volcanoes, a grid spacing of 500 ft (152.4 m) was used, resulting in approximately 44,500 grid points (38,000 grid points inside Hawai`i Volcanoes and 6,500 within the ½-mile buffer).
  - Define the acoustic zone boundaries in UTM coordinates.
  - Define the location of each measurement site. Within a particular acoustic zone, the distance to the nearest measurement site was calculated and assigned to each grid point within that acoustic zone.
  - Define the location of localized noise sources (four roads in Hawai`i Volcanoes were defined). The distance to each road was calculated and assigned to each grid point.

* The UTM system provides coordinates on a world wide flat grid for easy manipulation in GIS applications.
† Because NPATMA applies to all commercial air tour operations within the ½-mile outside the boundary of a national park, the park boundary included a ½-mile buffer.

- Assign a "measured" ambient sound level (and its associated ⅓-octave band, unweighted spectrum) to each grid point within an acoustic zone based on the measurement site nearest to it for each ambient type and metric (9 combinations as discussed in Section 6.4).
- Assign a "roadway" ambient sound level (and its associated ⅓-octave band, unweighted spectrum) to each grid point using the drop-off rates determined by TNM using the input parameters discussed in Section 6.4.2.
- Compute a combined "measured" and "roadway" ambient (and spectra), as appropriate, at each grid point (see Table 17). The resultant ambient maps are presented in Section 7.

Table 17. Determination of final, ambient sound levels at each grid point.

Metric	Existing Ambient	Existing Ambient Without Air Tours	Existing Ambient Without All Aircraft	Natural Ambient*
L_{Aeq}	Measured + Roadway	N/A	N/A	N/A
L_{50}	Measured + Roadway	Measured + Roadway	Measured + Roadway	Measured
L_{90}	Measured + Roadway	Measured + Roadway	Measured + Roadway	Measured

Note: The combined (Measured + Roadway) ambient were computed by using energy-addition, i.e., sound levels in decibels were converted to energy prior to addition. For a non-time-varying source, such as roadway noise, the TNM-computed L_{Aeq} sound level parameters were conservatively assumed to be equivalent to the L_{50} and L_{90} and, thus, used interchangeably as the "roadway" ambient.

* As defined in Section 6.4, Natural Ambient includes the natural sound conditions found in a study area, including all sounds of nature (i.e., wind, streams, wildlife, etc.), and excludes all human and mechanical sounds.

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7. RESULTS

This section presents a detailed discussion of the results of the study. Included is an overall summary of the final, ambient sound levels for each measurement site (Section 7.1), and the final, ambient, sound level maps developed in support of this.

Table 18 contains a summary of the daytime, ambient, sound level data measured at each Hawai`i Volcanoes measurement site. The table is arranged by acoustic zone, followed by measurement site number. The first three columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was located;
- *Site ID*: The unique two-character ID representing the site "number"; and
- *Total # Days*: The total number of days measured.

The next four primary columns define the additional types of ambient represented by the data: Existing, Existing Without Air Tours, Existing Without All Aircraft, and Natural, as defined in Section 6.4. Then for each type of ambient, the following data are presented: *

- L_{Aeq}: The equivalent, A-weighted sound level (in decibels). Presented is the energy-averaged value determined from daytime sound levels (6 a.m. to 6 p.m.), taking into account the data from all days of measurements (Note: This metric was computed for the Existing Ambient only);
- L_{50}: The L_{50} sound level (in decibels) determined by the sound level exceeded 50 percent of the daytime hours (6 a.m. to 6 p.m.), taking into account the data from all days of measurements;
- L_{90}: The L_{90} sound level (in decibels) determined by the sound level exceeded 90 percent of the daytime hours (6 a.m. to 6 p.m.), taking into account the data from all days of measurements; and

* As noted in Section 6.1, the FAA and NPS have agreed that any subsequent impact assessment should be conducted using ambient sound levels during the time that the aircraft operations occur. Because the majority of Hawai`i air tours operate during the daytime, all final ambient maps will be developed using daytime data. The specific hours to be defined as daytime will be park dependent. For example, a time period of 6 am to 6 pm were used for the analyses of the 6 national parks in Hawai`i. This time period is the typical operating hours for air tour operators conducting air tours in Hawai`i according to Flight Standard District Office personnel.

- *W/S*: The average wind speed (in mph). Presented is the algebraically averaged value determined from daytime sound levels (6 am to 6 pm), taking into account the data from all days of measurements.

Figure 49 through Figure 52 present the data in Table 21 graphically for each ambient type. Figure 53 through Figure 54 present the data graphically for each metric. Table 19 presents the associated spectral data for the two ambient maps agreed upon for use in analyses: Existing Ambient Without Air Tours (L_{50}) and Natural Ambient (L_{50}). ***(Note: For comparison purposes, Table 21 contains a summary of the ambient, sound level data for the entire measurement period, where daytime and nighttime hours were included.)***

Table 22 and Figure 55 contain a summary of the acoustic observer data logged at each Hawai`i Volcanoes measurement site. As discussed in Section 6.4.1, this data was used to determine short-term distributions of ambient data from the VoLARE measurement data as a function of acoustic state, and apply these short-term distributions to the long-term NoiseLogger™ data to develop the four types of ambient defined in Section 6.0. The first six columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was located;
- *Site ID*: The unique two-character ID representing the site "number";
- *Land Cover*: The land cover of the site in accordance with the National Land Cover Data 21-class land cover classification scheme;
- *Management Zone*: The NPS management zone that the site was located in;
- *Site Category*: A designator indicating expected visitor use (with "overlook" indicating high visitor use, "short hike" indicating moderate visitor use, and "wilderness/backcountry" indicating minimal or no visitor use) in the measurement site area;
- *Total Duration (s):* The duration in seconds of all acoustic observer logging performed at the measurement site.

The next six columns define the amount of time that different noise sources were audible to the acoustic observer:

- *Air Tour Aircraft*: The duration in seconds that air tour aircraft were audible;
- *Other Aircraft*: The duration in seconds that other aircraft (e.g., commercial, military, general aviation, and agricultural) were audible;
- *Human*: The duration in seconds that human noise sources (visitor- and mechanical-related) were audible;
- *Natural*: The duration in seconds that natural noise sources were audible;
- *% Air Tour*: The percentage of observer log time that air tour aircraft were audible; and
- *% All Aircraft*: The percentage of observer log time that all aircraft were audible (i.e., air tour and other aircraft).

In addition, Table 25 summarizes two additional metrics (per NPS request) determined using the acoustic observer logs taken during the ambient measurements:

- *Number of Events Per Hour (NEH):* The number of air tour operations audible within a specified time period, ideally each hour during the day (where sufficient operational data exists); and
- *Noise-Free Interval (NFI):* The length of time during which only natural sounds are audible.

The columns in the table are arranged as follows:

- *Acoustic Zone*: The acoustic and management zone in which the measurement site was located;
- *Site ID*: The unique two-character ID representing the site “number”;
- *Noise-Free Periods*: Periods of time during which only natural sounds were audible;
- *Air Tour Aircraft Events*: Periods of time during which air tour aircraft sounds were audible; and
- *Other Aircraft Events*: Periods of time during which non-air tour aircraft sounds were audible.

Figure 56 through Figure 65 present the roadway ambient map and the resultant, nine, baseline ambient maps, respectively, as above in Table 18.

Table 18. Summary of measured, daytime (6 am to 6 pm), ambient sound level data.

Acoustic Zone	Site ID	Total # Days	Existing L_{Aeq} (dBA)	Existing L_{50} (dBA)	Existing L_{90} (dBA)	Existing W/S (mph)	Existing Without Air Tours L_{50} (dBA)	Existing Without Air Tours L_{90} (dBA)	Existing Without Air Tours W/S (mph)	Existing Without All Aircraft L_{50} (dBA)	Existing Without All Aircraft L_{90} (dBA)	Existing Without All Aircraft W/S (mph)	Natural Ambient L_{50} (dBA)	Natural Ambient L_{90} (dBA)	Natural Ambient W/S (mph)
1: Shoreline*	1A	14	58.0	54.0	41.1	7.0	54.2	40.8	N/A	54.2	40.8	N/A	54.2	40.8	N/A
1: Shoreline	1B	14	51.7	46.8	42.3	9.0	46.7	43.1	33.0	46.7	43.1	33.0	46.6	43.1	33.1
2: Coastal Lowlands	2A	85	36.5	28.3	20.6	4.8	28.3	20.3	7.7	28.3	20.3	7.7	28.3	20.3	7.7
2: Coastal Lowlands	2B	17	45.0	32.4	22.2	6.1	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
2: Coastal Lowlands	2C	13	40.6	33.0	18.9	6.3	29.1	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9
3: Ka`ū Desert/ Kīlauea Summit	3A	118	42.1	28.2	17.2	4.7	30.3	18.0	6.1	31.4	18.0	5.9	31.4	18.0	5.9
3: Ka`ū Desert/ Kīlauea Summit	3B	18	44.2	29.6	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9	29.1	17.7	6.9
3: Ka`ū Desert/ Kīlauea Summit	3C	14	43.0	37.2	28.6	3.8	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
3: Ka`ū Desert/ Kīlauea Summit	3D	15	39.8	20.2	17.4	7.2	19.3	17.1	8.8	19.3	17.1	8.8	20.4	18.1	9.4
4: Ola`a Rain Forest	4A	114	39.7	33.1	25.6	0.4	33.0	25.0	0.0	33.5	27.3	0.0	33.5	27.3	0.0
5: Mauna Loa Forest	5A	56	42.5	34.9	26.5	1.7	35.0	26.3	2.3	35.0	26.7	2.3	35.0	26.7	2.3
5: Mauna Loa Forest	5B	15	33.3	23.4	17.4	1.8	23.3	17.2	2.0	22.1	17.1	1.9	22.1	17.1	1.9
5: Mauna Loa Forest	5C	17	36.7	27.6	20.3	4.7	27.7	20.2	4.4	27.7	20.2	4.4	27.5	19.9	4.4
6: Dry Ohi`a Woodlands	6A	108	39.4	28.9	23.7	4.9	28.0	23.8	7.8	28.0	23.8	7.7	28.0	23.8	7.7
6: Dry Ohi`a Woodlands	6B	27	42.5	30.8	23.8	6.4	28.0	23.8	7.8	28.0	23.8	7.7	28.0	23.8	7.7
6: Dry Ohi`a Woodlands	6C	25	53.3	33.1	23.2	5.6	32.7	22.2	8.7	32.7	22.2	8.7	32.7	22.2	8.7
8: Young Rain Forest	8A	113	46.6	43.0	36.9	0.7	42.8	36.6	1.1	42.8	36.6	1.1	42.6	36.6	1.1
8: Young Rain Forest	8B	15	46.1	38.3	32.7	0.7	38.2	32.7	0.2	38.2	32.2	0.2	38.2	32.2	0.2
8: Young Rain Forest	8C	15	42.0	31.4	24.4	0.9	31.3	24.4	1.6	29.7	23.3	1.7	29.7	23.3	1.7
9: New Lava Flows	9A	73	49.1	29.5	19.0	4.3	28.3	18.7	6.5	28.3	18.7	6.5	28.6	18.7	6.5
9: New Lava Flows	9B	17	39.7	33.0	20.2	7.0	28.3	18.7	6.5	28.3	18.7	6.5	28.6	18.7	6.5
9: New Lava Flows	9C	13	48.2	29.2	22.1	6.8	28.3	21.4	6.7	25.4	19.9	7.0	25.4	19.9	7.0

* Note that for sites with acoustic zone 1 (Shoreline), the 11 mph (5 m/s) wind speed threshold (see also Appendix E) was removed as the strong trade winds throughout the zone did not diminish during the data collection and would have resulted in an unacceptable data loss. As such, this data is contaminated with some wind noise and should be used with caution.

Table 19. Summary of measured, daytime (6 am to 6 pm), ambient sound level spectral data: Existing Ambient Without Air Tours. [*]

Frequency (Hz)	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	5A	5B	5C	6A	6B	6C	8A	8B	8C	9A	9B	9C
12.5	86.7	68.0	48.2	54.4	47.5	51.3	47.5	54.4	28.0	34.2	32.6	27.1	38.6	39.0	39.0	54.4	39.8	26.1	29.3	33.3	33.3	41.7
16	83.6	64.3	43.9	49.7	43.3	46.4	43.3	49.7	31.6	34.0	31.5	26.6	37.0	36.2	36.2	49.7	41.0	28.8	28.1	30.7	30.7	38.9
20	81.1	60.4	40.2	44.8	39.9	42.1	39.9	44.8	34.8	33.8	31.5	31.9	36.2	33.6	33.6	44.8	41.8	36.0	29.5	29.3	29.3	37.3
25	79.1	57.6	36.3	39.6	36.9	37.7	36.9	39.6	36.8	32.0	30.8	26.4	33.6	31.4	31.4	39.6	39.8	32.5	28.2	27.7	27.7	34.5
31	77.4	55.1	33.0	35.2	34.9	35.1	34.9	35.2	28.1	30.4	30.1	22.7	30.2	30.2	30.2	35.2	38.6	27.7	26.1	25.1	25.1	31.0
40	75.1	53.5	30.5	31.1	32.8	31.8	32.8	31.1	30.5	28.9	30.2	25.4	27.2	28.6	28.6	31.1	38.4	32.3	30.1	25.3	25.3	30.4
50	73.3	51.9	28.5	27.3	36.8	29.4	36.8	27.3	33.6	25.9	29.2	23.5	23.2	26.8	26.8	27.3	37.0	29.0	27.5	25.3	25.3	30.3
63	71.2	50.3	27.2	24.0	31.4	28.3	31.4	24.0	30.8	23.4	27.9	23.0	20.7	25.5	25.5	24.0	37.0	26.2	25.7	24.7	24.7	27.9
80	69.3	49.4	26.0	22.1	30.4	27.2	30.4	22.1	29.3	20.9	27.6	21.4	18.4	24.0	24.0	22.1	36.6	24.9	26.2	25.3	25.3	28.2
100	67.2	47.5	24.9	20.2	29.0	26.3	29.0	20.2	26.1	19.2	27.1	19.1	16.5	23.0	23.0	20.2	34.6	23.1	26.2	25.3	25.3	28.5
125	64.9	46.1	23.6	18.9	28.4	25.1	28.4	18.9	23.3	20.7	26.8	18.4	14.6	21.6	21.6	18.9	32.4	21.3	27.4	24.3	24.3	26.0
160	62.7	45.4	22.2	18.2	27.7	24.5	27.7	18.2	22.0	22.4	27.1	16.8	13.2	20.1	20.1	18.2	32.2	21.2	28.2	23.1	23.1	25.2
200	60.6	44.2	21.5	18.4	27.0	23.7	27.0	18.4	21.1	24.4	27.7	16.8	12.8	19.2	19.2	18.4	33.8	21.3	28.6	22.7	22.7	25.4
250	58.6	42.7	21.6	17.9	25.9	23.3	25.9	17.9	14.8	25.2	28.5	16.1	12.8	19.4	19.4	17.9	35.2	27.5	28.7	22.6	22.6	24.7
315	56.4	41.7	21.6	18.1	25.1	23.2	25.1	18.1	12.4	24.9	28.2	14.0	12.4	20.0	20.0	18.1	35.8	22.0	27.9	22.5	22.5	24.5
400	56.5	40.8	21.1	18.5	23.8	23.7	23.8	18.5	9.3	24.3	28.3	13.3	12.5	20.8	20.8	18.5	35.0	19.5	26.6	22.1	22.1	23.2
500	51.5	40.4	20.2	19.5	22.1	23.6	22.1	19.5	8.9	23.5	26.8	12.8	10.6	20.6	20.6	19.5	33.6	24.1	25.7	21.8	21.8	22.0
630	50.1	39.9	19.4	20.2	20.1	22.0	20.1	20.2	7.8	22.5	25.4	10.6	8.1	20.2	20.2	20.2	32.2	19.1	25.2	21.1	21.1	19.9
800	53.1	39.0	18.3	20.3	17.9	21.4	17.9	20.3	8.8	21.6	24.7	10.4	7.8	19.4	19.4	20.3	31.4	22.0	23.3	20.5	20.5	17.9
1000	48.5	38.2	17.7	20.7	16.6	20.3	16.6	20.7	10.3	20.4	23.4	9.5	8.2	18.6	18.6	20.7	30.0	19.9	21.8	19.5	19.5	15.9
1250	48.8	37.2	16.9	21.2	14.8	19.8	14.8	21.2	10.9	19.2	22.6	8.0	8.8	17.0	17.0	21.2	27.8	18.7	20.3	17.5	17.5	13.9
1600	48.4	35.9	15.6	20.6	13.2	18.7	13.2	20.6	12.8	18.6	22.0	7.9	9.9	15.8	15.8	20.6	26.6	18.8	18.5	15.8	15.8	11.9
2000	48.7	34.7	14.4	19.3	11.9	17.5	11.9	19.3	15.3	18.3	21.6	9.3	15.2	14.2	14.2	19.3	27.8	22.2	16.7	13.1	13.1	10.2
2500	47.7	33.6	14.1	19.2	10.1	15.5	10.1	19.2	17.9	17.9	20.9	9.9	19.0	13.4	13.4	19.2	32.0	26.9	15.7	10.5	10.5	9.4
3150	47.3	32.2	14.1	20.0	8.3	13.8	8.3	20.0	21.5	17.8	20.9	10.2	19.5	12.4	12.4	20.0	33.0	27.8	15.4	7.5	7.5	8.4
4000	46.3	30.3	14.4	20.7	8.3	12.0	8.3	20.7	25.0	24.1	21.3	10.0	16.7	11.4	11.4	20.7	32.0	32.9	20.4	5.1	5.1	10.4
5000	45.9	29.0	14.6	21.7	9.4	11.4	9.4	21.7	27.4	26.3	21.8	8.7	14.1	11.8	11.8	21.7	24.8	26.2	20.3	2.8	2.8	7.2
6300	45.2	27.2	16.9	21.9	10.6	10.5	10.6	21.9	27.2	15.6	22.0	7.2	12.1	11.8	11.8	21.9	14.0	16.4	17.9	-0.3	-0.3	7.4
8000	43.1	23.1	14.5	21.9	11.9	9.8	11.9	21.9	25.4	14.4	21.3	6.9	11.4	8.0	8.0	21.9	9.6	17.0	15.7	-2.9	-2.9	6.2
10000	42.1	20.8	14.1	22.4	13.5	9.2	13.5	22.4	29.2	13.0	18.4	8.4	13.7	7.6	7.6	22.4	7.0	16.8	14.3	-5.7	-5.7	6.5
12500	41.4	17.3	12.1	22.1	14.6	6.3	14.6	22.1	22.9	7.9	13.0	9.2	11.5	4.0	4.0	22.1	2.6	17.1	11.3	-10.0	-10.0	5.9
16000	39.9	20.9	9.5	22.3	13.8	3.4	13.8	22.3	21.8	4.2	7.5	8.1	11.7	-4.0	-4.0	22.3	-5.4	15.7	6.8	-14.1	-14.1	3.9
20000	35.3	17.6	4.8	22.0	12.3	0.7	12.3	22.0	19.0	1.2	4.0	6.4	9.0	-5.6	-5.6	22.0	-7.4	13.8	2.7	-13.5	-13.5	1.4

[*] As discussed in Section 5.4.3, the spectral data associated with the L_{50} exceedence level is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

Table 20. Summary of measured, daytime (6 am to 6 pm), ambient sound level spectral data: Natural Ambient. *

Frequency (Hz)	1A	1B	2A	2B	2C	3A	3B	3C	3D	4A	5A	5B	5C	6A	6B	6C	8A	8B	8C	9A	9B	9C
12.5	86.7	68.0	48.2	54.4	47.5	51.9	47.5	54.4	28.3	34.5	32.6	27.0	38.6	39.0	39.0	54.4	39.7	26.1	27.5	33.5	33.5	43.0
16	83.5	64.3	43.9	49.7	43.3	46.8	43.3	49.7	32.8	34.4	31.5	25.5	36.9	36.2	36.2	49.7	40.5	28.7	26.0	30.9	30.9	39.3
20	81.1	60.4	40.2	44.8	39.9	42.5	39.9	44.8	35.1	34.1	31.5	30.0	36.2	33.6	33.6	44.8	41.5	35.8	25.5	29.5	29.5	36.3
25	79.1	57.5	36.3	39.6	36.9	38.2	36.9	39.6	38.2	32.4	30.7	25.0	33.5	31.4	31.4	39.6	39.5	31.9	27.1	27.9	27.9	34.0
31	77.3	55.1	33.0	35.2	34.9	35.6	34.9	35.2	27.8	30.9	30.0	21.4	30.2	30.2	30.2	35.2	38.3	27.4	25.2	25.3	25.3	31.0
40	75.0	53.6	30.5	31.1	32.8	32.6	32.8	31.1	31.0	29.3	30.1	23.8	27.2	28.6	28.6	31.1	38.1	32.1	27.1	25.6	25.6	29.1
50	73.3	51.9	28.5	27.3	36.8	30.2	36.8	27.3	35.1	26.3	29.2	21.8	23.2	26.8	26.8	27.3	36.9	28.5	27.1	25.5	25.5	27.5
63	71.1	50.3	27.2	24.0	31.4	29.0	31.4	24.0	31.4	23.8	27.9	21.3	20.7	25.6	25.6	24.0	36.7	25.9	23.1	25.0	25.0	25.6
80	69.3	49.4	26.0	22.1	30.4	28.1	30.4	22.1	30.0	21.4	27.6	19.6	18.4	24.0	24.0	22.1	36.3	24.5	26.4	25.5	25.5	25.4
100	67.1	47.5	24.9	20.2	29.0	27.2	29.0	20.2	26.8	19.8	26.9	17.1	16.5	23.2	23.2	20.2	34.1	22.8	22.3	25.5	25.5	25.5
125	64.8	46.1	23.6	18.9	28.4	26.0	28.4	18.9	23.0	21.5	26.6	16.4	14.4	21.6	21.6	18.9	32.1	21.1	23.9	24.5	24.5	23.0
160	62.6	45.4	22.2	18.2	27.7	25.4	27.7	18.2	21.8	23.1	27.1	14.8	13.0	20.2	20.2	18.2	31.9	21.0	26.0	23.3	23.3	22.4
200	60.5	44.3	21.5	18.4	27.0	24.7	27.0	18.4	22.5	25.0	27.7	14.8	12.8	19.2	19.2	18.4	33.5	21.1	24.7	22.9	22.9	22.4
250	58.5	42.7	21.6	17.9	25.9	24.2	25.9	17.9	14.8	25.8	28.5	14.2	12.7	19.4	19.4	17.9	34.9	27.7	24.8	22.9	22.9	21.8
315	56.2	41.6	21.6	18.1	25.1	24.1	25.1	18.1	12.3	25.5	28.2	11.9	12.2	20.1	20.1	18.1	35.7	22.0	24.7	22.7	22.7	20.7
400	56.5	40.7	21.1	18.5	23.8	24.5	23.8	18.5	9.5	24.8	28.2	12.0	12.5	20.8	20.8	18.5	34.9	19.3	23.3	22.3	22.3	18.4
500	51.4	40.4	20.2	19.5	22.1	24.6	22.1	19.5	9.0	24.2	26.9	11.9	10.6	20.6	20.6	19.5	33.5	24.2	22.7	22.0	22.0	17.6
630	50.1	39.9	19.4	20.2	20.1	23.1	20.1	20.2	7.7	23.1	25.4	10.0	8.1	20.2	20.2	20.2	32.1	19.0	22.2	21.3	21.3	16.0
800	53.0	38.9	18.3	20.3	17.9	22.5	17.9	20.3	8.9	22.2	24.7	10.1	7.7	19.4	19.4	20.3	31.3	22.1	20.1	20.7	20.7	14.1
1000	48.5	38.2	17.7	20.7	16.6	21.6	16.6	20.7	10.5	21.0	23.4	9.3	8.2	18.6	18.6	20.7	30.1	20.0	18.6	19.7	19.7	11.9
1250	48.7	37.1	16.9	21.2	14.8	21.0	14.8	21.2	11.1	19.9	22.6	7.7	8.7	17.0	17.0	21.2	27.9	18.7	17.0	17.7	17.7	10.1
1600	48.4	35.8	15.6	20.6	13.2	20.0	13.2	20.6	13.3	19.2	22.1	7.3	9.9	16.0	16.0	20.6	26.7	18.7	15.0	16.1	16.1	8.3
2000	48.7	34.7	14.4	19.3	11.9	18.9	11.9	19.3	15.8	19.0	21.7	8.5	15.1	14.4	14.4	19.3	27.7	22.2	13.2	13.3	13.3	7.5
2500	47.6	33.5	14.1	19.2	10.1	16.8	10.1	19.2	18.3	18.7	21.0	8.8	19.0	13.4	13.4	19.2	31.9	26.9	12.2	10.8	10.8	7.7
3150	47.3	32.2	14.1	20.0	8.3	15.1	8.3	20.0	22.0	18.3	21.0	9.2	19.4	12.4	12.4	20.0	32.9	27.7	13.3	7.8	7.8	7.4
4000	46.3	30.3	14.4	20.7	8.3	13.4	8.3	20.7	25.3	24.4	21.4	9.2	16.7	11.6	11.6	20.7	31.9	32.9	19.5	5.4	5.4	11.3
5000	45.9	29.0	14.6	21.7	9.4	12.4	9.4	21.7	27.7	26.3	21.9	8.3	14.1	11.8	11.8	21.7	24.9	26.4	19.4	3.1	3.1	8.6
6300	45.1	27.3	16.9	21.9	10.6	11.5	10.6	21.9	27.6	16.1	22.2	7.2	12.1	11.8	11.8	21.9	13.9	16.3	14.9	-0.1	-0.1	8.3
8000	43.0	23.1	14.5	21.9	11.9	11.1	11.9	21.9	25.9	14.9	21.4	6.8	11.4	8.0	8.0	21.9	9.7	16.9	12.6	-2.7	-2.7	7.2
10000	42.0	20.8	14.1	22.4	13.5	10.3	13.5	22.4	29.6	13.3	18.6	8.2	13.7	7.6	7.6	22.4	7.1	16.4	11.9	-5.5	-5.5	7.3
12500	41.4	17.2	12.1	22.1	14.6	7.3	14.6	22.1	23.4	8.1	13.1	8.9	11.5	3.8	3.8	22.1	2.5	16.9	9.2	-9.7	-9.7	6.7
16000	39.9	20.8	9.5	22.3	13.8	4.2	13.8	22.3	22.3	4.6	7.5	7.8	11.7	-4.0	-4.0	22.3	-5.5	15.5	5.8	-13.9	-13.9	4.7
20000	35.3	17.5	4.8	22.0	12.3	1.5	12.3	22.0	19.3	1.4	4.0	6.1	9.0	-5.6	-5.6	22.0	-7.5	13.8	1.7	-13.3	-13.3	2.1

* As discussed in Section 5.4.3, the spectral data associated with the L_{50} exceedence level is constructed by determining the L_{50} from each one-third octave-band; therefore, it is not an actual measured one-third octave-band spectrum associated with a particular measurement sample.

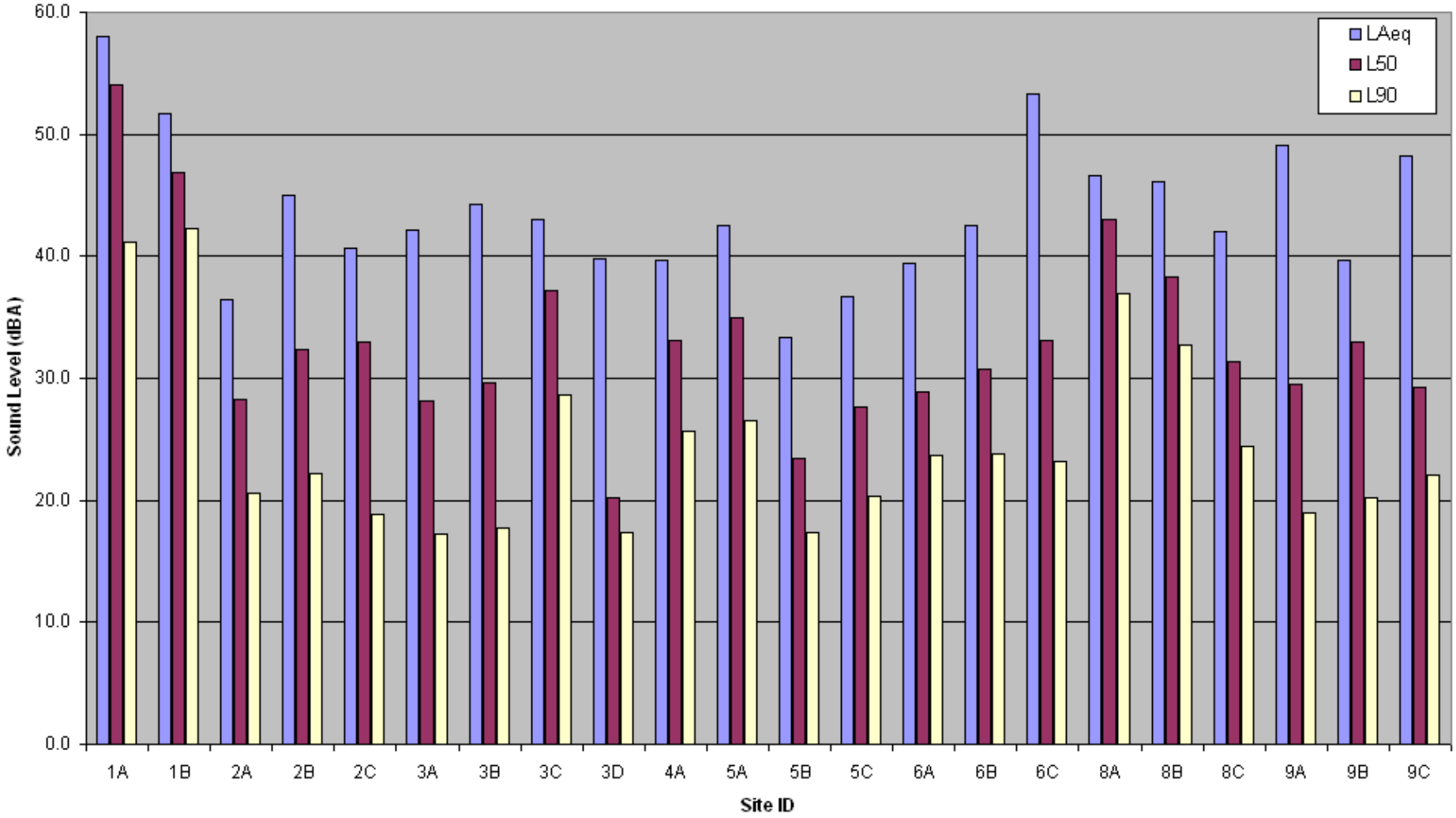


Figure 49. Summary of measured, daytime, ambient sound level data – Existing Ambient (L_{Aeq}, L_{50}, L_{90}).

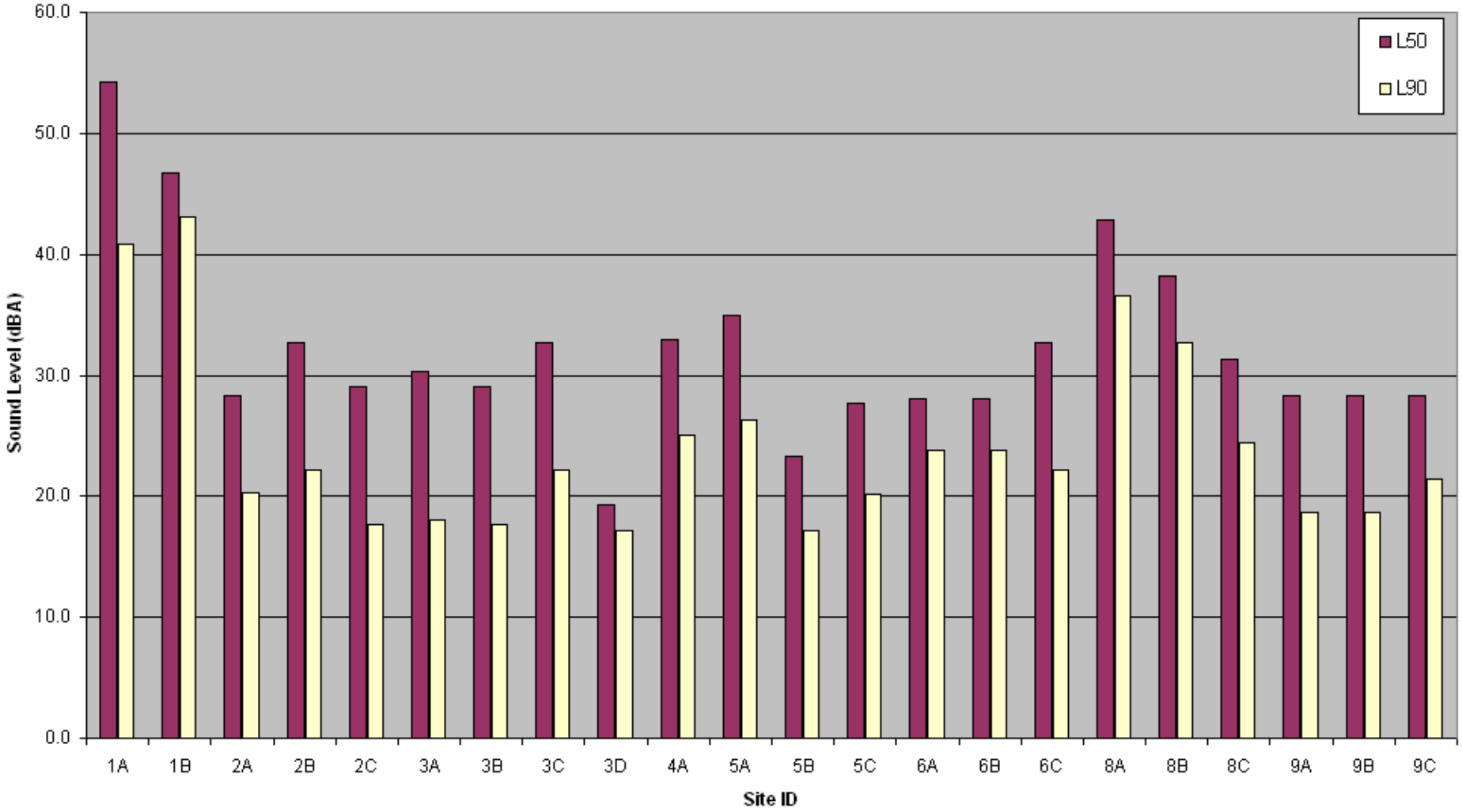


Figure 50. Summary of measured, daytime, ambient sound level data – Existing Ambient Without Air Tours (L_{50}, L_{90}).

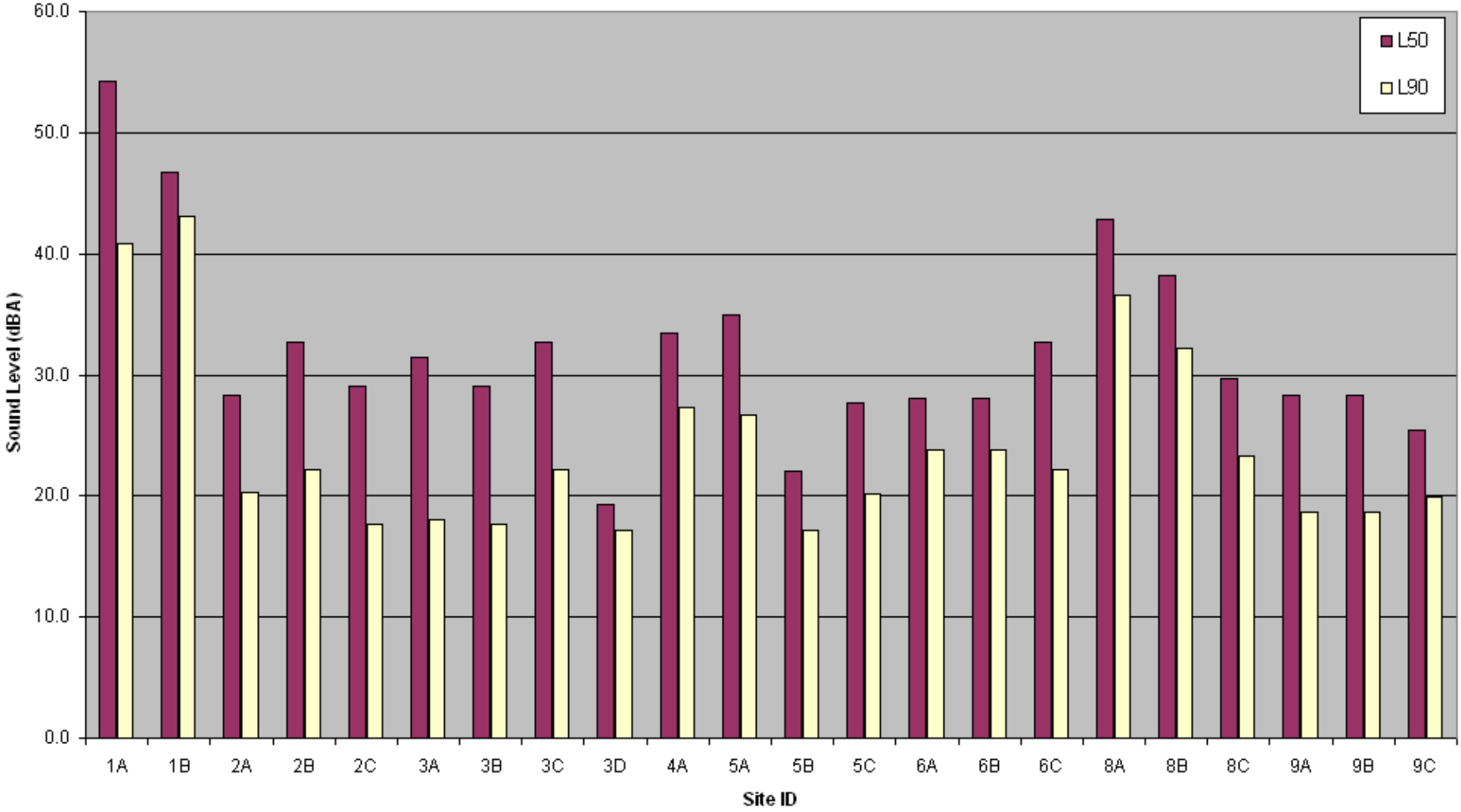


Figure 51. Summary of measured, daytime, ambient sound level data – Existing Ambient Without All Aircraft (L_{50}, L_{90}).

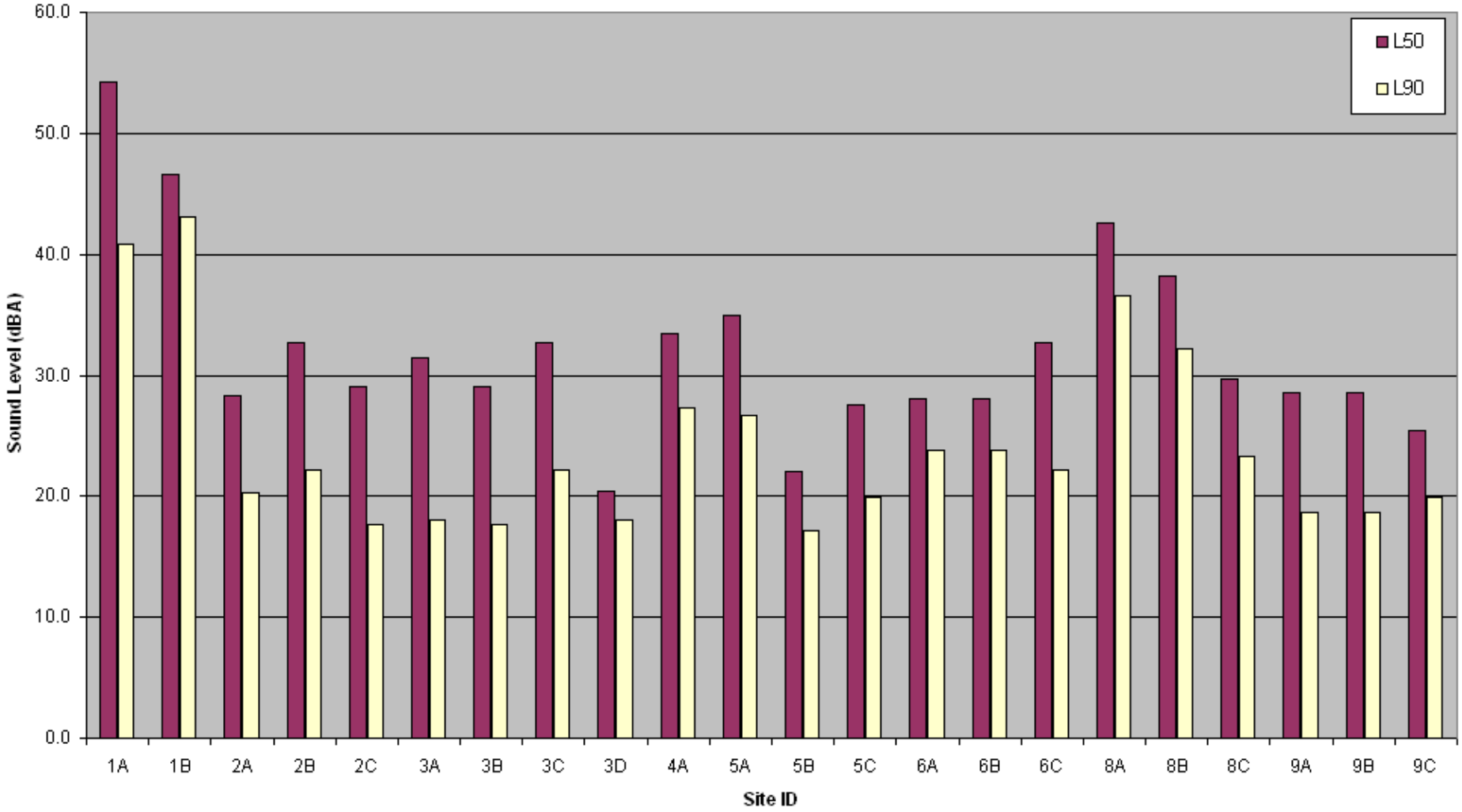


Figure 52. Summary of measured, daytime, ambient sound level data – Natural Ambient (L_{50}, L_{90}).

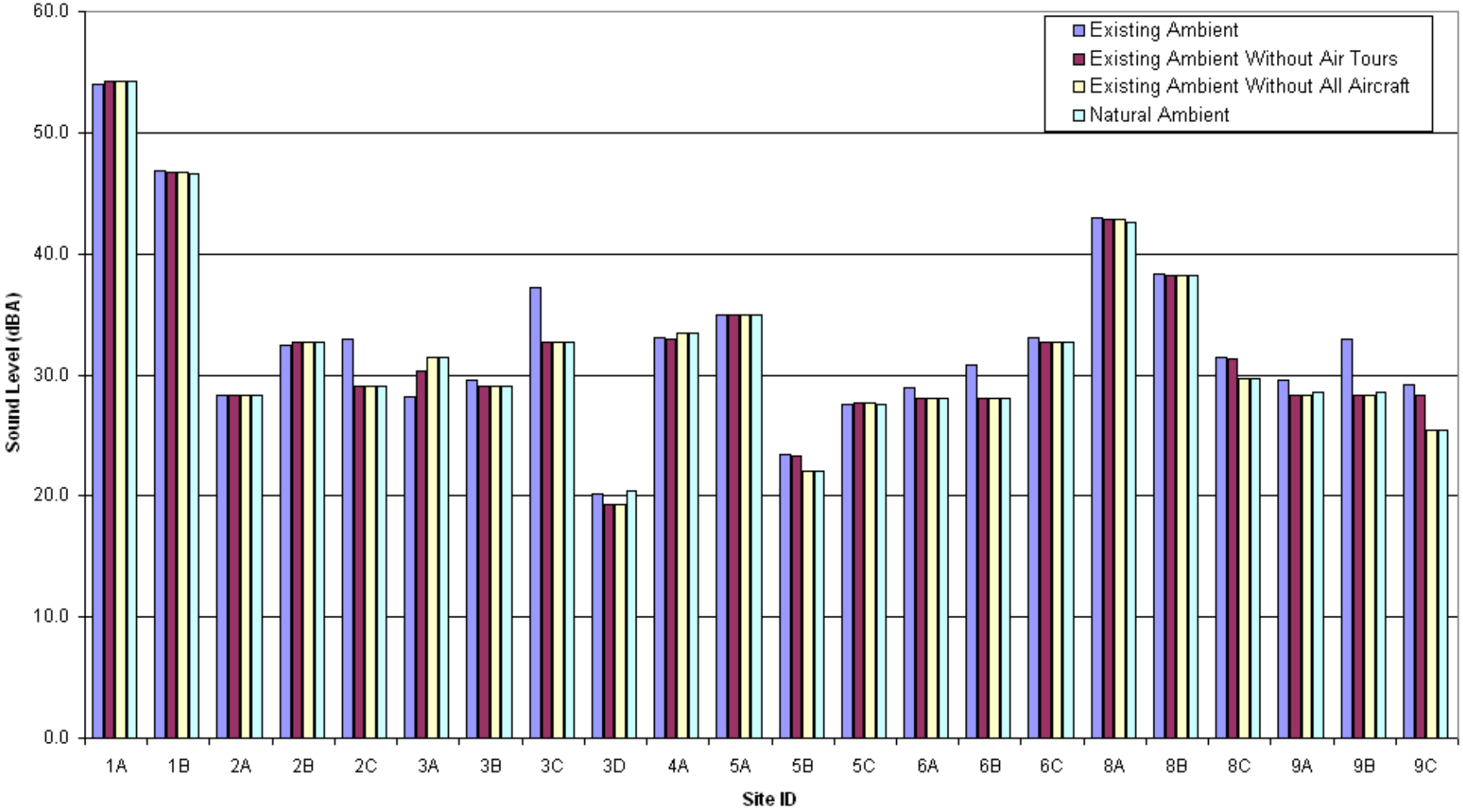


Figure 53. Summary of measured, daytime, ambient sound level data – L_{50}.

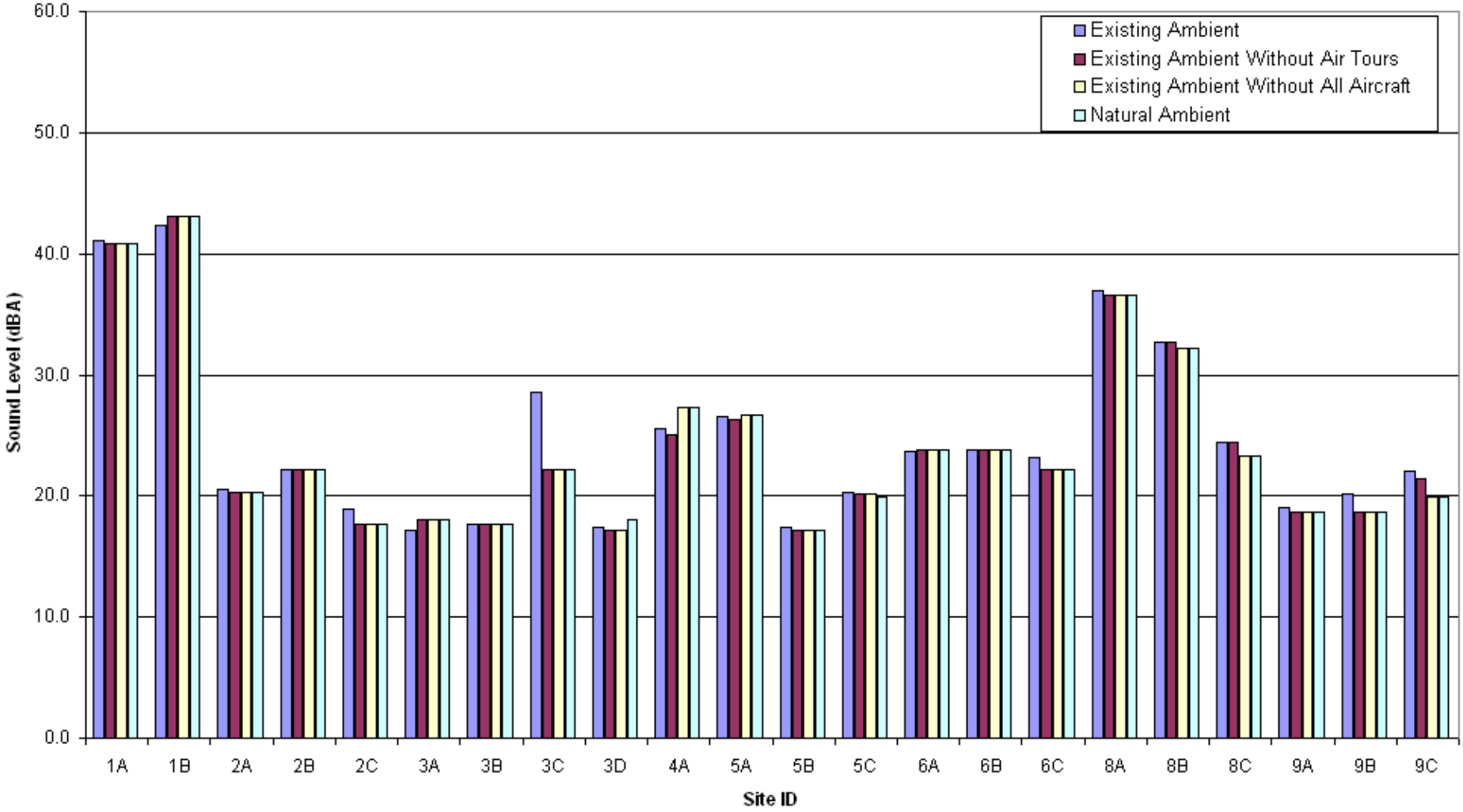


Figure 54. Summary of measured, daytime, ambient sound level data – L_{90}.

Table 21. Summary of measured ambient sound level data (daytime and nighttime included).

Acoustic Zone	Site ID	Total # Days	Existing L_{Aeq} (dBA)	Existing L_{50} (dBA)	Existing L_{90} (dBA)	Existing W/S (mph)	Existing Without Air Tours L_{50} (dBA)	Existing Without Air Tours L_{90} (dBA)	Existing Without Air Tours W/S (mph)	Existing Without All Aircraft L_{50} (dBA)	Existing Without All Aircraft L_{90} (dBA)	Existing Without All Aircraft W/S (mph)	Natural Ambient L_{50} (dBA)	Natural Ambient L_{90} (dBA)	Natural Ambient W/S (mph)
1: Shoreline*	1A	1A	56.5	51.3	38.6	7.5	51.5	38.6	N/A	51.5	38.6	N/A	51.5	38.6	N/A
1: Shoreline	1B	1B	50.3	46.4	42.3	9.2	46.3	43.1	33.0	46.3	43.1	33.0	46.2	43.1	33.1
2: Coastal Lowlands	2A	2A	44.3	32.3	22.5	4.5	32.3	22.1	7.7	32.3	22.1	7.7	32.3	22.1	7.7
2: Coastal Lowlands	2B	2B	51.4	33.2	22.9	5.7	33.4	22.9	8.7	33.4	22.9	8.7	33.4	22.9	8.7
2: Coastal Lowlands	2C	2C	47.7	35.1	22.9	5.7	28.8	16.1	6.9	28.8	16.1	6.9	28.8	16.1	6.9
3: Ka`ū Desert/ Kīlauea Summit	3A	3A	40.6	25.2	16.4	4.4	27.3	16.8	6.1	28.4	16.8	5.9	28.4	16.8	5.9
3: Ka`ū Desert/ Kīlauea Summit	3B	3B	41.5	29.4	16.1	6.6	28.8	16.1	6.9	28.8	16.1	6.9	28.8	16.1	6.9
3: Ka`ū Desert/ Kīlauea Summit	3C	3C	42.2	38.2	28.9	3.4	33.4	22.9	8.7	33.4	22.9	8.7	33.4	22.9	8.7
3: Ka`ū Desert/ Kīlauea Summit	3D	3D	35.5	18.4	17.0	7.3	17.9	17.0	8.8	17.9	17.0	8.8	18.6	17.4	9.4
4: Ola`a Rain Forest	4A	4A	44.6	37.3	25.9	0.4	36.9	25.0	0.0	38.3	28.3	0.0	38.3	28.3	0.0
5: Mauna Loa Forest	5A	5A	40.1	30.2	17.6	1.7	29.9	17.3	2.3	29.9	17.5	2.3	29.9	17.5	2.3
5: Mauna Loa Forest	5B	5B	30.6	19.5	15.7	1.4	19.3	15.8	2.0	18.1	15.8	1.9	18.1	15.8	1.9
5: Mauna Loa Forest	5C	5C	34.2	23.7	16.9	4.0	23.7	17.0	4.4	23.7	17.0	4.4	23.4	16.9	4.4
6: Dry Ohi`a Woodlands	6A	6A	45.0	27.9	23.3	4.6	26.8	23.3	7.8	26.8	23.3	7.7	26.8	23.3	7.7
6: Dry Ohi`a Woodlands	6B	6B	43.7	28.6	22.1	6.3	26.8	23.3	7.8	26.8	23.3	7.7	26.8	23.3	7.7
6: Dry Ohi`a Woodlands	6C	6C	50.9	32.7	22.5	5.5	33.4	22.9	8.7	33.4	22.9	8.7	33.4	22.9	8.7
8: Young Rain Forest	8A	8A	51.0	45.7	36.7	0.7	45.3	36.1	1.1	45.3	36.1	1.1	44.9	36.1	1.1
8: Young Rain Forest	8B	8B	45.8	40.5	32.5	0.7	40.3	32.4	0.2	40.3	31.7	0.2	40.3	31.7	0.2
8: Young Rain Forest	8C	8C	46.4	37.5	25.3	0.8	37.0	25.2	1.6	33.8	23.7	1.7	33.8	23.7	1.7
9: New Lava Flows	9A	9A	46.5	32.4	20.0	3.7	31.6	19.5	6.5	31.6	19.5	6.5	31.8	19.5	6.5
9: New Lava Flows	9B	9B	39.0	32.1	19.2	7.1	31.6	19.5	6.5	31.6	19.5	6.5	31.8	19.5	6.5
9: New Lava Flows	9C	9C	45.2	32.4	22.7	6.0	31.2	21.9	6.7	27.1	20.2	7.0	27.1	20.2	7.0

* For sites with acoustic zone 1 (Shoreline), the 11 mph (5 m/s) wind speed threshold (see also Appendix E) was removed as the strong trade winds throughout the zone did not diminish during the data collection and would have resulted in an unacceptable data loss. As such, this data should be used with caution.

Table 22. Summary of acoustic observer log data.

Acoustic Zone	Site ID	Land Cover	Management Zone	Site Category	Total Duration (s)	Seconds Audible: Aircraft Sound Sources - Air Tours	Seconds Audible: Aircraft Sound Sources - Other	Seconds Audible: Human Sound Sources	Seconds Audible: Natural Sound Sources	% Time Audible: Air Tour	% Time Audible: All Aircraft
1: Shoreline*	1A	Bare Rock/Sand/Clay	Natural	Short Hike	3380	102	0	8	3270	**3.0%**	**3.0%**
1: Shoreline	1B	Bare Rock/Sand/Clay	Natural	Overlook	3171	738	0	260	2173	**23.3%**	**23.3%**
2: Coastal Lowlands	2A	Grasslands/Herbaceous	Wilderness (Natural subzone)	Wilderness	346	0	0	0	346	**0.0%**	**0.0%**
2: Coastal Lowlands	2B	Grasslands/Herbaceous	Natural	Short Hike	651	0	0	0	651	**0.0%**	**0.0%**
2: Coastal Lowlands	2C	Bare Rock/Sand/Clay	Natural	Short Hike	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
3: Ka`ū Desert/ Kīlauea Summit	3A	Bare Rock/Sand/Clay	Natural	Short Hike	1412	0	151	0	1261	**0.0%**	**10.7%**
3: Ka`ū Desert/ Kīlauea Summit	3B	Bare Rock/Sand/Clay	Natural	Overlook	1011	0	0	0	1011	**0.0%**	**0.0%**
3: Ka`ū Desert/ Kīlauea Summit	3C	Grasslands/Herbaceous	Natural	Overlook	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
3: Ka`ū Desert/ Kīlauea Summit	3D	Bare Rock/Sand/Clay	Natural	Short Hike	295	0	0	137	158	**0.0%**	**0.0%**
4: Ola`a Rain Forest	4A	Evergreen Forest	Wilderness (Natural Subzone)	Wilderness	4901	0	427	471	4003	**0.0%**	**8.7%**
5: Mauna Loa Forest	5A	Evergreen Forest	Natural	Overlook	7633	0	491	82	7060	**0.0%**	**6.4%**
5: Mauna Loa Forest	5B	Shrubland	Natural	Overlook	3637	0	745	65	2827	**0.0%**	**20.5%**
5: Mauna Loa Forest	5C	Shrubland	Natural	Short Hike	1059	0	0	30	1029	**0.0%**	**0.0%**
6: Dry Ohi`a Woodlands	6A	Grasslands/Herbaceous	Natural	Short Hike	3733	104	36	0	3593	**2.8%**	**3.8%**
6: Dry Ohi`a Woodlands	6B	Grasslands/Herbaceous	Natural	Backcountry	1073	0	531	0	542	**0.0%**	**49.5%**

* It should be noted that for sites with acoustic zone 1 (Shoreline), the 11 mph (5 m/s) wind speed threshold (see also Appendix E) was removed as the strong trade winds throughout the zone did not diminish during the data collection and would have resulted in an unacceptable data loss. As such, this data is contaminated with some wind noise and should be used with caution.

Acoustic Zone	Site ID	Land Cover	Management Zone	Site Category	Total Duration (s)	Seconds Audible: Aircraft Sound Sources - Air Tours	Seconds Audible: Aircraft Sound Sources - Other	Seconds Audible: Human Sound Sources	Seconds Audible: Natural Sound Sources	% Time Audible: Air Tour	% Time Audible: All Aircraft
6: Dry Ohi`a Woodlands	6C	Grasslands/Herbaceous	Natural	Short Hike	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
8: Young Rain Forest	8A	Evergreen Forest	Natural	Short Hike	7193	476	0	2166	4551	**6.6%**	**6.6%**
8: Young Rain Forest	8B	Evergreen Forest	Natural	Short Hike	3322	0	581	0	2741	**0.0%**	**17.5%**
8: Young Rain Forest	8C	Evergreen Forest	Natural	Backcountry	3528	0	2175	0	1353	**0.0%**	**61.6%**
9: New Lava Flows	9A	Transitional	Wilderness (Natural Subzone)	Backcountry	14964	690	4	129	14141	**4.6%**	**4.6%**
9: New Lava Flows	9B	Transitional	Natural	Overlook	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)	(No logging at this site)
9: New Lava Flows	9C	Transitional	Natural	Backcountry	4347	0	2272	0	1951	**0.0%**	**52.3%**

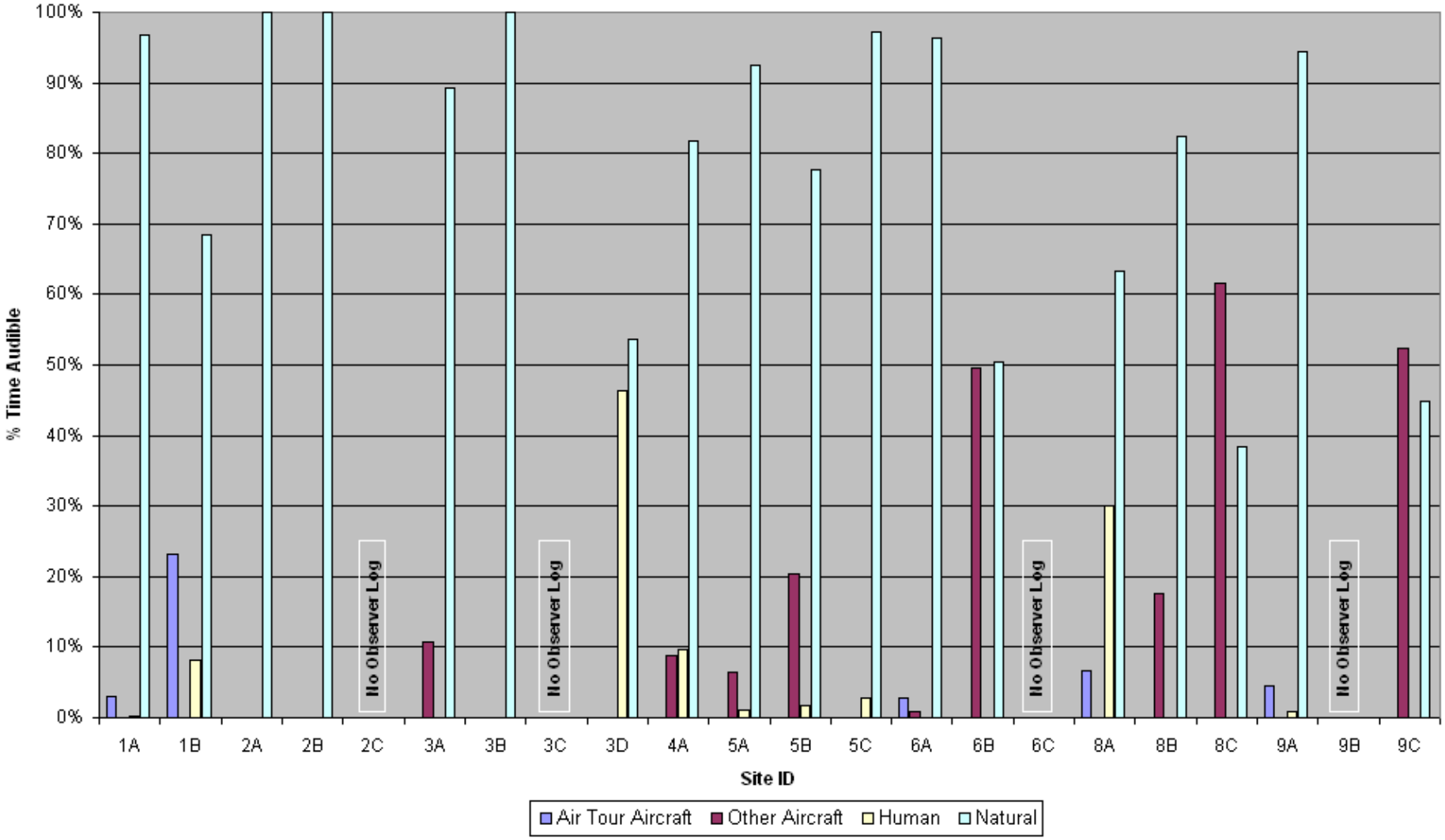


Figure 55. Summary of acoustic observer log data.

Table 23. Summary of acoustic observer log data: number of events per hour and noise-free interval.

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Number Periods/Events:	1: Shoreline	1A	4	2	0
Mean Time (minutes):	1: Shoreline	1A	0:13:37	0:00:51	0:00:00
Minimum Time (minutes):	1: Shoreline	1A	0:01:40	0:00:48	0:00:00
Maximum Time (minutes):	1: Shoreline	1A	0:28:00	0:00:54	0:00:00
Total Time (minutes):	1: Shoreline	1A	0:54:30	0:01:42	0:00:00
Number Periods/Events:	1: Shoreline	1B	9	11	0
Mean Time (minutes):	1: Shoreline	1B	0:02:01	0:01:07	0:00:00
Minimum Time (minutes):	1: Shoreline	1B	0:00:11	0:00:11	0:00:00
Maximum Time (minutes):	1: Shoreline	1B	0:07:49	0:03:19	0:00:00
Total Time (minutes):	1: Shoreline	1B	0:36:13	0:12:18	0:00:00
Number Periods/Events:	2: Coastal Lowlands	2A	7	0	0
Mean Time (minutes):	2: Coastal Lowlands	2A	0:02:12	0:00:00	0:00:00
Minimum Time (minutes):	2: Coastal Lowlands	2A	0:00:10	0:00:00	0:00:00
Maximum Time (minutes):	2: Coastal Lowlands	2A	0:08:32	0:00:00	0:00:00
Total Time (minutes):	2: Coastal Lowlands	2A	0:15:22	0:00:00	0:00:00
Number Periods/Events:	2: Coastal Lowlands	2B	1	0	0
Mean Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Minimum Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Maximum Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
Total Time (minutes):	2: Coastal Lowlands	2B	0:21:39	0:00:00	0:00:00
(No logging performed here)	2: Coastal Lowlands	2C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3A	7	1	0
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:08:12	0:06:58	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:00:08	0:06:58	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:29:59	0:06:58	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3A	0:57:27	0:06:58	0:00:00

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3B	20	2	0
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:04:17	0:00:48	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:00:05	0:00:45	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	0:58:35	0:00:52	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3B	1:25:32	0:01:37	0:00:00
(No logging performed here)	3: Ka`ū Desert/ Kīlauea Summit	3C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	3: Ka`ū Desert/ Kīlauea Summit	3D	8	0	0
Mean Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:00:40	0:00:00	0:00:00
Minimum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:00:07	0:00:00	0:00:00
Maximum Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:01:29	0:00:00	0:00:00
Total Time (minutes):	3: Ka`ū Desert/ Kīlauea Summit	3D	0:05:22	0:00:00	0:00:00
Number Periods/Events:	4: Ola`a Rain Forest	4A	53	7	0
Mean Time (minutes):	4: Ola`a Rain Forest	4A	0:01:44	0:01:18	0:00:00
Minimum Time (minutes):	4: Ola`a Rain Forest	4A	0:00:01	0:00:04	0:00:00
Maximum Time (minutes):	4: Ola`a Rain Forest	4A	0:17:48	0:02:25	0:00:00
Total Time (minutes):	4: Ola`a Rain Forest	4A	1:32:17	0:10:28	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5A	16	9	0
Mean Time (minutes):	5: Mauna Loa Forest	5A	0:06:57	0:01:02	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5A	0:00:03	0:00:08	0:00:00
Maximum Time (minutes):	5: Mauna Loa Forest	5A	0:34:24	0:02:12	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5A	1:58:14	0:08:14	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5B	126	9	0
Mean Time (minutes):	5: Mauna Loa Forest	5B	0:00:22	0:01:23	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5B	0:00:01	0:00:03	0:00:00

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Maximum Time (minutes):	5: Mauna Loa Forest	5B	0:02:31	0:04:07	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5B	0:47:09	0:12:25	0:00:00
Number Periods/Events:	5: Mauna Loa Forest	5C	32	0	0
Mean Time (minutes):	5: Mauna Loa Forest	5C	0:00:32	0:00:00	0:00:00
Minimum Time (minutes):	5: Mauna Loa Forest	5C	0:00:01	0:00:00	0:00:00
Maximum Time (minutes):	5: Mauna Loa Forest	5C	0:02:46	0:00:00	0:00:00
Total Time (minutes):	5: Mauna Loa Forest	5C	0:17:20	0:00:00	0:00:00
Number Periods/Events:	6: Dry Ohi`a Woodlands	6A	29	3	0
Mean Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:03:17	0:01:13	0:00:00
Minimum Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:00:02	0:00:13	0:00:00
Maximum Time (minutes):	6: Dry Ohi`a Woodlands	6A	0:35:54	0:02:30	0:00:00
Total Time (minutes):	6: Dry Ohi`a Woodlands	6A	1:31:55	0:03:40	0:00:00
Number Periods/Events:	6: Dry Ohi`a Woodlands	6B	6	4	0
Mean Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:01:31	0:02:58	0:00:00
Minimum Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:00:30	0:01:40	0:00:00
Maximum Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:02:59	0:04:39	0:00:00
Total Time (minutes):	6: Dry Ohi`a Woodlands	6B	0:09:07	0:08:53	0:00:00
(No logging performed here)	8: Young Rain Forest	6C	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	8: Young Rain Forest	8A	58	11	0
Mean Time (minutes):	8: Young Rain Forest	8A	0:01:49	0:01:19	0:00:00
Minimum Time (minutes):	8: Young Rain Forest	8A	0:00:02	0:00:22	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8A	0:18:09	0:03:52	0:00:00
Total Time (minutes):	8: Young Rain Forest	8A	1:45:02	0:14:24	0:00:00
Number Periods/Events:	8: Young Rain Forest	8B	34	9	0
Mean Time (minutes):	8: Young Rain Forest	8B	0:01:21	0:01:05	0:00:00

Metric	Acoustic Zone	Site ID	Noise-Free Periods	Air Tour Aircraft Events	Other Aircraft Events
Minimum Time (minutes):	8: Young Rain Forest	8B	0:00:04	0:00:27	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8B	0:07:41	0:02:15	0:00:00
Total Time (minutes):	8: Young Rain Forest	8B	0:45:43	0:09:41	0:00:00
Number Periods/Events:	8: Young Rain Forest	8C	22	16	0
Mean Time (minutes):	8: Young Rain Forest	8C	0:01:01	0:01:54	0:00:00
Minimum Time (minutes):	8: Young Rain Forest	8C	0:00:05	0:00:40	0:00:00
Maximum Time (minutes):	8: Young Rain Forest	8C	0:03:28	0:06:10	0:00:00
Total Time (minutes):	8: Young Rain Forest	8C	0:22:33	0:36:15	0:00:00
Number Periods/Events:	9: New Lava Flows	9A	87	19	0
Mean Time (minutes):	9: New Lava Flows	9A	0:03:06	0:00:53	0:00:00
Minimum Time (minutes):	9: New Lava Flows	9A	0:00:08	0:00:01	0:00:00
Maximum Time (minutes):	9: New Lava Flows	9A	0:16:27	0:04:53	0:00:00
Total Time (minutes):	9: New Lava Flows	9A	4:32:11	0:20:15	0:00:00
(No logging performed here)	9: New Lava Flows	9B	(No Logging)	(No Logging)	(No Logging)
Number Periods/Events:	9: New Lava Flows	9C	28	9	0
Mean Time (minutes):	9: New Lava Flows	9C	0:00:33	0:02:48	0:00:00
Minimum Time (minutes):	9: New Lava Flows	9C	0:00:03	0:00:11	0:00:00
Maximum Time (minutes):	9: New Lava Flows	9C	0:02:09	0:10:18	0:00:00
Total Time (minutes):	9: New Lava Flows	9C	0:05:35	0:42:00	0:00:00

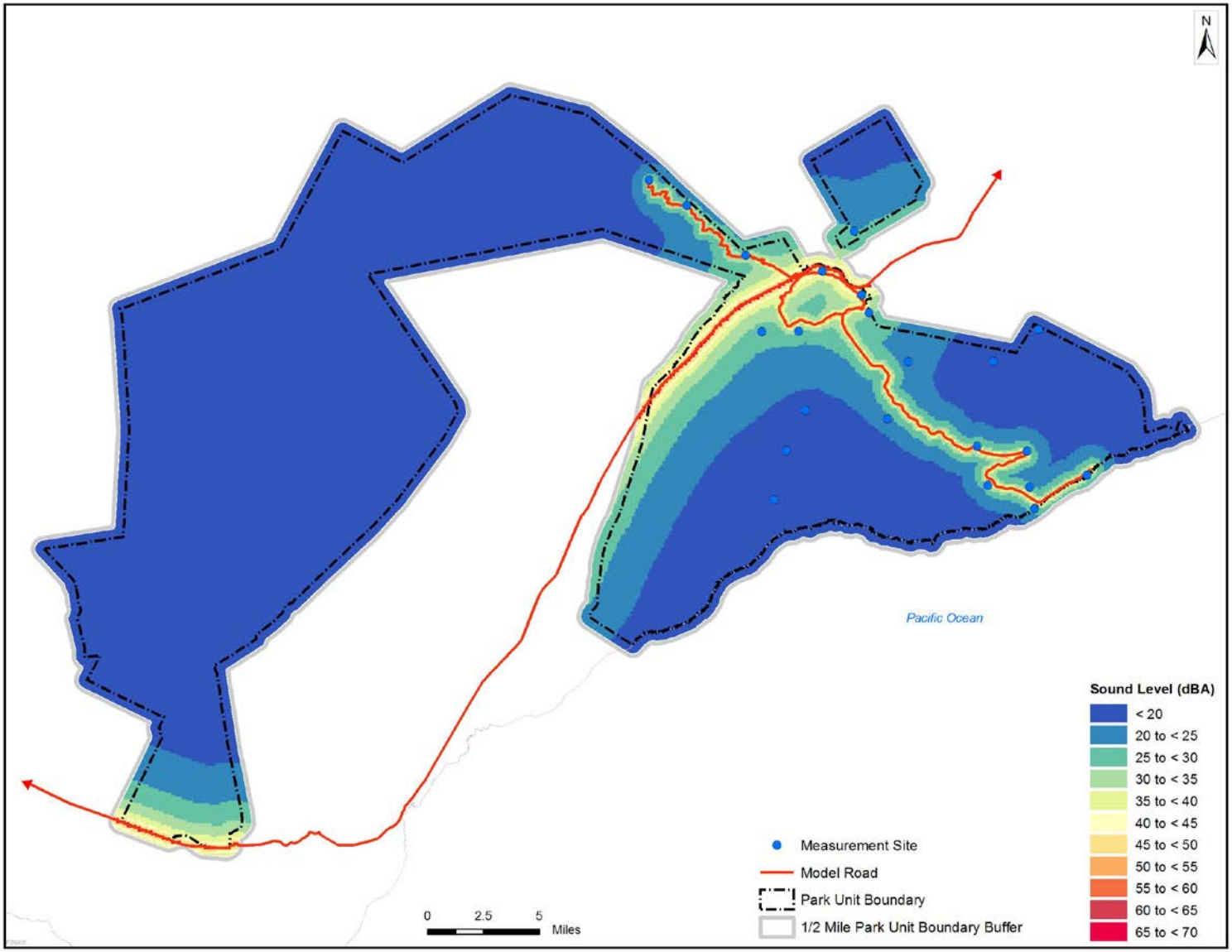


Figure 56. Roadway ambient map.

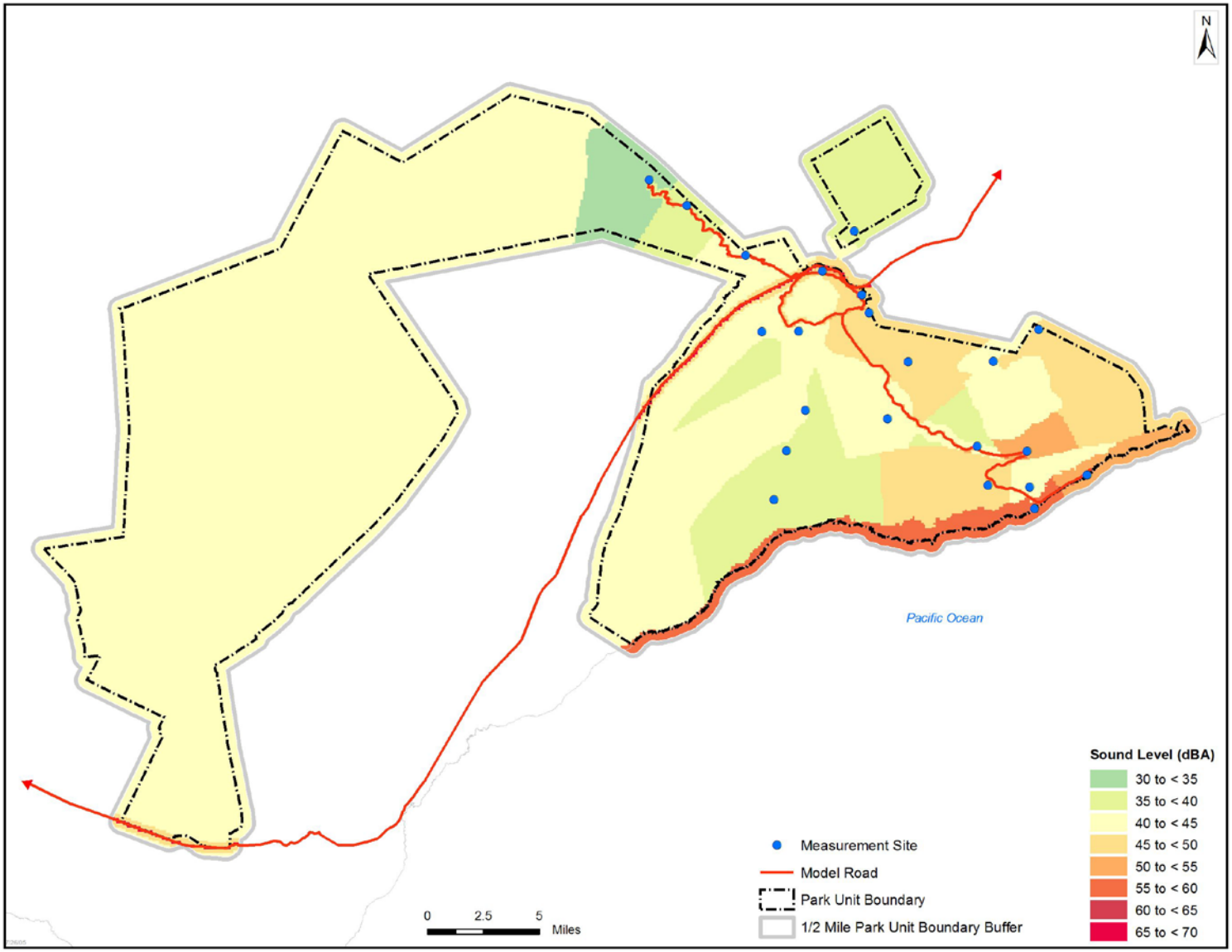


Figure 57. Baseline ambient map – Existing Ambient: L_{Aeq}.

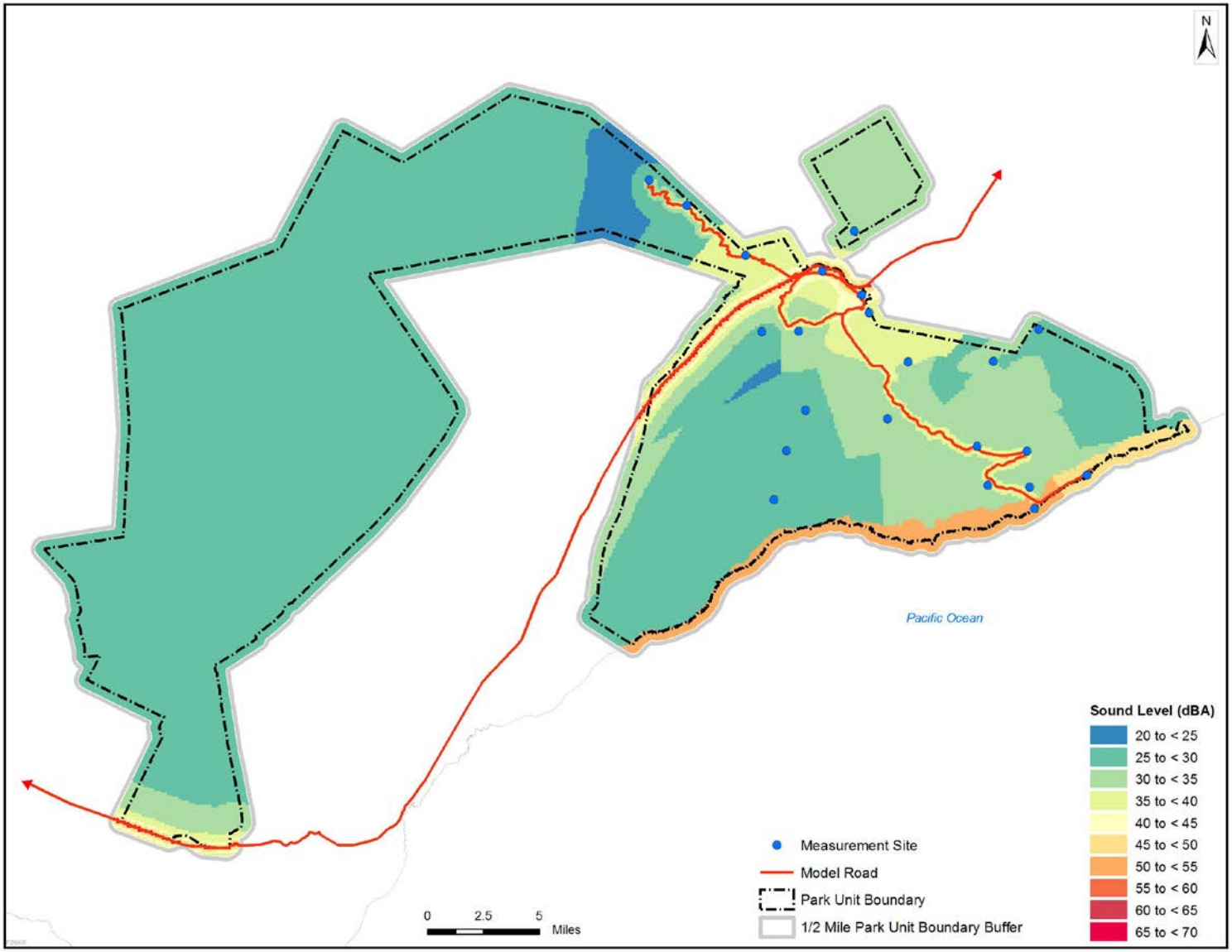


Figure 58. Baseline ambient map – Existing Ambient: L_{50}.

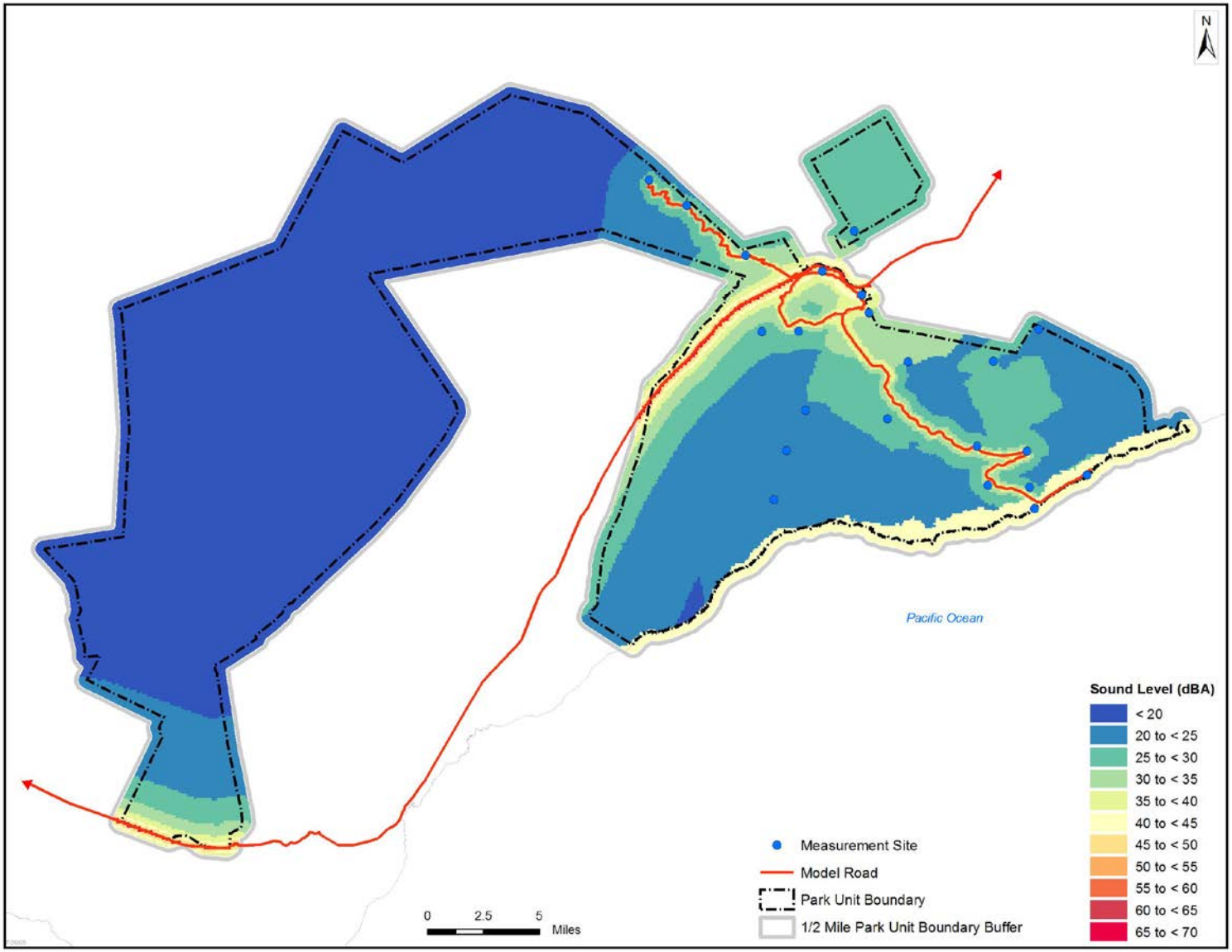


Figure 59. Baseline ambient map – Existing Ambient: L_{90}.

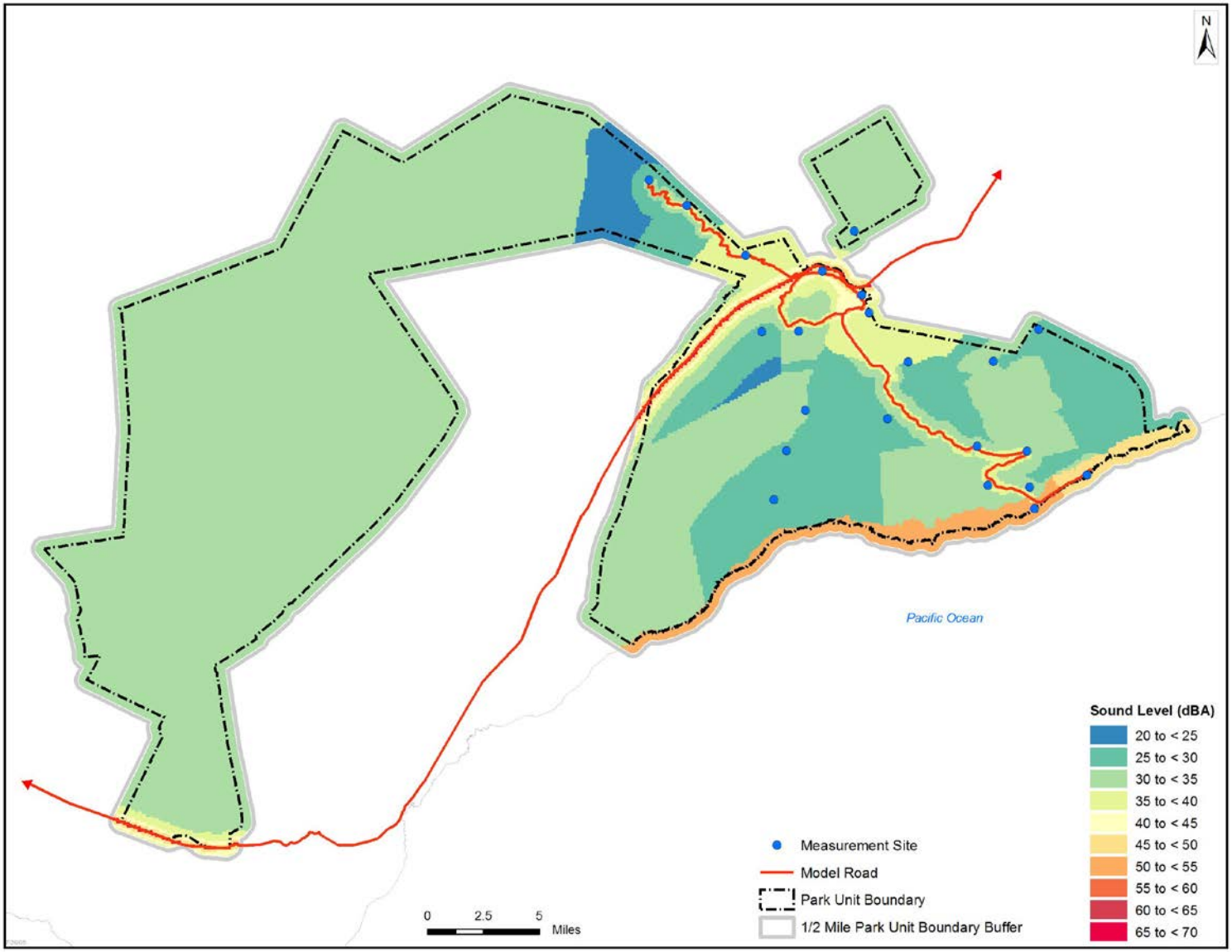


Figure 60. Baseline ambient map – Existing Ambient Without Air Tours: L_{50}.

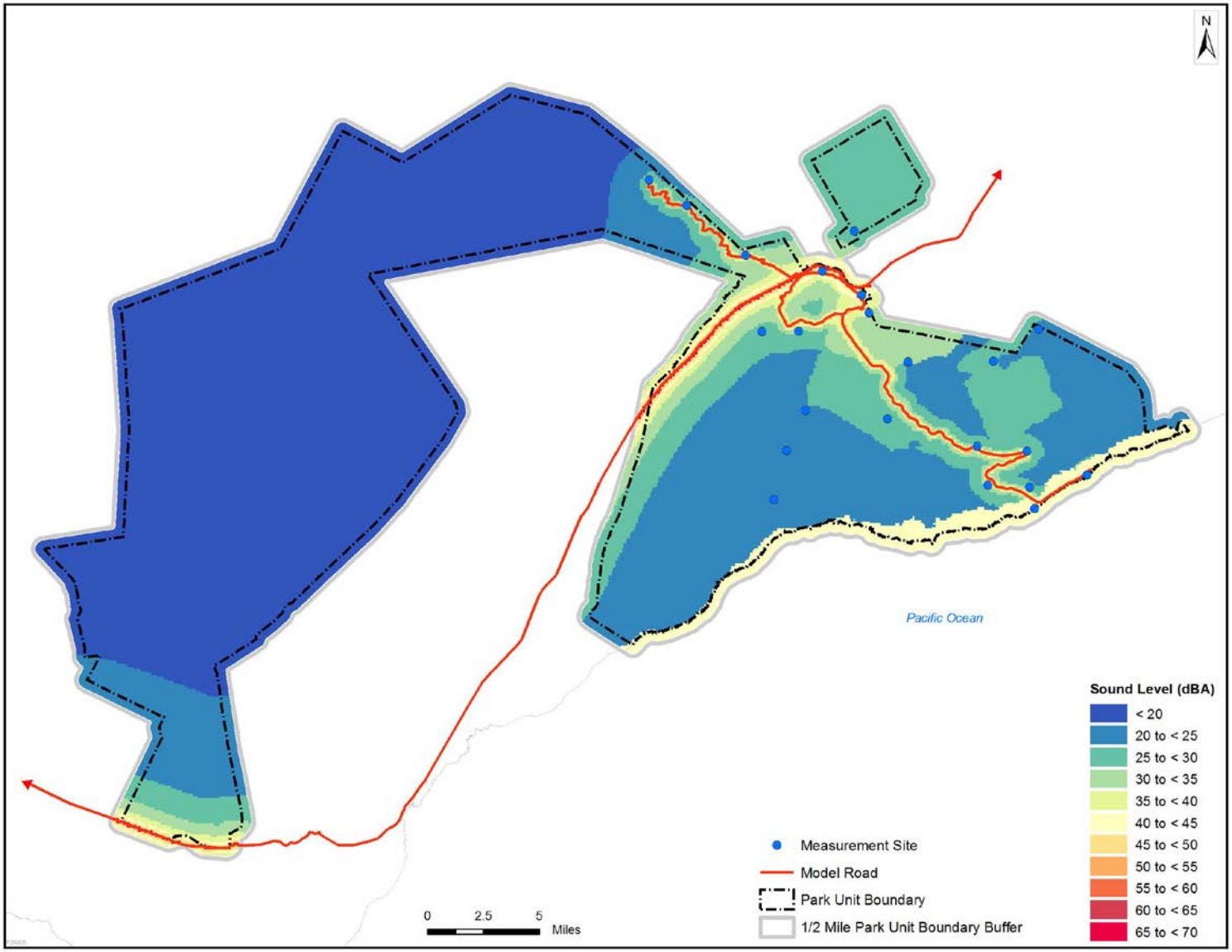


Figure 61. Baseline ambient map – Existing Ambient Without Air Tours: L_{90}.

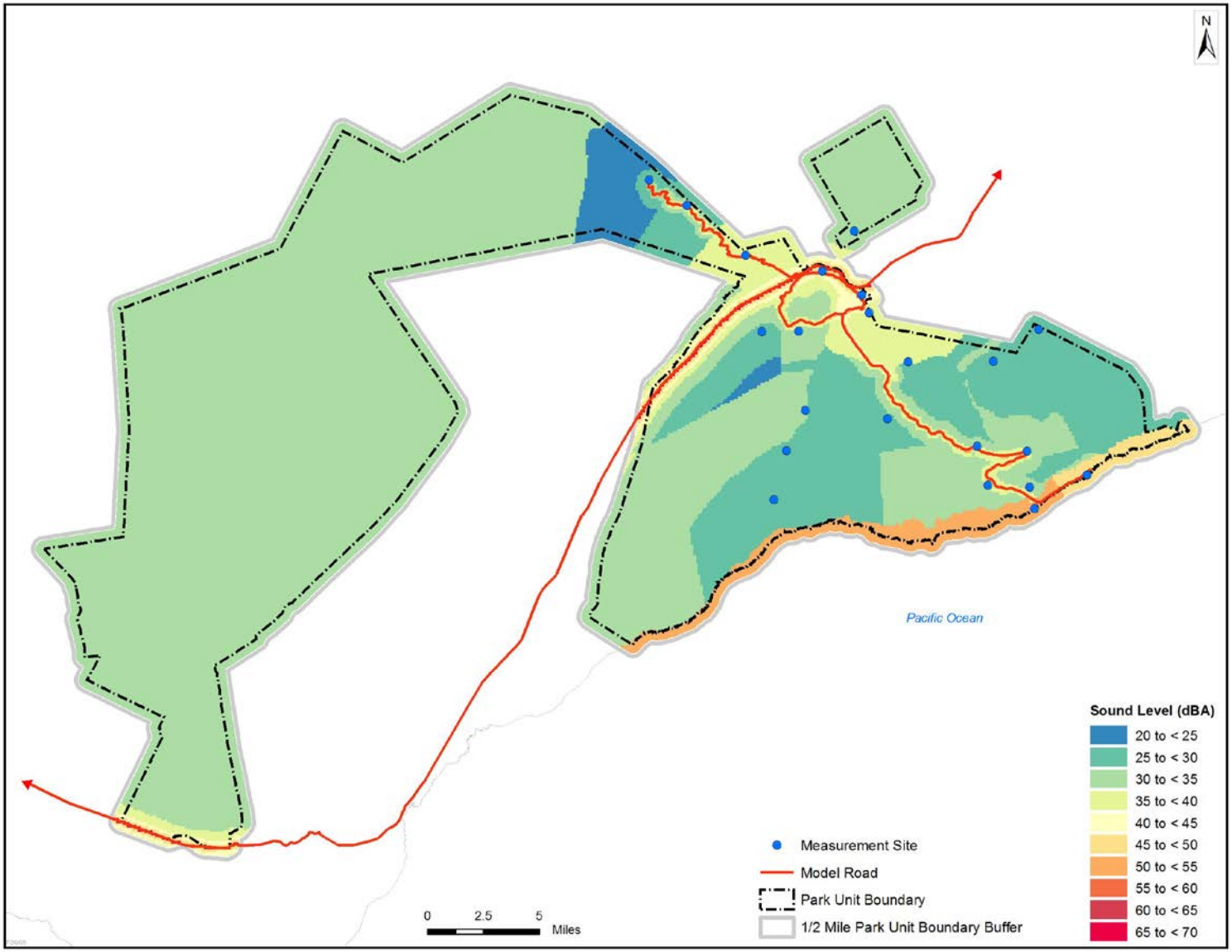


Figure 62. Baseline ambient map – Existing Ambient Without All Aircraft: L_{50}.

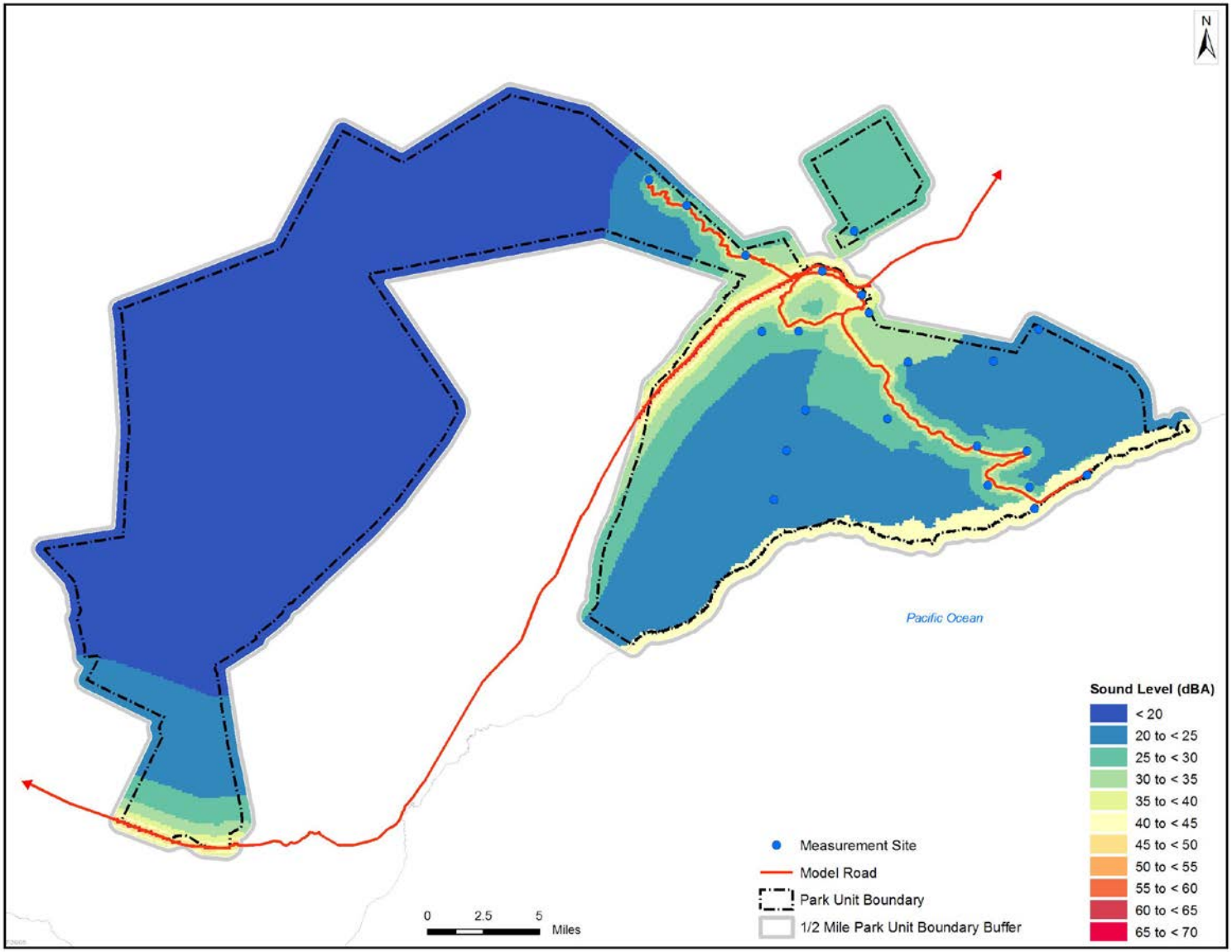


Figure 63. Baseline ambient map – Existing Ambient Without All Aircraft: L_{90}.

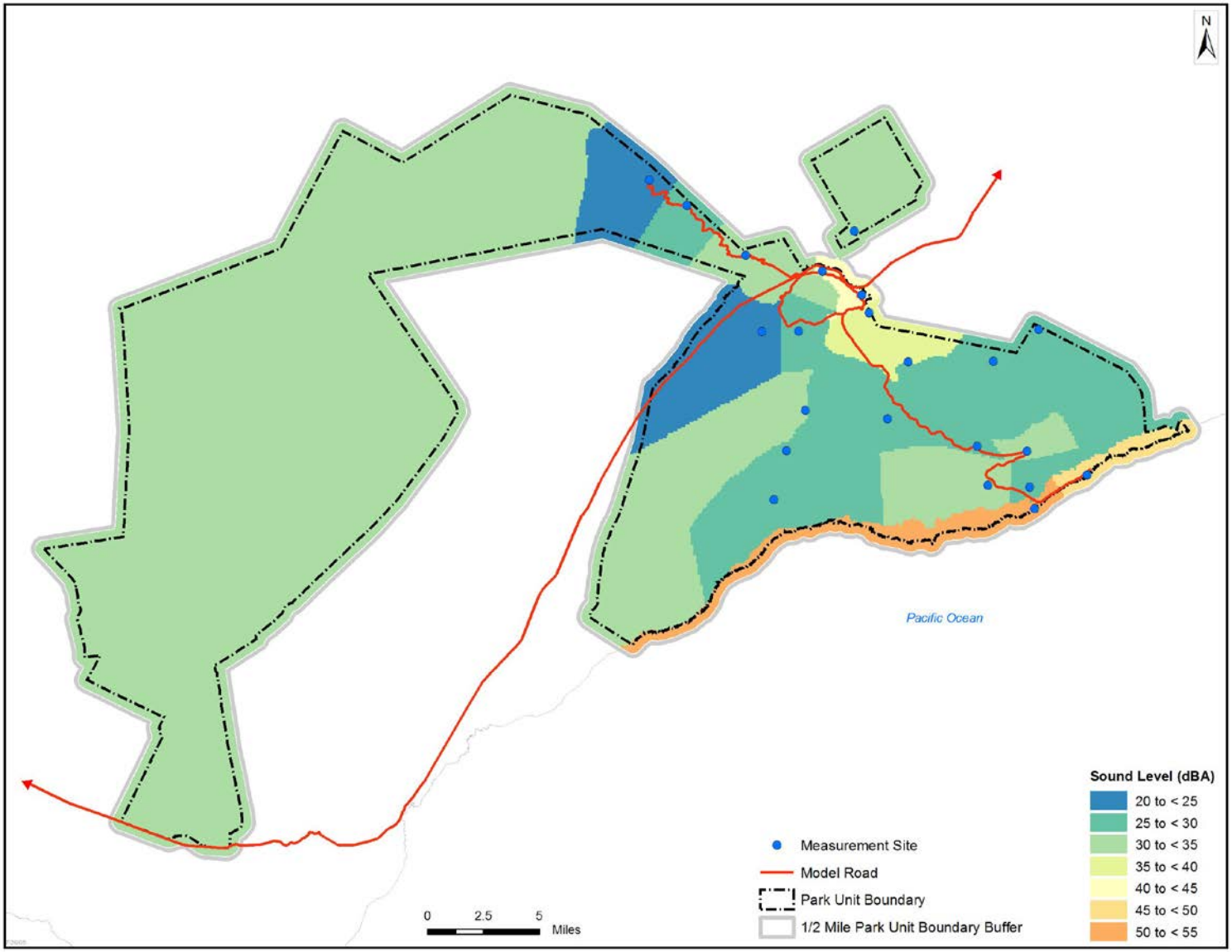


Figure 64. Baseline ambient map – Natural Ambient: L_{50}.

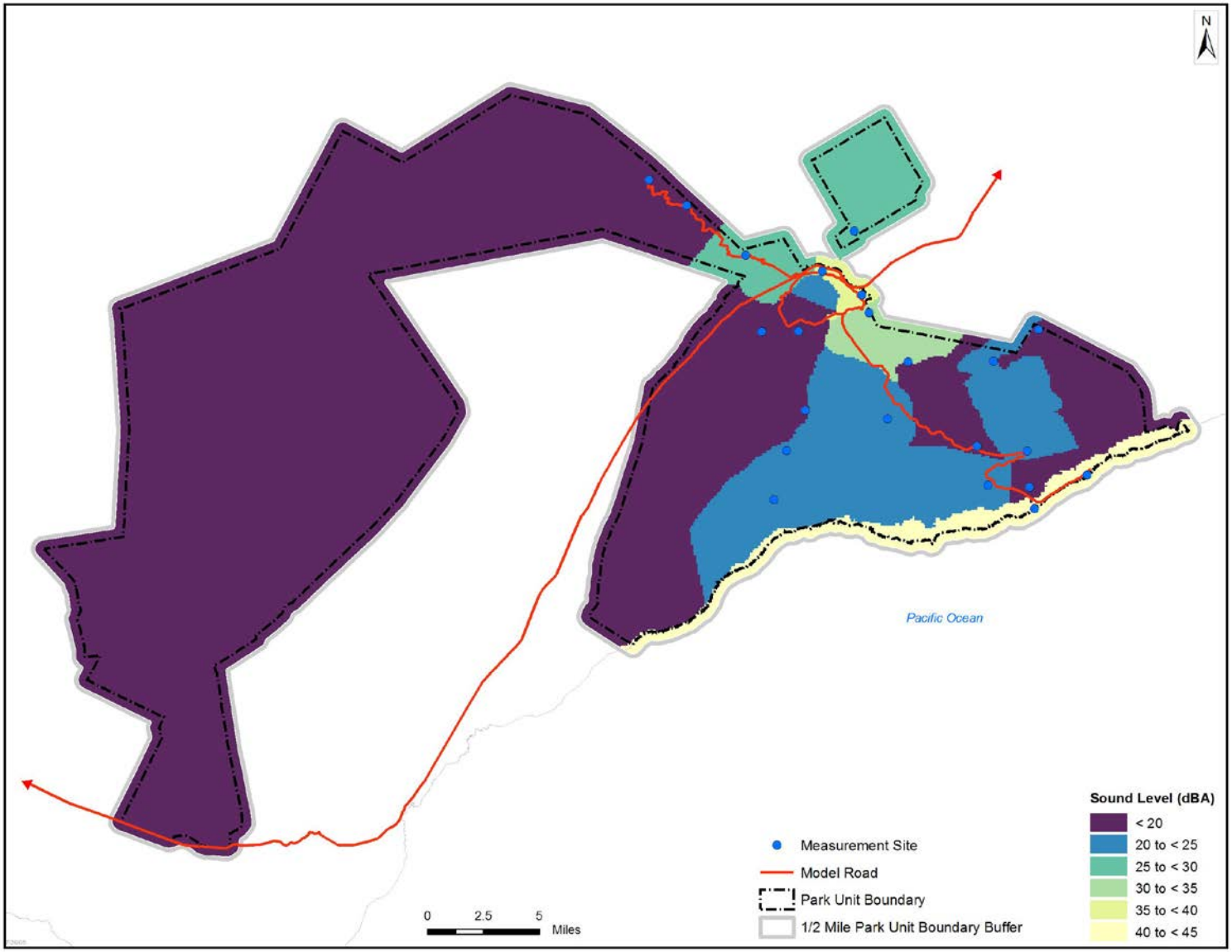


Figure 65. Baseline ambient map – Natural Ambient: L_{90}.

APPENDIX A. MEASUREMENT SITE DETAILS

All Hawai`i Volcanoes measurement sites are shown in Figure 66 and described here in detail.

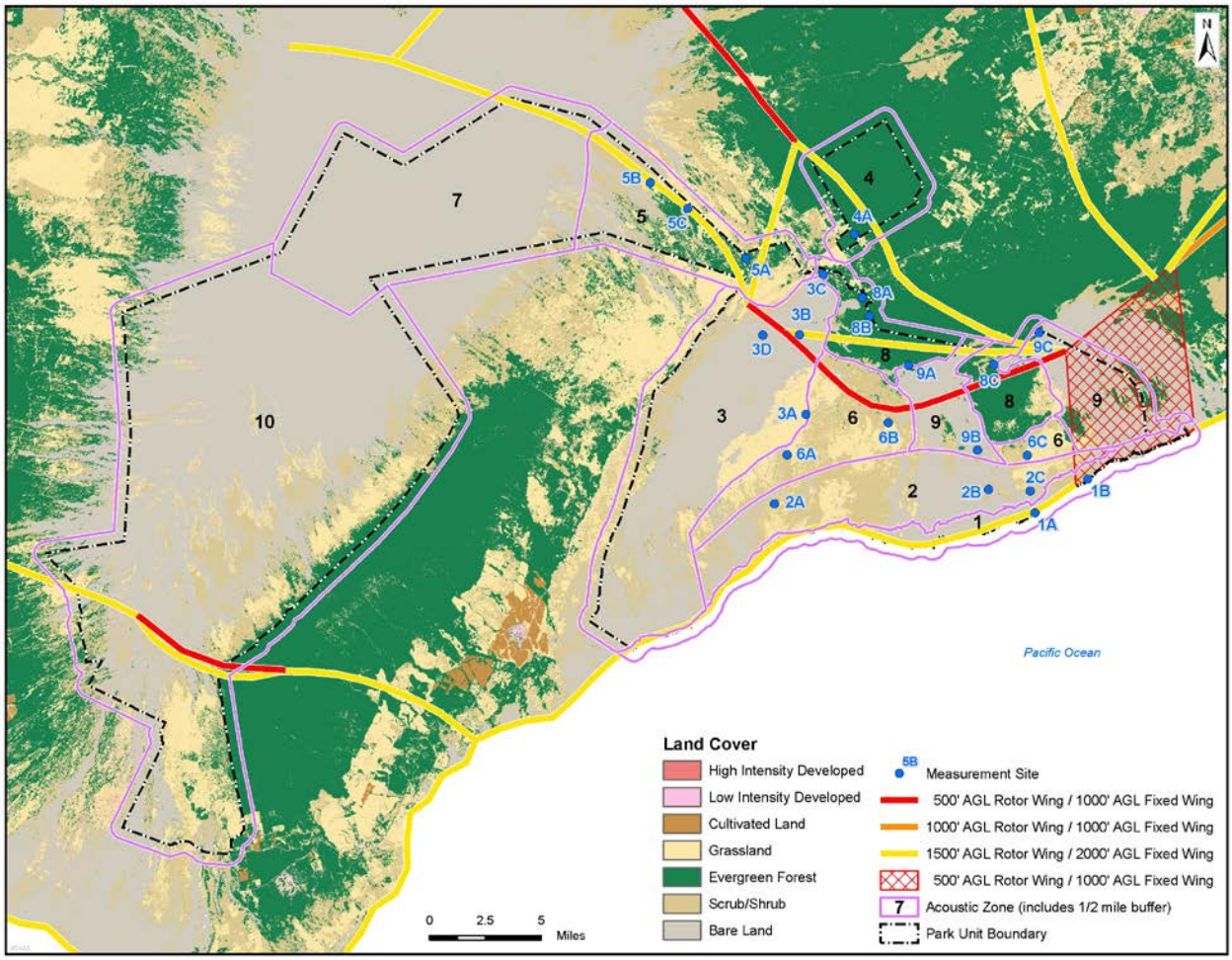


Figure 66. Final measurement sites for Hawai`i Volcanoes.

For each site, the following are included:

- A table providing site description and arranged as follows:
  - *Site ID:* The unique two-character ID representing the site "number";
  - *Site Name:* The name of the site;
  - *# Measurement Days and Dates:* The total number of days measured and the dates the measurements started and ended, respectively;
  - *System # and Type:* The numeric identifier and type of the continuous monitoring system

used at the site (see Table 7 in Section 4.1);

- *Latitude/Longitude (decimal degrees):* The latitudinal and longitudinal location of the site in decimal degrees;
- *Approximate Elevation (ft):* The elevation of the site above mean sea level (MSL) in feet;
- *Slope:* The percentage amount and direction of ground incline;
- *Ecological Domain:* The geographic ecosystem unit of the site (see also Appendix F);
- *Ecological Division:* The geographic ecosystem subunit of the site (see also Appendix F);
- *Land Cover Class:* The land cover class of the site in accordance with the National Land Cover Data (NLCD) 21-class land cover classification scheme (see also Appendix F);
- *Land Cover Subclass:* The land cover subclass of the site in accordance with the National Land Cover Data (NLCD) 21-class land cover classification scheme (see also Appendix F);
- *Management Zone:* The NPS management zone that the site was located in (see also Section 2.5);
- *Site Category:* A designator indicating expected visitor use (with "overlook" indicating high visitor use, "short hike" indicating moderate visitor use, and "backcountry" indicating minimal or no visitor use) in the measurement site area;
- *Site Type:* A designator indicating if the site was a long-term "permanent" site (i.e., data were collected for up to eight continuous months), or a short-term, "mobile" site (i.e., data were collected for approximately one to three weeks);
- *Site Description:* A short textual description of the site;
- *Access Considerations:* A short textual description of any access considerations related to the site; and
- *Potential Sound Sources:* Per discussions with the NPS during final site selection (see Section 2.6) and from site visits, the sound sources that may be and were heard at the site.

- A photograph of the area;
- A graphic presenting the daily A-weighted sound levels using three hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to the Terminology section for definitions), as well as average daily wind speeds for two-week periods over the entire measurement period.

- A graphic presenting average, hourly sound level data using three hourly A-weighted metrics (L_{Aeq}, L_{50}, and L_{90} - refer to the Terminology section for definitions), as well as average hourly wind speeds; and
- A graphic presenting distribution plots of the number of samples of each sound pressure level measured during the daytime hours, and during the nighttime hours. The average wind speed for each hour is also plotted.

Note: As stated in Section 5.5 and discussed in Appendix E, several quality assurance filters and checks (e.g., high wind filter) and then several adjustments (e.g., noise floor adjustments) were applied to the acoustic data prior to data analysis. Additional discussion on the use of ecological domains/divisions and land cover categories to correlate data in accordance with acoustic zone analyses can be found in Appendix F.

A.1 Site 1A – Shoreline Measurement Site

Table 24. Site 1A: description.

Site ID	**1A**
Site Name	20-Minute Trail
# Measurement Days and Dates	14 days - October 24, 2002 to November 6, 2002
System # and Type	7 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1219 / 19.2787
Approximate Elevation (ft)	40
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Permanent
Site Description	Black sand beach with bare lava fields just above coastal bluffs
Access Considerations	1-mile round trip hike on trail
Potential Sound Sources	Aircraft, Vehicles, Hikers, Birds, Wind, Surf

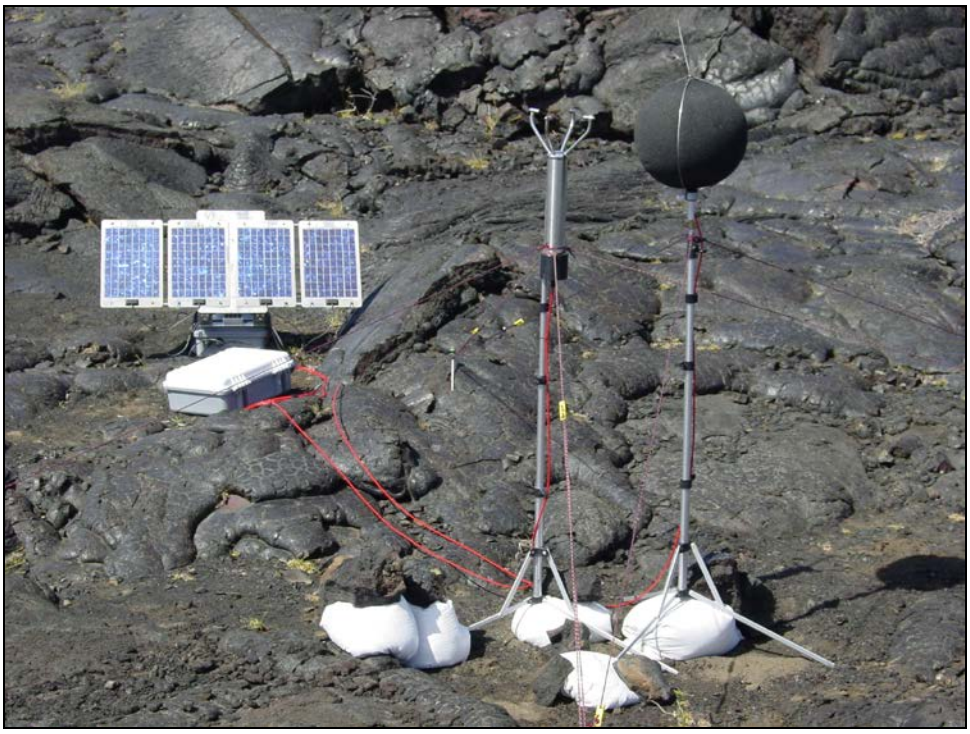


Figure 67. Site 1A: Description and photograph.

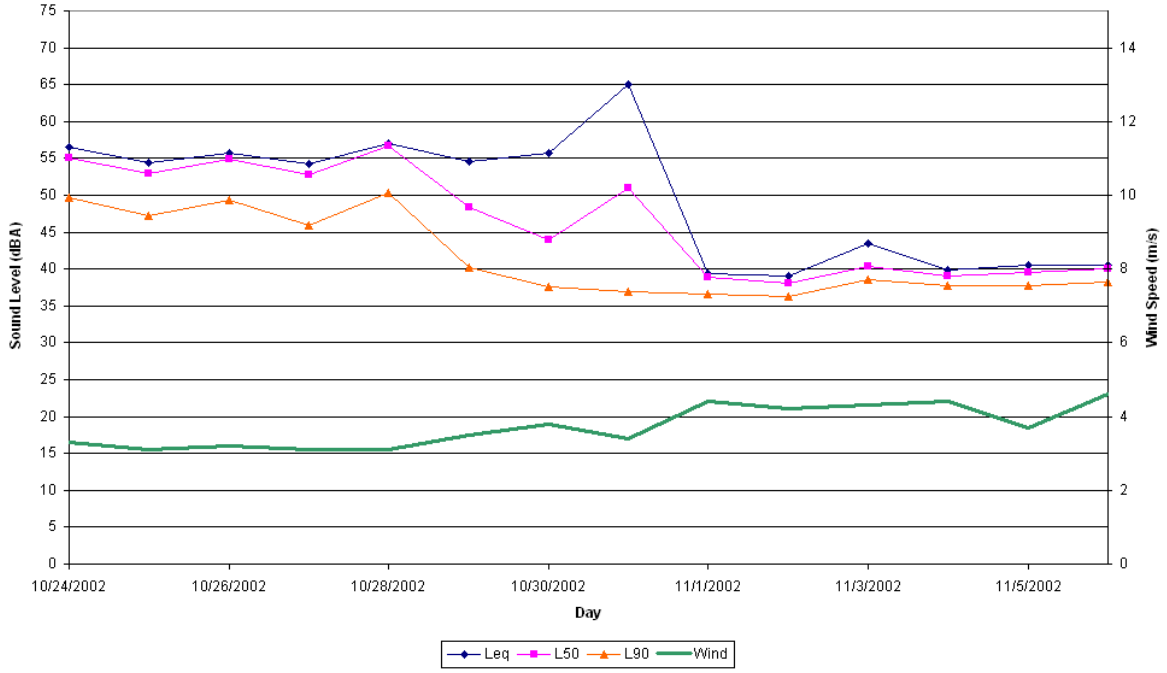


Figure 68. Daily sound levels and wind speeds: Site 1A.*

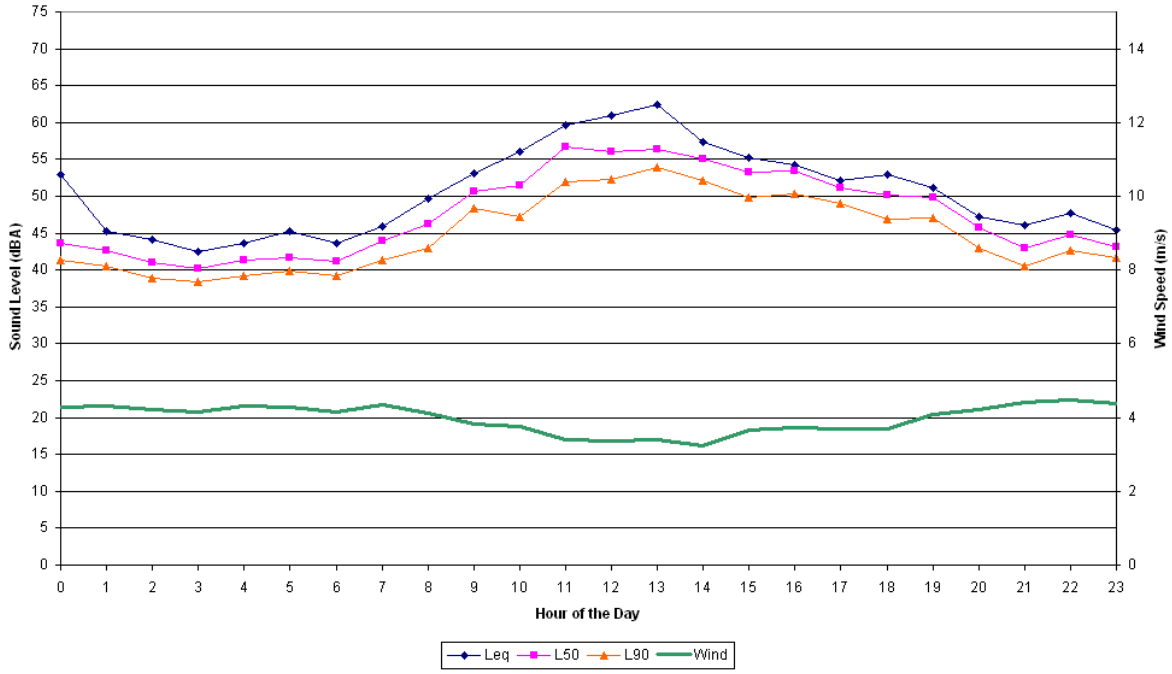


Figure 69. Average hourly sound levels and wind speeds: Site 1A.

* Note: Increases in sound level between 10/31/02 to 11/1/02 are attributed to rain storms.

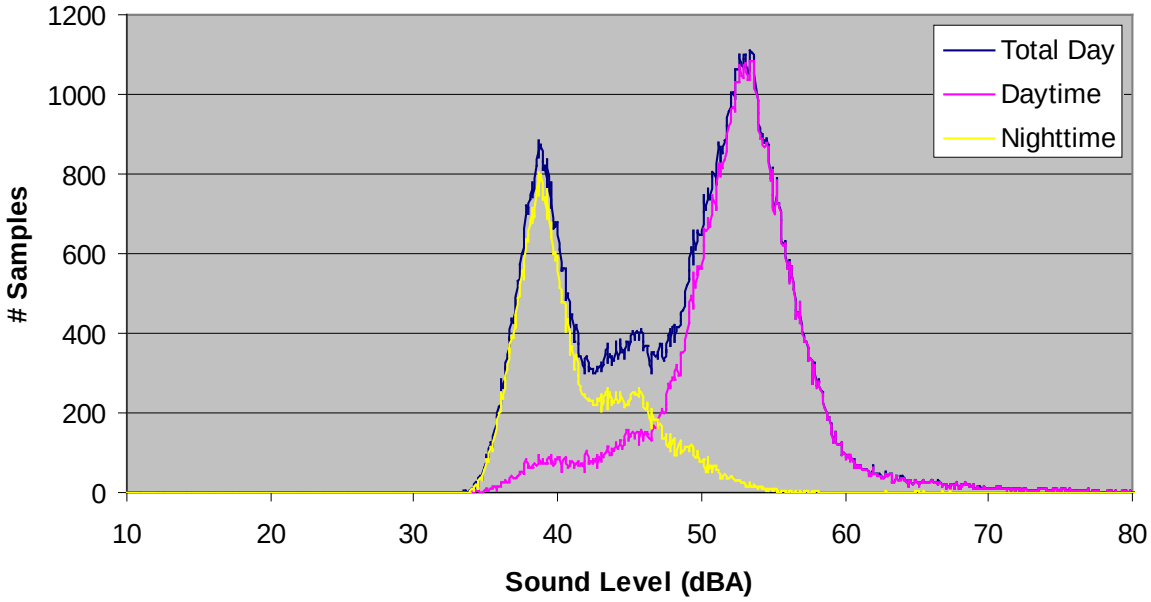


Figure 70. Distribution of data: Site 1A.

The distribution data shown above shows a definite diurnal signature, which indicates human activity affects this site during the day. This site is characterized by wind and surf noise throughout the day with some helicopter activity during the mid-morning.

A.2 Site 1B – Shoreline Measurement Site

Table 25. Site 1B: description.

Site ID	**1B**
Site Name	Current Eruption Viewing
# Measurement Days and Dates	14 days - October 24, 2002 to November 6, 2002
System # and Type	5 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.0857 / 19.3004
Approximate Elevation (ft)	10
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Overlook
Site Type (see Section 2.7.2)	Mobile
Site Description	Newest black sand beach with bare lava fields just above coastal bluffs
Access Considerations	0.2-mile round trip hike off trail
Potential Sound Sources	Aircraft, Vehicles, Hikers, Birds, Wind, Surf



Figure 71. Site 1B: Description and photograph.

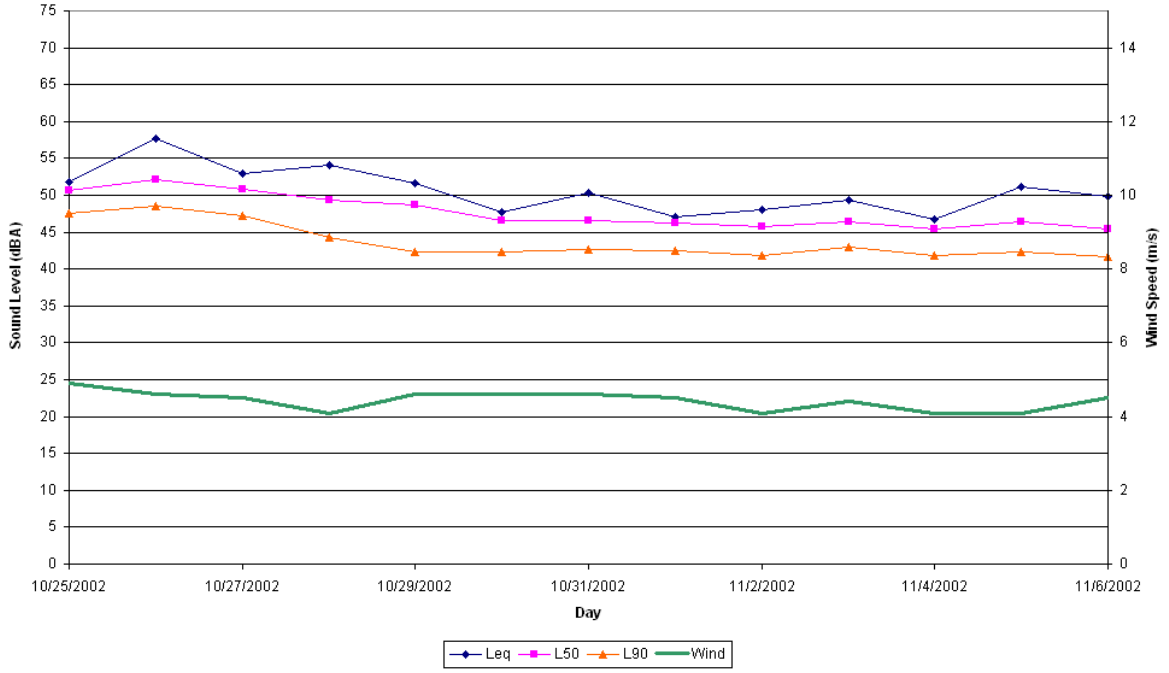


Figure 72. Daily sound levels and wind speeds: Site 1B.

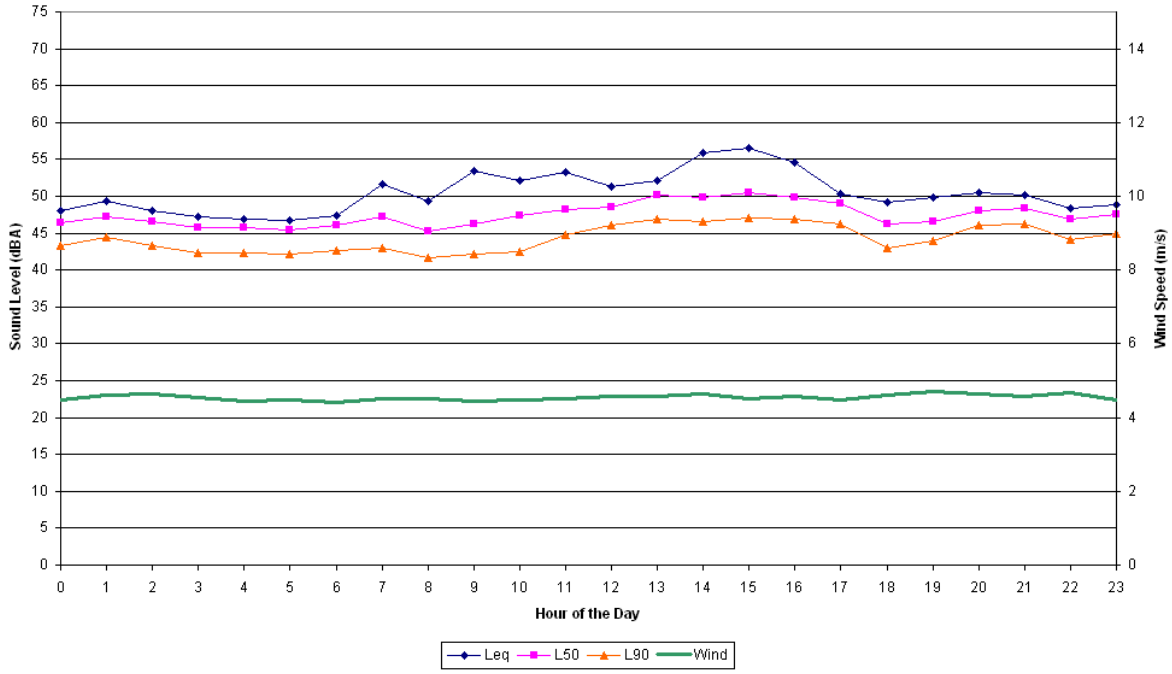


Figure 73. Average hourly sound levels and wind speeds: Site 1B.

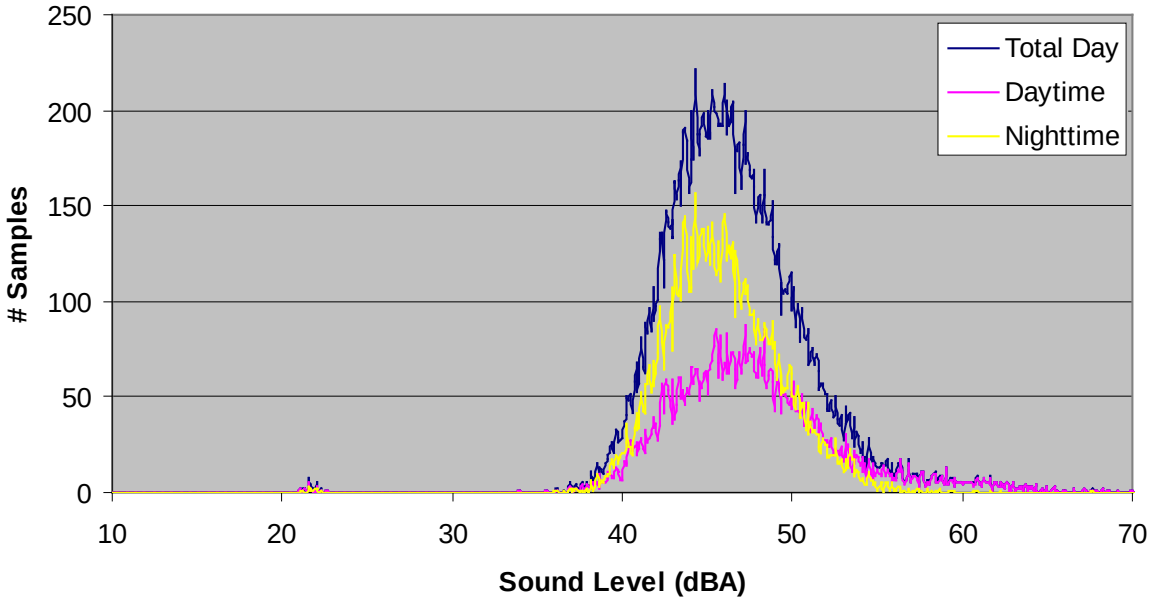


Figure 74. Distribution of data: Site 1B.

This site is characterized by wind and surf noise with helicopter activity during the day and evening. As this site was closest to the lava eruption viewing area, it experienced the greatest concentration of visitor activity (hikers, motorists, and air tours) in the entire park.

A.3 Site 2A –Coastal Lowlands Measurement Site

Table 26. Site 2A: description.

Site ID	**2A**
Site Name	Base of Hilina Pali
# Measurement Days and Dates	85 days - October 25, 2002 to January 23, 2003
System # and Type	9 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.3004 / 19.2847
Approximate Elevation (ft)	800
Slope	< 10% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Wilderness (Natural subzone)
Site Category (see Section 2.5.1)	Backcountry
Site Type (see Section 2.7.2)	Permanent
Site Description	Grassland with occasional barren lava flows
Access Considerations	4-mile round trip hike on steep 1500-ft. switchback trail
Potential Sound Sources	Aircraft, Wind

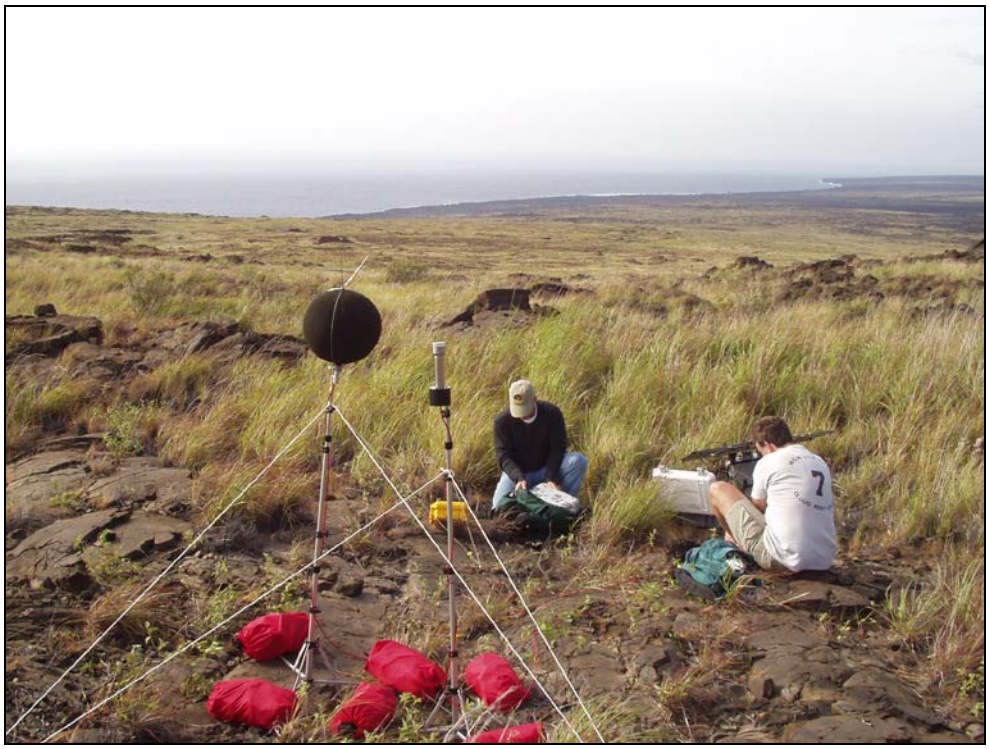


Figure 75. Site 2A: Description and photograph.

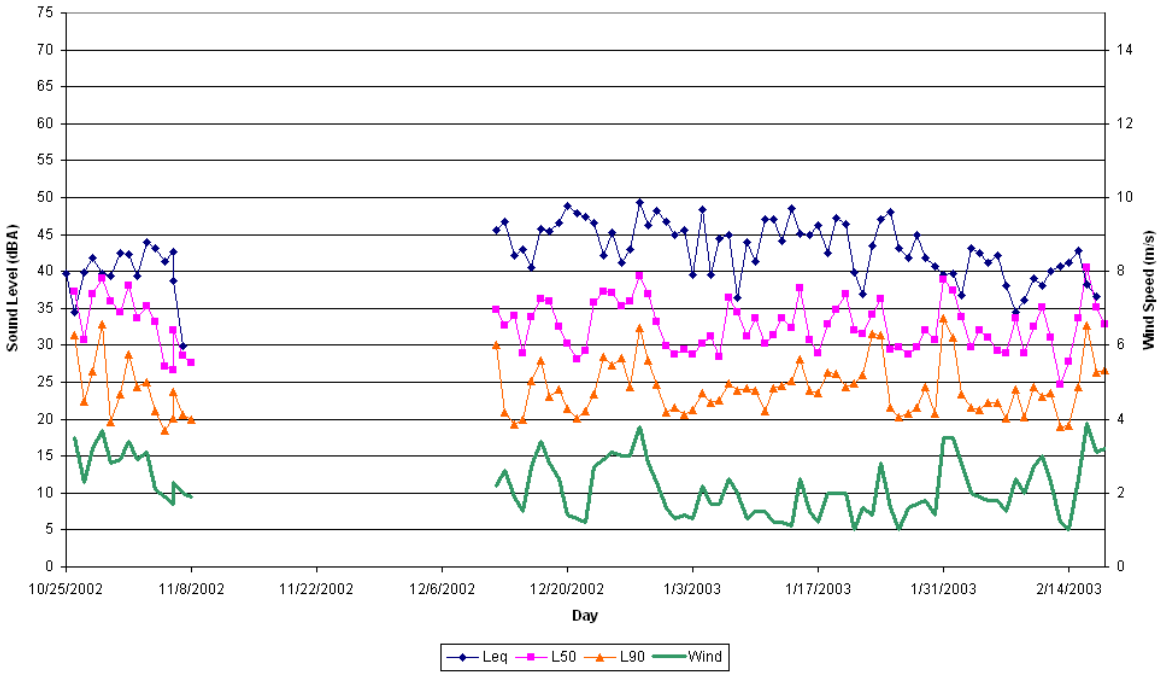


Figure 76. Daily sound levels and wind speeds: Site 2A.

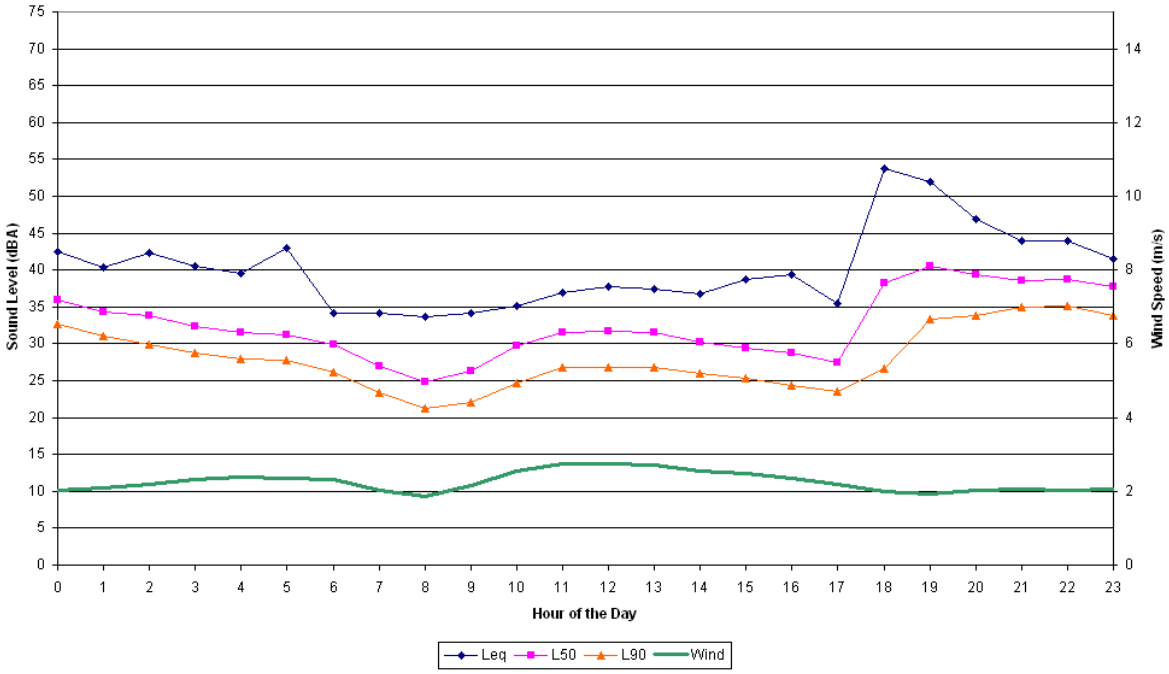


Figure 77. Average hourly sound levels and wind speeds: Site 2A.

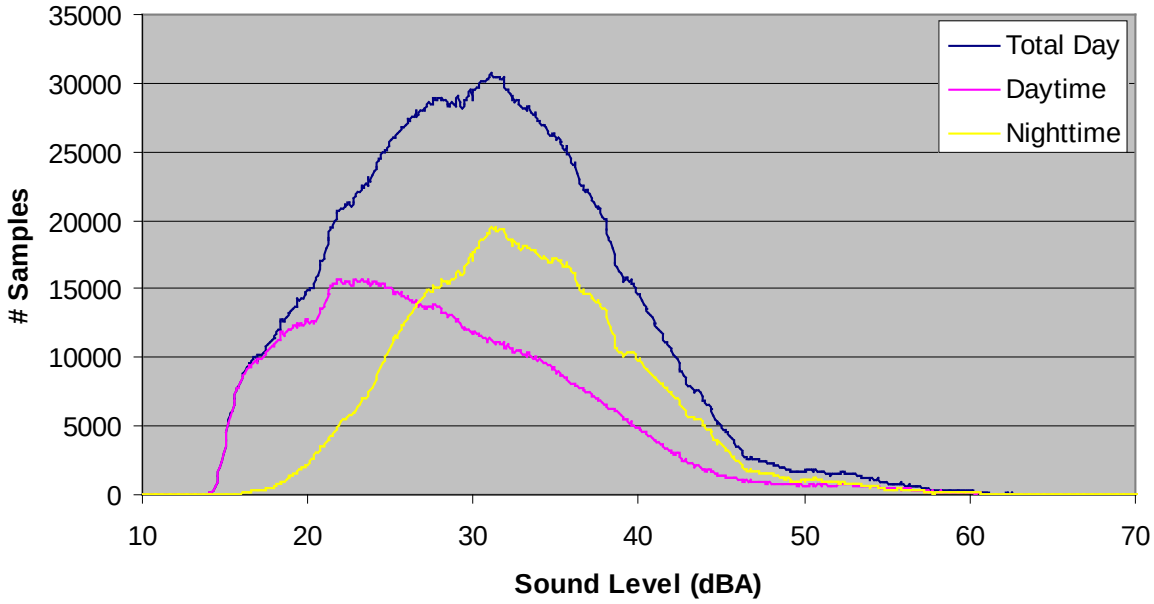


Figure 78. Data distributions: Site 2A.

This site is characterized by wind noise through the grass, nocturnal insect noise and the occasional helicopters.

A.4 Site 2B – Coastal Lowlands Measurement Site

Table 27. Site 2B: description.

Site ID	**2B**
Site Name	Kealakomo Waena
# Measurement Days and Dates	17 days - November 27, 2002 to December 13, 2002
System # and Type	2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1537 / 19.2938
Approximate Elevation (ft)	450
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Grassy Kipuka (oasis of undisturbed land within a lava field)
Access Considerations	Approximately 0.6-mile round trip hike off trail
Potential Sound Sources	Aircraft, Vehicles, Wind



Figure 79. Site 2B: Description and photograph.[37]

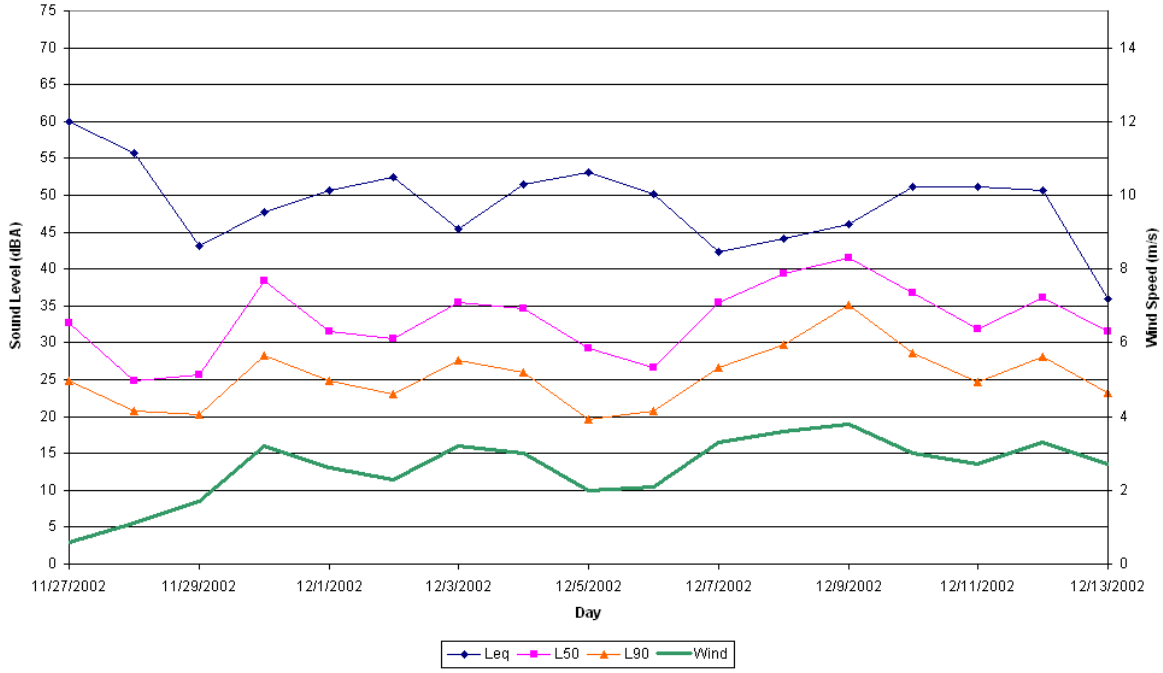


Figure 80. Daily sound levels and wind speeds: Site 2B.

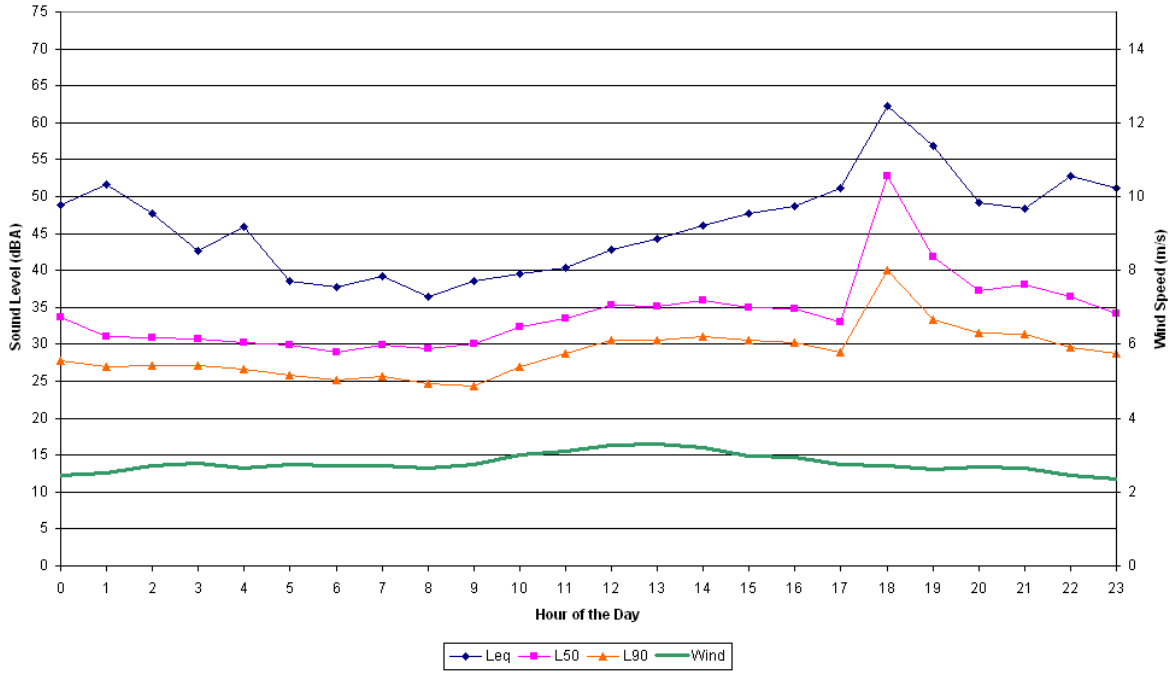


Figure 81. Average hourly sound levels and wind speeds: Site 2B.

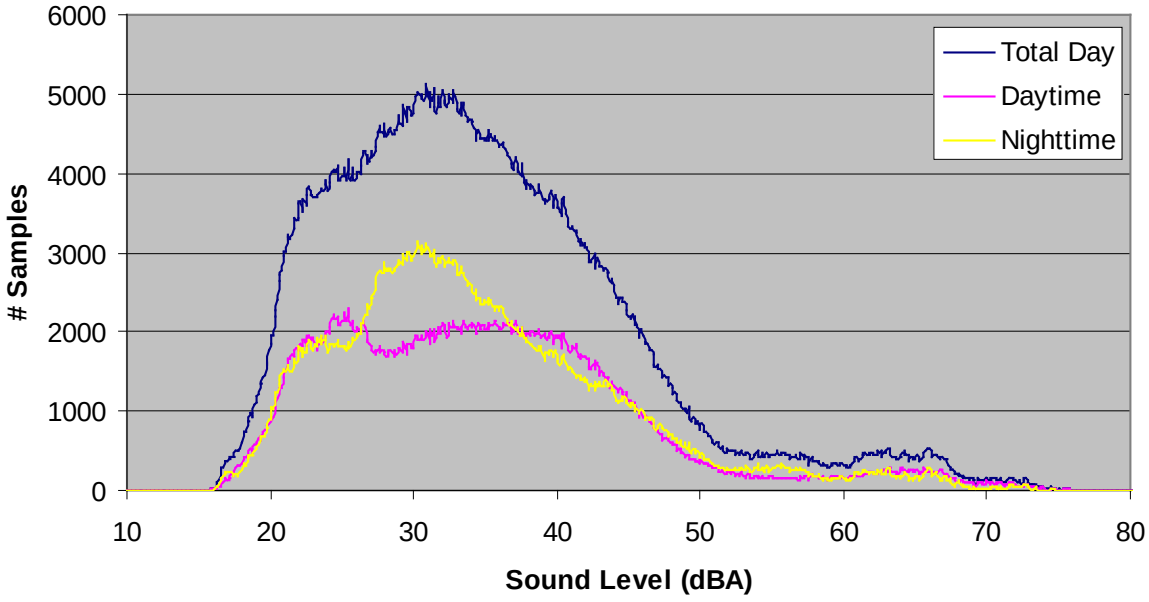


Figure 82. Data distributions: Site 2B.

This site is characterized by wind noise through the grass, insect noise and vehicle noise. Nighttime insect noise is also present.

A.5 Site 2C – Coastal Lowlands Measurement Site

Table 28. Site 2C: description.

Site ID	**2C**
Site Name	Pu`u Loa Petroglyphs
# Measurement Days and Dates	13 days - November 25, 2002 to December 7, 2002
System # and Type	7 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1252 / 19.2927
Approximate Elevation (ft)	170
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Lava plain with sparse grass and shrubs
Access Considerations	Approximately 0.4 miles off a trail near the Pu`u Loa Petroglyphs
Potential Sound Sources	Aircraft, Wind



Figure 83. Site 2C: Description and photograph.[37]

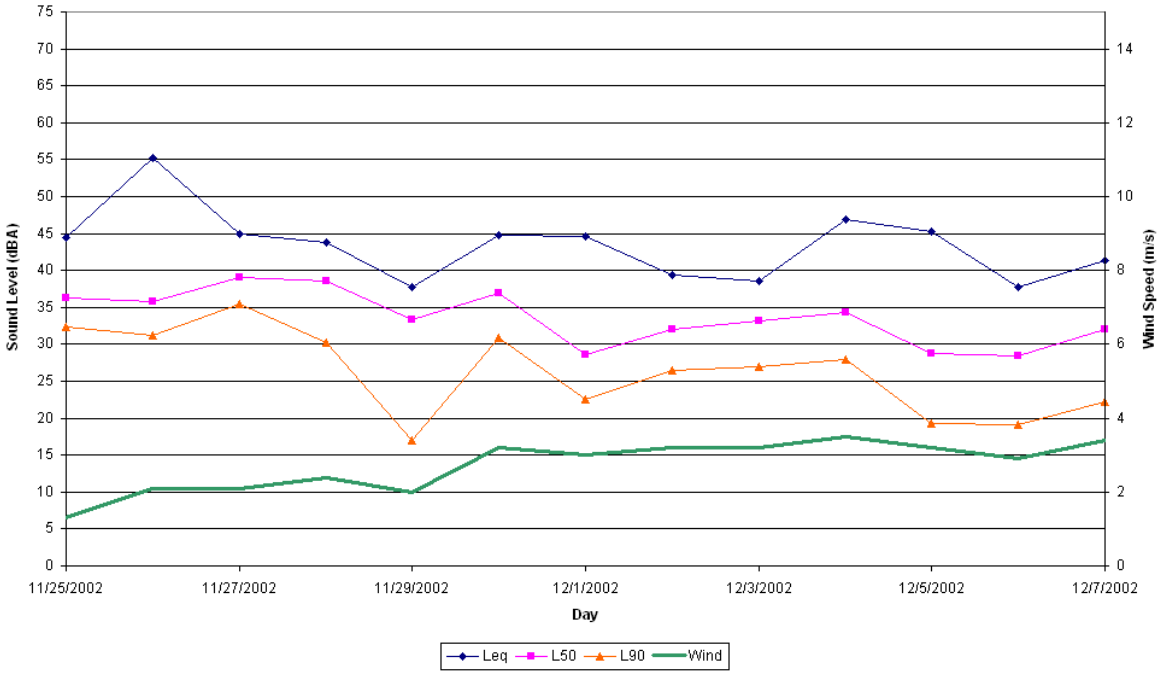


Figure 84. Daily sound levels and wind speeds: Site 2C.

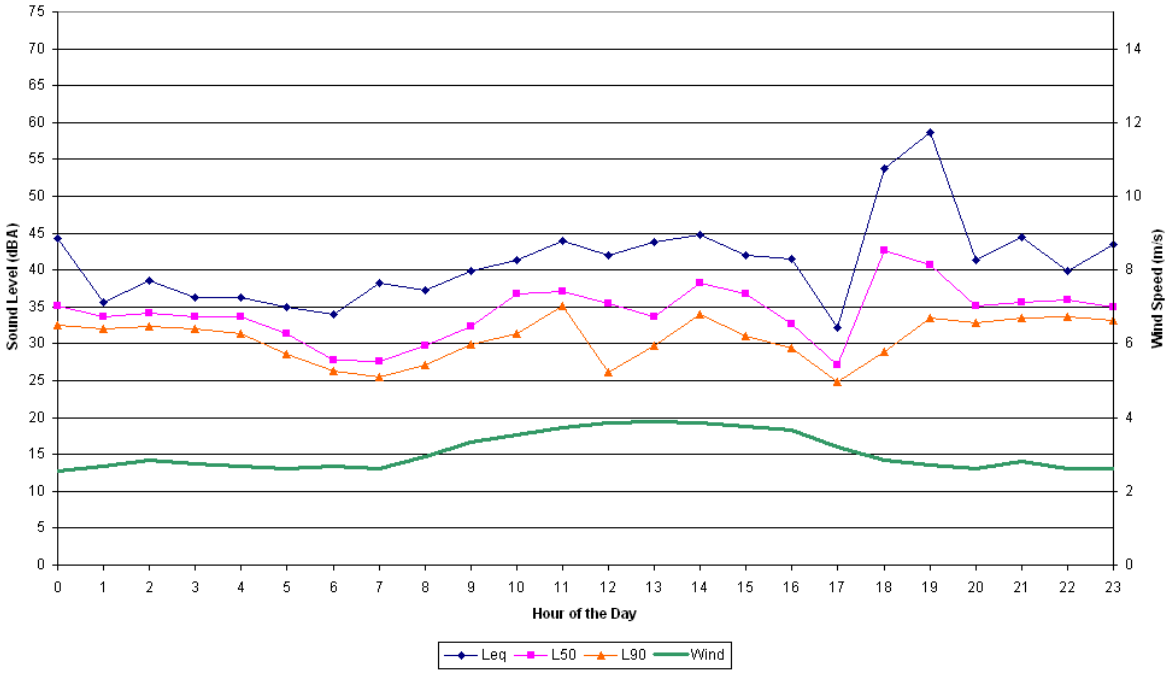


Figure 85. Average hourly sound levels and wind speeds: Site 2C.

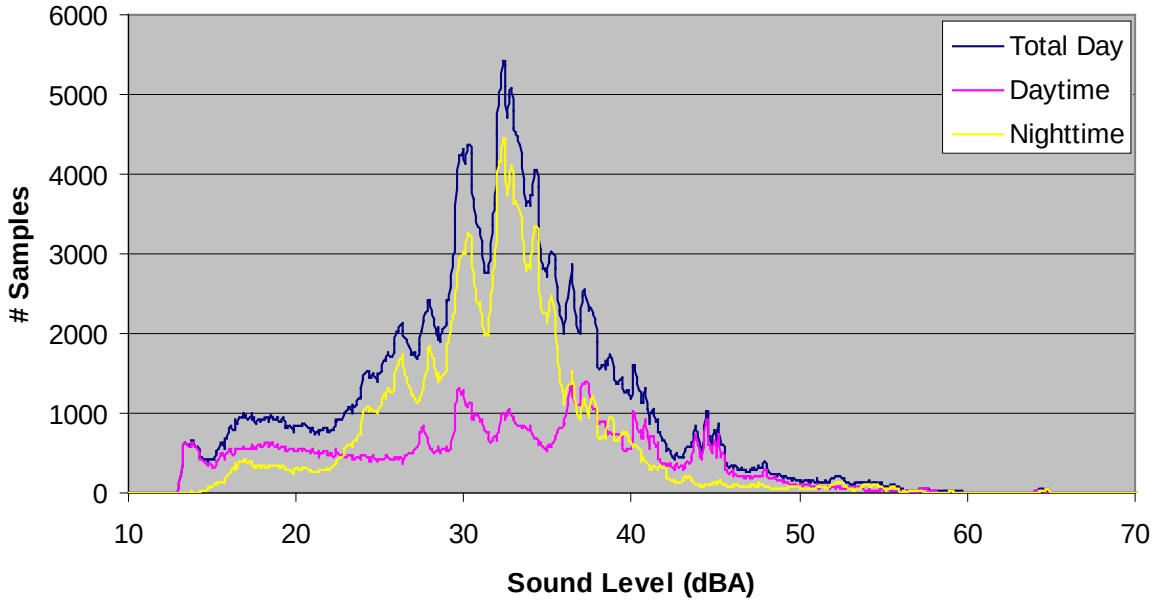


Figure 86. Data distributions: Site 2C.

This site is characterized by wind noise through the grass, insect noise and vehicle noise. The distribution shows minimal diurnal effect, which indicates that although insect noise was detectable it was not significantly higher than daytime levels.

A.6 Site 3A – Ka`ū Desert / Kīlauea Summit Site

Table 29. Site 3A: description.

Site ID	**3A**
Site Name	Mauna Iki Trail
# Measurement Days and Dates	118 days - October 25, 2002 to February 25, 2003
System # and Type	4 (NoiseLogger™ Plus)
Latitude / Longitude (decimal degrees)	155.2788 / 19.3426
Approximate Elevation (ft)	2700
Slope	< 5% Southwest
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Permanent
Site Description	Mostly bare lava deserts with scattered shrubs
Access Considerations	0.8-mile round trip hike on trail
Potential Sound Sources	Aircraft, Wind

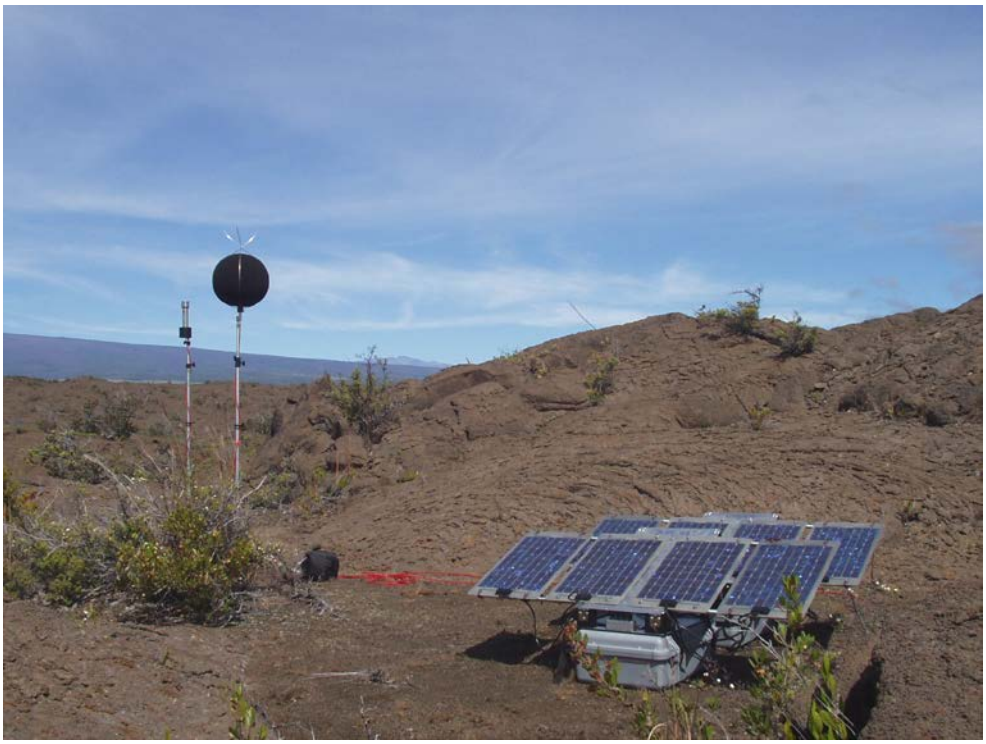


Figure 87. Site 3A: Description and photograph.

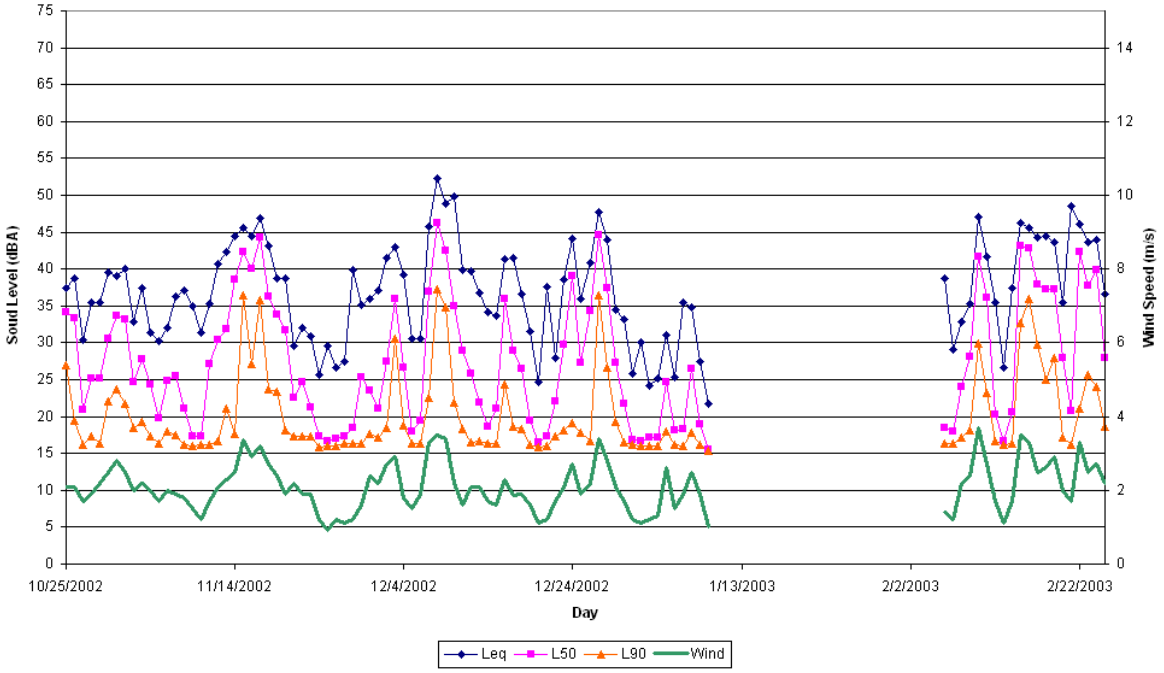


Figure 88. Daily sound levels and wind speeds: Site 3A.

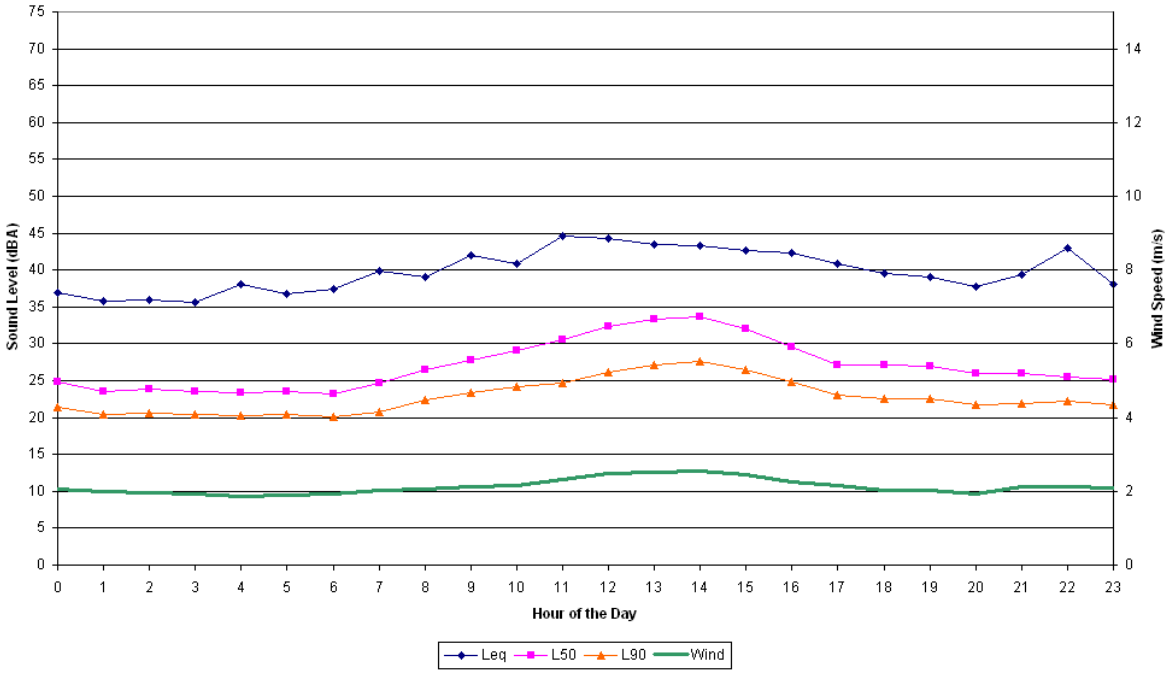


Figure 89. Average hourly sound levels and wind speeds: Site 3A.

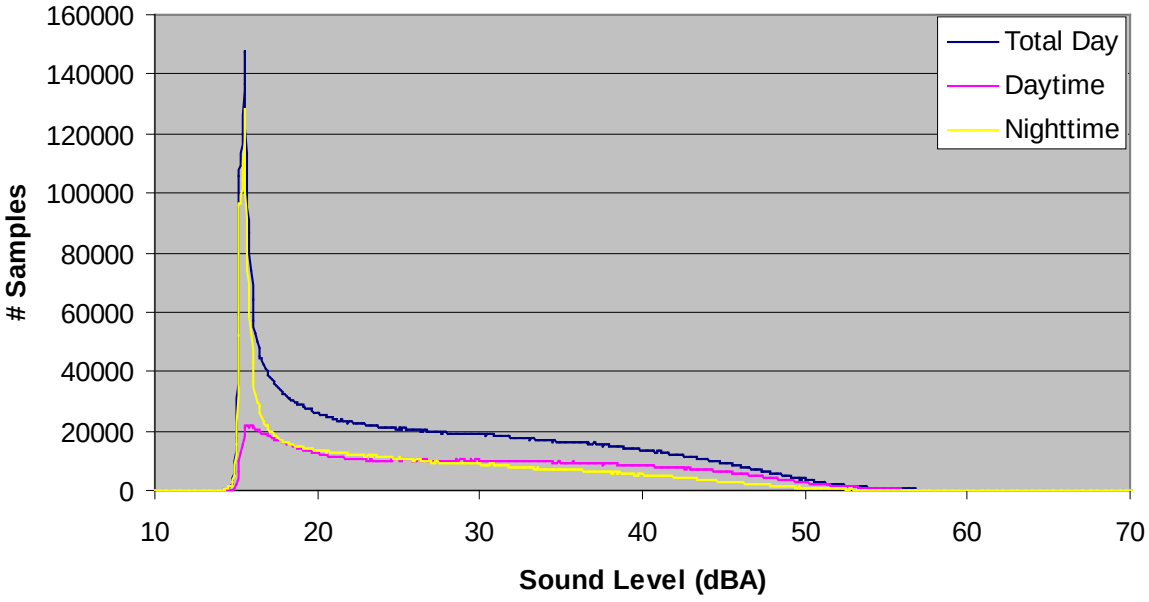


Figure 90. Data distributions: site 3A.

This site is characterized by noise due to high winds at this site, some insect noise and distinct aircraft activity. The distribution for this site is heavily skewed toward lower sound levels due to their predominance during nighttime hours.

A.7 Site 3B – Ka`ū Desert / Kīlauea Summit Site

Table 30. Site 3B: description.

Site ID	**3B**
Site Name	Halema`uma`u
# Measurement Days and Dates	18 days - January 17, 2003 to February 27, 2003
System # and Type	2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2835 / 19.3941
Approximate Elevation (ft)	3600
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Overlook
Site Type (see Section 2.7.2)	Mobile
Site Description	Bare lava and ash
Access Considerations	Off Crater Rim Trail in the high visitor-use Halema`uma`u Crater area
Potential Sound Sources	Vehicles, Hikers, Wind



Figure 91. Site 3B: Description and photograph (Note: System not shown).[37]

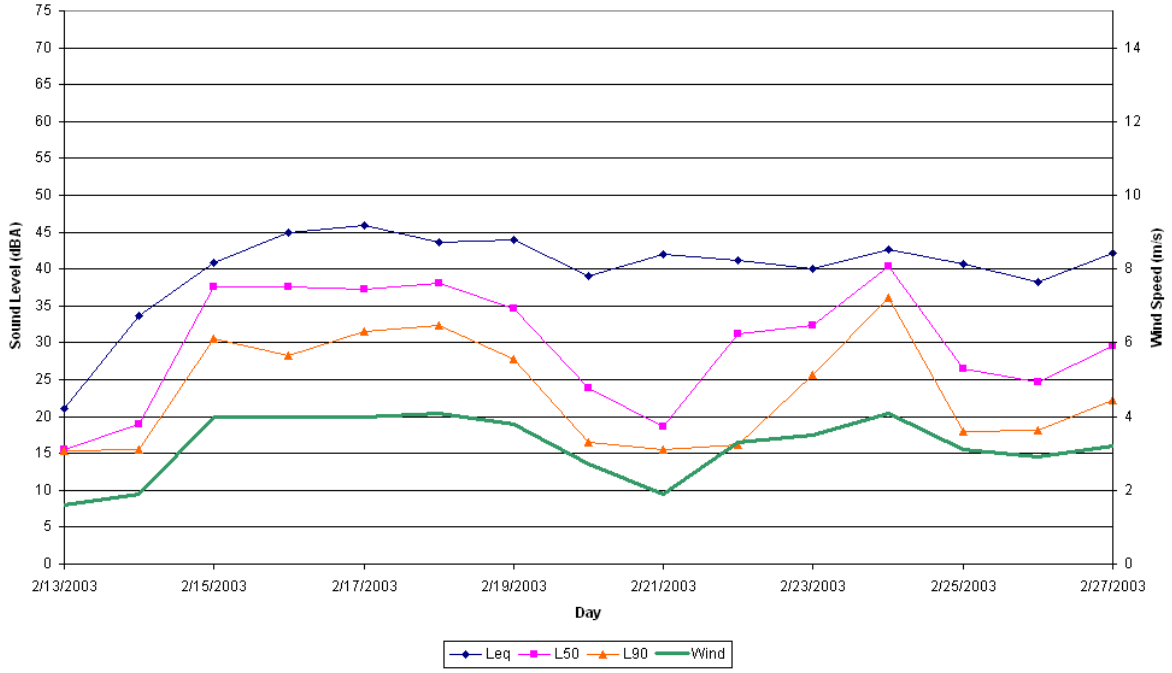


Figure 92. Daily sound levels and wind speeds: Site 3B.

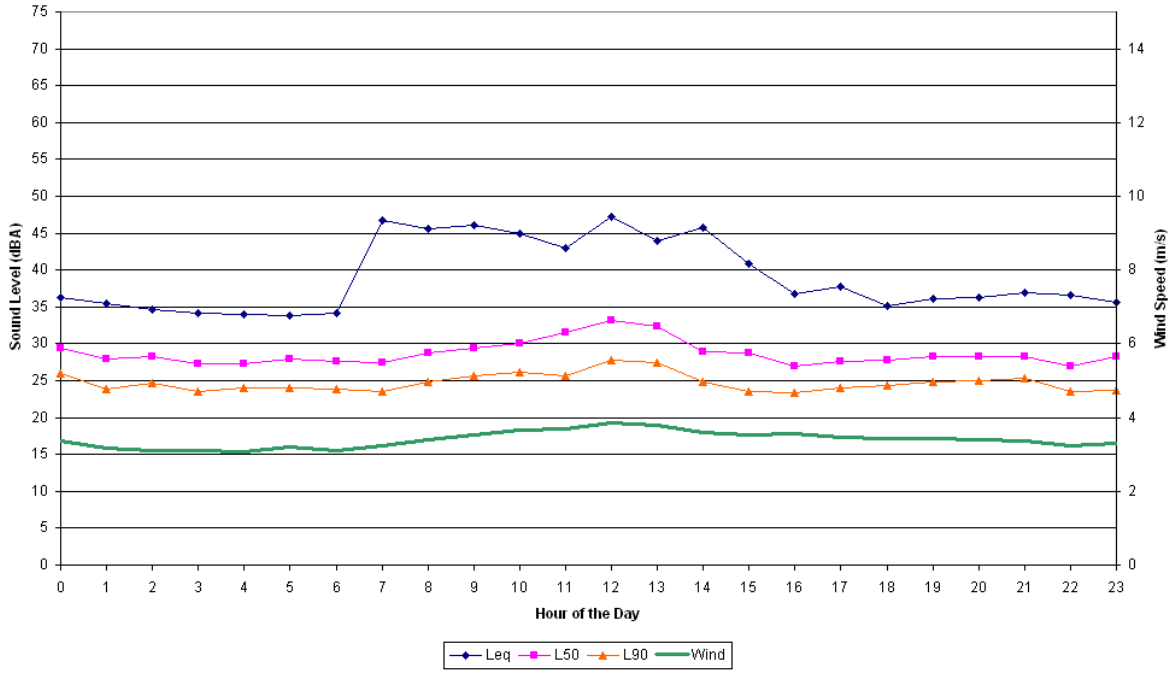


Figure 93. Average hourly sound levels and wind speeds: Site 3B.

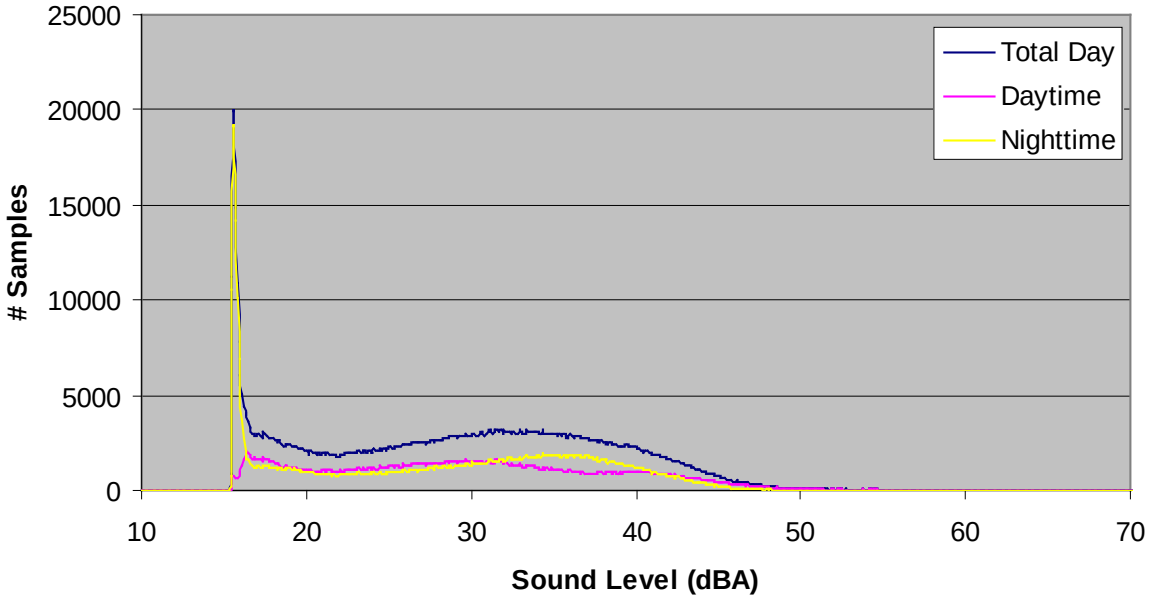


Figure 94. Data distributions: Site 3B.

This site is characterized by wind noise, some insect noise, and distinct helicopter flyovers. Similar to Site 3A, the distribution for this site is heavily skewed toward lower sound levels due to their predominance during nighttime hours. However, this site also shows more sound levels in the 25-45 decibel range, which correlates with increased daytime activity due to the site's proximity to Halema`uma`u Trail in the Kīlauea Caldera.

A.8 Site 3C – Ka`ū Desert / Kīlauea Summit Site

Table 31. Site 3C: description.

Site ID	**3C**
Site Name	Steam Vents
# Measurement Days and Dates	14 days - November 7, 2002 to November 20, 2002
System # and Type	7 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2672 / 19.4332
Approximate Elevation (ft)	4000
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Overlook
Site Type (see Section 2.7.2)	Mobile
Site Description	Grassy field with trees and shrubs in steam vents area
Access Considerations	East of the Kīlauea Military Camp off Crater Rim Drive in steam vents area, approximately 0.25-mile round trip hike off the trail
Potential Sound Sources	Aircraft, Vehicles, Wind



Figure 95. Site 3C: Description and photograph.[37]

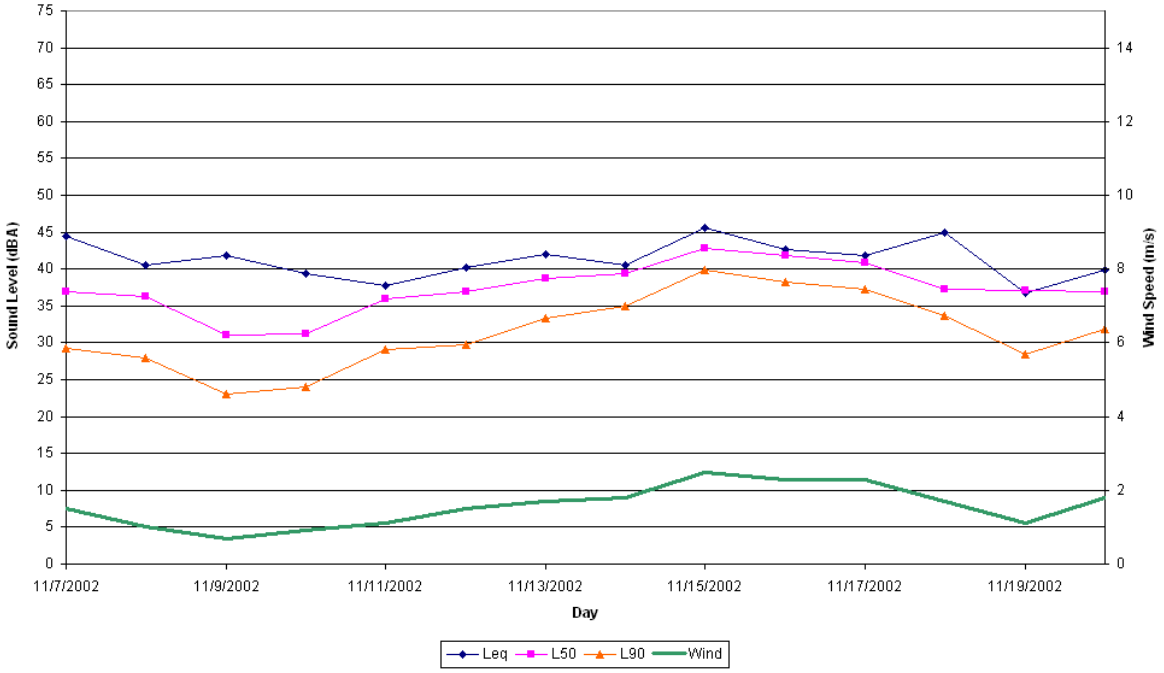


Figure 96. Daily sound levels and wind speeds: Site 3C.

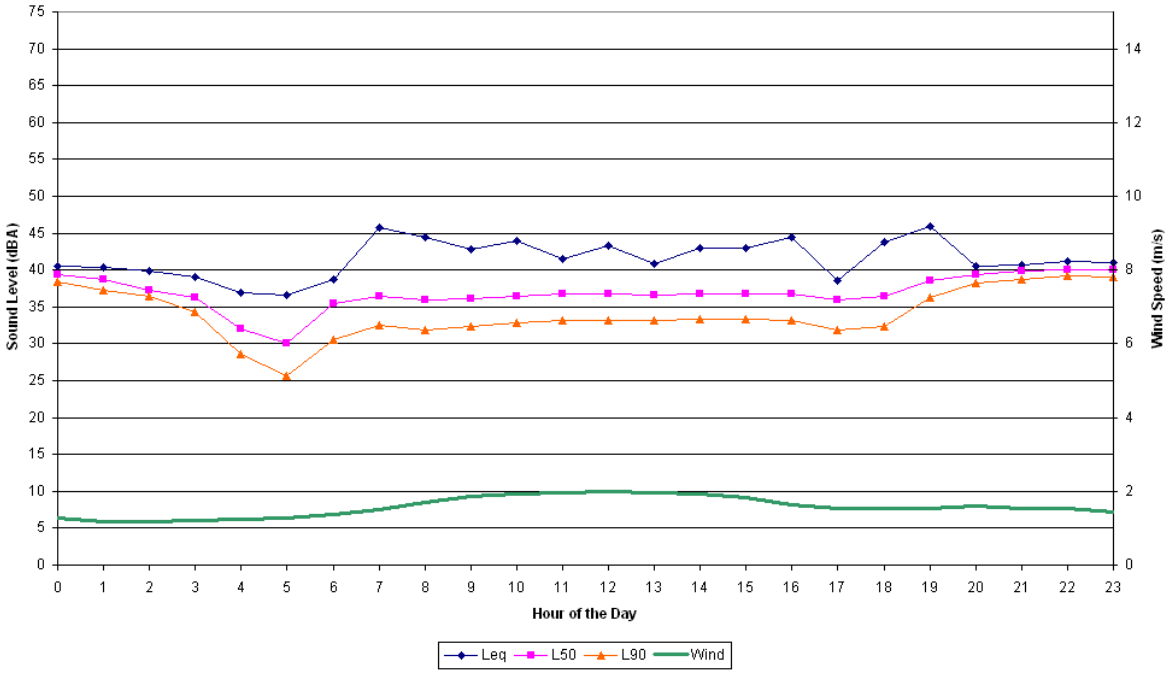


Figure 97. Average hourly sound levels and wind speeds: Site 3C.

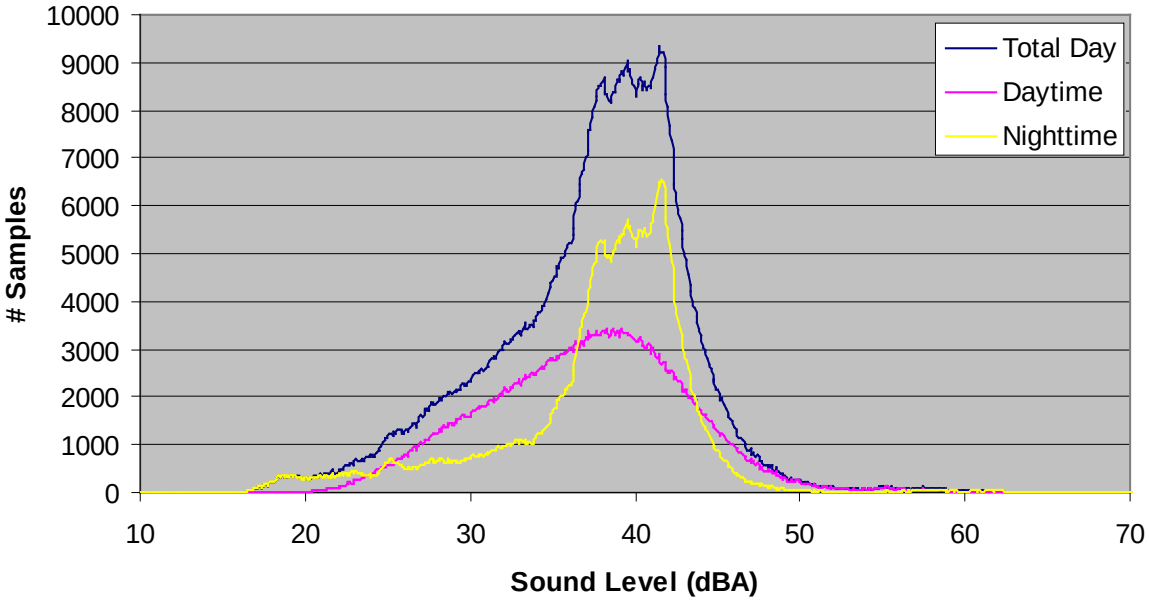


Figure 98. Data distributions: Site 3C.

This site is characterized by wind noise, bird vocalizations, motorist noise, and aircraft activity. This site exhibited greater sound levels than all other sites within this zone, which correlates with the amount of daytime activity observed due to the site's proximity to the Steam Vents.

A.9 Site 3D – Ka`ū Desert / Kīlauea Summit Site

Table 32. Site 3D: description.

Site ID	**3D**
Site Name	Cone Peak
# Measurement Days and Dates	15 days - January 16, 2003 to January 30, 2003
System # and Type	8 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.3086 / 19.3937
Approximate Elevation (ft)	3600
Slope	< 5% Southwest
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(31) Bare Rock/Sand/Clay
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Bare lava and ash
Access Considerations	Approximately 0.25-mile round trip hike off the Ka`ū Desert Trail south of the Halema`uma`u Crater area
Potential Sound Sources	Vehicles, Hikers, Wind

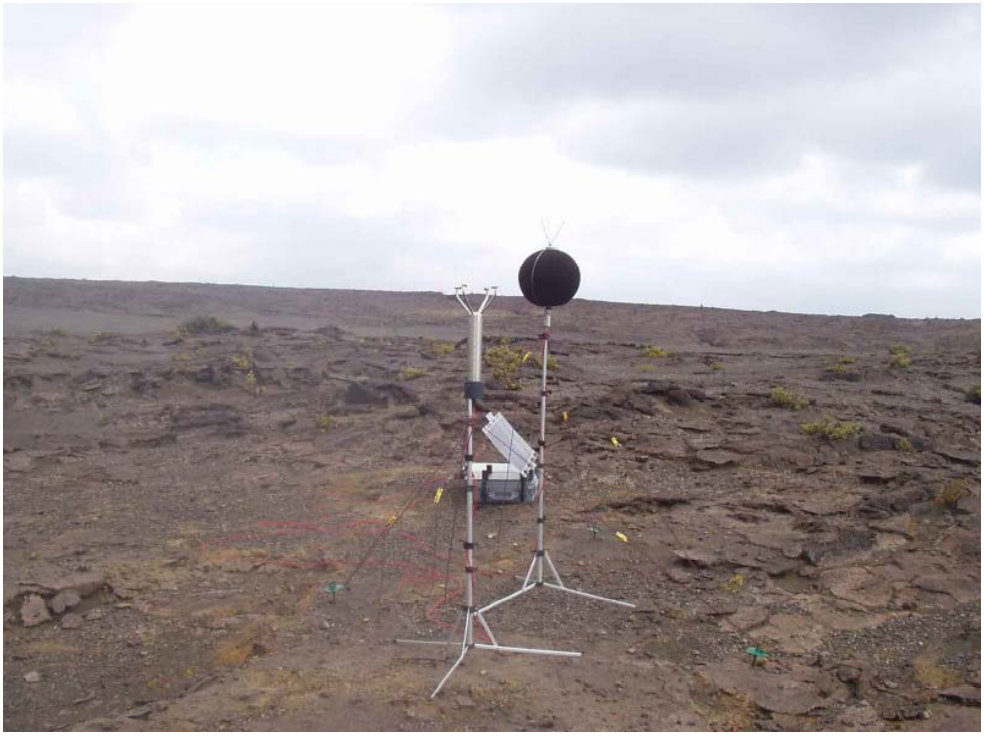


Figure 99. Site 3D: Description and photograph.[37]

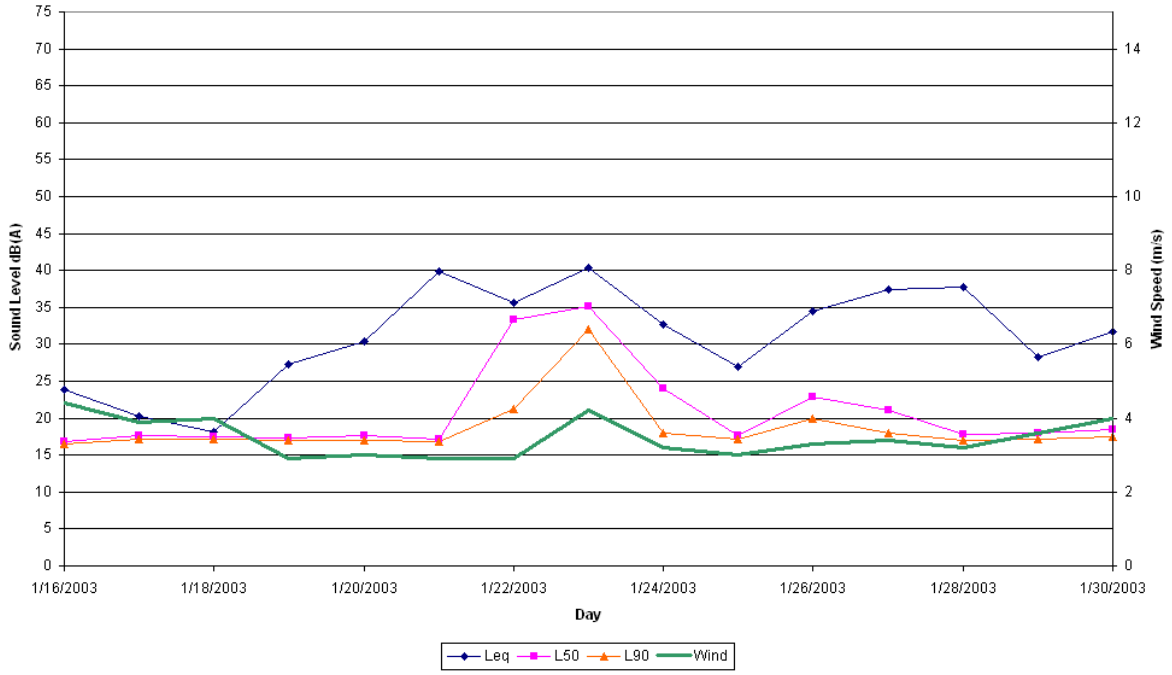


Figure 100. Daily sound levels and wind speeds: Site 3D.

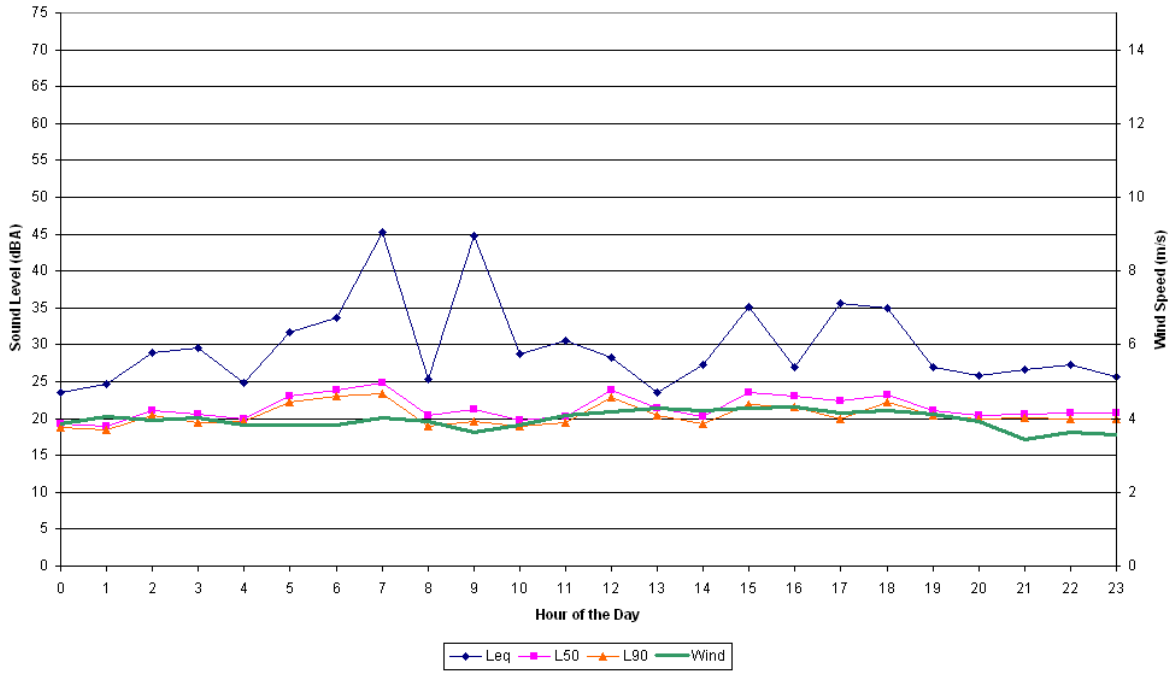


Figure 101. Average hourly sound levels and wind speeds: Site 3D.

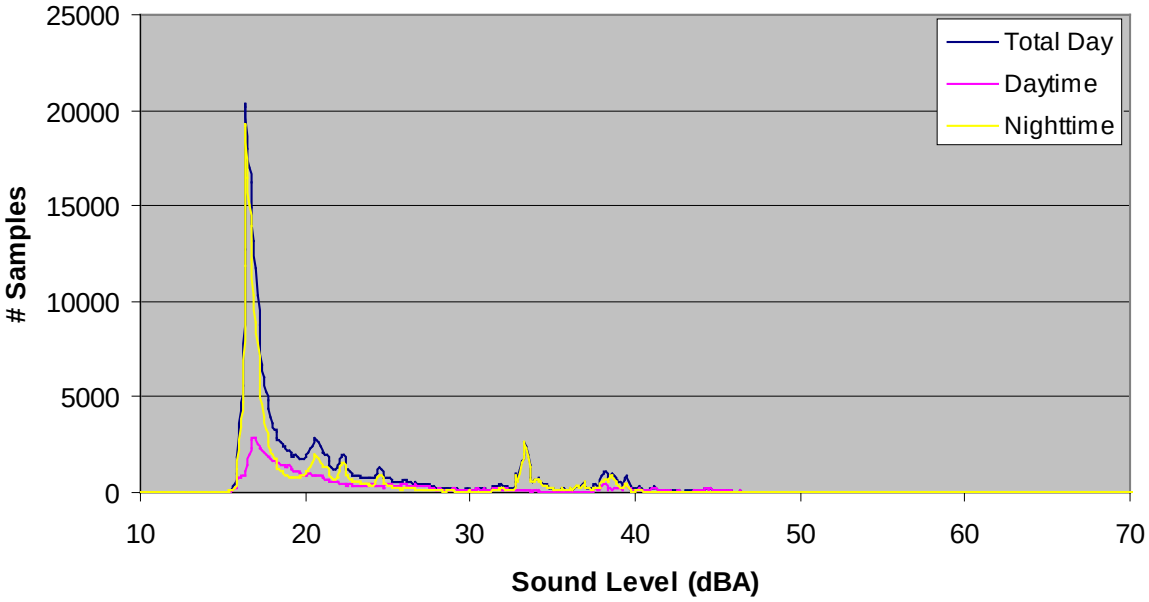


Figure 102. Data distributions: Site 3D.

This site is characterized by some wind noise and aircraft activity. The distribution for this site shows a large amount of data at very low sound levels during nighttime hours and also shows some localized "mini" distributions between 30-40 decibels which suggests somewhat constant levels that may be an indication of wildlife activity.

A.10 Site 4A – Ola`a Rain Forest Measurement Site

Table 33. Site 4A: description.

Site ID	**4A**
Site Name	Ola`a Transect 19
# Measurement Days and Dates	114 days - October 25, 2002 to January 17, 2003
System # and Type	1 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2454 / 19.4592
Approximate Elevation (ft)	3800
Slope	< 5% East
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(4) Forested Upland
Land Cover Subclass (see Appendix G)	(42) Evergreen Forest
Management Zone (see Section 2.5)	Wilderness (Natural subzone)
Site Category (see Section 2.5.1)	Wilderness
Site Type (see Section 2.7.2)	Permanent
Site Description	Dense rainforest with tree ferns
Access Considerations	0.1-mile round trip hike on trail off Wright Road
Potential Sound Sources	Aircraft, Birds, Insects, Rain



Figure 103. Site 4A: Description and photograph.

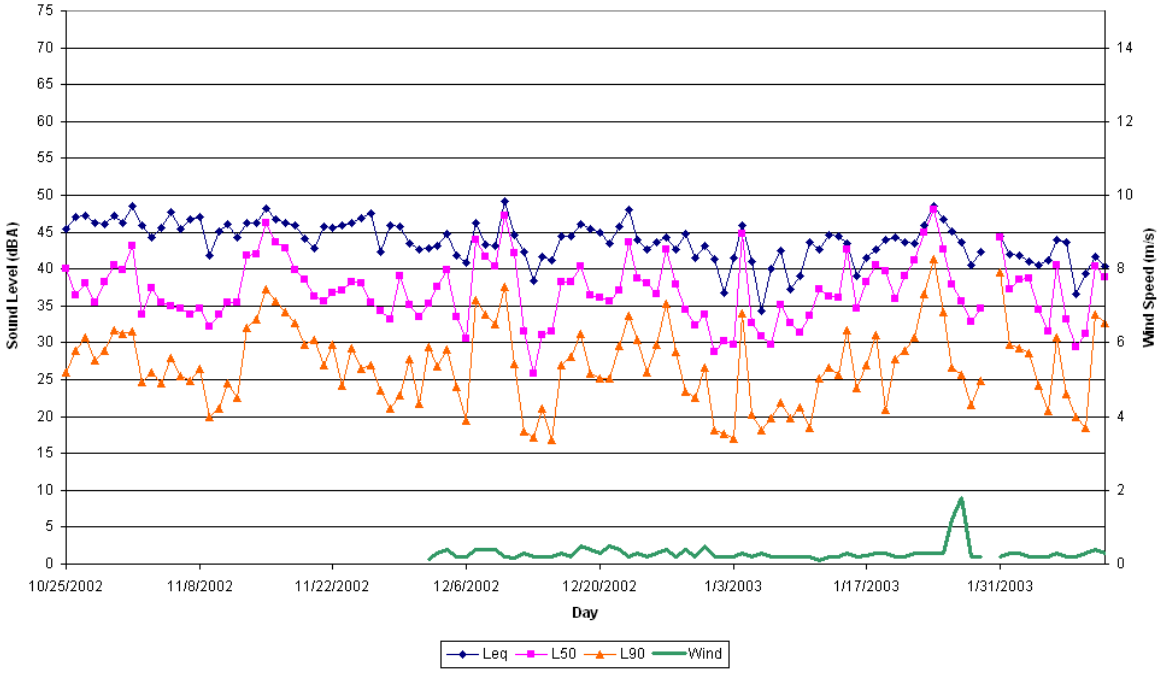


Figure 104. Daily sound levels and wind speeds: Site 4A.*

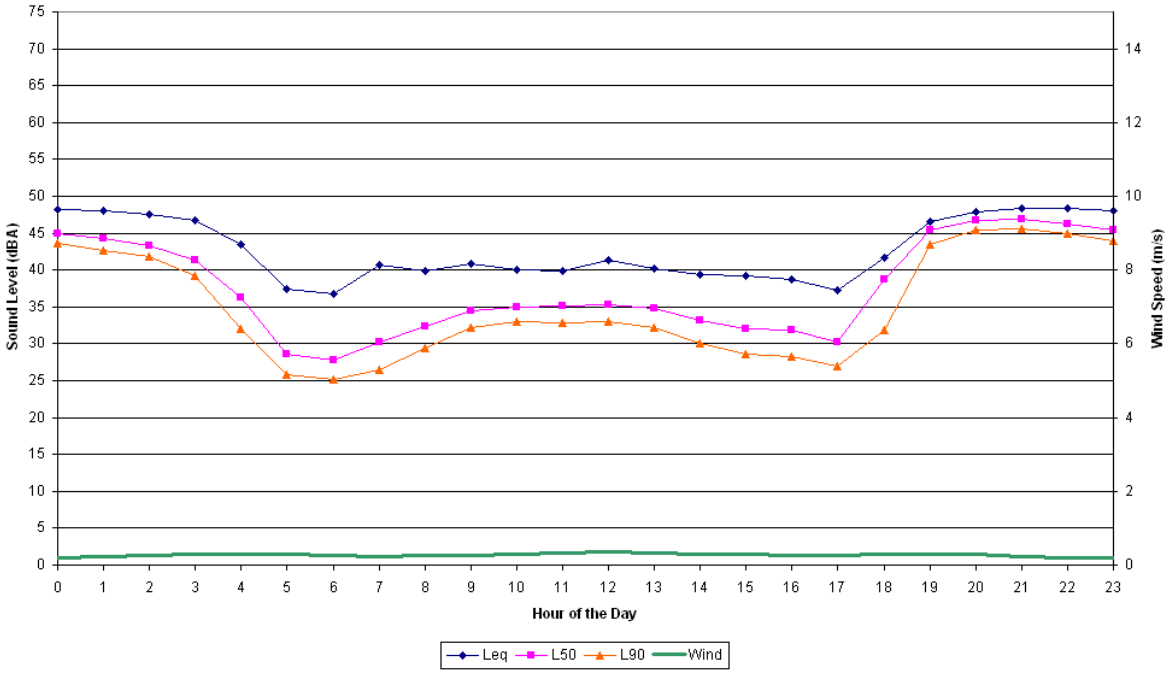


Figure 105. Average hourly sound levels and wind speeds: Site 4A.

* Note: Wind data were not collected from 10/25/02 through 12/1/02 due to anemometer malfunction. As wind conditions for the remainder of the measurement period were relatively stable (the site being shielded within the rainforest), it was assumed that earlier sound level data was not contaminated by wind.

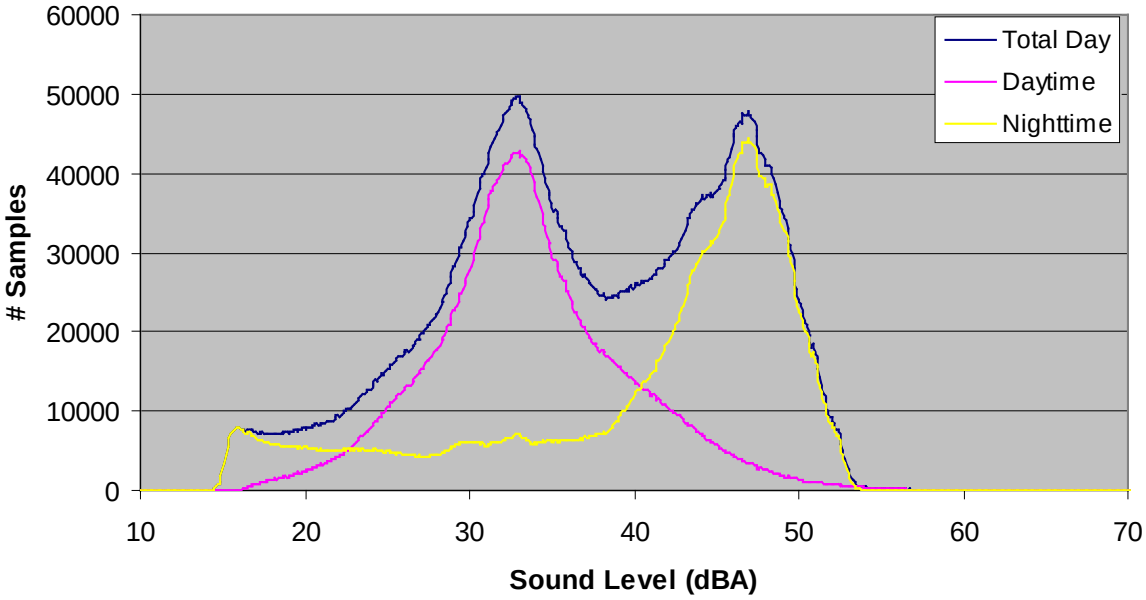


Figure 106. Data distributions: Site 4A.

This site exhibits a strong diurnal effect with bird vocalizations during the day, and even greater sound levels due to insect activity occurring during the nighttime.

A.11 Site 5A – Mauna Loa Forest Measurement Site

Table 34. Site 5A: description.

Site ID	**5A**
Site Name	Kīpuka Kī
# Measurement Days and Dates	56 days - October 24, 2002 to January 8, 2003
System # and Type	3 (NoiseLogger™ Plus)
Latitude / Longitude (decimal degrees)	155.3199 / 19.4436
Approximate Elevation (ft)	4200
Slope	10-15% Southeast
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(4) Forested Upland
Land Cover Subclass (see Appendix G)	(42) Evergreen Forest
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Overlook
Site Type (see Section 2.7.2)	Permanent
Site Description	Mesic (a moderately moist habitat) forest
Access Considerations	400-ft hike off trail off Mauna Loa Strip Road
Potential Sound Sources	Aircraft, Vehicles, Birds, Wind



Figure 107. Site 5A: Description and photograph.

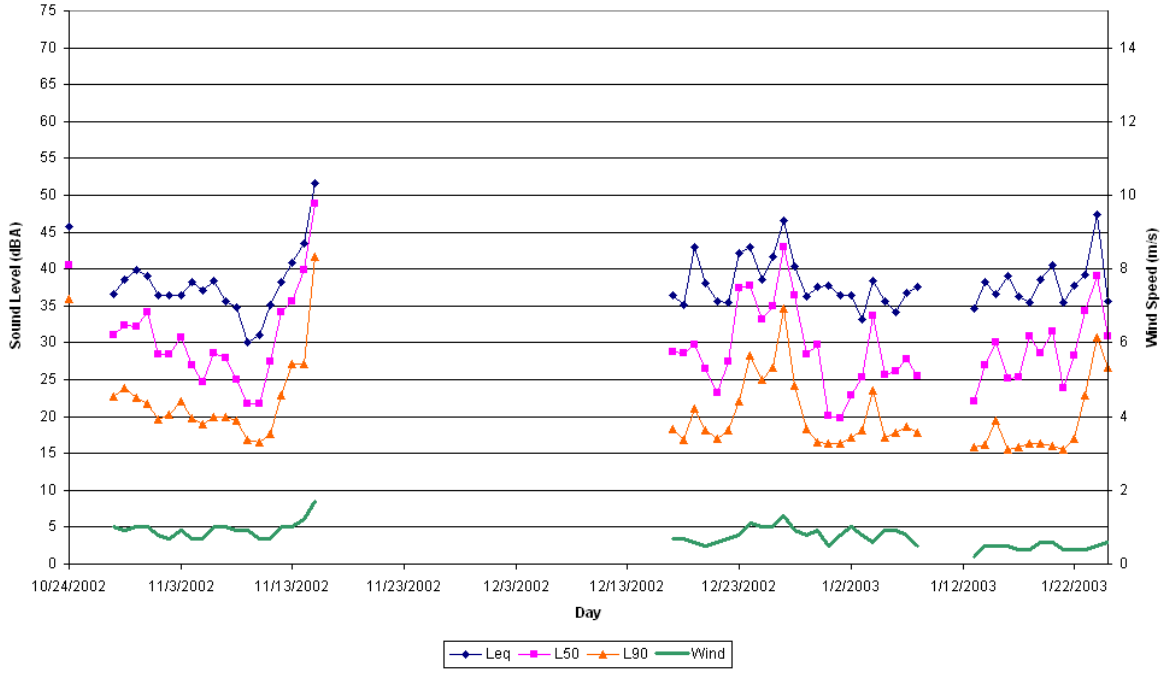


Figure 108. Daily sound levels and wind speeds: Site 5A.

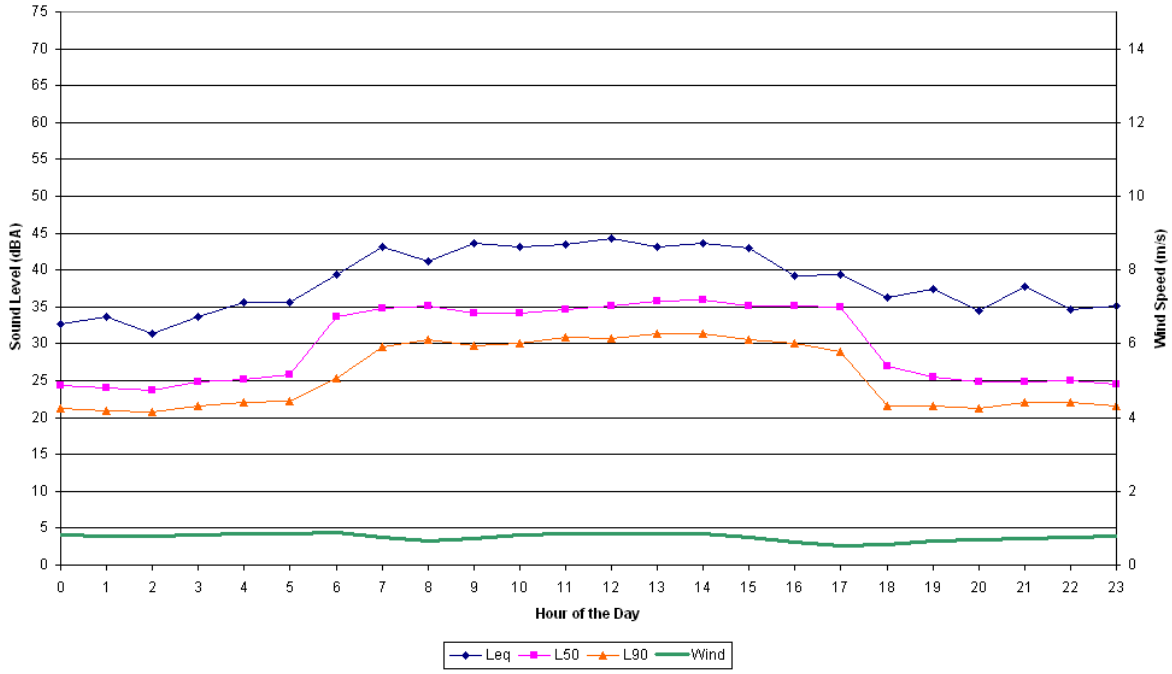


Figure 109. Average sound levels and wind speeds: Site 5A.

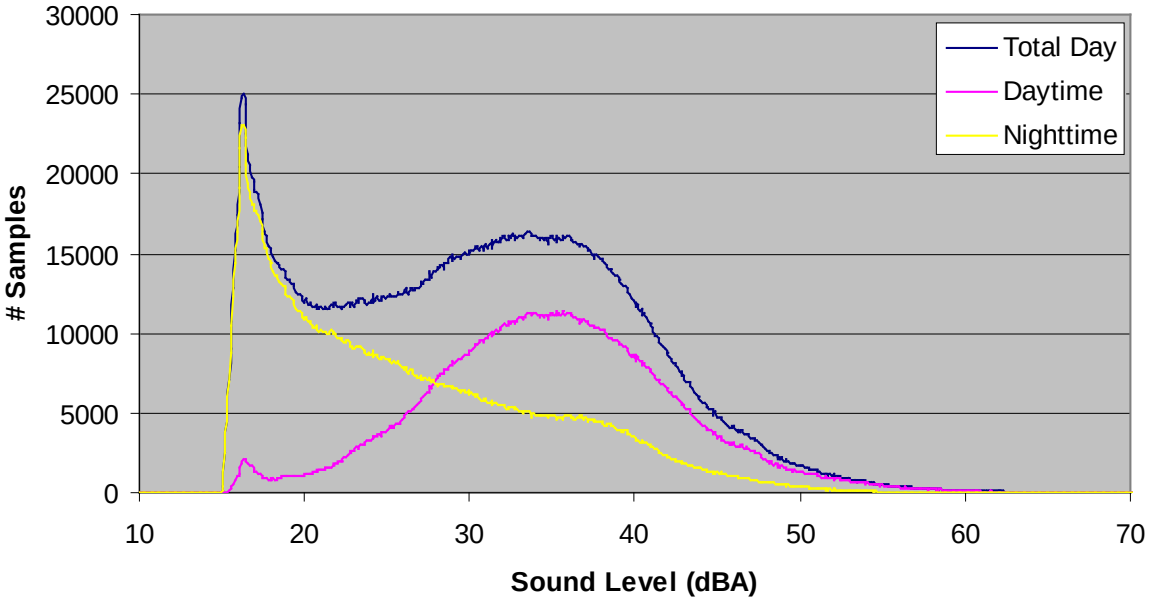


Figure 110. Data distributions: Site 5A.

This site is generally quiet with some bird vocalizations, and motorist and aircraft activity. The distribution shows large amount of sound levels of approximately 35 decibels throughout the day – likely distant traffic noise on Mauna Loa Strip Road.

A.12 Site 5B – Mauna Loa Forest Measurement Site

Table 35. Site 5B: description.

Site ID	**5B**
Site Name	Top of Strip Road
# Measurement Days and Dates	15 days - October 24, 2002 to November 7, 2002
System # and Type	2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.3859 / 19.4925
Approximate Elevation (ft)	6700
Slope	10-15% Southeast
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(5) Shrubland
Land Cover Subclass (see Appendix G)	(51) Shrubland
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Mesic forest, verging on shrubland
Access Considerations	500-ft hike from Mauna Loa Lookout parking at top of Mauna Loa Strip Road
Potential Sound Sources	Aircraft, Vehicles, Birds, Wind



Figure 111. Site 5B: Description and photograph.

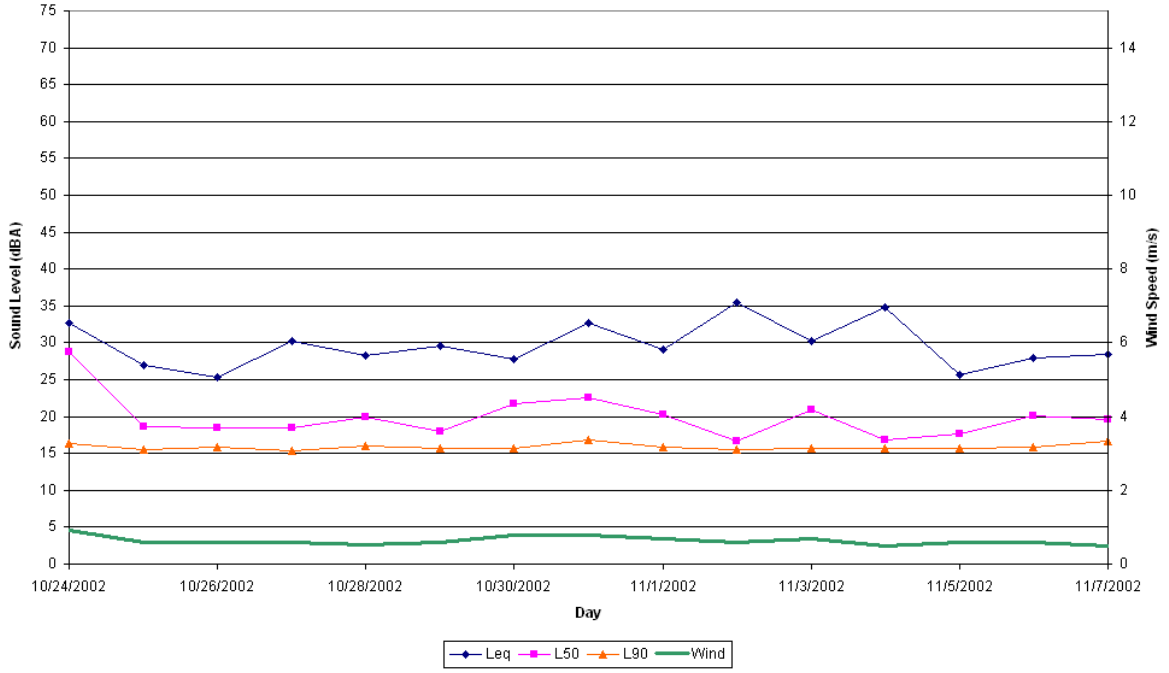


Figure 112. Daily sound levels and wind speeds: Site 5B.

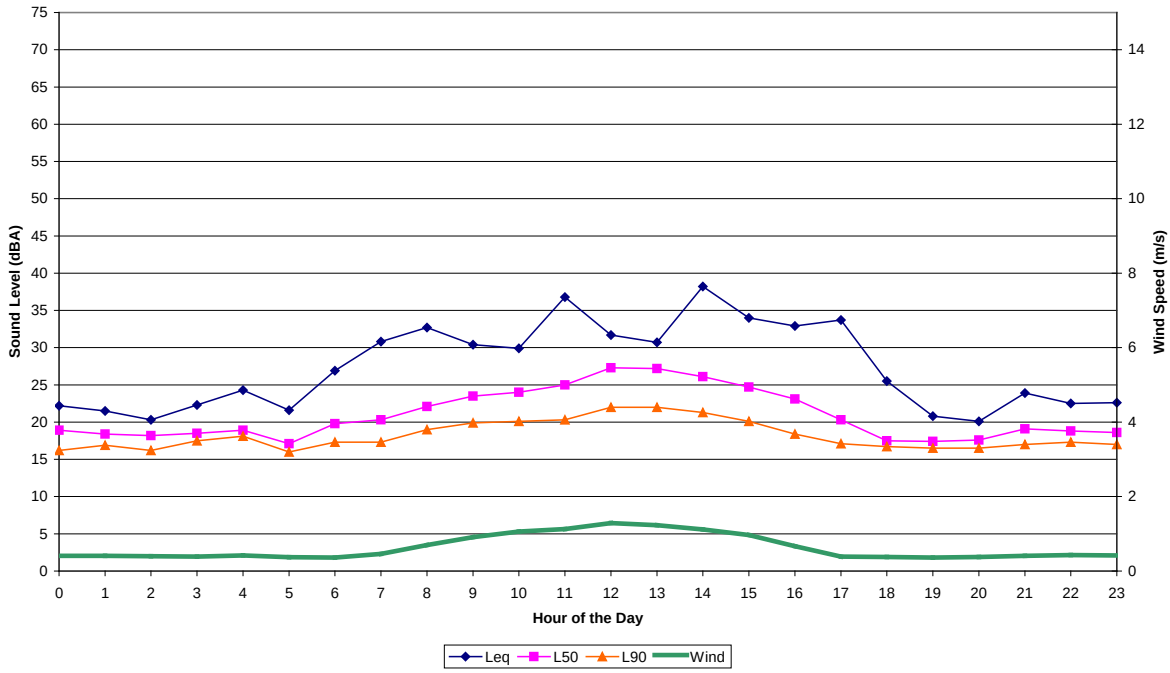


Figure 113. Average hourly sound levels and wind speeds: Site 5B.

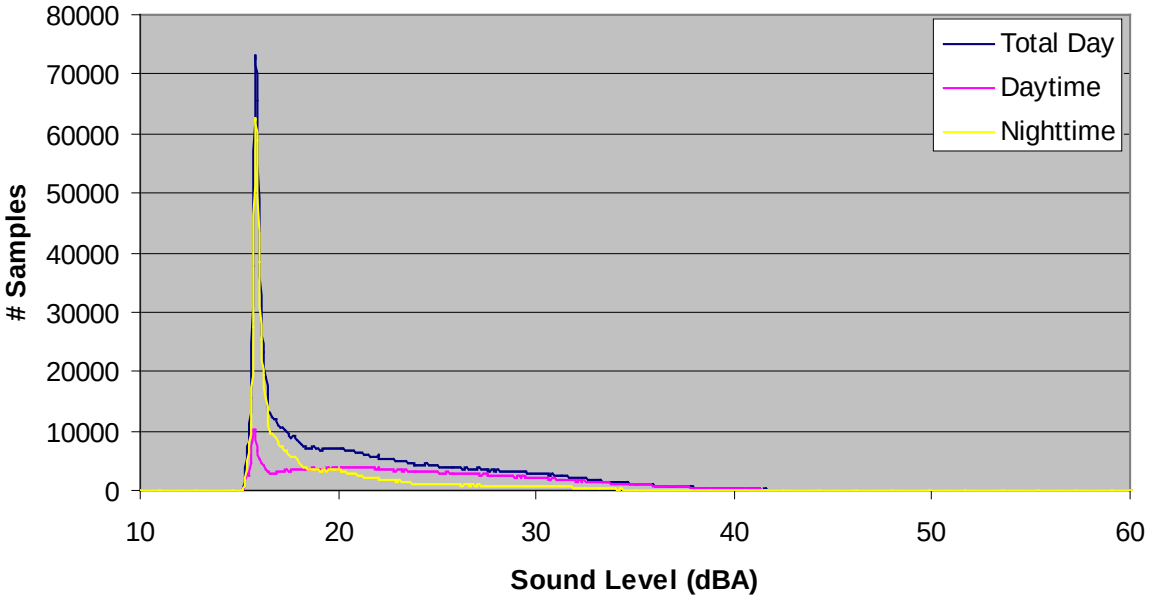


Figure 114. Data distributions: Site 5B.

This site is generally quiet with some bird vocalizations, and motorist and aircraft activity. As this site is located at the end of Mauna Loa Strip Road, the consistent sound levels of vehicle pass-bys are not seen in the distribution.

A.13 Site 5C – Mauna Loa Forest Measurement Site

Table 36. Site 5C: description.

Site ID	**5C**
Site Name	Strip Road Weather
# Measurement Days and Dates	17 days - January 31, 2003 to February 19, 2003
System # and Type	8 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.3601 / 19.4759
Approximate Elevation (ft)	5500
Slope	< 5% Southeast
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(5) Shrubland
Land Cover Subclass (see Appendix G)	(51) Shrubland
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Mesic forest, verging on shrubland
Access Considerations	500-ft hike off trail off Mauna Loa Strip Road
Potential Sound Sources	Aircraft, Vehicles, Birds, Wind



Figure 115. Site 5C: Description and photograph (Note: System not shown).[37]

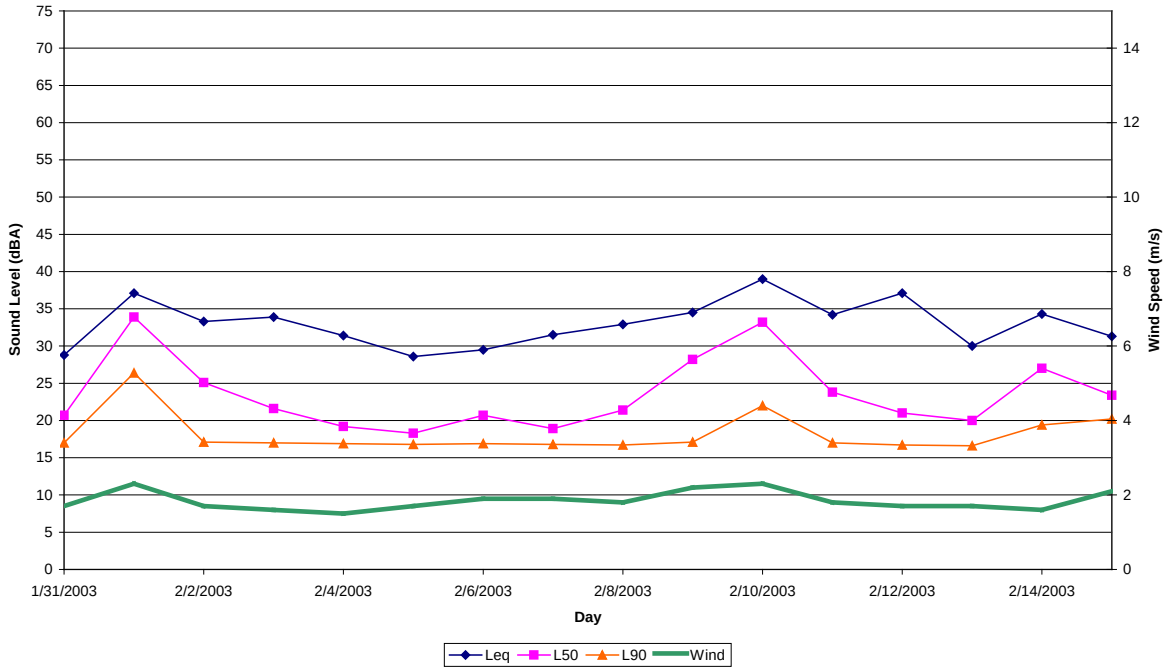


Figure 116. Daily sound levels and wind speeds: Site 5C.

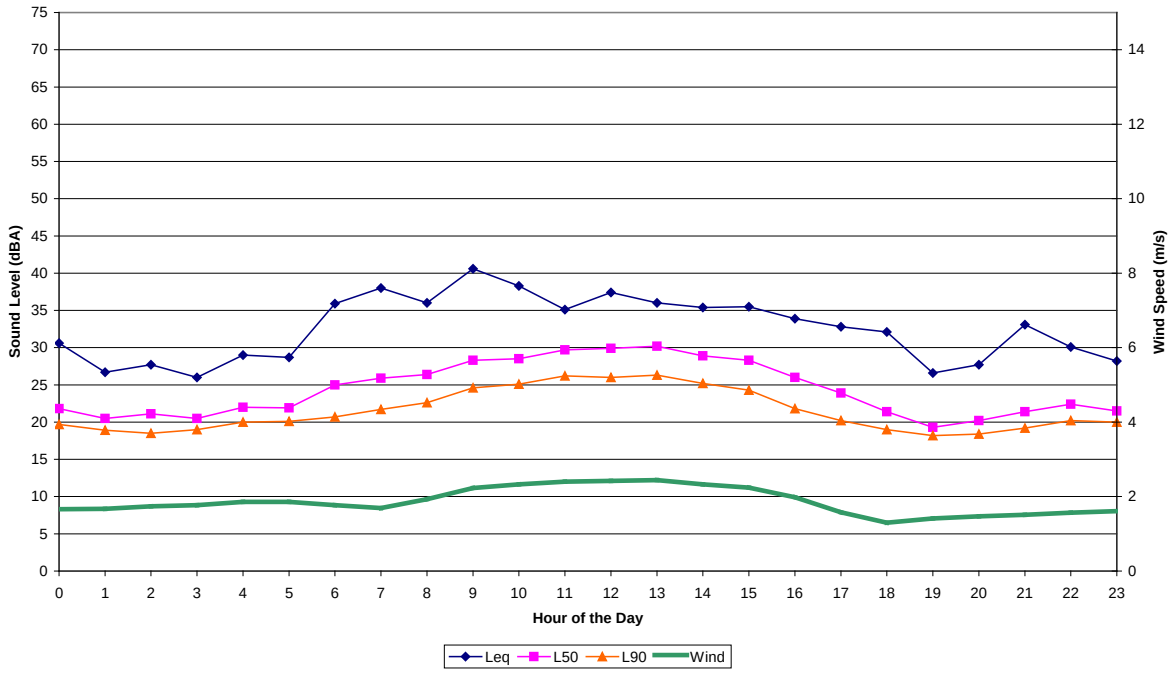


Figure 117. Average hourly sound levels and wind speeds: Site 5C.

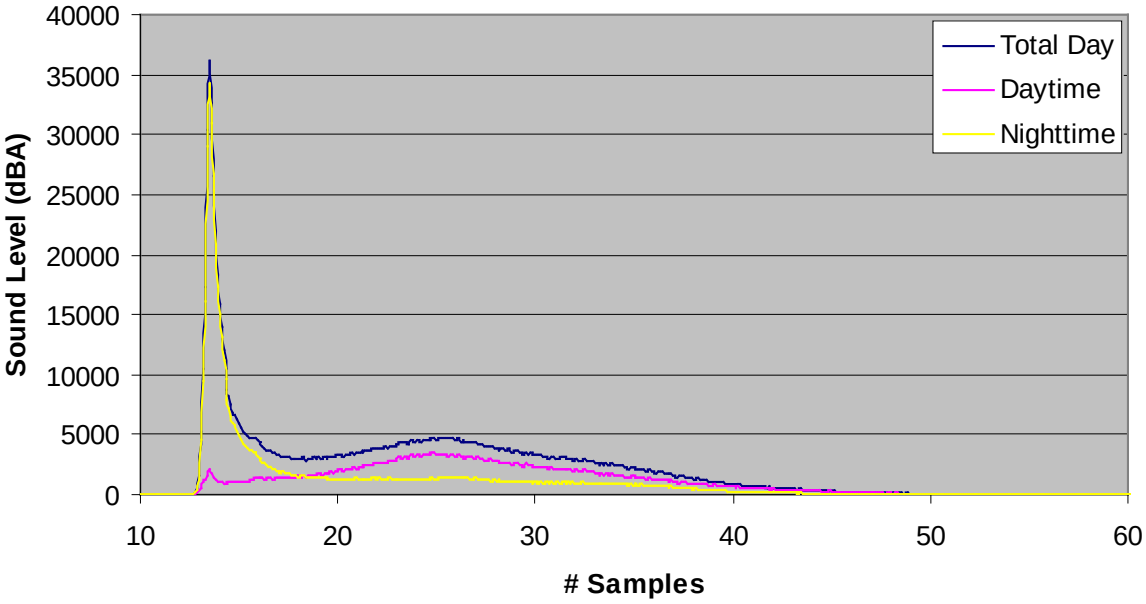


Figure 118. Data distributions: Site 5C.

This site is generally quiet with some bird vocalizations, and motorist and aircraft activity. This site is located off Mauna Loa Strip Road between Sites 5A and 5B, and exhibits a data distribution with attributes from both sites as well – i.e., a generally quiet site with some consistent sound levels during the daytime due to the distant traffic noise on Mauna Loa Strip Road.

A.14 Site 6A – Dry Ohi`a Woodlands Measurement Site

Table 37. Site 6A: description.

Site ID	**6A**
Site Name	Hilina Pali Road/Weather Station
# Measurement Days and Dates	108 days - October 23, 2002 to February 19, 2003
System # and Type	10 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2918 / 19.3163
Approximate Elevation (ft)	2700
Slope	< 10% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Permanent
Site Description	Grassy savanna with scattered shrubs
Access Considerations	0.25-mile round trip hike off trail off Hilina Pali Road
Potential Sound Sources	Aircraft, Wind



Figure 119. Site 6A: Description and photograph (with VoLARE system).

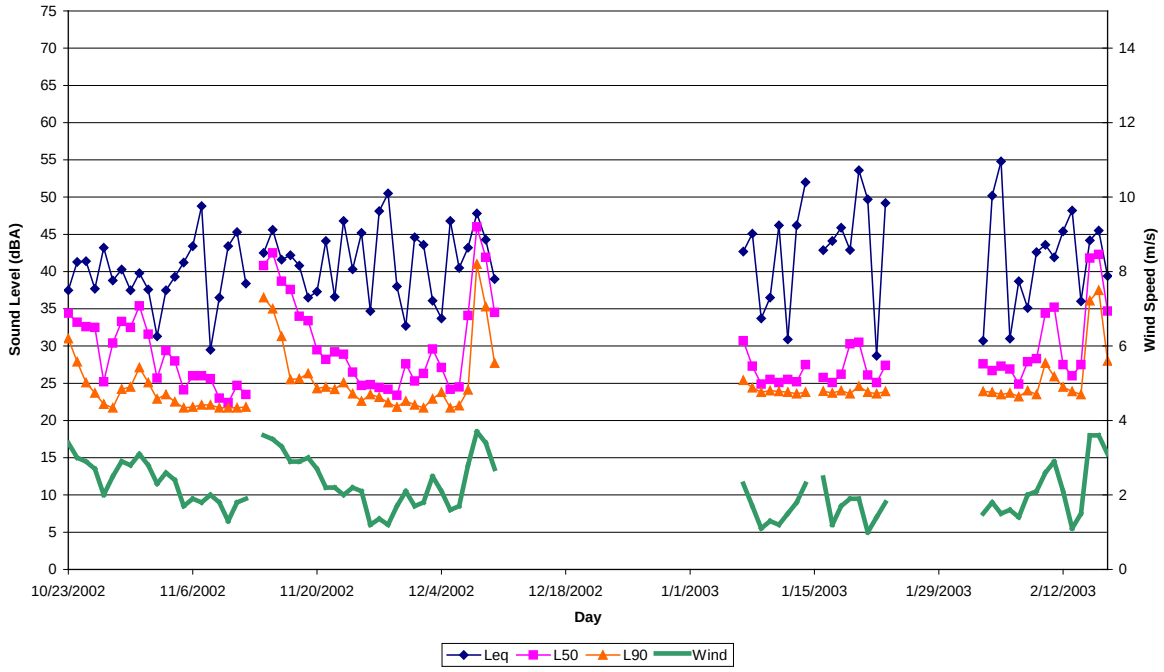


Figure 120. Daily sound levels and wind speeds: Site 6A.

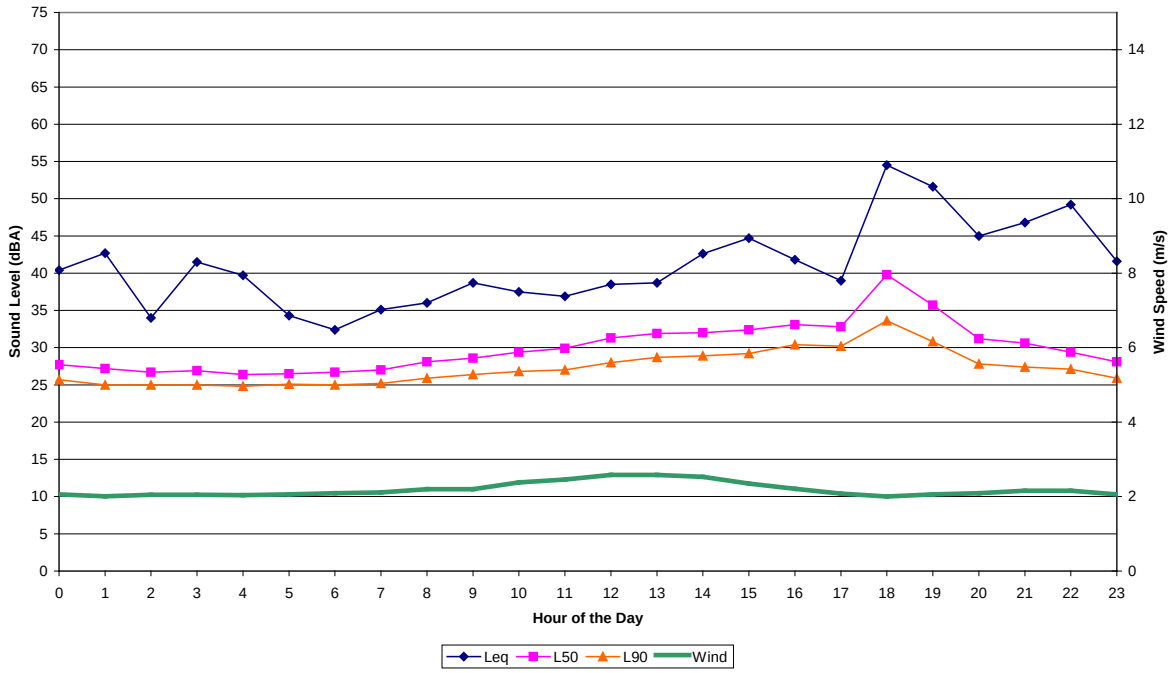


Figure 121. Average hourly sound levels and wind speeds: Site 6A.

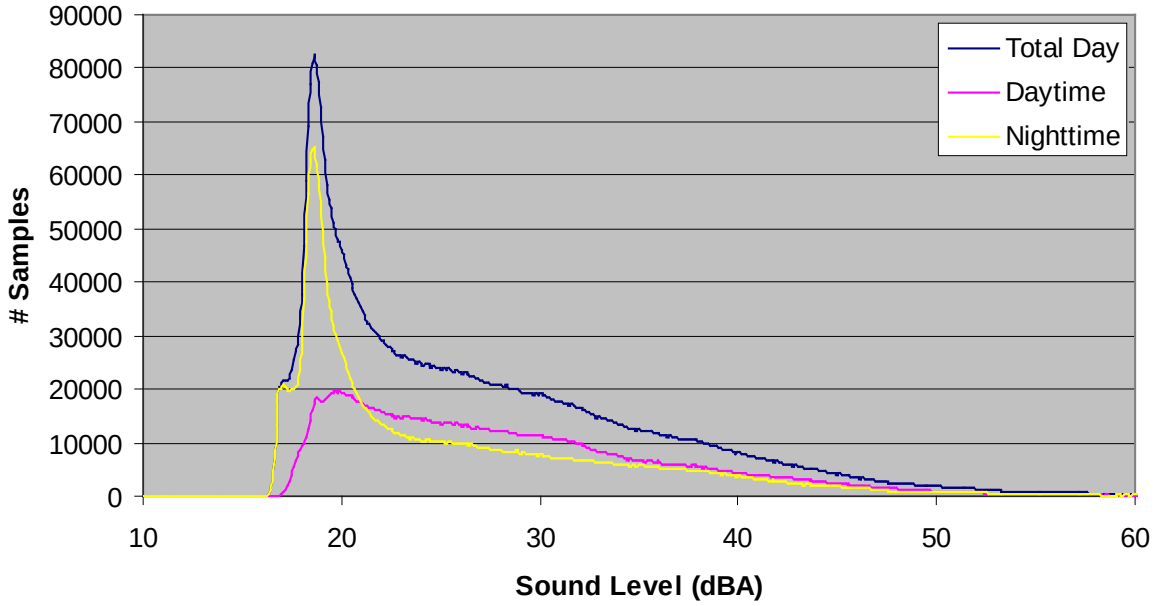


Figure 122. Data distributions: site 6A.

This site is characterized by brush noise due to wind, insect noise and some aircraft events. The distribution for this site shows large content at the noise floor due to quiet conditions during the nighttime.

A.15 Site 6B – Dry Ohi`a Woodlands Measurement Site

Table 38. Site 6B: description.

Site ID	**6B**
Site Name	ʻĀinahou Education Center (restricted access to sanctuary for the endangered, Hawaiian Nene)
# Measurement Days and Dates	27 days - December 13, 2002 to January 14, 2003
System # and Type	8 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2225 / 19.3371
Approximate Elevation (ft)	2800
Slope	< 5% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Backcountry
Site Type (see Section 2.7.2)	Mobile
Site Description	Tall thick grass and shrubs with scattered trees
Access Considerations	4WD vehicle on road and short hike
Potential Sound Sources	Aircraft, Wind

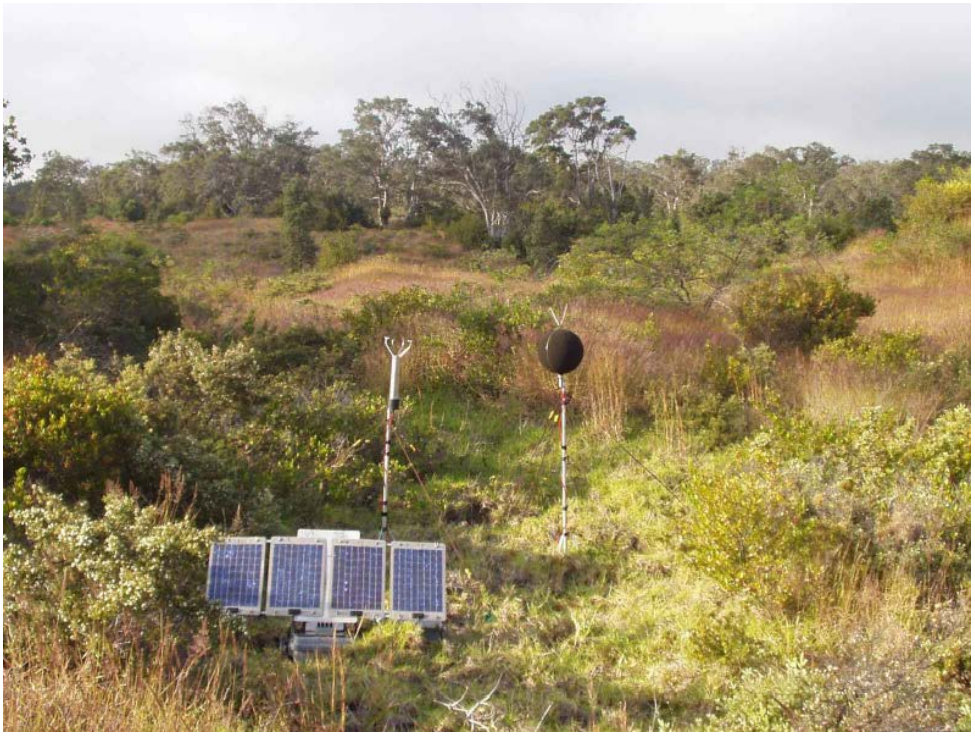


Figure 123. Site 6B: Description and photograph.[37]

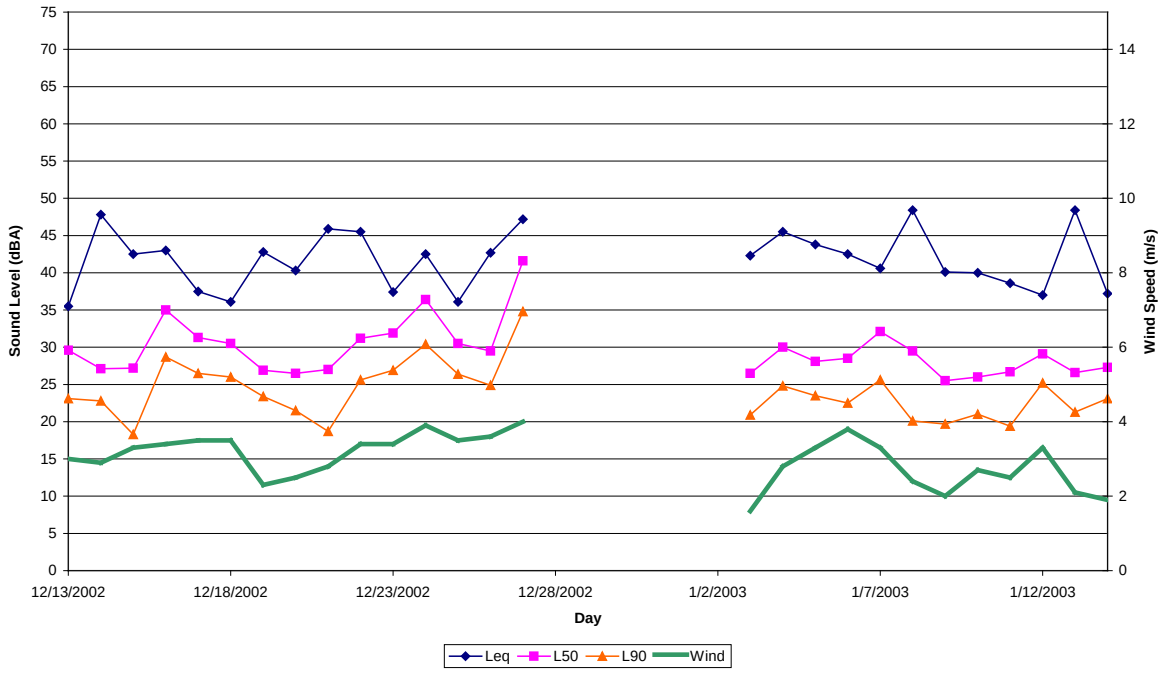


Figure 124. Daily sound levels and wind speeds: Site 6B.

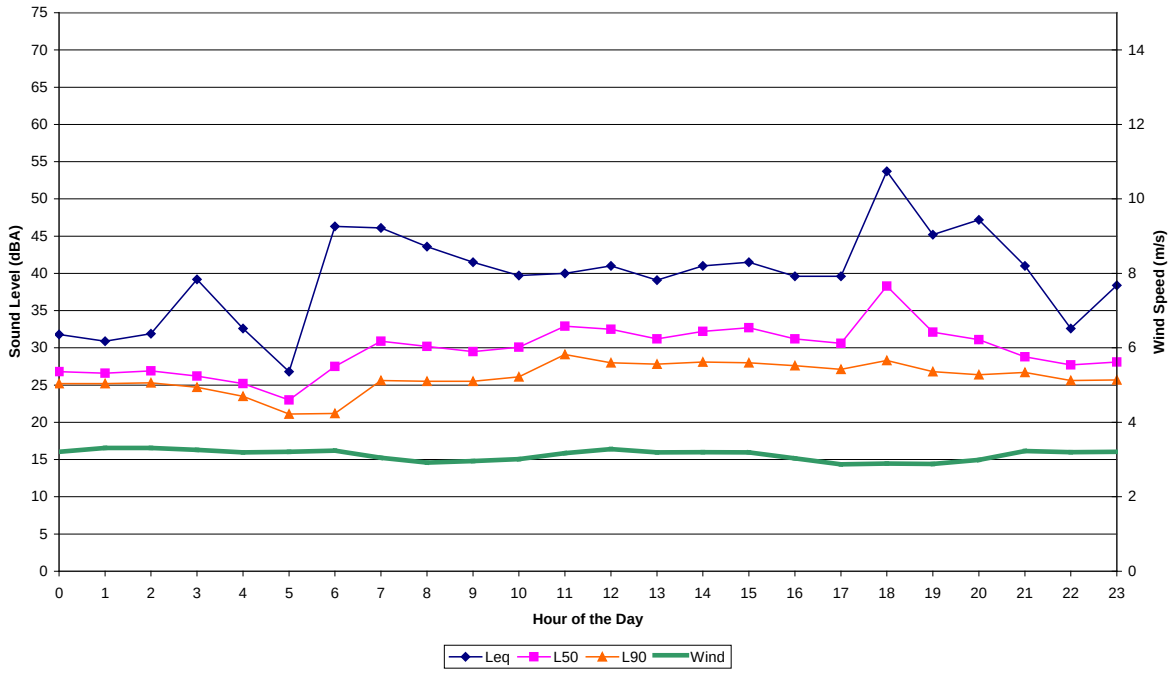


Figure 125. Average hourly sound levels and wind speeds: Site 6B.

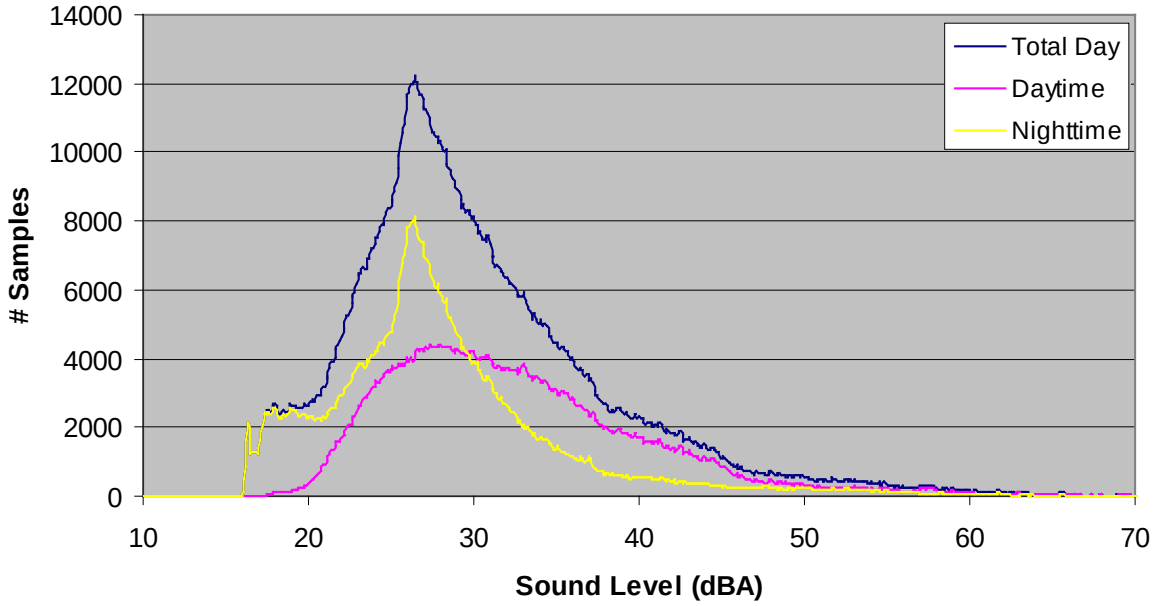


Figure 126. Data distributions: Site 6B.

This site is characterized by wind noise through the vegetation, insect noise and some aircraft activity.

A.16 Site 6C – Dry Ohi`a Woodlands Measurement Site

Table 39. Site 6C: description.

Site ID	**6C**
Site Name	Hairpin Turn
# Measurement Days and Dates	25 days - December 13, 2002 to January 6, 2003
System # and Type	2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1271 / 19.3159
Approximate Elevation (ft)	1300
Slope	< 10% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(7) Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass (see Appendix G)	(71) Grasslands/Herbaceous
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Thick grass with scattered shrubs and trees and old lava outcrops
Access Considerations	0.3-mile round trip hike from the sloped trail off the hairpin turn of Chain of Craters Road above Hōlei Pali
Potential Sound Sources	Aircraft, Wind



Figure 127. Site 6C: Description and photograph (Note: System not shown).[37]

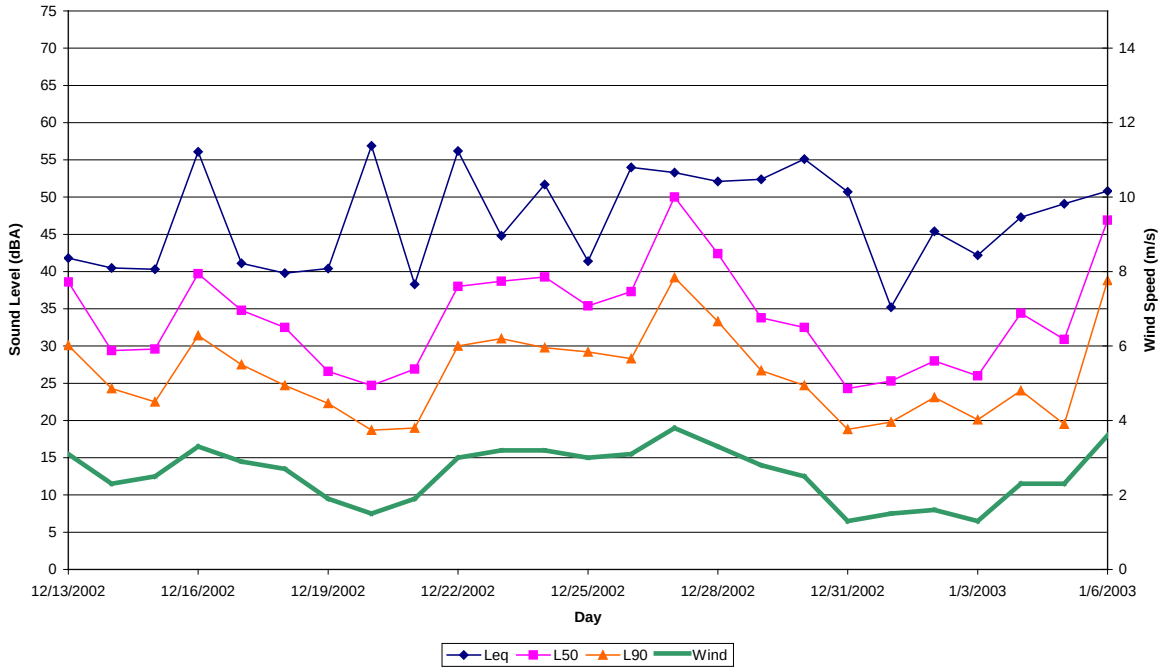


Figure 128. Daily sound levels and wind speeds: Site 6C.

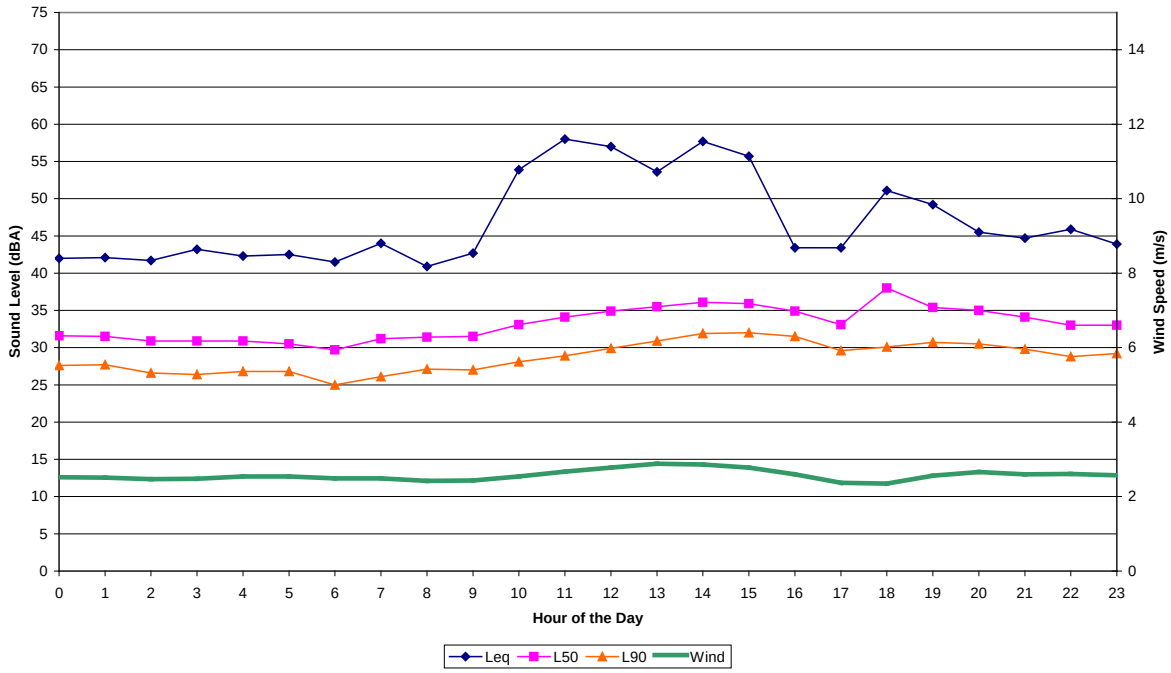


Figure 129. Average hourly sound levels and wind speeds: Site 6C.

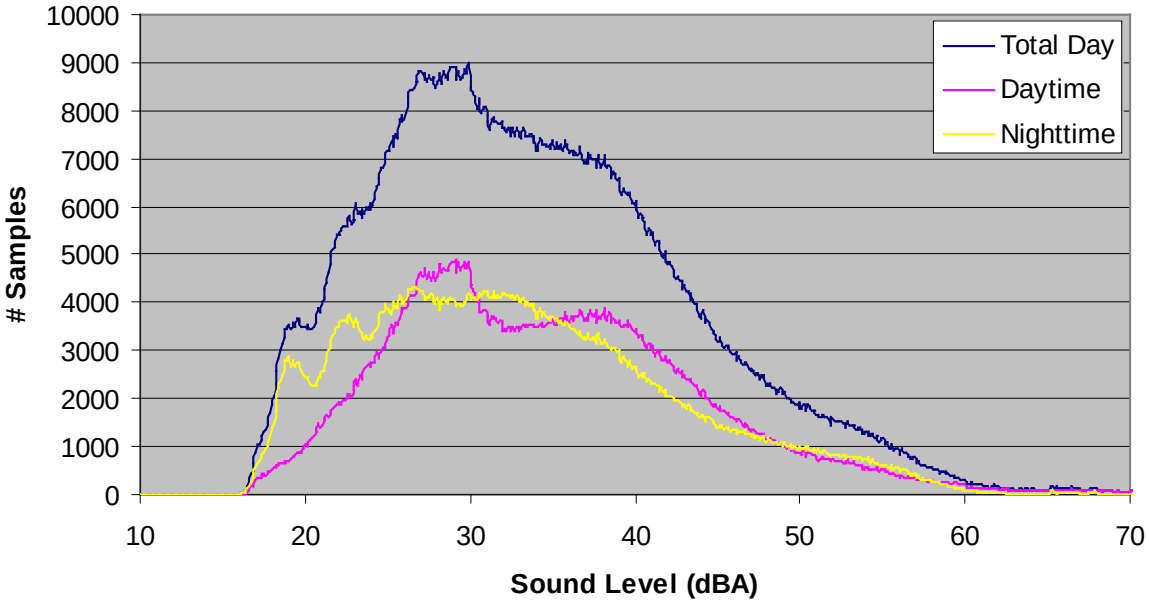


Figure 130. Data distributions: Site 6C.

This site is characterized by wind noise, insect noise and some loud aircraft activity. The distribution shows similar sound levels during day and night time periods caused by the consistent high winds in this area.

A.17 Site 8A – Young Rainforest Measurement Site

Table 40. Site 8A: description.

Site ID	**8A**
Site Name	Escape Road/Orchid Farm
# Measurement Days and Dates	113 days - October 24, 2002 to Feb 17, 2003, and April 25, 2003 to May 5, 2003
System # and Type	11 (NoiseLogger™) and 3 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2401 / 19.4178
Approximate Elevation (ft)	3900
Slope	< 1% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(4) Forested Upland
Land Cover Subclass (see Appendix G)	(42) Evergreen Forest
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Permanent
Site Type (see Section 2.7.2)	Short Hike
Site Description	Dense tree fern and Ohi`a tree forest
Access Considerations	1.4-mile round trip drive with 4WD vehicle on Escape Road (closed to vehicles) off Crater Rim Drive and short walk
Potential Sound Sources	Aircraft, Vehicles, Hikers, Insects, Birds, Rain



Figure 131. Site 8A: Description and photograph.

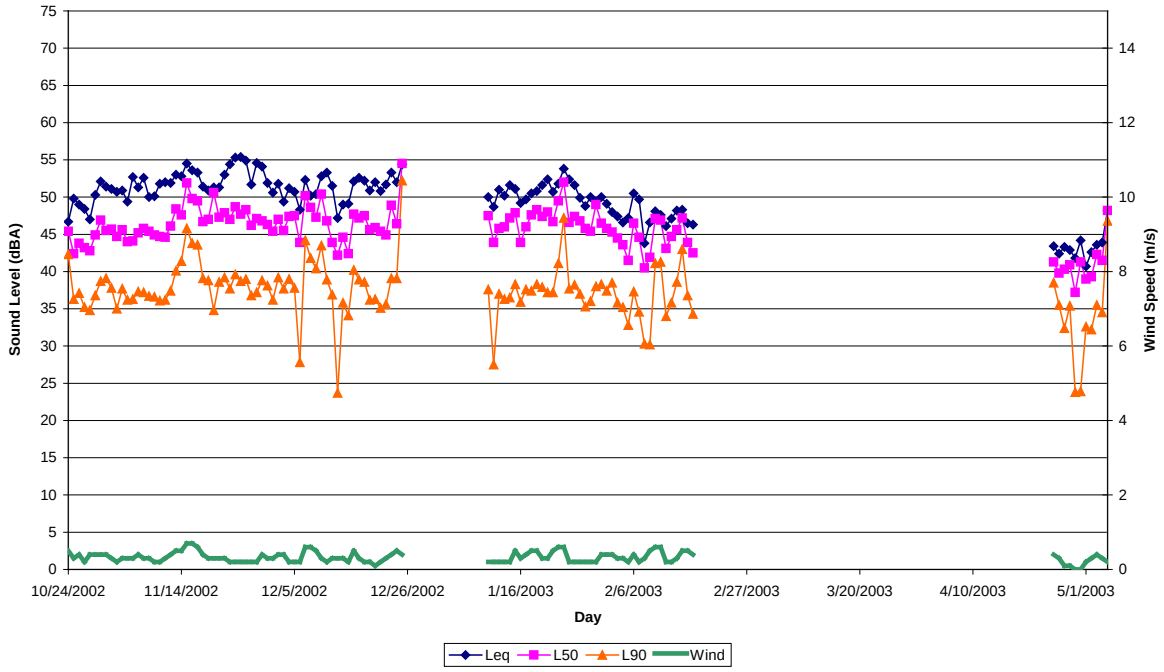


Figure 132. Daily sound levels and wind speeds: Site 8A.

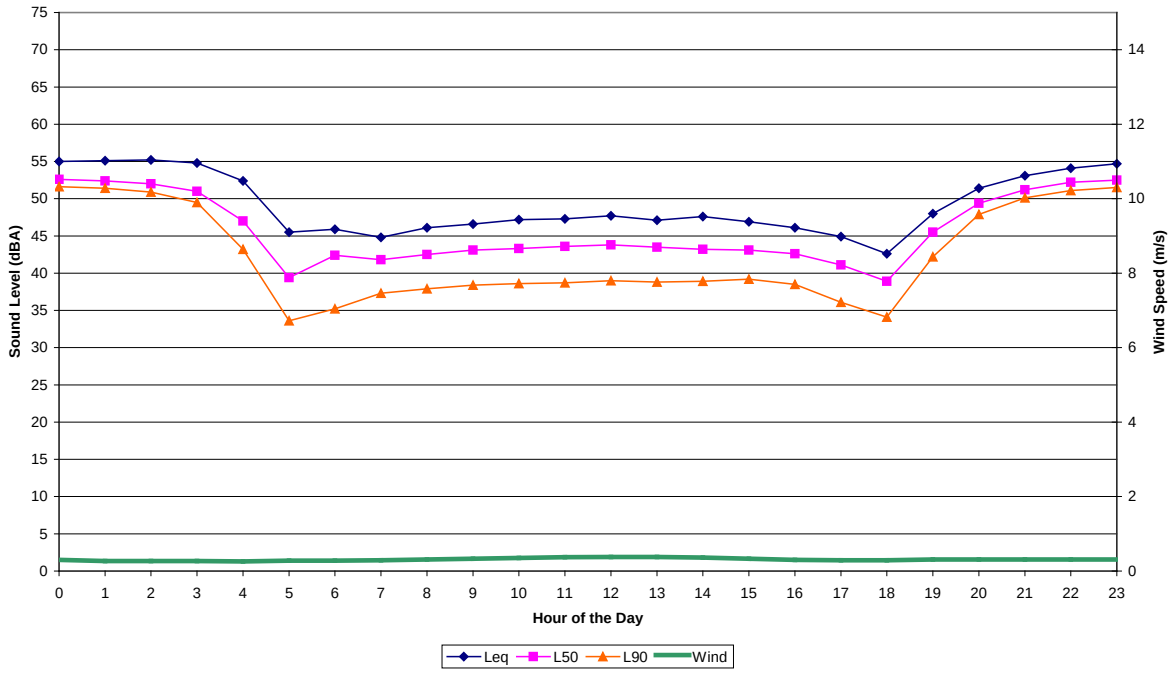


Figure 133. Average hourly sound levels and wind speeds: Site 8A.

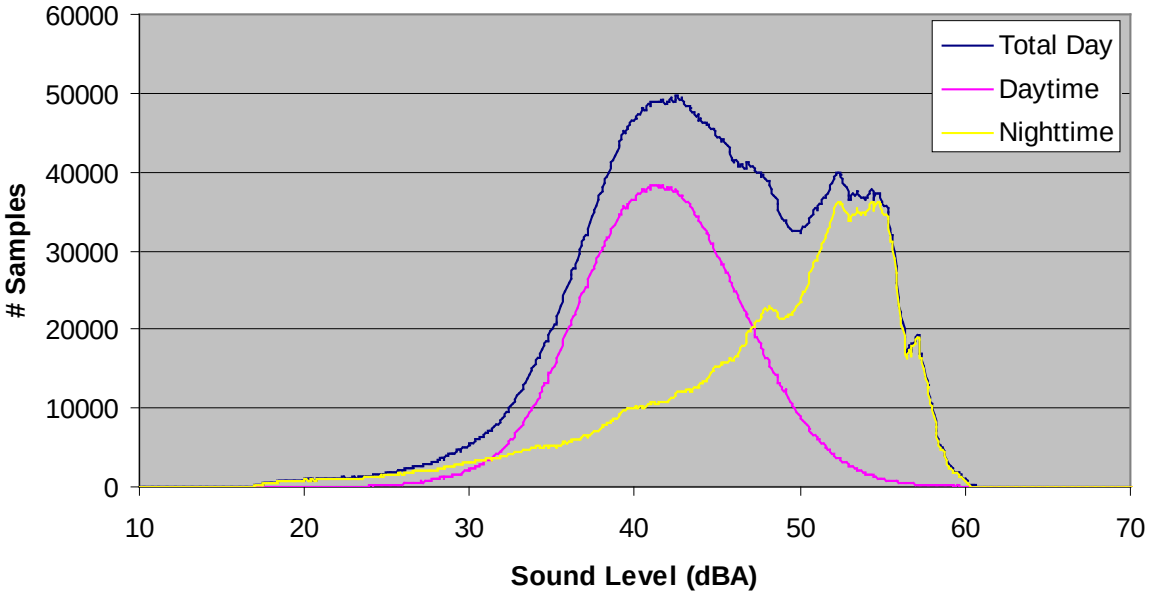


Figure 134. Data distributions: Site 8A.

This site exhibits a strong diurnal effect with bird vocalizations and traffic noise (from Highway 11) during the day, and even greater sound levels due to insect activity occurring during the nighttime. The diurnal effect is similar to Site 4A, also located in a rainforest environment.

A.18 Site 8B – Young Rainforest Measurement Site

Table 41. Site 8B: description.

Site ID	**8B**
Site Name	Escape Road/Thurston
# Measurement Days and Dates	15 days - April 25, 2002 to May 9, 2003
System # and Type	2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2351 / 19.406
Approximate Elevation (ft)	3800
Slope	< 1% South
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(4) Forested Upland
Land Cover Subclass (see Appendix G)	(42) Evergreen Forest
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Short Hike
Site Type (see Section 2.7.2)	Mobile
Site Description	Dense tree fern and Ohi`a tree forest
Access Considerations	1-mile round trip hike on trail near Escape Road (closed to vehicles) south of Thurston Lava Tube
Potential Sound Sources	Aircraft, Vehicles



Figure 135. Site 8B: Description and photograph.

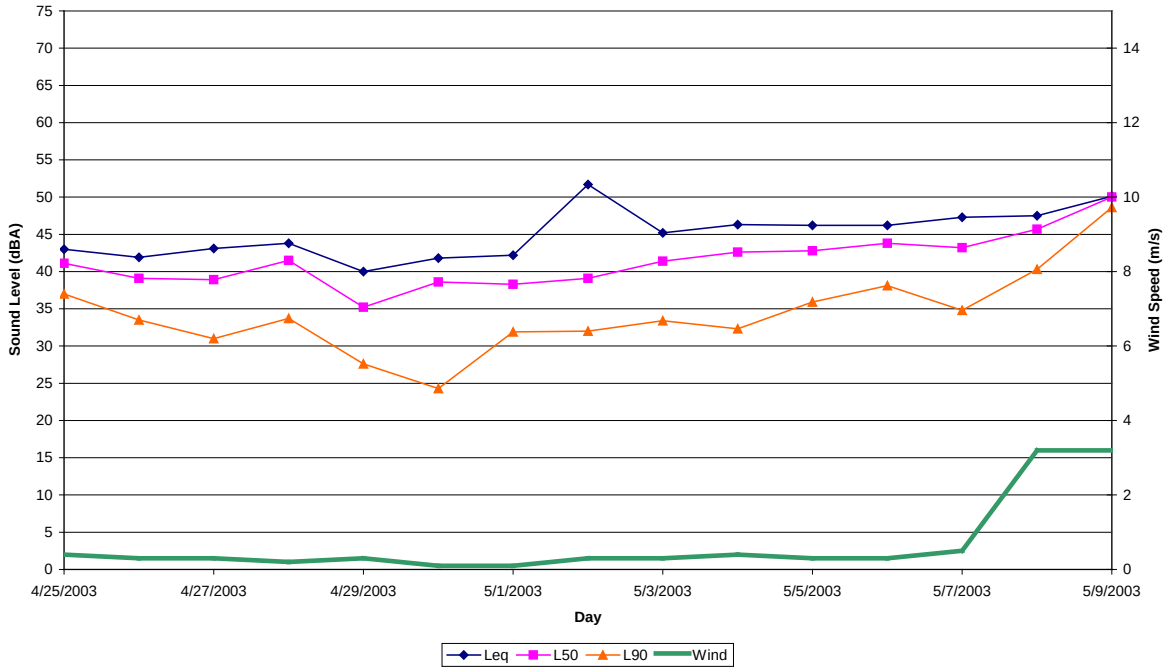


Figure 136. Daily sound levels and wind speeds: Site 8B.

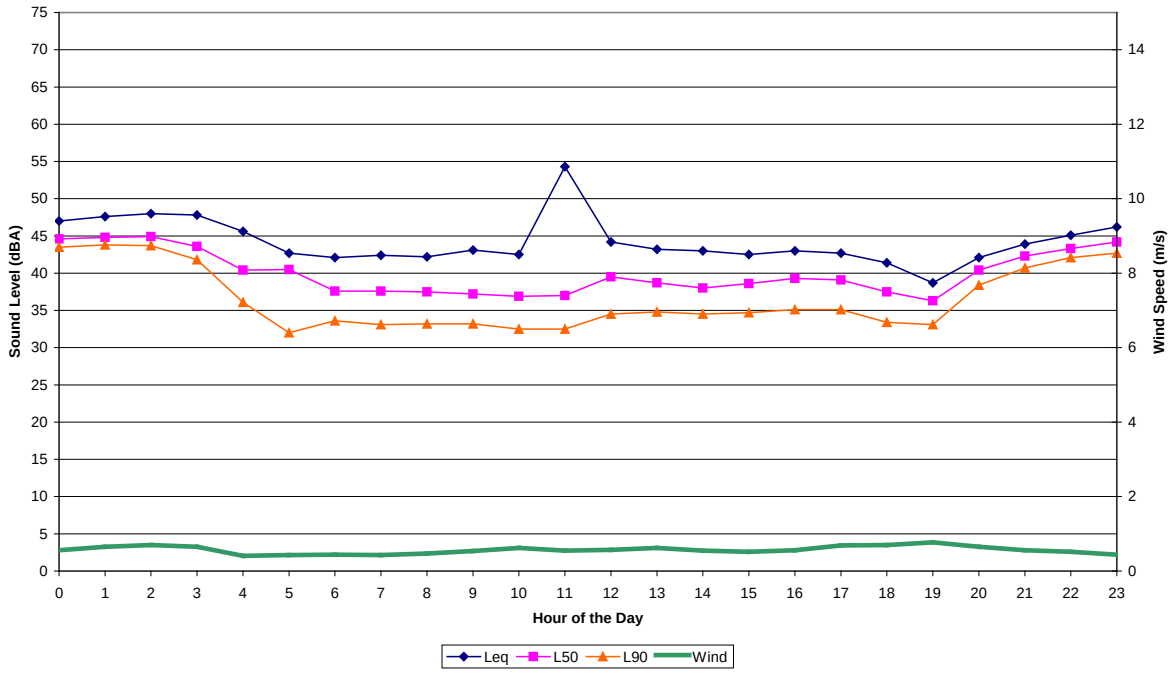


Figure 137. Average hourly sound levels and wind speeds: Site 8B.

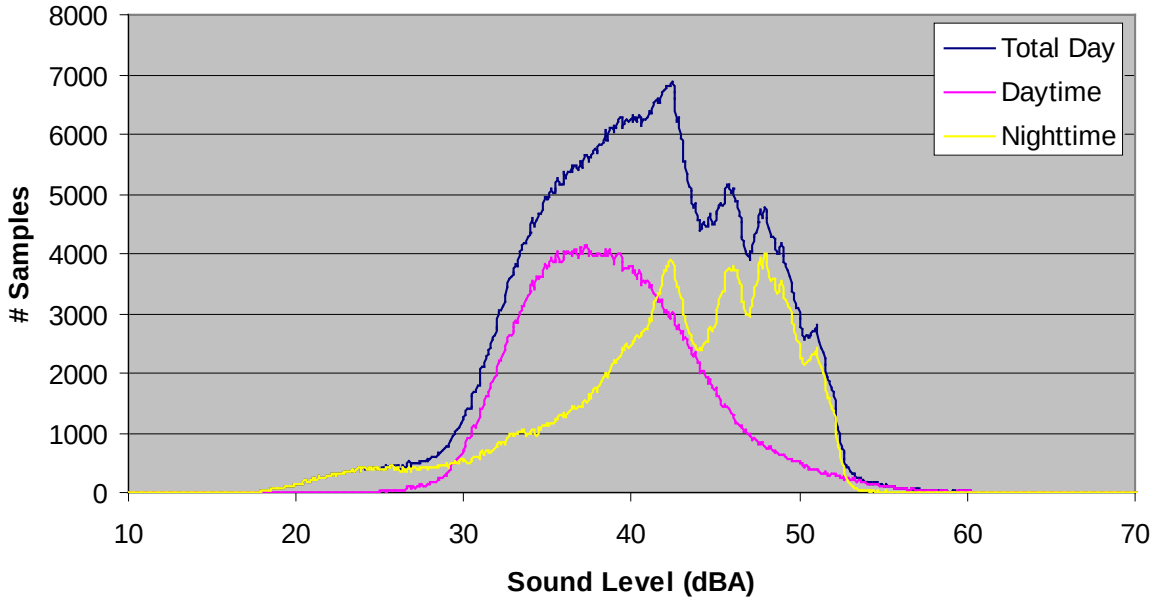


Figure 138. Data distributions: Site 8B.

This site exhibits a strong diurnal effect with bird vocalizations and traffic noise (from Highway 11) during the day, and even greater sound levels due to insect activity occurring during the nighttime. The diurnal effect is similar to Site 8A, located approximately 1 mile north of this site.

A.19 Site 8C – Young Rainforest Measurement Site

Table 42. Site 8C: description.

Site ID	**8C**
Site Name	Nāpau Crater
# Measurement Days and Dates	15 days - April 25, 2002 to May 9, 2003
System # and Type	1 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1499 / 19.3745
Approximate Elevation (ft)	2700
Slope	< 1% East
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(4) Forested Upland
Land Cover Subclass (see Appendix G)	(42) Evergreen Forest
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Backcountry
Site Type (see Section 2.7.2)	Mobile
Site Description	Tree fern and Ohi`a tree forest
Access Considerations	Helicopter access only - approximately 13-mile round trip hike on Nāpau Crater Trail to Nāpau Crater
Potential Sound Sources	Aircraft, Hikers



Figure 139. Site 8C: Description and photograph (Note: System not shown).

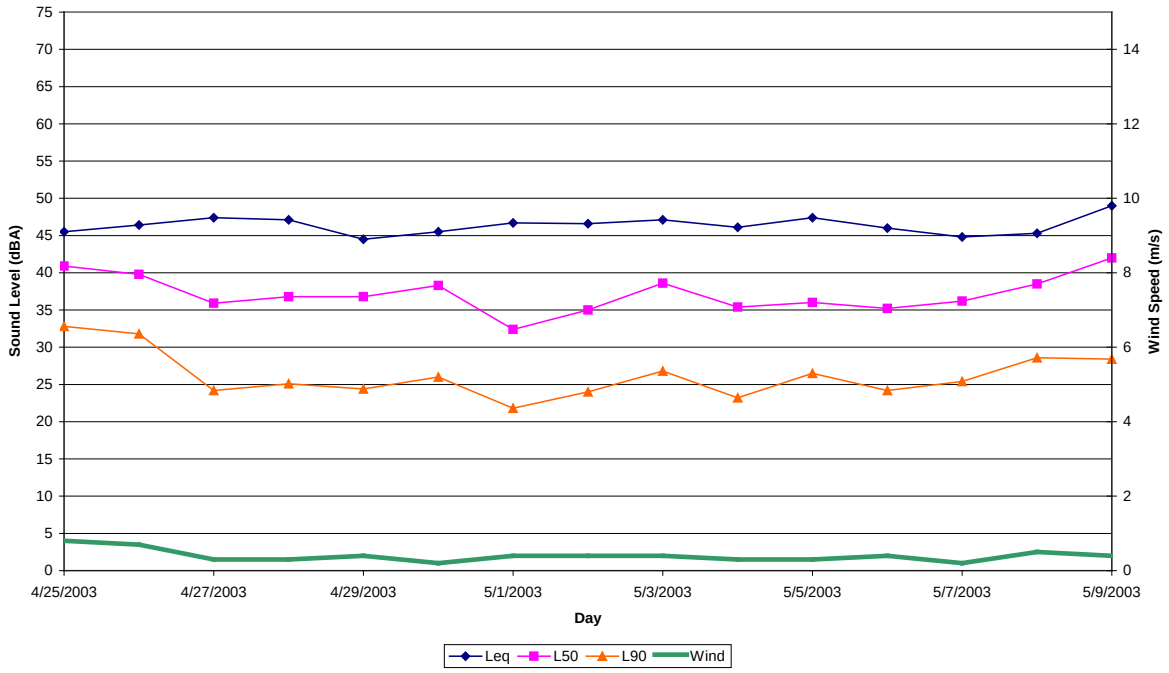


Figure 140. Daily sound levels and wind speeds: Site 8C.

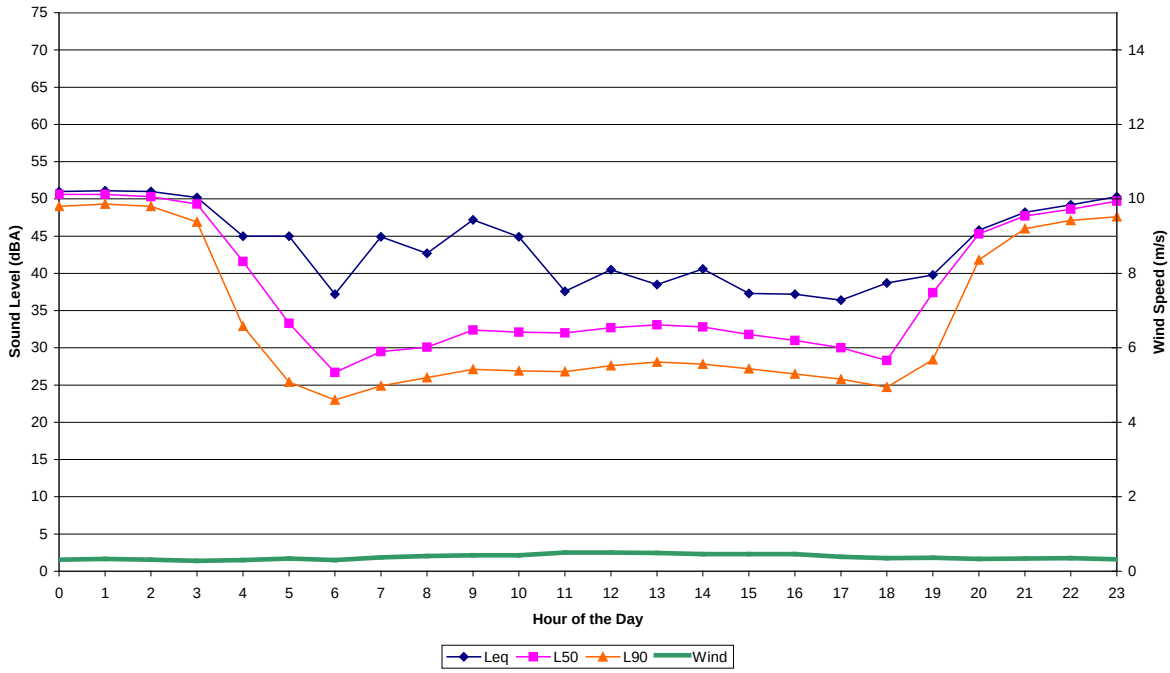


Figure 141. Average hourly sound levels and wind speeds: Site 8C.

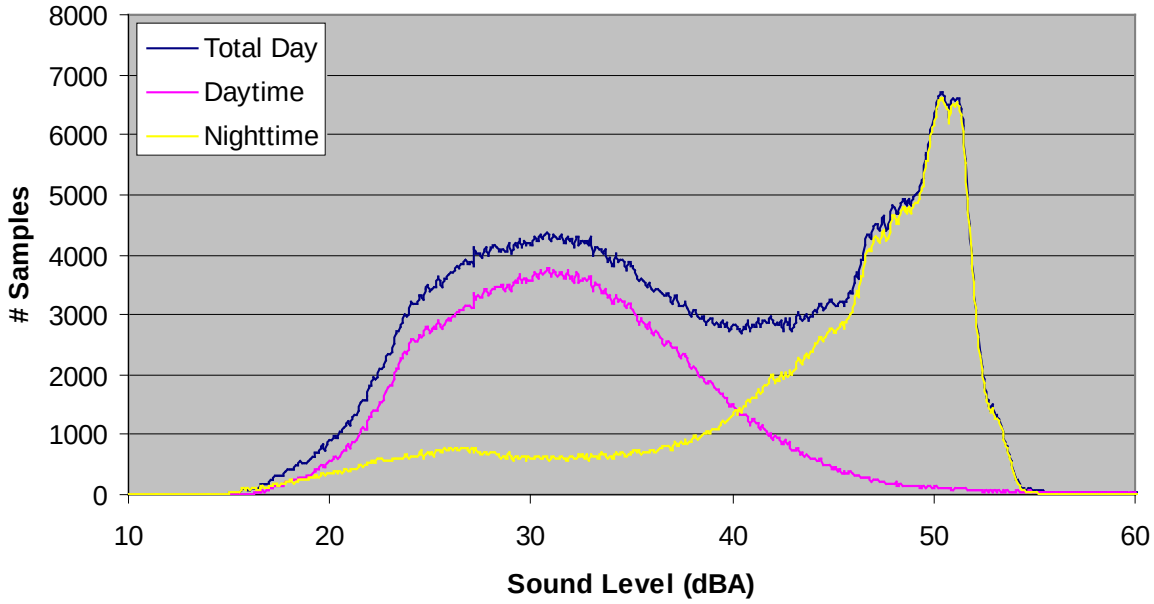


Figure 142. Data distributions: Site 8C.

This site exhibits a strong diurnal effect with bird vocalizations and aircraft noise during the day, and insect activity occurring during the nighttime. The diurnal effect is similar to the other two sites located in this acoustic zone, with the added aircraft activity due to the site's proximity to Napau Crater, which is en route to Pu`u O`o.

A.20 Site 9A – New Lava Flows Measurement Site

Table 43. Site 9A: description.

Site ID	**9A**
Site Name	Pu`u Huluhulu/Lava Trees
# Measurement Days and Dates	73 days - October 25, 2002 to January 28, 2003 and May 16 to May 24, 2003
System # and Type	6 (NoiseLogger™) and 2 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.2083 / 19.3742
Approximate Elevation (ft)	3300
Slope	< 1% Northwest
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(33) Transitional
Management Zone (see Section 2.5)	Wilderness (Natural Subzone)
Site Category (see Section 2.5.1)	Backcountry
Site Type (see Section 2.7.2)	Permanent
Site Description	Recent lava with young Ohi`a trees and shrubs
Access Considerations	Approximately 1.5-mile round trip hike along Nāpau Crater Trail
Potential Sound Sources	Aircraft, Wind



Figure 143. Site 9A: Description and photograph (with VoLARE system).

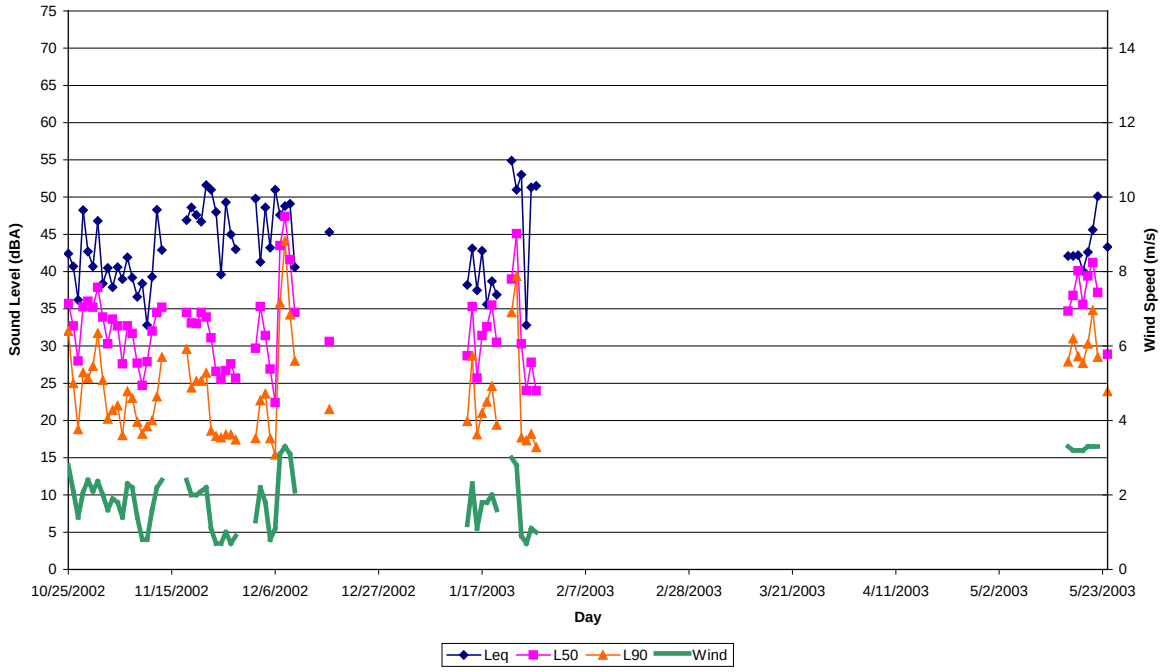


Figure 144. Daily sound levels and wind speeds: Site 9A.

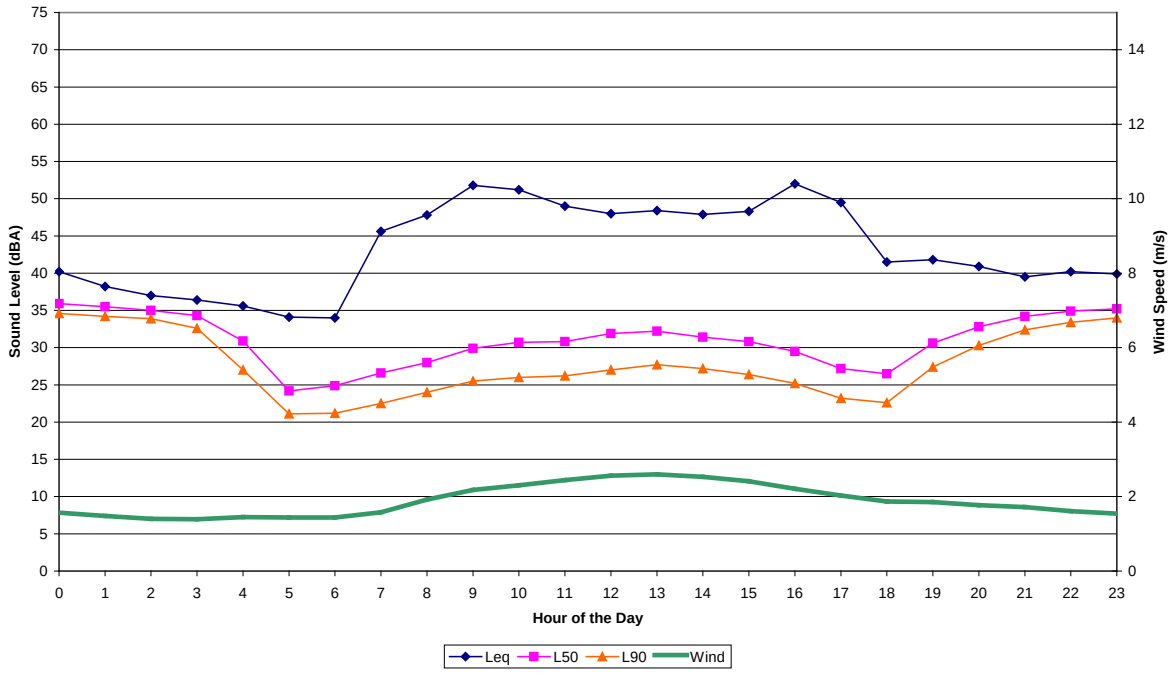


Figure 145. Average hourly sound levels and wind speeds: Site 9A.

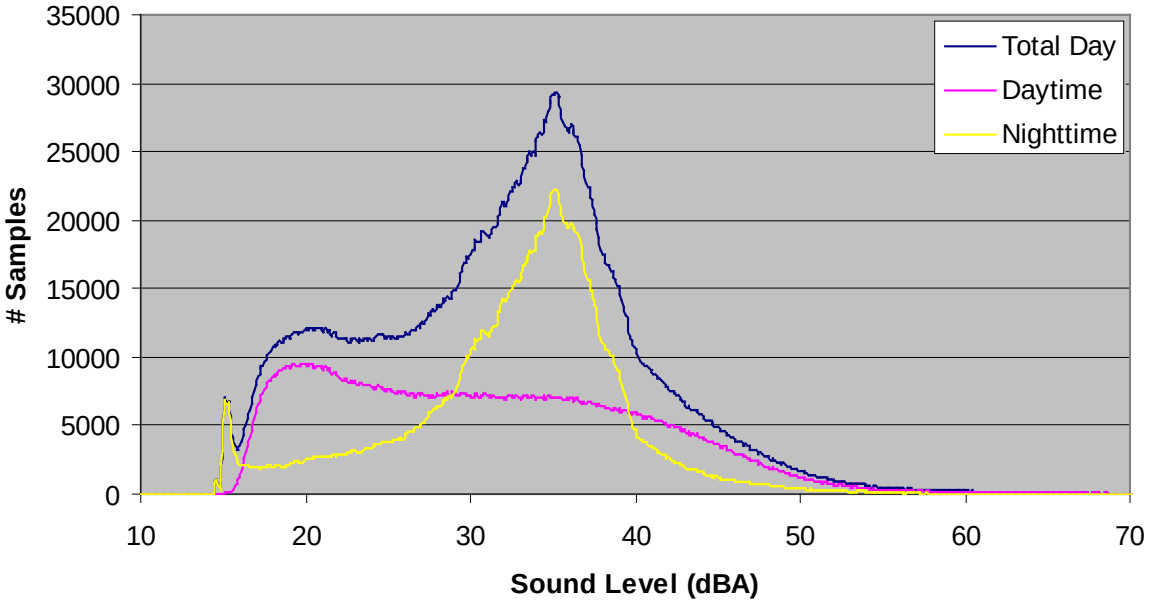


Figure 146. Data distributions: Site 9A.

This site exhibits wildlife activity (birds and insects) and a large amount of aircraft activity due to its location, which is along the typical flight path used by air tours departing from Kona en route to Pu`u O`o. The L_{Aeq} data shows the dichotomy between day and night hours – daytime is dominated by aircraft flyovers and nighttime is quieter with some insect activity.

A.21 Site 9B – New Lava Flows Measurement Site

Table 44. Site 9B: description.

Site ID	**9B**
Site Name	Kealakomo
# Measurement Days and Dates	17 days - May 16, 2003 to June 1, 2003
System # and Type	3 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1611 / 19.3193
Approximate Elevation (ft)	2100
Slope	< 5% Northwest
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(33) Transitional
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Overlook
Site Type (see Section 2.7.2)	Mobile
Site Description	Bare, recent lava flows
Access Considerations	Approximately 0.25-mile round trip hike on trail near the Kealakomo Overlook by the head of the Nāulu Trail off Chain of Craters Road
Potential Sound Sources	Aircraft, Vehicles, Wind

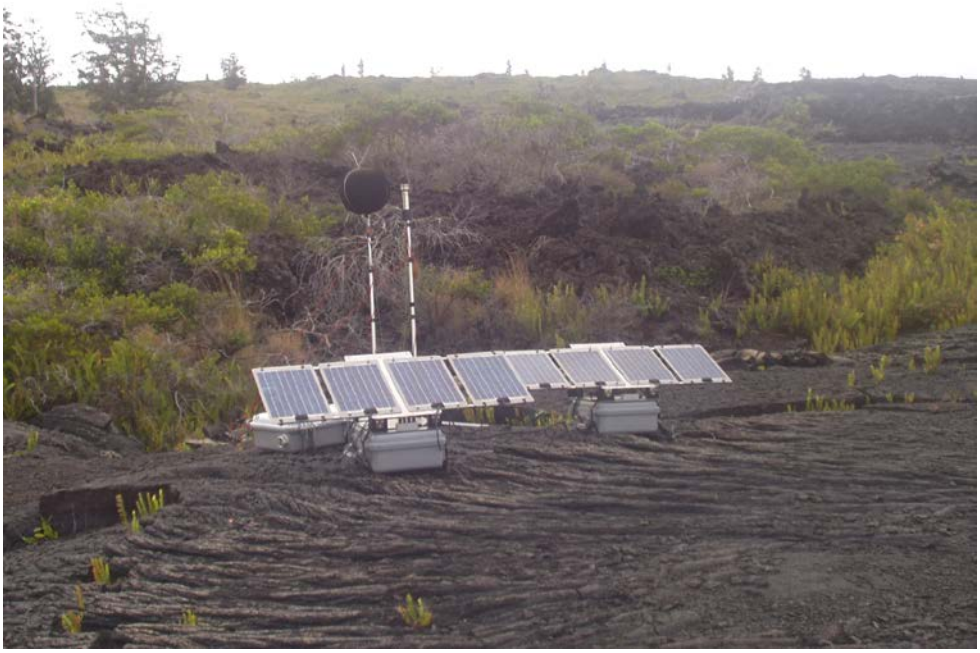


Figure 147. Site 9B: Description and photograph.

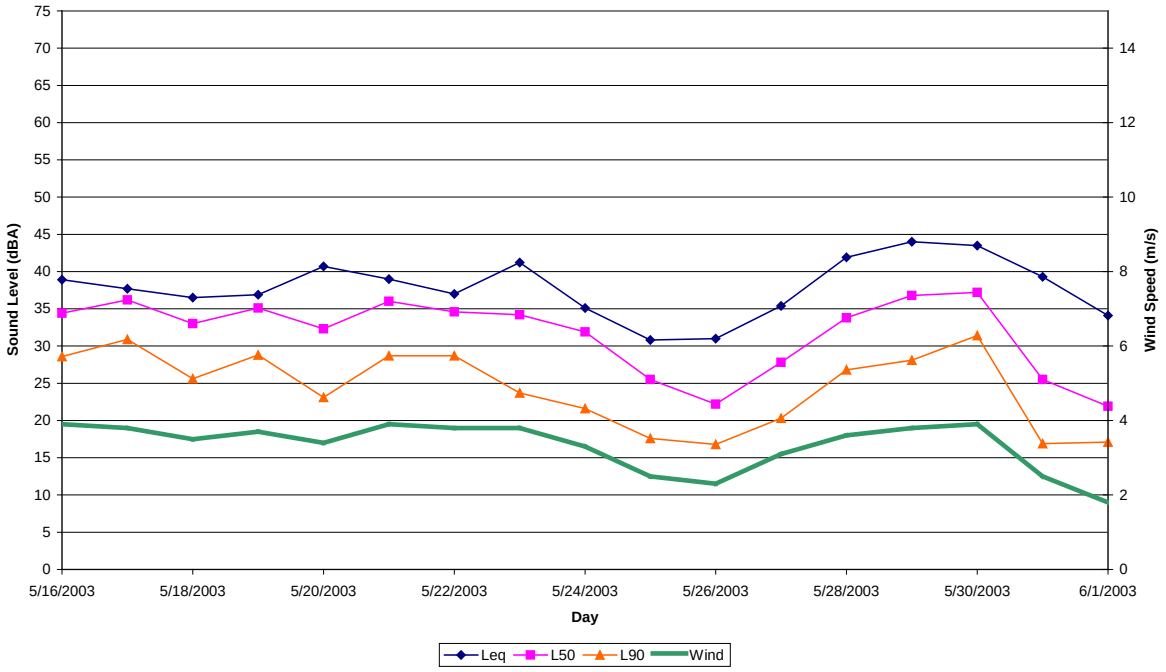


Figure 148. Daily sound levels and wind speeds: Site 9B.

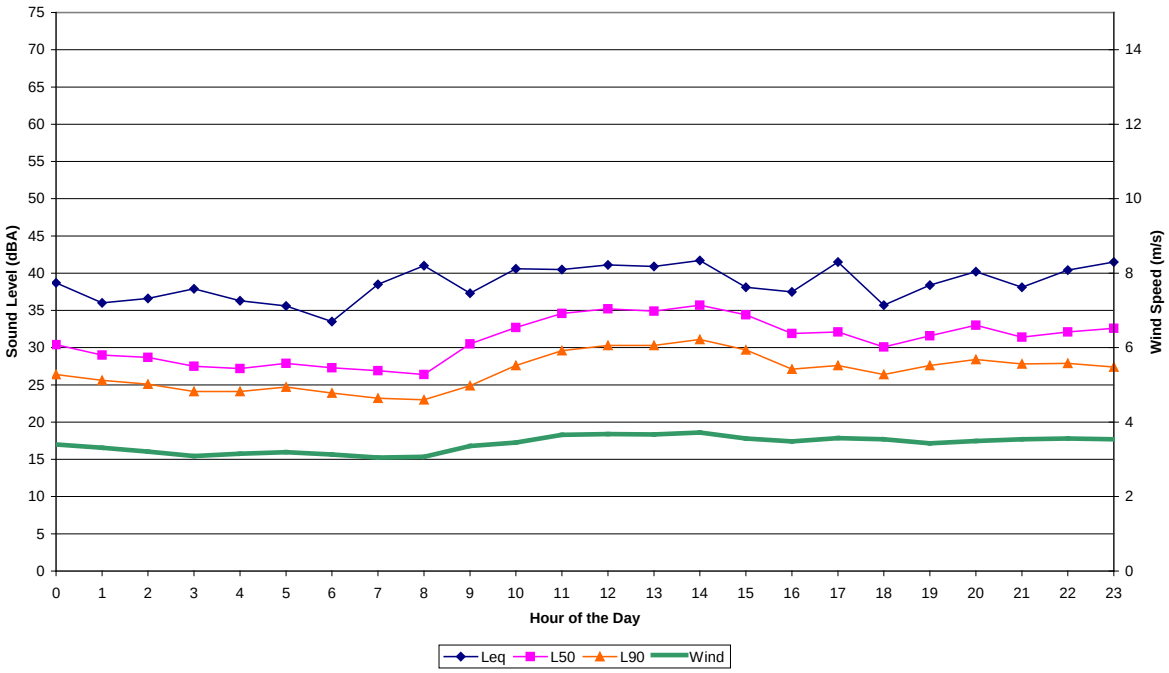


Figure 149. Average hourly sound levels and wind speeds: Site 9B.

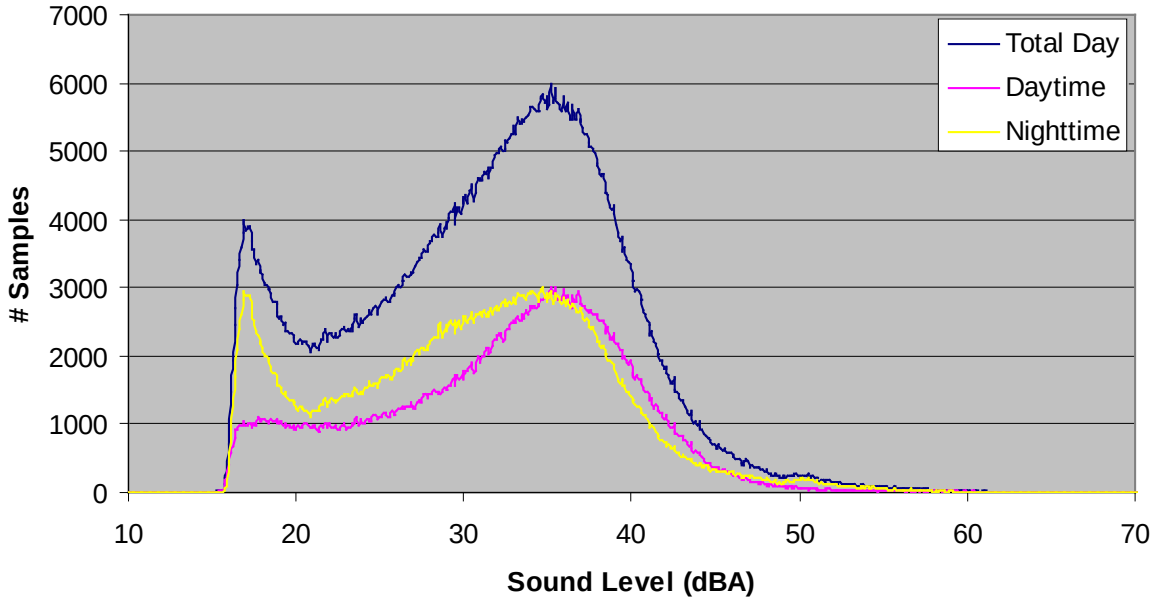


Figure 150. Data distributions: Site 9B.

This site was characterized by strong wind noise, motorist, and distant aircraft activity. The distribution shows similar sound levels during day and night time periods caused by the consistent high winds in this area.

A.22 Site 9C – New Lava Flows Measurement Site

Table 45. Site 9C: description.

Site ID	**9C**
Site Name	Pu`u Ō`ō
# Measurement Days and Dates	13 days - May 16, 2003 to May 28, 2003
System # and Type	1 (NoiseLogger™)
Latitude / Longitude (decimal degrees)	155.1187 / 19.3951
Approximate Elevation (ft)	2400
Slope	< 1% Northwest
Ecological Domain (see Appendix G)	(400) Humid Neotropical
Ecological Division (see Appendix G)	(412) Hawaiian Highlands
Land Cover Class (see Appendix G)	(3) Barren
Land Cover Subclass (see Appendix G)	(33) Transitional
Management Zone (see Section 2.5)	Natural
Site Category (see Section 2.5.1)	Backcountry
Site Type (see Section 2.7.2)	Mobile
Site Description	Bare, recent lava flows
Access Considerations	Helicopter access only - approximately 10 miles down Nāpau Crater Trail towards the base of Pu`u Ō`ō
Potential Sound Sources	Aircraft, Wind

Note: No photographs are available for this site.

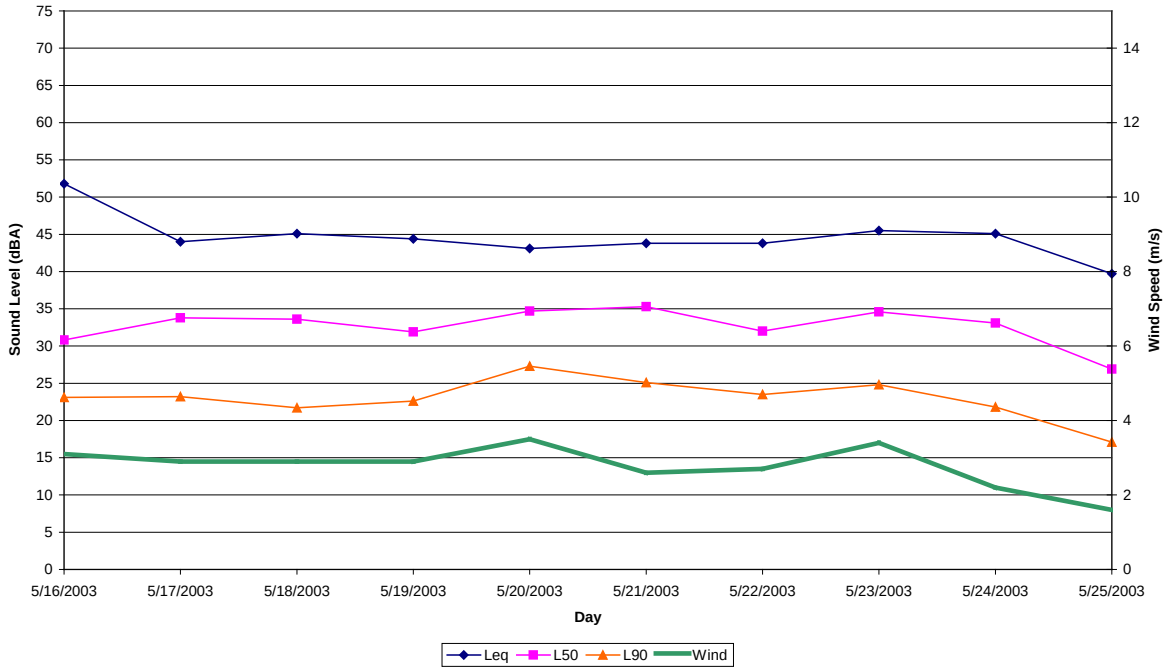


Figure 151. Daily sound levels and wind speeds: Site 9C.

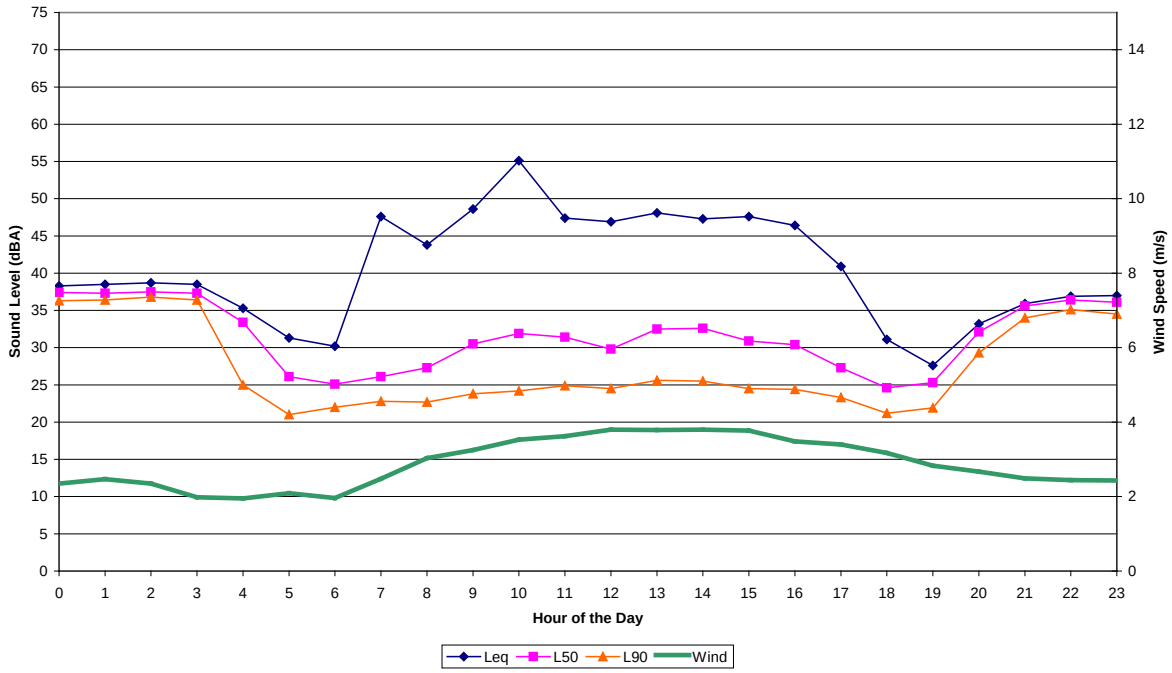


Figure 152. Average hourly sound levels and wind speeds: Site 9C.

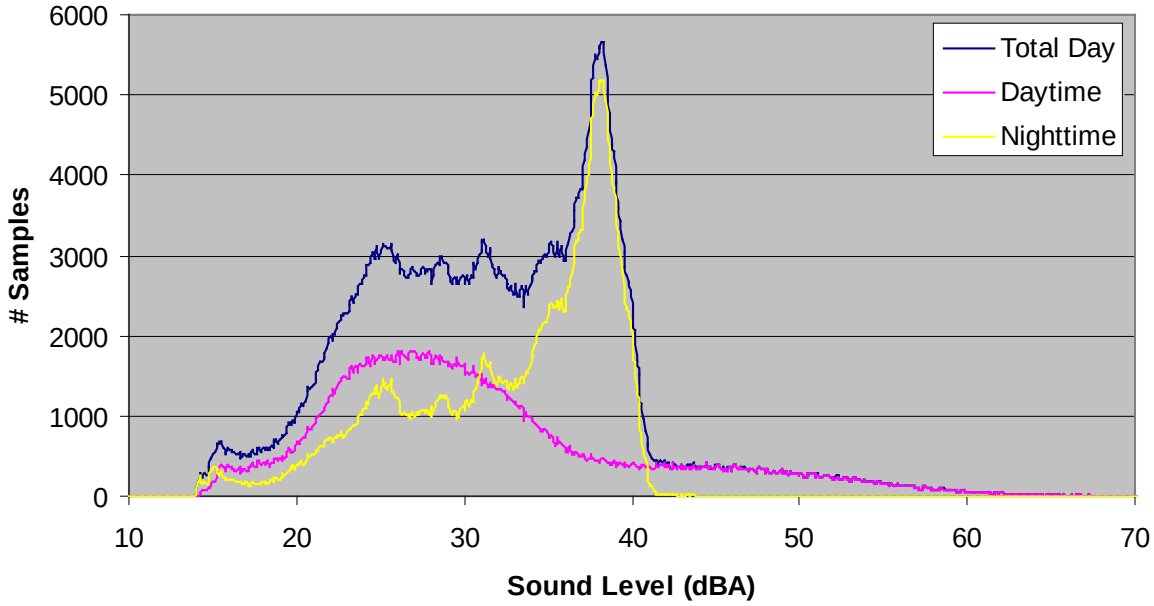


Figure 153. Data distributions: Site 9C.

This site exhibits wildlife activity (birds and insects) and a large amount of aircraft activity due to its close location en route to Pu`u O`o. Similar to Site 9A, the L_{Aeq} data shows the dichotomy between day and night hours – daytime is dominated by aircraft flyovers, and nighttime by insect activity.

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APPENDIX B. NOISELOGGER™ AND NOISELOGGER PLUS™ CONTINUOUS SYSTEM REFERENCE

This appendix presents the step-by-step procedures for the deployment, setup, and dismantling of the NoiseLogger™ and NoiseLogger Plus™ systems. Sections 3.1 and 3.2 discuss the systems' component instrumentation in more detail.

B.1 Overview

The NoiseLogger™ system is a specialized measurement system used to conduct unattended, long-term (30+ days), continuous 1/3-octave band noise measurements in outdoor environments. It is compact, light, rugged, and can run for days with external battery power, or continuously with solar panels, thus, making the system able to store more data than any known portable system. The NoiseLogger Plus™ system is similar to the NoiseLogger™ system, but modified to also support the capability to record live audio samples. It can record sounds on both a periodic basis, e.g., a 5-second recording every five minutes, and on a threshold basis, e.g., a recording is triggered when a sound level exceeds a user-defined threshold. Table 46 and Figure 154 and Figure 155 illustrate the basic components to these systems.

Table 46. NoiseLogger™ and NoiseLogger Plus™ system instrumentation list.

Components	NoiseLogger™ System	NoiseLogger Plus™ System
Microphone System	GRAS 40 AE ½-inch Microphone PRM902 Preamp Microphone Cable with 7-pin Connsector Large Foam Windscreen	GRAS 40 AE ½-inch Microphone PRM902 Preamp Microphone Cable with 7-pin Connector Large Foam Windscreen
Windscreen System	Gill WindObserver II Anemometer *or* FT702 Ultrasonic Anemometer Anemometer Cable with 6-pin Connector	Gill WindObserver II Anemometer *or* FT702 Ultrasonic Anemometer Anemometer Cable with 6-pin Connector
Recorder System	LD824 Sound Level Meter Husky fex21 Computer 128-MB Flash Cards	LD824 Sound Level Meter Fujitsu Lifebook P1110 Computer
Power System	217-AH Gell Cells 1 Solar Panel Array	4 17-AH Gell Cells2 Solar Panel Arrays
Ancillary Equipment	Garmin GPS Plus III Unit B&K 4231 Calibrator Microphone Simulator	Garmin GPS Plus III Unit B&K 4231 Calibrator Microphone Simulator

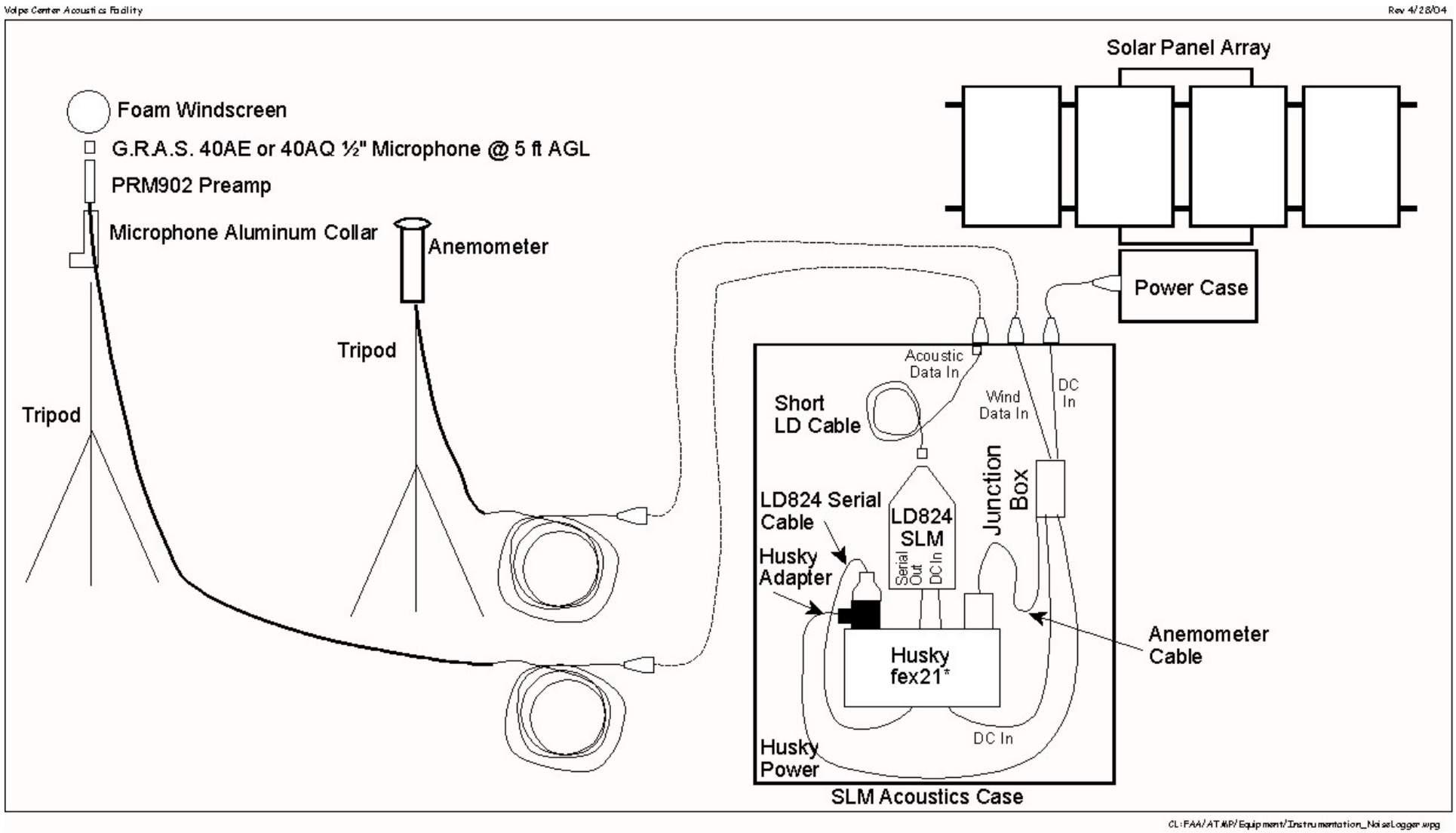


Figure 154. NoiseLogger™ continuous monitoring system.

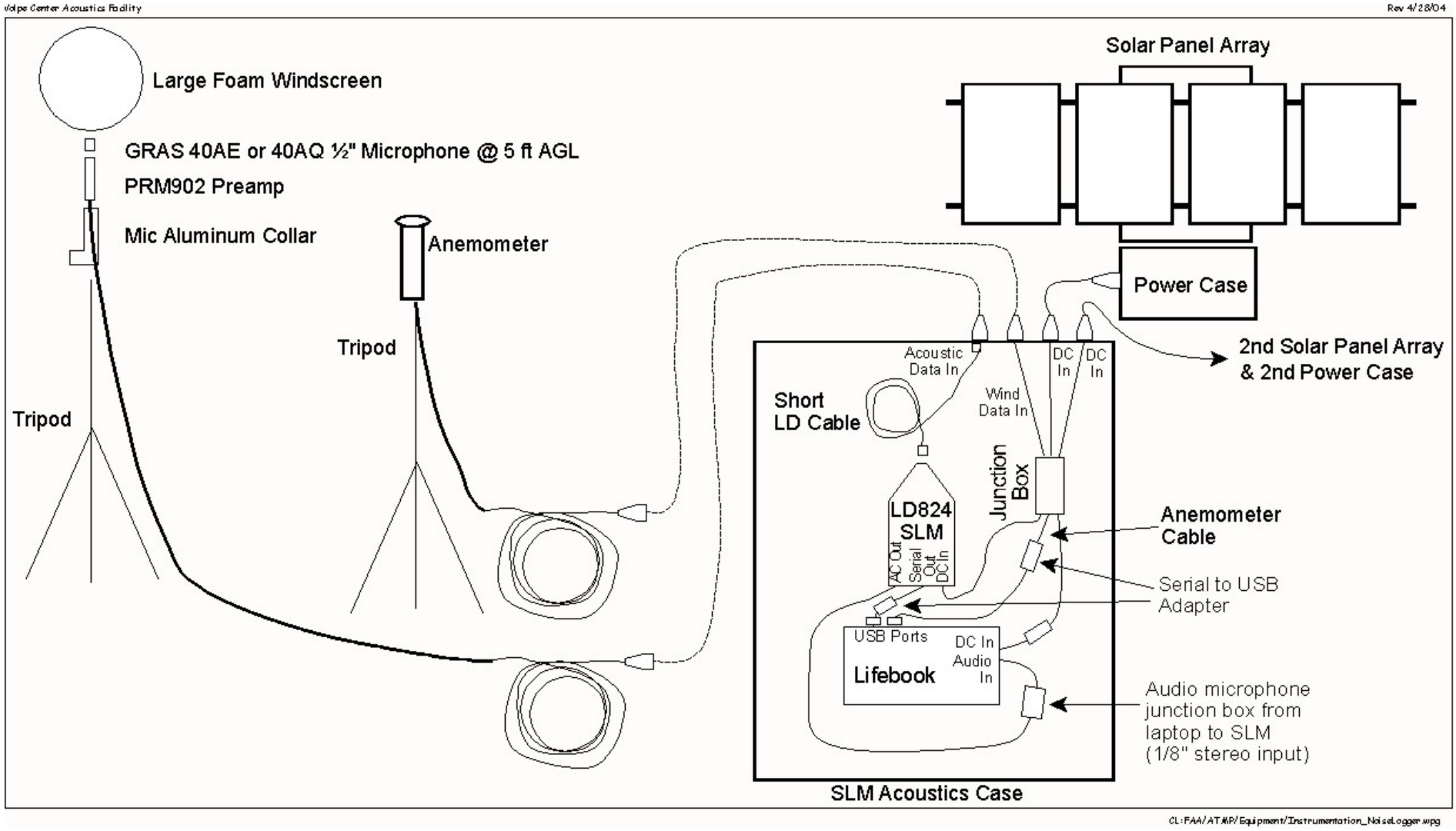


Figure 155. NoiseLogger Plus™ continuous monitoring system.

B.2 Deployment

1. Locate an approximate 5x5 ft area that is both relatively flat and at least 50 ft (15 m) from reflective objects.
2. Carefully unpack the system backpacks.

B.2.1 Wind Sensor System

1. Extend tripod so that the legs are flat on the ground.
2. Attach anemometer (see Figure 156) to tripod.
   a. If using a Gill WindObserver II anemometer, connect one end of anemometer cable (red cable, black connector, 6-pin connector with twist locking collar) to the base of the anemometer. Mount anemometer on tripod.

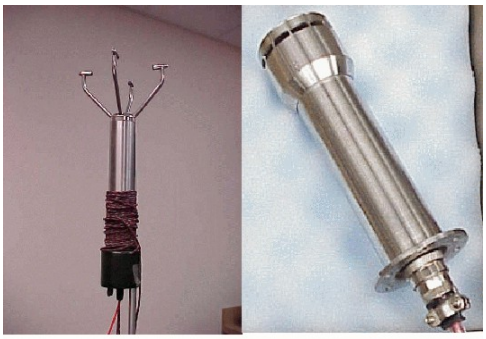


Figure 156. Gill WindObserver II and FT702 anemometers.

   b. If using a FT702 anemometer, the anemometer is stored in the SLM acoustics case. Remove mount from anemometer. Screw the mount onto the tripod. Connect one end of anemometer cable to the base of the anemometer THRU the mount. Secure anemometer to mount using hex key and screws.
3. Adjust tripod height such that top of the anemometer sensor is 5 ft (1.5 m) above the ground.
4. Orient the anemometer properly toward North direction (look for the “N” marked on the anemometer). A compass can be found in the calibration kit.
5. Carefully wrap the anemometer cable around the tripod or tie with zip-ties, so that it will not hit the tripod in the wind. Connect other end of cable to the SLM case external connector.
6. Anchor the tripod to the ground or a nearby stationary object using the rope, stakes, and sandbags, as necessary, so that it will not sway in the wind.

B.2.2 Microphone System

1. Extend tripod so that the legs are flat on the ground. Attach the microphone aluminum collar to top of tripod.
2. Attach the microphone to the preamp. Connect the mic/preamp to the microphone cable (red cable, black connector, 7-pin connector with twist locking collar) and carefully slide mic/preamp/cable into the aluminum collar from the top (see Figure 157).
3. Adjust tripod height such that top of the microphone is 5 ft (1.5 m) above the ground and oriented vertically.
4. Carefully slide the large foam windscreen over the top of the mic/preamp until the windscreen mount reaches the black line on the microphone collar. Finger-tighten the plastic set screw to the collar (not the preamp).
5. Carefully wrap the microphone cable around the tripod or tie with zip-ties, so that it will not hit the tripod in the wind. Connect one end of microphone cable to the SLM case external connector.



Figure 157. Microphone/preamp assembly.

6. Anchor the tripod to the ground or a nearby stationary object using the rope, stakes, and sandbags, as necessary, so that it will not sway in the wind.

B.2.3 Power System

1. Unfold the metal panel and carefully remove solar panels. Align panels one though four from left to right (see Figure 158). Remove the two smooth rods and 4 panel rods from the array accessories bag.
2. Insert the two smooth rods into the metal "panel plate" and black corner blocks on the base plate to prop up "panel plate" at about 60-degree angle.

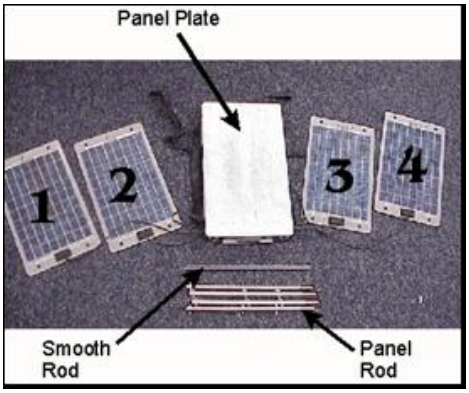


Figure 158. Unpack solar panel array

3. Place left inner orange loop on the right upper panel plate tube; place right inner orange loop on the left upper panel plate tube (see Figure 159).
4. Place a panel rod into each side of the upper panel plate tube. Rotate panel rod so that the connection points are facing away from the panel plate.
5. Place the outer left loop of the orange line to the outer end of the left panel rod. Place the outer right loop of the orange line to the outer end of the right panel rod. The inner orange lines should now form an "X" pattern behind the "panel plate."

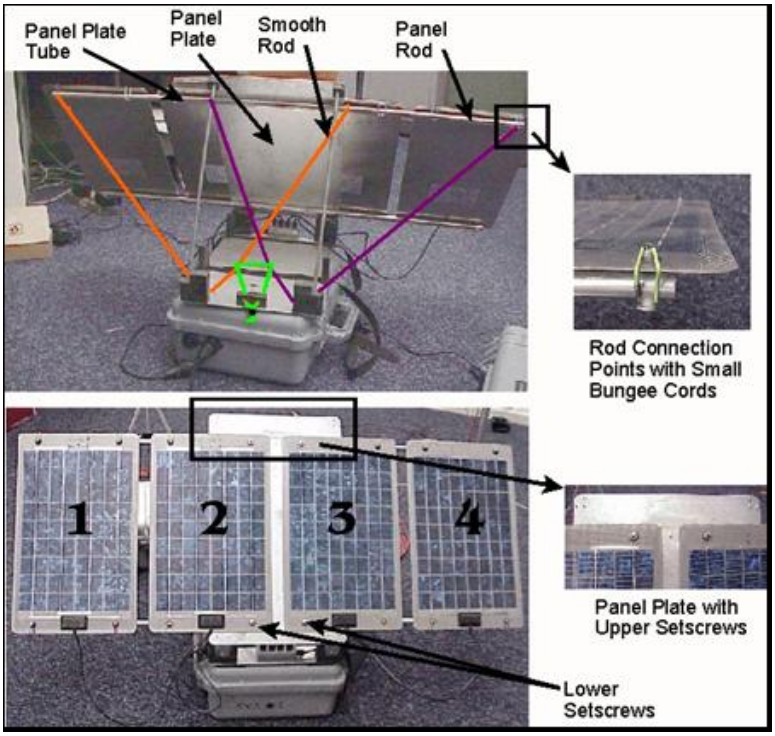


Figure 159. Solar panel array setup.

6. Tighten the "X" pattern by pulling the small string loop at the base of the "X" and raising the tension knob (see Figure 160).
7. Insert the two lower panel rods into the tubes at the bottom of the "panel plate."



Figure 160. Close-in view of string tensioner.

8. First attach panel #2 to the left inner position and panel #3 to the right inner position and secure with the four thumbscrews, which can be found in a small plastic bag within the array accessories bag. Make sure that the black cables are at the bottom of the plate and not between the lower panel rods and the panel.
9. Attach the outer panel #1 to the left outer position, and panel #4 to the right outer position.
10. Attach the small bungee cords (found in small plastic) bag to the rod connection points on the faces of the solar panels and to the back of the rod.
11. Connect the solar panel power cable to the power case (3-pin connector with twist locking collar).
12. Verify that the green "charging" LED is lit on the Sun Saver 6 input block.
13. Verify that the vent knob on the front of the power case is removed and placed inside the case.
14. Close the power case.
15. Place solar panel array on top of the power case. Secure the array to the power case with the black straps.
16. Orient the entire solar panel array in the desired position for the specific site location (typically in a southerly direction).
17. Connect the system power cable (2-pin connector with twist locking collar) to the SLM case external connector and to the power case external connector.
18. For the NoiseLogger Plus™ system, a second solar panel array should be setup similarly.

B.3 Operation

B.3.1 NoiseLogger™ Startup

1. See Section B.3.2 for NoiseLogger Plus startup.
2. Open SLM acoustics case. Remove top foam piece.
3. Verify connections as shown in Figure 161, specifically verify that the silver connector/red cable is connected to right Husky™ com port and the black Husky™ adapter/beige serial cable is connected to the left com port, also that the small black

cable is connected to the side of the black Husky™ adapter. Verify also that the cable from the "Mic In" connector to the top of the LD824 is connected.

4. Open the plastic back plate to the Husky™ by squeezing the two clips on the back of the Husky™ and check to ensure a 128-MB CompactFlash™ card (Storage Card) is in one of the two card slots. Restore the back plate.
5. Power up the Husky™ by pressing the red center button below the screen. Note: If the Husky™ hasn't been turned on for a long time, the unit may display several screens to calibrate the touch screen and perform time zone setup on the unit.

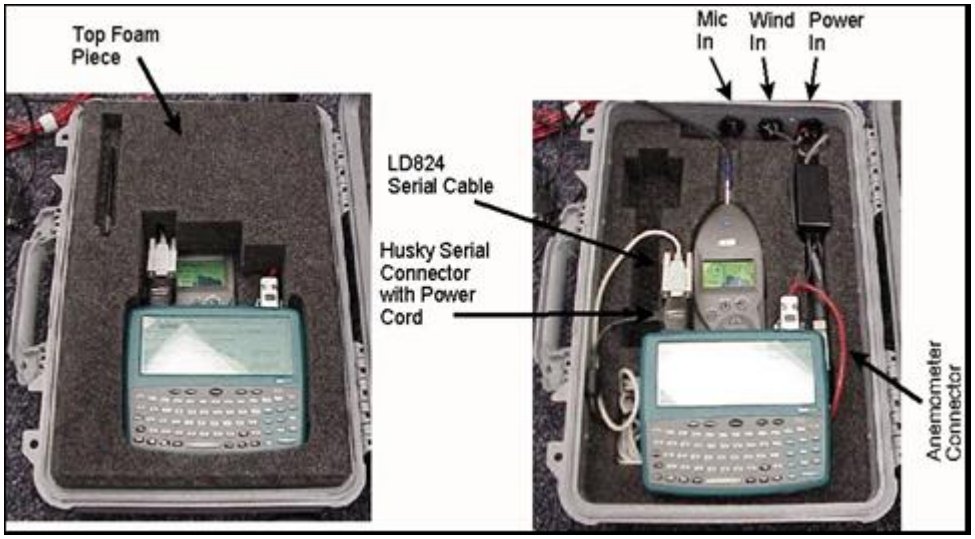


Figure 161. SLM acoustics case.

6. Power up the LD824 by pressing the lighted green (left-most) button on the front panel Note: The LD824 may power up automatically when the Husky™ is started.
7. Reset/reboot the Husky™ by pressing both the contrast and brightness buttons on either side of the power button.
8. Using the red tip of the stylus, select "My Handheld PC" icon on the desktop.
9. A Windows browser is displayed. Select the "Storage Card" directory to access the 128-MB CompactFlash™ card. Select the "NoiseLogger™ ver 2.1.0.0" folder and then run the NoiseLogger.exe program by double clicking the filename with the stylus.
10. An "About NoiseLogger" dialog is displayed. Select OK.

11. Per the program instructions, enter a unique three-character ID representing the site "number" (e.g., 6A1 for Hawai`i Volcanoes Site 6A), and the site's name (e.g., Hilina Pali Road/Weather Station).
12. Select "Equipment Info" and proceed to the GPS Synchronization (Section B.3.3).

B.3.2 NoiseLogger Plus™ Startup

1. Open SLM acoustics case. Remove top foam piece.
2. Verify Fujitsu™ laptop computer connections as shown in Figure 162, specifically that the USB cable from the LD824 is connected to the left USB com port and the USB cable from the anemometer is connected to the right USB com port. Verify also that the AC In power cable and microphone (for wave file recording) cable are connected.

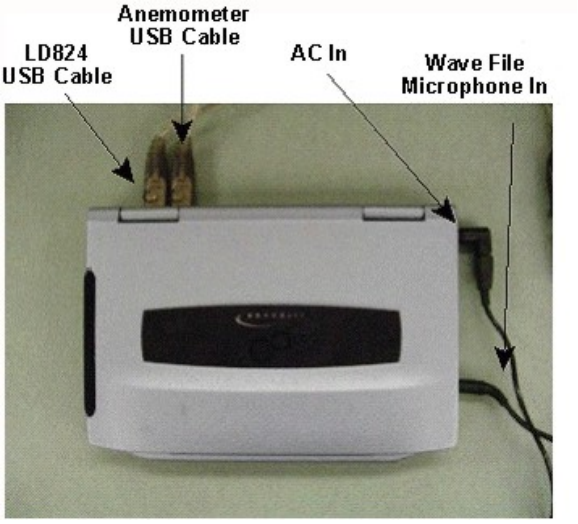


Figure 162. NoiseLogger Plus™ Fujitsu™ computer.

3. Power up the laptop by pressing silver button below the screen.
4. Power up the LD824 by pressing the lighted green (left-most) button on the front panel Note: The LD824 may power up automatically when the laptop is started.
5. Using the mouse pad, move the mouse to select OK and skip log in.
6. Select the NoiseLogger Plus™ folder and then run the NoiseLogger Plus™ program by double clicking the icon.
7. An "About NoiseLogger" dialog is displayed. Select OK.

8. Per the program instructions, enter a unique three-character ID representing the site "number" (e.g., 6A1 for Hawai`i Volcanoes Site 6A), and the site's name (e.g., Hilina Pali Road/Weather Station).
9. Select the following digital audio recording settings:
   a. *Sampling Rate:* Set to 20 kHz to collect most audible sounds. Equal to two times the highest frequency that is recorded by the wave file;
   b. *Sound Quality:* Set to 16 Bits to collect the widest range of sounds. This determines the dynamic range of the sound that is recorded by the wave file;
   c. *Periodic Wave Collection:* Check the box to enable automatic wave file collection, then select the option to record a 30-second wave file every 30 minutes;
   d. *Event Triggered:* Check the box to enable automatic wave file collection when certain threshold parameters (see Item e) are met in order to try and capture certain noise events;
   e. *Threshold:* Typically set to 50 dBA for quiet sites, and 60 dBA for other sites. This is the sound level that is needed in order for an event-triggered wave file to begin collection;
   f. *Trigger Arming Duration:* Set to 5 seconds. This is equal to the number of seconds that either the broadband or tonal triggering conditions must be met in order for wave file collection to begin (e.g., if events are selected with a threshold of 55 dBA and an arming duration of 5 seconds, then the sound level must be equal to or greater than 55 dBA for 5 seconds for a wave file to begin collection). This helps to avoid collection of impulsive bird chirping events;
   g. *Trigger Reset Duration:* Set to 10 seconds. In order to avoid constant wave file collection, this is equal to the number of seconds that the threshold triggering condition must NOT be met in order for another wave file to be collected (e.g., if events are selected with a threshold of 55 dBA, an reset duration of 10 seconds, then after a wave file is collected, it is necessary of the sound level to be below 55 dBA for 10 seconds in a row before another wave file can be collected);
   h. *Number of Wave Files Per Day:* Set to 200. This is the total number of event wave files (Note: Periodic wave files are not counted) that can be collected in

each day. This is set to avoid collecting too many wave files within a short period of time and expending all of the laptop's internal hard drive space.

10. Select "Equipment Info" and proceed to the GPS Synchronization (Section B.3.3).

B.3.3 GPS Synchronization

1. A GPS unit and cable can be found in the calibration kit.
   a. *For the NoiseLogger™ system*, connect the serial end of the GPS cable to the Husky™ right-side com port. If the anemometer cable is already connected to this com port, disconnect the silver connector with red cable, and then connect the black GPS cable.
   b. *For the NoiseLogger Plus™ system*, connect the serial end of the GPS cable to the serial-USB adapter cable connected to the right the laptop's USB com port. If the anemometer cable is already connected to this adapter cable, disconnect the wind sensor cable from the adapter, and then connect the black GPS cable.
2. Connect the other end of the GPS cable to the back of the GPS unit.
3. Turn on the GPS unit by pressing the red light-bulb button. When the unit has adequate satellite communication, the unit will display "3-D Navigation," which may take several minuets. Use the "PGDN" button to display latitude, longitude, and elevation information. Write this information onto the site log sheet.
4. Select the [Sync with GPS] button on the computer screen. Date, time, and satellite information will begin to scroll for approximately 2 minutes. Note: If you are unable to sync with GPS, manually update the date and time and select the "Update" button.
5. Disconnect the GPS unit and cable from the computer when data stops scrolling and a message is displayed on the computer screen that says "Please disconnect GPS…"
6. Turn off the GPS unit by pressing the light-bulb button on its front panel.
7. Reconnect the anemometer cable.
8. Select the [Close] button on the screen and proceed to Section B.3.4.

B.3.4 Equipment Information

1. Verify that the wind sensor (anemometer) cable is connected properly to the computer.

2. Select the type of anemometer being used in the pull-down menu in the "Equipment Info" dialog. Note: This must be performed even if the anemometer is the default type. Select [Continue].
3. If an anemometer error occurs or a com port error message is displayed, check the connection, then press [Continue] and select [Equipment Info] again. If the problem persists continue on to the [Calibrate SLM] procedure (Section B.3.4).
4. Enter the sound level meter type and serial number. Refer to the equipment info sheet taped to the inside cover of the case). Note: The info sheet should be checked as some equipment may have been switched out in the field.
5. Enter the anemometer type and serial number.
6. Select the desired calibration level. If a level other than 94 or 114 dB is selected, enter the level in the field to the right. Verify that the "Frequency" field shows 1000.
7. Enter the calibrator type and serial number. A calibrator can be found in the calibration kit.
8. Select the [Continue] button.
9. Enter the microphone type and serial number.
10. Enter the preamp type and serial number.
11. Enter the GPS unit type and serial number.
12. Enter the computer type and serial number.
13. Enter operator name and comments.
14. Select the [Finish] button. If prompted to "Sync with GPS" again, select the [Cancel] button. Proceed to Section B.3.5

B.3.5 Calibration

1. The NoiseLogger™/ NoiseLogger Plus™ program sends commands to the LD824 to control it during calibration and data logging. There is no need to handle the LD824 other than ensuring the preamp cable connection, serial data connection and power connection.

2. Carefully remove the large foam windscreen and apply the calibrator to microphone (see Figure 163). A calibrator can be found in one of the calibration kits. Note: To ensure the calibrator is seated properly, gently rotate it clockwise ¼ turn.
3. Carefully apply power to calibrator by pressing the left button on the calibrator (94-dB setting).
4. Select the [Calibrate SLM] button on the computer screen.



Figure 163. System calibration.

5. Verify information in the resultant calibrator info dialog. Select [Calibrate] button.
6. Verify that the LD824 is responding to the calibration process (a sound level of approximately 94 dBA at 1000 Hz should be displayed. When calibration is complete, a message is displayed on the computer screen with the calibration offset (typically between –45 and –50 dB). Write this offset level on the site log sheet. Note: During strong wind conditions, it may be difficult to observe a steady calibration signal. In such instances, cover the calibrator and mic/preamp assembly with a bag (such as the solar array accessories bag) and select the [Calibrate] button to redo calibration, taking care not to disturb the microphone and calibrator during this process.
7. After system calibration is completed, record approximately 30 seconds of the calibrator tone by selecting the [Collect Data] button. Verify that the anemometer cable is securely connected to the computer and select [Yes].
8. Verify that the sound level being reporting on the computer screen is approximately 94 dB for A, C, and flat weighting.
9. After about 30 seconds, stop data collection by selecting the [Stop Collection] button. Select [Yes] to verify.
10. Carefully de-activate the calibrator and remove it from the microphone.
11. After recording the calibration signal, carefully de-activate the calibrator and remove it from the microphone. Carefully replace the large foam windscreen.

B.3.6 System Integrity Check

1. System integrity is checked prior to the start of data collection to ensure that there is no outside signal influence on the system. This is performed by recording the sound level with a dummy microphone.
2. Carefully remove the large foam windscreen. Carefully replace the microphone on the preamp with a microphone simulator. Place the microphone back in its holder during this exercise for safekeeping.
3. In the "Sound Level Range" (located in the upper right corner of the computer screen) pull-down menu, change the sound level range to 60.
4. Select the [Collect Data] button. Verify that the anemometer cable is securely connected to the computer and select [Yes].
5. Verify that the sound level being reporting is low, approximately 10-15 decibels for A, C, and flat weighting.
6. After about 20 seconds, stop data collection by selecting the [Stop Collection] button. Select [Yes] to verify.
7. Replace the microphone simulator on the preamp with the microphone.
8. Carefully replace the large foam windscreen over the top of the mic/preamp until the windscreen mount reaches the black line on the microphone collar. Finger-tighten the plastic set screw to the collar (not the preamp).

B.4 Data Collection

1. Carefully slide the large foam windscreen over the top of the mic/preamp until the windscreen mount reaches the black line on the microphone collar. Finger-tighten the plastic set screw to the collar (not the preamp).
2. In the "Sound Level Range" (located in the upper right corner of the computer screen) pull-down menu, select the desired sound level range (90 dB is the default). Note: This level is the anticipated maximum sound level to be measured at the site. Given this user-selected "maximum," the NoiseLogger™ program automatically sets both a designated amount of gain and an absolute sound level limit ("ceiling") to LD824 (see Table 47 below). For example, for sites where a wide range of natural and mechanical sound sources was expected, this range should be set to 90 dB. At this setting, 20 dB of gain is automatically applied to

the LD824, and the loudest sound level that could be measured is 108 dB. For quieter sites, the "Sound Level Range" should be set to lower levels, as appropriate.

Table 47. LD Model 824 SLM sound level range and associated gain setting and ceiling level.

Sound Level Range (dB)	LD824 Gain Setting (dB)	Ceiling Level (dB)
110	0	128
100	+10	118
90	+20	108
80	+30	98
70	+40	88
60	+50	78

3. Select the [Collect Data] button. Verify that the anemometer cable is securely connected to the computer and select [Yes].
4. Verify that data is being collected: "Samples saved" is incrementing, and wind and sound level data are being read.
5. Replace top foam piece carefully over the computer. Verify that data appears reasonable and that "Samples saved" is incrementing. Also verify a battery reading above 11.0. Note: The system will not run properly if the battery reading is below 11.0. A fully charged system would display approximately 12.5.
6. Close the SLM case and secure the site.

B.5 Data Download

1. Stop data collection by selecting the [Stop Collection] button. Select [Yes] to verify.
2. Perform an end-calibration by recording the sound level with a calibrator applied.
3. Carefully remove the large foam windscreen. Apply the calibrator to microphone. A calibrator can be found in one of the calibration kits. Note: To ensure the calibrator is seated properly, gently rotate it clockwise ¼ turn.
4. Carefully apply power to calibrator by pressing the left button on the calibrator (94-dB setting).
5. Select the [Collect Data] button. Verify that the anemometer cable is connected to the Husky™ and select [Yes].

6. Verify that the sound level being reporting on the computer screen is approximately 94 dB for A, C, and flat weighting. Note: During strong wind conditions, it may be difficult to observe a steady calibration signal. In such instances, cover the calibrator and mic/preamp assembly with a bag (such as the solar array accessories bag), taking care not to disturb the microphone and calibrator during this process.
7. After about 30 seconds, stop data collection by selecting the [Stop Collection] button. Select [Yes] to verify.
8. Download the data from the computer:
   a. *For the NoiseLogger™ system,* press the power button below the computer screen to power down the computer. Carefully remove the plastic back plate by squeezing the two clips on the back of the Husky™. Remove the plastic back plate and push the lever with green handle (do not pull it) like a plunger to pop out the 128-MB CompactFlash™ card. Make sure the flashcard is properly labeled with site info, date and other pertinent information. A wax pen can be found in one of the calibration kits. Also write this information, including the card number, on the site log sheet. If this is the end of the measurement period for this site, proceed to Section B.6 for instructions on dismantling the system. If measurements are to continue, install new flashcard, reinstall the plastic back plate, reconnect black Husky™ adapter ensuring that the Husky™ power cord is attached to the adapter, and power up the computer. Note the new card number on the site log sheet.
   b. *For the NoiseLogger Plus™ system,* connect an external hard drive to the serial com port. Open Windows Explorer by double clicking on the program icon on the screen. Copy all the wave files stored in the laptop's hard drive to the external hard drive. Disconnect the external hard drive. If this is the end of the measurement period for this site, power down the computer by selecting the [Start] button and [Shut Down], and then proceed to Section B.6 for instructions on dismantling the system. If measurements are to continue, erase all the existing wave files from the laptop.
9. Perform calibration (see Section B.3.5).
10. Start data collection (see Section B.4).

B.6 System Dismantling

B.6.1 SLM Acoustics Case

1. Verify that the computer is powered down:
   a. *For the NoiseLogger™ system*, disconnect the power cable from the side of the Husky™ adapter on the left com port. Press the red center button above the keyboard of the Husky™ keypad to power down the computer.
   b. *For the NoiseLogger Plus™ system*, power down the computer by selecting the [Start] button and [Shut Down].
2. Power down the LD824 if it has not already shut down by pressing and holding down the lighted green (left-most) button on the LD824.
3. Disconnect main power cable from SLM case and Power case.
4. Disconnect mic/preamp cable and anemometer cable from SLM case.
5. Store the stylus, hex key, and small screwdriver, replace top foam piece on the Husky, and close SLM acoustics case.

B.6.2 Wind Sensor System

1. Remove anemometer from tripod.
   a. If a Gill WindObserver anemometer was used, lift anemometer off tripod and disconnect the anemometer cable from the base of the anemometer.
   b. If a FT702 anemometer was used, remove the anemometer from its mount by using the hex key to remove the screws. Disconnect the anemometer cable from the base of the anemometer THRU the mount. Unscrew the mount from the tripod. Replace the anemometer onto the mount with the screws. Place the anemometer/mount assembly in the SLM acoustics case.
2. Collapse the anemometer tripod.
3. Roll up the anemometer cable.

B.6.3 Microphone System

1. Remove large foam windscreen.
2. Remove mic/preamp/cable assembly from aluminum collar.
3. Carefully remove the microphone from the preamp and place it in its protective case.

4. Disconnect preamp from cable, replace the protective red cap on preamp (microphone end) and insert preamp into plastic tube (connector end first, not red cap).
5. Remove aluminum collar from tripod. Place collar and preamp tube in the SLM acoustics case.
6. Roll up the microphone cable
7. Collapse the microphone tripod.

B.6.4 Power System

1. Disconnect power cable from solar array to the power case.
2. Remove small bungee cords from the solar panels, place in plastic bag, and then place in solar-array accessories bag.
3. Remove the outer two panels and carefully place on the ground, panel facing up.
4. Remove the four setscrews holding the two inner panels, place set screws in bag with bungee cords.
5. Remove the two inner panels and place on ground facing up.
6. Disconnect orange loop from ends of upper panel rods.
7. Remove all four panel rods and place in solar-array accessories bag.
8. Remove smooth rods and place in solar-array accessories bag.
9. With the panel plate upright, place panel #4 on base plate with panel facing up.
10. Place panel #3 facing down on top of panel #4, making sure that panel #4 and #3 power cable connection blocks are on opposite sides of each other.
11. Loop power cables in between panel faces.
12. Place panel #2, metal to metal on top of panel #3, so that the panel is facing up.
13. Place panel #1 facing down on top of panel #2, making sure that panel #1 and #2 power cable connection blocks are on opposite sides of each other.
14. Loop power cables in between panel faces.
15. Route main power cable over the top of panel #1 so the connector is actually beyond the panel slightly and won't crush either the connector or the top panel when the panel plate is closed (see Figure 164).
16. Close panel plate over the top of the stack of panels and secure with black straps.



Figure 164. Packing the solar panel array.

Note: Once the system is fully dismantled, place the components into their appropriate backpack. Perform a visual inspection of the site to ensure nothing was left behind.

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APPENDIX C. INSTRUMENTATION FREQUENCY RESPONSE ADJUSTMENTS

All NoiseLogger™ and NoiseLogger Plus™ acoustic data were adjusted prior to data analysis to account for microphone and windscreen frequency response biases – that is, the diffraction and interference effects that occur at the microphone diaphragm when it is placed in a diffuse sound field (Section C.1) and the acoustic effects, i.e., insertion losses, that occur when using a microphone windscreen (Section C.2). These adjustments were either measured or determined from the instrument's calibration certificate.* This appendix presents a description of these adjustments.

C.1 Microphone Frequency Response Adjustments

The frequency response of a microphone varies with the angle of incidence between the sound waves and the microphone diaphragm. In measuring ambient noise, the locations of the sound sources are somewhat arbitrary, i.e., randomly occurring. As a result, the random-incidence, frequency response of each microphone was determined from its annual calibration certificate and used to adjust the acoustic data prior to data analysis (see Table 48 and Figure 165). It should be noted that systems 1-4 and 8 used GRAS Model 40AQ microphones, while the other systems used GRAS Model 40AE microphones (see Table 7 in Section 4.1).

* Note: All acoustic instrumentation, including microphones, preamplifiers, sound level meters, and sound-level calibrators are calibrated annually by their manufacturer or other certified laboratory to verify accuracy. All calibrations are traceable to the National Institute of Standards and Technology (NIST).

Table 48. Microphone frequency responses by System number.

Frequency (Hz)	1	2	3	4	5	6	7	8	9	10	11
12.5	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
20	-0.06	0	0.14	-0.03	-0.03	0.06	0	0.05	-0.03	0.03	-0.03
25	0.05	0	0.05	-0.1	0.06	0.1	-0.01	0.11	0.02	0.02	-0.05
31	-0.04	0	0.05	0.01	0.02	-0.01	0	0.01	0.01	-0.01	-0.01
40	-0.03	0	0.01	0	-0.01	-0.01	0.01	0.02	0.04	-0.01	0.02
50	-0.04	0	-0.03	0	0.03	0.01	0	0.01	0.02	0.01	-0.01
63	-0.06	0	0.04	0.04	0	0.01	0	0	0.03	0.02	0.04
80	-0.04	0	0	0.02	0.01	0.03	-0.02	0.01	0.01	0	0.01
100	-0.03	0	0.02	0	0.03	0.01	0.01	0	0	-0.01	0
125	-0.04	0	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.03
160	-0.04	0	0	0.02	-0.04	0.01	0.01	0	0	0	0
200	-0.04	0	-0.01	0.01	0.04	0.03	0	0.01	0.01	-0.01	-0.01
250	0	0	0	0	0	0	0	0	0	0	0
315	-0.04	0	0.01	0	0.02	0.01	-0.01	0.02	-0.01	0	-0.01
400	-0.04	0	0	0.02	0	0.01	0	0.01	-0.02	-0.02	-0.01
500	-0.04	0	0	0.03	-0.02	-0.01	-0.01	0	-0.02	-0.03	0.05
630	-0.05	-0.032	0	0.01	-0.04	-0.02	-0.01	0.01	-0.03	-0.04	-0.05
800	-0.05	-0.003	0.01	0.01	-0.05	-0.04	-0.04	0.01	-0.06	-0.06	-0.06
1000	-0.04	-0.009	0.01	0.01	-0.04	-0.03	0	0.02	-0.06	-0.09	-0.06
1250	-0.05	-0.006	0.01	0.01	-0.06	-0.05	-0.03	0	-0.08	-0.17	-0.09
1600	-0.06	0.001	0	0.02	-0.18	-0.09	-0.07	0.03	-0.15	-0.22	-0.13
2000	-0.07	0.037	0.03	0.03	-0.29	-0.18	-0.14	0	-0.26	-0.36	-0.25
2500	-0.09	0.067	0.04	0.04	-0.47	-0.33	-0.27	0.02	-0.43	-0.52	-0.41
3150	-0.6	0.123	0.14	0.11	-0.71	-0.49	-0.42	0.05	-0.65	-0.88	-0.63
4000	-0.1	0.068	0.18	0.12	-1.09	-0.86	-0.74	0.06	-1.05	-1.34	-1.04
5000	-0.14	0.006	0.25	0.15	-1.5	-1.31	-1.13	0.15	-1.55	-1.88	-1.61
6300	-0.12	0.217	0.48	0.25	-1.91	-1.8	-1.6	0.28	-2.09	-2.38	-2.14
8000	0.17	0.504	0.83	0.66	-2.11	-2.19	-2.05	0.77	-2.4	-2.62	-2.74
10000	-0.15	0.744	1.06	0.22	-2.15	-2.57	-2.67	0.62	-2.96	-2.97	-3.47
12500	-1.57	0.858	-0.3	-1.59	-2.86	-3.33	-3.73	-0.62	-3.82	-3.32	-4.73
16000	-2.83	-0.366	-1.71	-3.18	-4.12	-3.87	-4.77	-2.03	-4.6	-4.02	-6.15
20000	-6.31	-3.45	-5.34	-6.27	-8.13	-5.63	-8.21	-6.19	-7.75	-8.06	-9.61

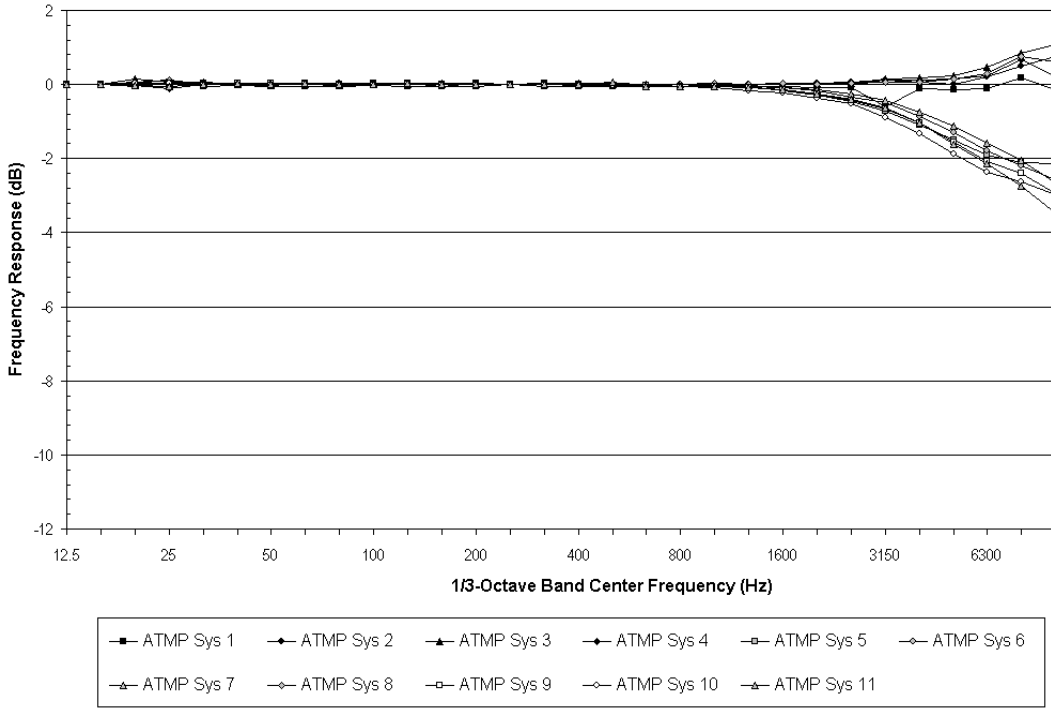


Figure 165. Microphone frequency responses (see Table 7 in Section 4.1).

C.2 Windscreen Frequency Response Adjustments

As discussed in Section 3.1.1, a 12-in (30-cm) diameter foam windscreen (400 pores/sq. in. porosity), custom designed by Musashi Kasei Co., Ltd. for outdoor sound monitoring applications was placed atop each microphone to reduce the effects of wind-generated noise at the microphone diaphragm. The windscreens used in this study were manufactured in two batches – the first batch was used on the NoiseLogger™ systems 1 to 4, and the second batch was used with systems 5 to 11. The attenuation of both sets of windscreens was measured utilizing a diffuse sound source and is shown as a function of frequency in Table 49 and Figure 166. A discussion of how the attenuation data were measured can be found in Reference 37.

Table 49. Windscreen frequency responses by System number.

Frequency (Hz)	1	2	3	4	5	6	7	8	9	10	11
12.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
125	0.07	0.07	0.07	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09
160	0.16	0.16	0.16	0.16	0.03	0.03	0.03	0.03	0.03	0.03	0.03
200	0.17	0.17	0.17	0.17	0.11	0.11	0.11	0.11	0.11	0.11	0.11
250	0.09	0.09	0.09	0.09	0.13	0.13	0.13	0.13	0.13	0.13	0.13
315	0.24	0.24	0.24	0.24	0.21	0.21	0.21	0.21	0.21	0.21	0.21
400	0.44	0.44	0.44	0.44	0.28	0.28	0.28	0.28	0.28	0.28	0.28
500	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
630	0.57	0.57	0.57	0.57	0.24	0.24	0.24	0.24	0.24	0.24	0.24
800	0.40	0.40	0.40	0.40	0.21	0.21	0.21	0.21	0.21	0.21	0.21
1000	0.16	0.16	0.16	0.16	-0.41	-0.41	-0.41	-0.41	-0.41	-0.41	-0.41
1250	-0.46	-0.46	-0.46	-0.46	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02
1600	-0.85	-0.85	-0.85	-0.85	-1.35	-1.35	-1.35	-1.35	-1.35	-1.35	-1.35
2000	-1.09	-1.09	-1.09	-1.09	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40	-1.40
2500	-1.13	-1.13	-1.13	-1.13	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01	-2.01
3150	-1.26	-1.26	-1.26	-1.26	-2.28	-2.28	-2.28	-2.28	-2.28	-2.28	-2.28
4000	-1.66	-1.66	-1.66	-1.66	-2.66	-2.66	-2.66	-2.66	-2.66	-2.66	-2.66
5000	-2.14	-2.14	-2.14	-2.14	-2.93	-2.93	-2.93	-2.93	-2.93	-2.93	-2.93
6300	-2.51	-2.51	-2.51	-2.51	-3.57	-3.57	-3.57	-3.57	-3.57	-3.57	-3.57
8000	-3.05	-3.05	-3.05	-3.05	-4.13	-4.13	-4.13	-4.13	-4.13	-4.13	-4.13
10000	-3.74	-3.74	-3.74	-3.74	-5.04	-5.04	-5.04	-5.04	-5.04	-5.04	-5.04
12500	-4.16	-4.16	-4.16	-4.16	-5.76	-5.76	-5.76	-5.76	-5.76	-5.76	-5.76
16000	-4.64	-4.64	-4.64	-4.64	-6.53	-6.53	-6.53	-6.53	-6.53	-6.53	-6.53
20000	-6.15	-6.15	-6.15	-6.15	-7.18	-7.18	-7.18	-7.18	-7.18	-7.18	-7.18

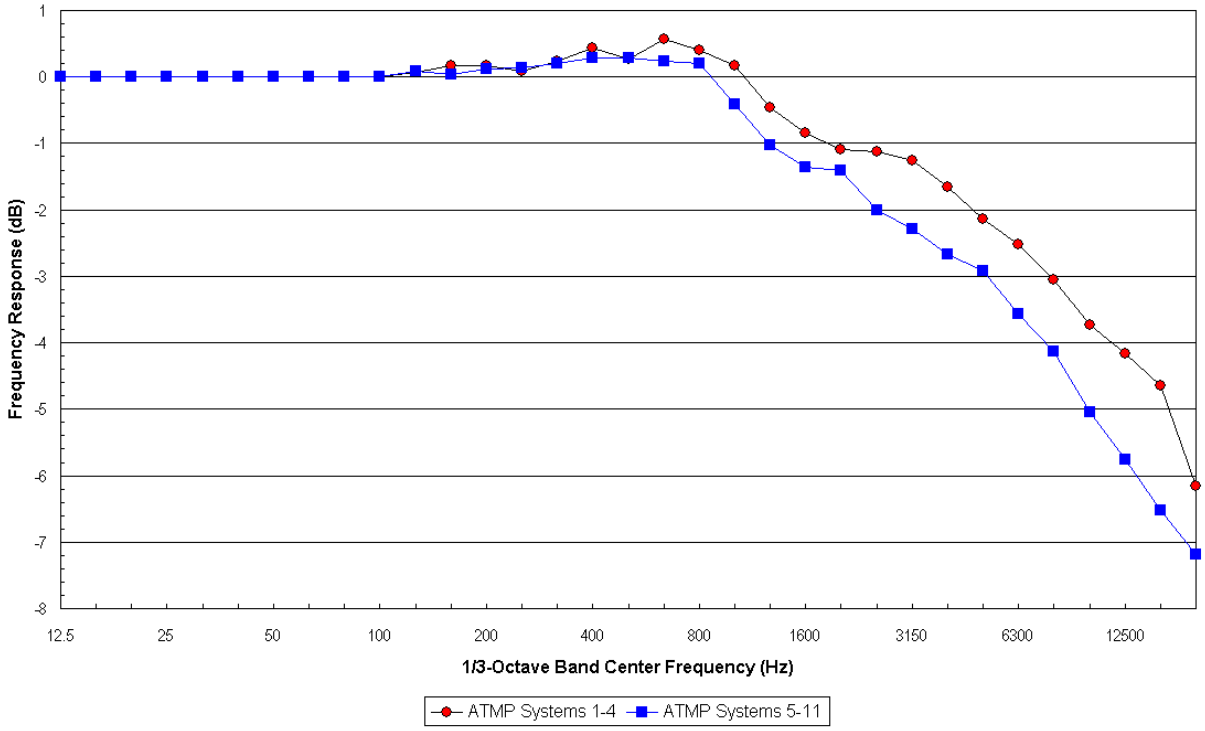


Figure 166. Windscreen frequency responses.

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APPENDIX D. INSTRUMENTATION NOISE FLOOR ADJUSTMENTS

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 this study were performed with two primary types of systems: the robust, long-term, NoiseLogger™ system; and the ultra-sensitive, short-term, VoLARE system (see Section 3 for detailed system descriptions). 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. A methodology was developed (see Section D.2), to adjust the NoiseLogger™ data for contamination effects of the system noise floor. Because of the VoLARE system's ability to measure sound levels below that of the NoiseLogger™ systems, data measured simultaneously using the VoLARE system were used to check for reasonableness the data adjusted using the developed methodology. Application of these adjustments provide for more accurate estimation of the true ambient sound levels without being limited by the equipment's electrical noise floor. This appendix presents the methodology used to determine the noise floor of each of eleven NoiseLogger™ systems, as well as the final noise-floor adjustments used during data reduction.

D.1 Data Summary

Over one thousand days of acoustical and meteorological data collected at thirty-one sites during three baseline ambient studies were considered for this analysis (see Table 50): Hawai`i Volcanoes; Haleakala; and Badlands National Park (Badlands). During these studies, over twenty-two hours of data were collected simultaneously using both the NoiseLogger™ and VoLARE systems with a field observer present (see Table 51). A breakdown of which systems were used at which site is provided in Table 52.

Table 50. Summary of analysis parks and sites.

Park	# Sites	# Days
Hawai`i Volcanoes National Park	22	917
Haleakala National Park	9	171
Badlands National Park	3	36

Table 51. Summary of simultaneous VoLARE data.

Park	Site	Date
Hawai`i Volcanoes National Park	6A	10/29/2002
Hawai`i Volcanoes National Park	8A	10/29/2002
Hawai`i Volcanoes National Park	9A	10/28/2002
Hawai`i Volcanoes National Park	9A	10/31/2002
Haleakala National Park	P1	02/27/2003
Haleakala National Park	P1	02/28/2003
Haleakala National Park	P2	03/07/2003
Haleakala National Park	P3	03/04/2003
Haleakala National Park	ST4	02/28/2003
Haleakala National Park	ST7	03/07/2003
Haleakala National Park	ST9	03/03/2003
Badlands National Park	B01	09/24/2003
Badlands National Park	B02	09/23/2003
Badlands National Park	B03	09/22/2003

Table 52. Summary of systems used at each site.

System #	System Type	Hawai`i Volcanoes Sites	Haleakala Sites	Badlands Sites
1	NoiseLogger™	4A, 8C, 9C		
2	NoiseLogger™	2B, 3B, 3C, 5B, 6C, 8B, 9A (from 5/16-5/24)		
3	NoiseLogger™ Plus	5A, 8A (from 4/25-5/5), 9B	P3	
4	NoiseLogger™ Plus	3A		
5	NoiseLogger™	1B	ST6, ST7	
6	NoiseLogger™	9A (from 10/25-1/28)	P1	
7	NoiseLogger™	1A, 2C		
8*	NoiseLogger™	3D, 5C, 6B	ST4, ST5	B02
9	NoiseLogger™	2A		B01
10	NoiseLogger™	6A	ST8, ST9	B03
11	NoiseLogger™	8A (from 10/24-2/17)	P2	

* Note: Systems 7 and 8 were identical except for the microphone, which was replaced due to a small amount of corrosion that developed from extended exposure to the sulphuric atmosphere present at the Hawai`i Volcanoes shoreline Site 1A. No similar corrosion was visible on the microphone used at the other Hawai`i Volcanoes shoreline site, Site 1B.

D.2 Methodology

The methodology for noise floor adjustments described herein combines several elements of the methodology presented by HMMH in Reference 37, as well as other additional criteria developed by the Volpe Center. The noise floor of each NoiseLogger™ system was examined by first plotting the sound level distributions of all the measured data samples for each one-third octave frequency band (bands 11 through 43 or 12.5 Hz through 20 kHz, respectively). Figure 167 below shows an example of the distribution of data for bands 11 through 43 measured at Site 6A in Hawai`i Volcanoes using NoiseLogger™ System #10. It should be noted that only data samples collected during low wind conditions (i.e., wind speeds between 0 m/s and 0.5 m/s) were utilized to eliminate any potential influences due to wind (see Section D.4.1).

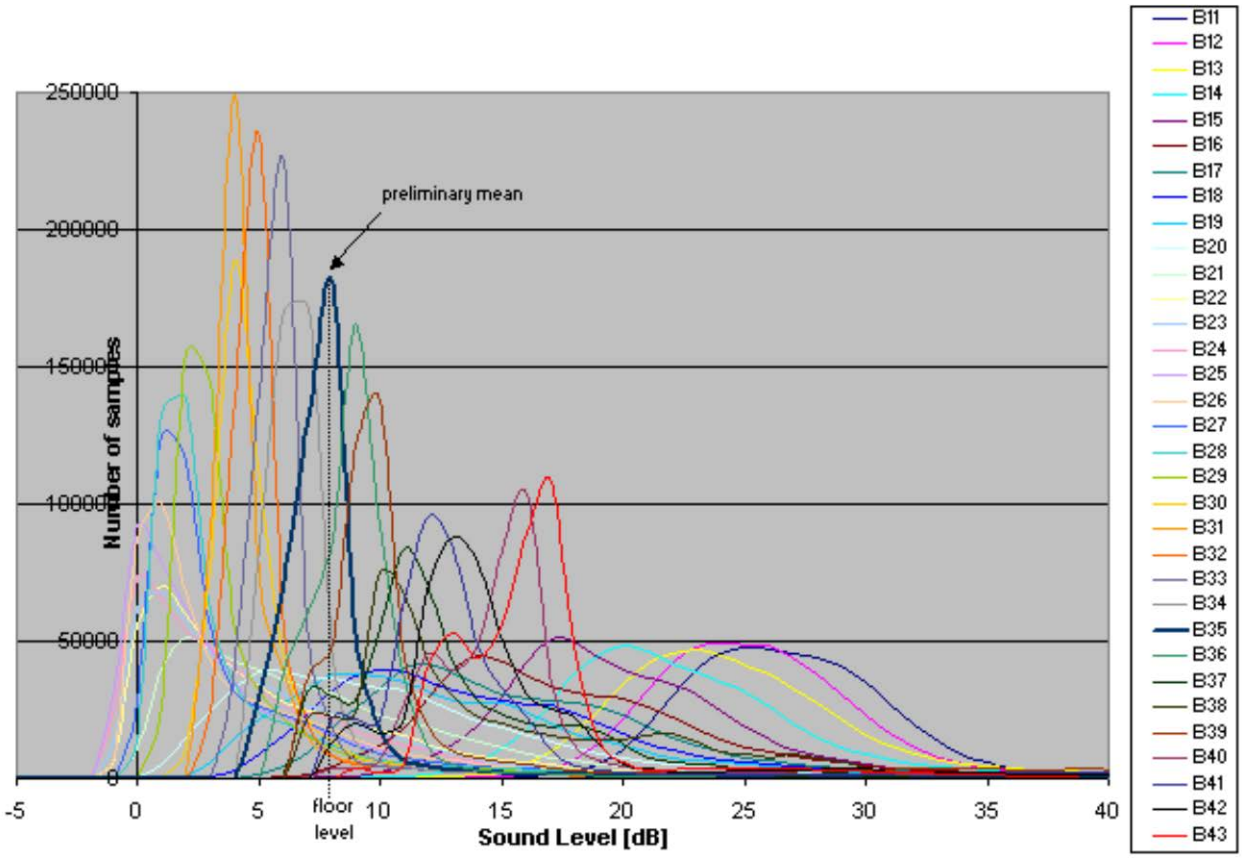


Figure 167. Example distribution of samples vs. sound level for each ⅓-octave frequency band

From the distribution, two criteria are used to determine the first significant peak in the data, known as the "preliminary mean" (shown in Figure 167): (1) the peak must include at least 5% of the total number of data samples; and (2) the mean is taken at the local maximum of the distribution, D. The "true mean" of the data is then found based on the assumption that data near the noise floor behave randomly. A Gaussian distribution is assumed resulting in a slight upward shift in the sound level associated with the preliminary mean.

The process is described in detail below:

- Preserve the data on the left side of the preliminary mean. "Flip" the left side of the Gaussian curve relative to the preliminary mean to build a symmetrical Gaussian distribution, $\boldsymbol{D_s}$, relative to the preliminary mean. The preliminary mean, $\boldsymbol{\mu}$, is therefore the mean of the constructed distribution. The number of samples associated with the preliminary mean is denoted as $\boldsymbol{n_P}$.
- Calculate the standard deviation, $\boldsymbol{\sigma}$, of the symmetrical distribution, $\boldsymbol{D_s}$.
- Pick points within the distribution ($\boldsymbol{L_i}$, $\boldsymbol{n_i}$) that are between ***1.5*** and ***4 σ's*** from the value of the preliminary mean. The range of ***1.5*** to ***4 σ's*** was selected because it is far enough from the preliminary mean, but not too far into the lower sound levels, such that the number of observations remains meaningful and substantial.
- Build a Gaussian curve by equating the equation of the exponential function to the number of samples:

$$n_i = n_P \times e^{\{-0.5\times[(L_i-\mu_G)/\sigma_G]^2\}} \qquad \text{(Eq. 1)}$$

Where: $\boldsymbol{\mu_G}$ is the true mean of the Gaussian distribution; and

$\boldsymbol{\sigma_G}$ is the true standard deviation of an ideal Gaussian.

One way to find the true mean, $\boldsymbol{\mu_G}$, is to work with the statistical ***Z***-score, which is defined by the expression:

$$Z = (L - \mu_G)/\sigma_G \qquad \text{(Eq. 2)}$$

Therefore, substituting Equation 2 into Equation 1, the equation can be rewritten as:

$$n_i = n_P \times e^{[-0.5\times(Z)^2]} \quad \text{(Eq. 3)}$$

It also follows that the Z-score can be expressed as:

$$Z = -\sqrt{-2\times\ln(n_i / n_p)} \quad \text{(Eq. 4)}$$

- Calculate the Z-score, $\boldsymbol{Z_i}$, of each point, $\boldsymbol{n_i}$, selected between ***1.5*** to ***4 σ's*** from the preliminary mean, $\boldsymbol{\mu}$.
- Plot the Z-score of the points versus their associated sound level. Build a linear regression using the points ($\boldsymbol{L_i}$, $\boldsymbol{Z_i}$).
- Using Equation 2 from above, the point where $\boldsymbol{Z = 0}$, i.e., where $\boldsymbol{L = \mu_G}$ is found.

The result of this process is the true mean, $\boldsymbol{\mu_G}$, found by correcting the preliminary mean, $\boldsymbol{\mu}$, for each one-third octave-frequency band with a Gaussian curve-fit.

D.3 Resultant Noise Floors

Table 53 and Figure 168 show the resultant noise floor levels (for one-third octave-frequency bands 30 through 43) obtained using the above methodology. As shown in the figure, Systems 1 through 9 have noise floors that are relatively similar. Because of the relatively small amounts of data collected using Systems 10 and 11 as compared with the other systems, it is recommended that their noise floors be later re-analyzed when additional data are collected with these systems.

To ensure confidence in the resultant noise floors, several additional analyses were performed prior to the implementation of noise floor adjustments into the NLcrunch data processing software:

- An examination of the effect of environmental parameters on noise floor levels was performed (see Section D.4); and
- A comparison with data measured simultaneously using the VoLARE system was performed (see Section D.5).

Table 53. Derived noise floors for 11 NoiseLogger™ systems.

Frequency (Hz)	Frequency Band	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11
12.5	**11**	19.7	21.2	19.4	20.7	23.2	17.4	20.7	19.7	26.7	17.2	23.2
16	**12**	17.9	20.7	18.7	18.7	22.7	15.3	19.7	18.7	25.2	16.9	22.2
20	**13**	16.4	19.4	18.2	16.2	21.7	13.1	18.9	17.4	23.7	15.8	21.2
25	**14**	15.1	17.4	16.4	14.1	19.7	11.3	18.2	15.3	21.2	14.8	19.2
31	**15**	14.1	16.2	14.6	12.6	17.9	9.1	16.9	13.6	18.7	14.1	23.7
40	**16**	11.1	14.3	12.6	10.3	17.2	7.4	16.2	11.1	16.4	12.3	14.1
50	**17**	8.8	12.8	12.6	8.3	16.2	6.4	14.3	9.6	14.3	11.1	19.7
63	**18**	6.4	11.8	10.8	6.8	15.1	5.3	12.1	8.0	12.8	10.1	22.9
80	**19**	4.0	9.8	10.6	5.3	13.5	4.0	9.1	6.4	11.6	9.1	11.1
100	**20**	1.5	7.4	8.8	3.2	11.6	2.6	6.3	3.7	9.6	8.0	8.8
125	**21**	0.8	4.5	7.1	1.0	8.8	1.0	2.4	0.6	8.0	6.4	6.9
160	**22**	0.5	2.4	5.0	-0.4	6.0	-0.4	-0.2	-0.9	5.5	5.0	2.1
200	**23**	0.2	1.8	4.1	-1.9	3.7	-1.2	-0.9	-1.5	4.6	5.0	2.9
250	**24**	0.2	1.3	4.0	-2.5	2.7	-1.5	-0.9	-2.3	4.0	4.3	3.2
315	**25**	-0.4	1.5	3.4	-2.5	2.2	-1.5	-0.9	-2.8	3.7	3.2	6.8
400	**26**	-0.4	1.8	2.6	-2.5	2.4	-1.2	-0.4	-2.5	4.1	3.7	3.7
500	**27**	-0.2	1.8	2.2	-2.3	2.4	-0.7	-0.5	-2.1	4.0	3.2	4.3
630	**28**	0.2	1.8	1.8	-1.7	2.2	-0.3	-0.2	-1.5	3.4	3.2	4.5
800	**29**	0.5	1.8	1.8	-1.1	2.4	0.4	0.3	-0.8	3.2	3.7	3.7
1000	**30**	1.1	1.8	1.7	-0.2	2.9	1.3	0.9	0.1	3.4	5.3	3.4
1250	**31**	1.8	2.1	1.7	0.7	3.1	2.0	1.5	0.8	4.0	5.0	3.7
1600	**32**	2.2	2.1	2.1	1.5	3.2	2.6	2.0	1.3	4.1	5.5	4.5
2000	**33**	3.1	2.9	2.9	2.2	3.7	3.7	2.7	1.9	4.5	6.4	6.0
2500	**34**	4.8	3.7	4.0	2.9	4.1	4.5	2.9	2.7	5.0	7.1	8.5
3150	**35**	6.8	4.3	5.0	3.4	4.6	5.5	3.2	3.4	5.5	8.3	18.4
4000	**36**	5.8	5.0	6.0	4.5	5.1	5.5	4.3	4.5	6.1	9.6	8.6
5000	**37**	6.1	6.0	6.1	5.5	5.6	5.8	5.0	5.3	7.4	10.1	7.4
6300	**38**	6.4	6.4	6.6	6.0	5.5	6.0	5.1	5.8	7.4	10.6	7.4
8000	**39**	6.8	7.4	7.4	6.8	6.0	6.1	5.3	6.1	7.4	9.6	6.9
10000	**40**	6.9	8.1	7.6	6.9	6.4	6.4	5.5	6.6	8.0	15.3	10.1
12500	**41**	6.0	8.0	6.6	6.0	5.6	5.5	5.1	6.4	6.9	11.8	6.4
16000	**42**	5.6	8.3	6.1	5.5	5.5	5.5	4.1	5.5	6.9	12.6	6.4
20000	**43**	5.3	7.4	5.5	4.6	5.3	4.8	2.9	5.0	7.4	16.2	9.6

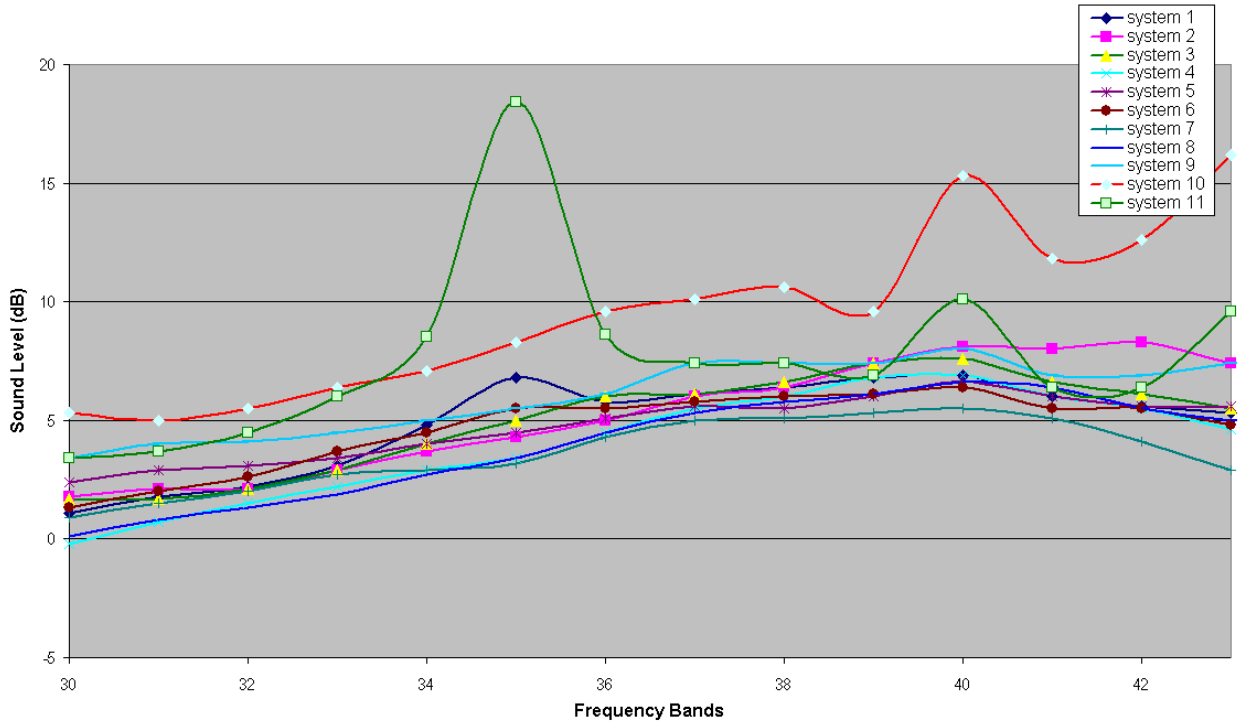


Figure 168. Derived noise floors for 11 NoiseLogger™ systems.

D.4 Effect of Environmental Parameters on Noise Floor Levels

In the dynamic environment of the outdoors, it is logical to assume that certain environmental parameters may have an effect on the noise floor levels – for example, wind and system temperature were considered as possible factors that could affect the noise floors. The results of the examination of the effects of these and other parameters are reported below.*

D.4.1 Effect of Wind

This examination showed that the noise floors appeared to increase with increasing wind speed, particularly for frequencies greater than 1 kHz. Hence, a low-end wind speed filter of 0.5 m/s was used to establish the noise floors. It should be noted that additional analyses examining the effects of wind on higher sound levels (i.e., not approaching the noise floor) were also performed. This is a completely separate discussion outlined in Appendix E.

* It is possible that additional parameters, such as atmospheric pressure and precipitation, may be examined in future analyses; however, currently, these data were not available.

D.4.2 Effect of System Temperature

Although ambient temperature data were not directly measured, the system temperature of the LD824 sound level meter was used as a relative gauge of external temperature, as the instrument was stored within a protective case and kept outdoors for extended periods of time. Examination showed that system temperature appeared to have some effect on system noise floor at the lower frequencies (less than 1 kHz), but the effect tended to correlate with wind speed. So, it may not have been a temperature effect, but rather a wind effect as discussed in Section D.4.2. Figure 169 shows that temperature was not found to have a definitive effect on system noise floor. Note: As a point of reference, an estimate of the human "auditory system noise" derived from an international standard threshold of hearing is also shown in Figure 169 (ISO 389-7:1996).[38,39] Portions of the sound pressure level spectra shown below this auditory system curve are not audible to the human ear.

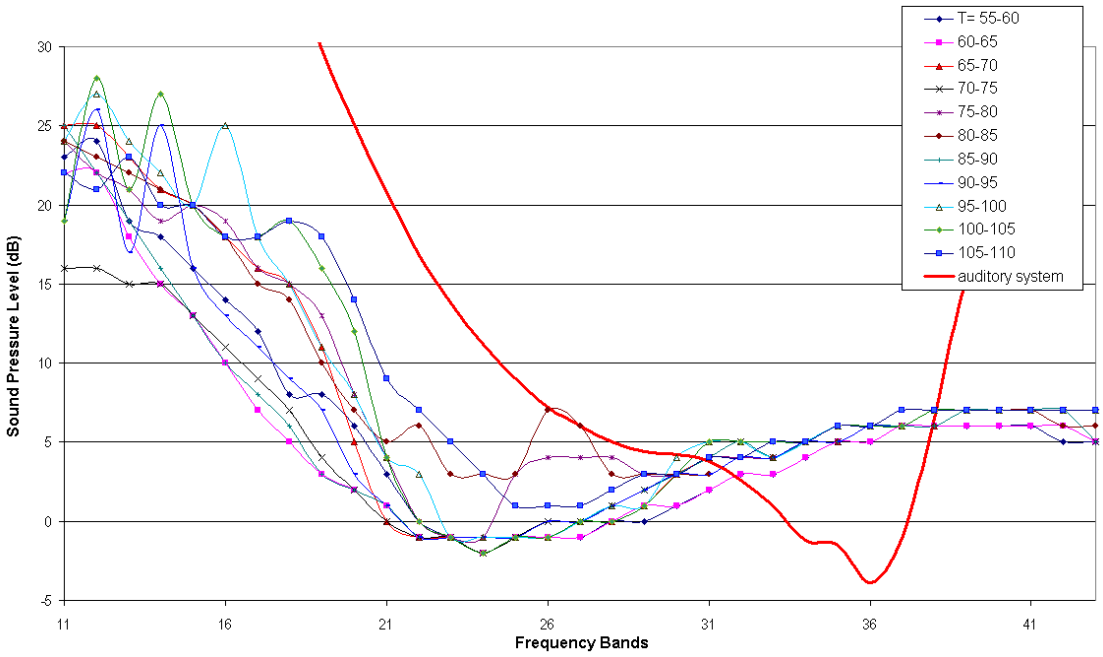


Figure 169. Effect of system temperature on noise floor sound levels, from Hawai`i Volcanoes data measured at Site 1A.

D.4.3 Effect of Calibration

Calibration occurred on a regular basis (i.e., at the start and end of every measurement sample). An examination was performed to determine if calibration drift between start

and end of a measurement period would result in a similar shift in magnitude in the noise floor levels. Because calibration levels did not vary significantly, the resultant calibration drifts were also insignificant. There was no observed effect in the system noise floor data.

D.4.4 Effect of Time-of-Day

Because it was anticipated that the lowest ambient sound levels would typically occur during late night, an examination was performed to compare the noise floors determined from data collected during these late-night hours (between 1 am and 6 am) with the noise floors determined from data collected during the entire day. It was observed that although average sound levels were lower during the night, similar low-level samples were also measured at other times of the day. As a result, time-of-day was not found to have an effect on system noise floor data.

D.5 Applying Noise Floor Adjustments

The algorithm used in applying noise floor adjustments is based on HMMH's work as presented at the Inter-Noise Conference in August 2002.[40] The method applies the noise floor adjustments as an energy subtraction from the sound levels in each frequency band, whenever the measured-band sound level is within 1 dB of the noise floor of the system. At the ⅓-octave frequency band where the subtraction criterion is no longer met, the remainder of the spectrum (out to ⅓-octave frequency band 43, or 20 kHz) is extrapolated downward using a constant slope. The overall A-weighted sound level is then computed using the reconstructed spectrum

The sensitivity of the sloping algorithm was tested by: (1) evaluating the use of different difference criteria (from 1 to 3 dB); and (2) evaluating the use of different slopes (also between 1 dB and 3 dB) on low-noise data measured in Badlands (Volpe's most extensive and lowest sound level dataset thus far).* The results of these evaluations were as follows: (1) the variation of the difference between using 1 and 3 dBA as the difference criterion (D) did not have a significant effect; and (2) the most appropriate constant slope for use in the algorithm was determined to be

* Baseline ambient sound level measurements in support of ATMP or VA development were performed in Badlands National Park during September 2003.

between 2.0 and 3.0 dBA. Figure 170 below illustrates these results. Consequently, the use of a 1-dB subtraction criterion and a 2.5-dB constant slope were utilized.

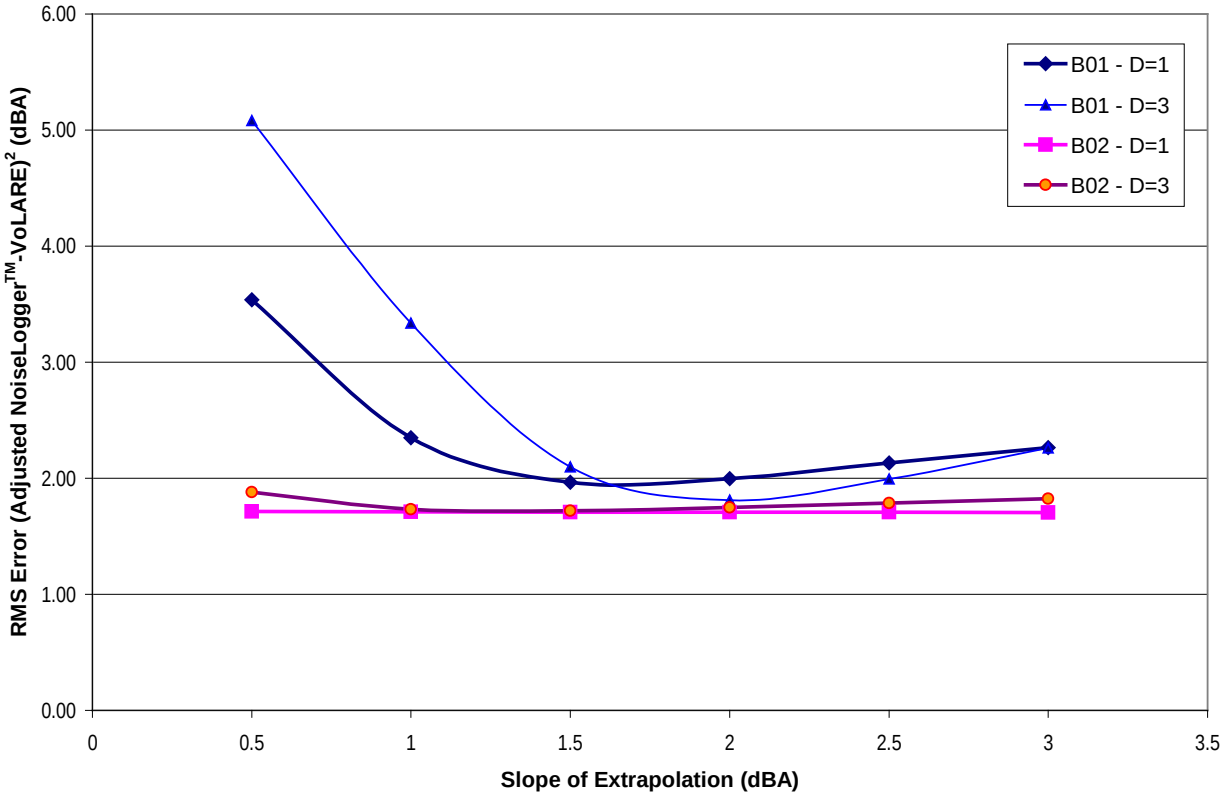


Figure 170. Root-mean-square (RMS) error (Adjusted NoiseLogger-VoLARE) versus slope of extrapolation for several difference criteria (D), from Badlands data measured at sites B01 and B02.

D.6 Comparison With VoLARE Data

As stated earlier, because of the VoLARE system's ability to measure sound levels below that of the NoiseLogger™ system, data measured simultaneously using the VoLARE system were used to validate the noise floor adjustments applied to NoiseLogger™ data, which approached or were below the "noise floor" of the NoiseLogger™ systems. In comparing raw NoiseLogger™ and VoLARE data, it was observed that the NoiseLogger™ low-level data tended to fluctuate around VoLARE levels. As a result, small variations of raw NoiseLogger™ sound levels in the vicinity of the floor level caused large and usually short variations in the adjusted NoiseLogger™ sound levels. To resolve these fluctuations, raw 1-second L_{eq} samples were time-averaged to 30- and 120-second samples for this part of the analysis. Figure 171 through Figure 173 present several

example comparisons for data collected at Badlands and Haleakala using a time-history plot of 120-second L_{eq}'s.* As shown, the adjusted NoiseLogger™ data follows the trend of the raw NoiseLogger™ data. Excellent overall agreement is seen between the adjusted NoiseLogger™ data and the higher quality VoLARE data.

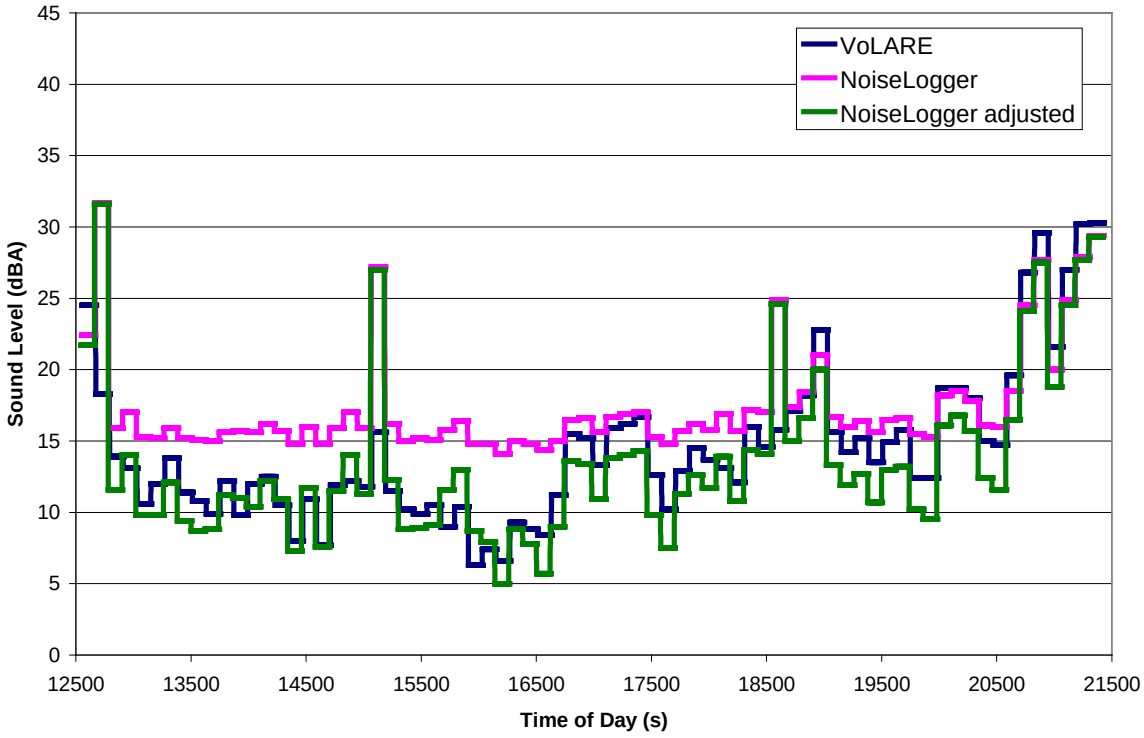


Figure 171. Example comparison of adjusted NoiseLogger™ with raw and VoLARE data for Badlands National Park site B01.

* As mentioned earlier, baseline ambient sound level measurements in support of ATMP or VA development were performed in Badlands National Park during September 2003.

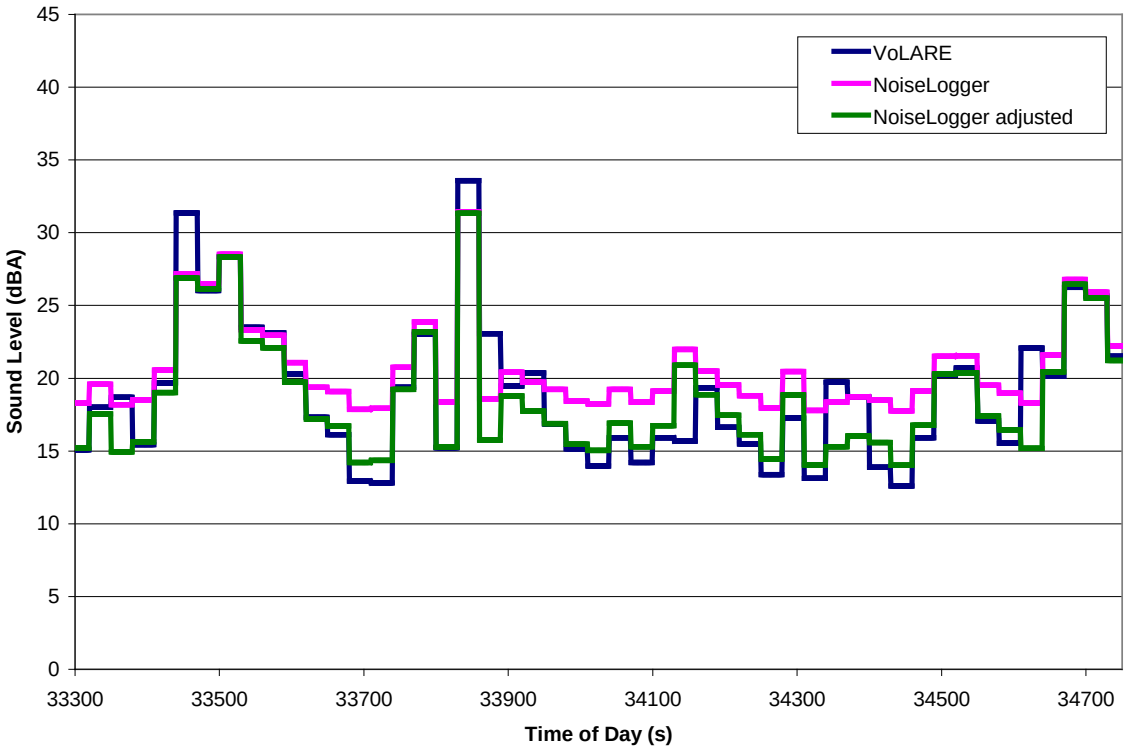


Figure 172. Example comparison of adjusted NoiseLogger™ with raw and VoLARE data for Badlands National Park Site B02.

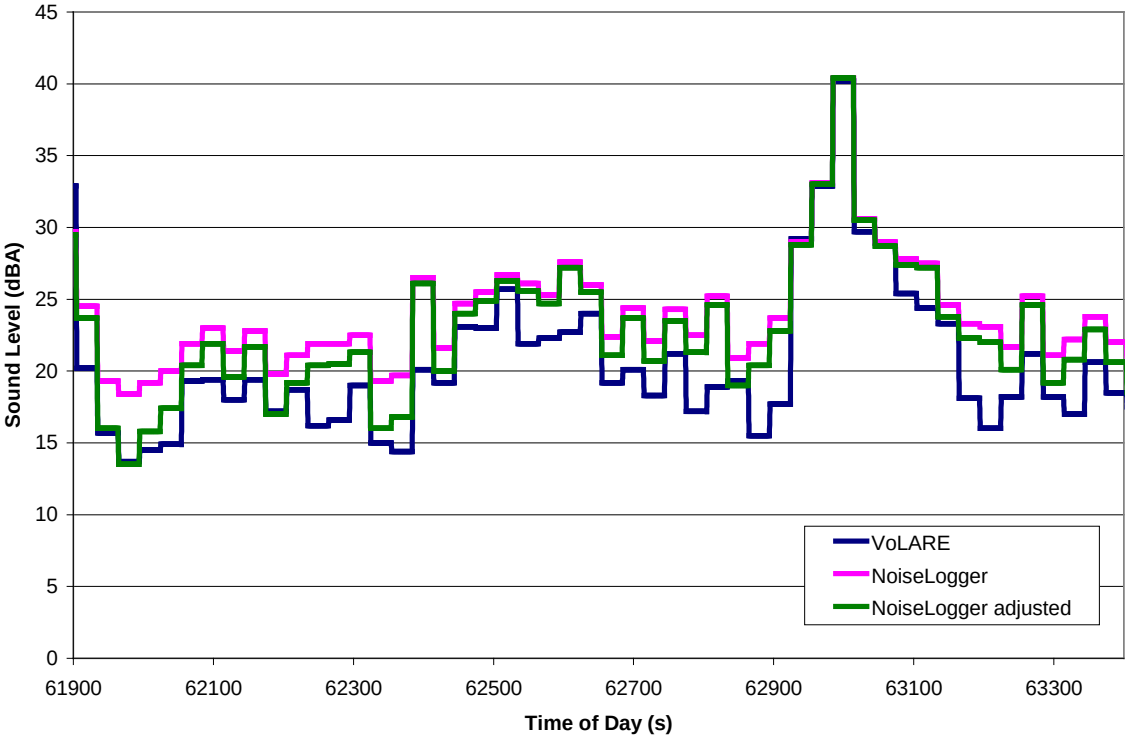


Figure 173. Example comparison of adjusted NoiseLogger™ with raw and VoLARE data for Haleakala Site P1.

It should be noted that comparisons between adjusted NoiseLogger™ and VoLARE data are based on two underlying assumptions: (1) the VoLARE data represents a more accurate measurement; and (2) the methodology used to develop noise floor adjustments is accurate. The first assumption is confirmed with the VoLARE's ultra-sensitive microphone affording it the ability to measure well below the noise floor of the NoiseLogger™ system. The second assumption has shown good results with comparisons performed thus far with Hawai`i Volcanoes, Haleakala, and Badlands data. However, it is recommended that the algorithm be revisited to ensure accuracy and applicability in future parks. Because the methodology tends to determine the lowest noise floor of a system for all of the sites measured with the system, the adjustments are predisposed to under-correct measured sound levels. Currently, these under-corrections have not been shown to be significant.

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APPENDIX E. DETERMINATION OF UPPER WIND LIMIT

For NoiseLogger™ data that approached or were below the "noise floor" of the NoiseLogger™ systems, noise floor adjustments were developed and are discussed in Appendix D. The development of these adjustments is one of the primary purposes for collecting simultaneous data using the VoLARE system. When measured sound levels are well above the NoiseLogger™ system's noise floor, both systems are expected to measure similar sound levels. However, this was not always the case. In some instances, significant differences were observed between data measured with the NoiseLogger™ and VoLARE systems. This prompted additional investigations to try to determine the factors that might have caused these differences. This section presents the results of these investigations.

E.1 Data Summary

Similar to the noise floor analysis discussed in Appendix D, the data collected during three baseline ambient studies were considered for this analysis (see Table 54): Hawai`i Volcanoes; Haleakala; and Badlands. During these studies, over twenty-two hours of data were collected simultaneously, using both the NoiseLogger™ and VoLARE systems with a field observer present (see Table 55).

Table 54. Summary of analysis parks and sites.

Park	# Sites	# Days
Hawai`i Volcanoes National Park	22	917
Haleakala National Park	9	171
Badlands National Park	3	36

Table 55. Summary of simultaneous VoLARE data.

Park	Site	Date
Hawai`i Volcanoes National Park	6A	10/29/2002
Hawai`i Volcanoes National Park	8A	10/29/2002
Hawai`i Volcanoes National Park	9A	10/28/2002
Hawai`i Volcanoes National Park	9A	10/31/2002
Haleakala National Park	P1	02/27/2003
Haleakala National Park	P1	02/28/2003
Haleakala National Park	P2	03/07/2003

Park	Site	Date
Haleakala National Park	P3	03/04/2003
Haleakala National Park	ST4	02/28/2003
Haleakala National Park	ST7	03/07/2003
Haleakala National Park	ST9	03/03/2003
Badlands National Park	B01	09/24/2003
Badlands National Park	B02	09/23/2003
Badlands National Park	B03	09/22/2003

E.2 Overall Analysis

In comparing NoiseLogger™ data with VoLARE data, there is a strong correlation between the observed deltas and wind speed. That is, there is a strong tendency for the deltas 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 12-in (30 cm) diameter foam windscreen (400 pores/sq. in. porosity) custom designed by Musashi Kasei Co., Ltd. for outdoor monitoring applications; whereas, the VoLARE system utilizes a tripod-mounted, two-stage windscreen, which consists of a 20-in (51 cm) diameter, fabric-covered, outer stage, and a conventional, B&K Model UA0207 3.5-in (9 cm) diameter, foam windscreen making up the inner stage. The dual-stage windscreen of the VoLARE system was expected to outperform the single-stage windscreen used by the NoiseLogger™ system.

Figure 174 below plots the average deltas between NoiseLogger™ and VoLARE data versus wind speed. 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 differences are relatively independent of wind speed; and
- For wind speeds greater than 5.4 m/s (12 mph), the uncertainty between the two datasets becomes unacceptably large, as the mean value starts to fluctuate and standard deviations increase. At those higher wind speeds, predictions of delta versus wind speed are not possible.

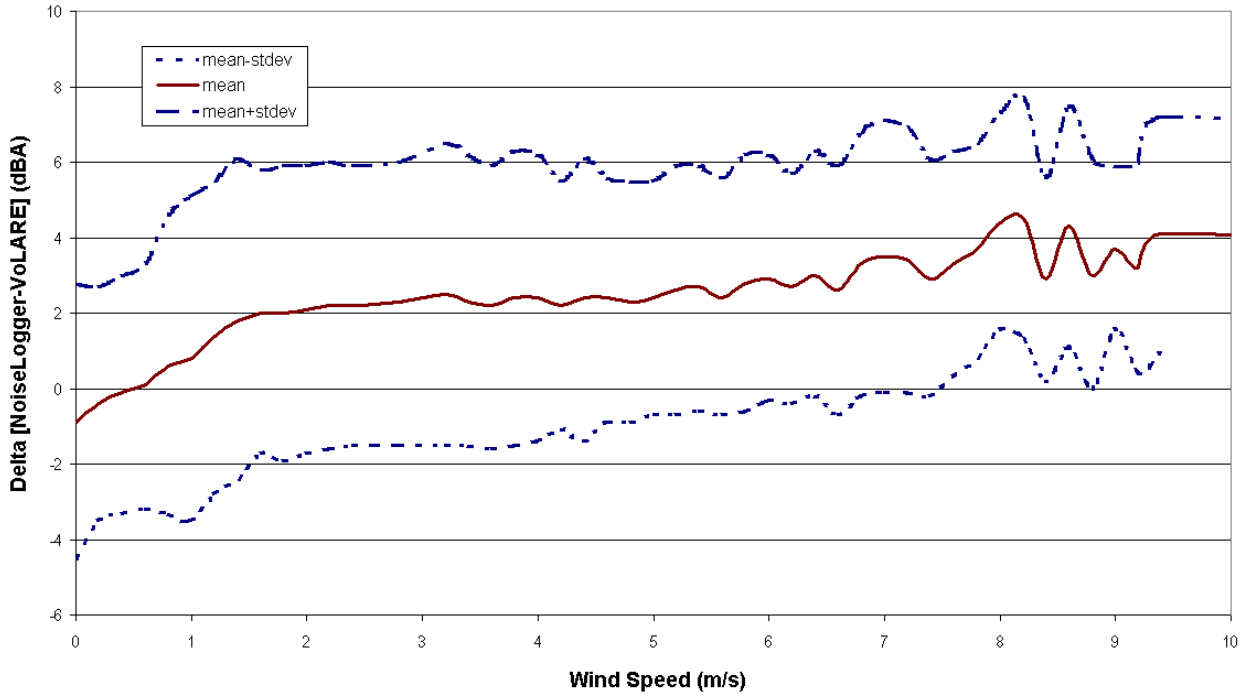


Figure 174. Average deltas between NoiseLogger™ and VoLARE data versus wind speed for 3 parks: Hawai`i Volcanoes, Haleakala and Badlands.

These conclusions indicated that a cutoff filter for wind speeds would be highly beneficial to the analysis and would minimize the deltas seen between NoiseLogger™ and VoLARE data. A wind filter would effectively help offset the lower performance of the NoiseLogger™ windscreen relative to the VoLARE two-stage windscreen. However, in deciding upon a wind filter, an additional factor was considered – amount of resultant data loss. Figure 175 below plots the cumulative distributions of both data sets versus wind speed. Examining Figure 175 in light of the previous conclusions, the following findings were made:

- For wind speeds up to approximately 1.5 m/s (3.4 mph), implementing an upper wind speed limit of 1.5 m/s would result in a significant loss of data – approximately 40 percent; and
- For wind speeds between 1.5 m/s (3.4 mph) and 5 m/s (11.2 mph), implementing an upper wind speed limit of 5 m/s would result in a loss of a much smaller amount of data – approximately 10 percent.

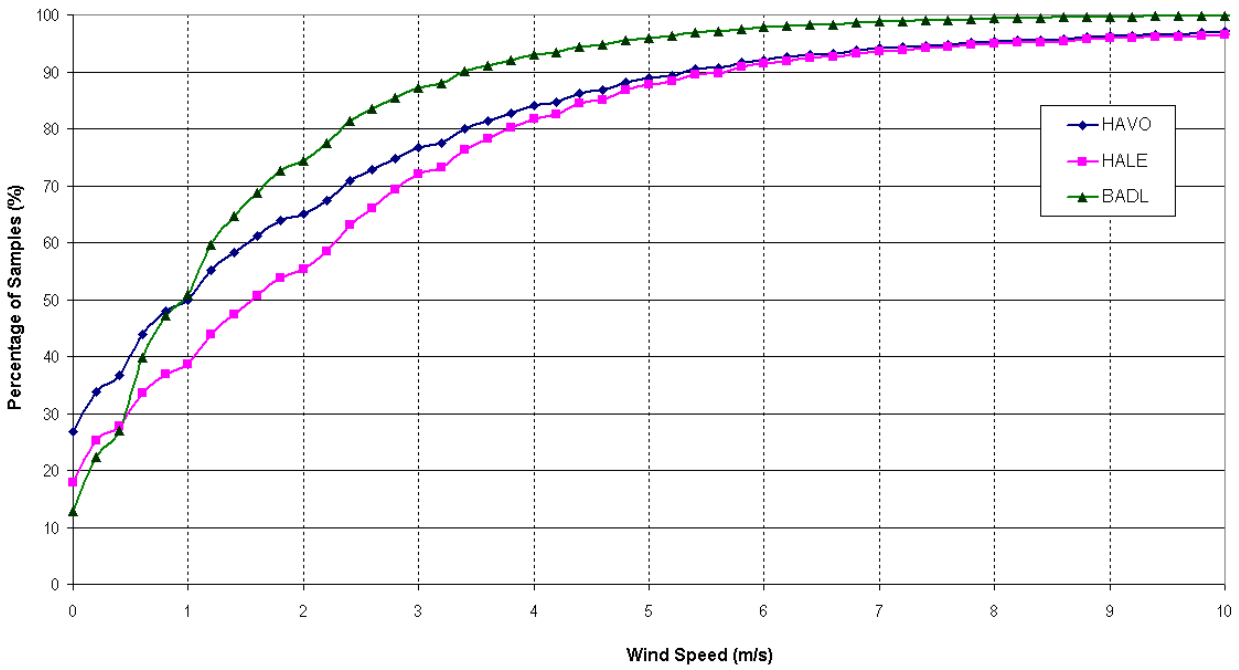


Figure 175. Cumulative distributions of data versus wind speed for 3 parks: Hawai`i Volcanoes, Haleakala and Badlands.

Because the effects of wind on the sound level differences for wind speeds between 1.5 m/s (3.4 mph) and 5 m/s (11.2 mph) are similar, and because implementing an upper wind speed limit of 5 m/s would result in an insignificant amount of data loss – approximately 90 percent of the data would be retained – a 5 m/s (11 mph) wind cutoff filter was initially decided upon.

E.2 Detailed Spectral Analysis

Prior to definitively implementing the 5 m/s wind cutoff filter, a more detailed analysis was performed to determine if the wind criterion could be refined. Another way of examining the effects of wind on NoiseLogger™ versus VoLARE data was to examine the spectrum L_{eq} for both datasets to determine where they begin to diverge. Figure 176 through Figure 185 present the NoiseLogger™ versus VoLARE spectrum L_{eq}'s from 0-10 m/s (0-22 mph) in wind-speed bins of 1-m/s intervals. A clear divergence in the spectra can be seen, starting at about 7 m/s. In general, the deltas in the datasets for the lower ⅓-octave frequency bands (bands 11 through 15, or 12.5 through 31.5 Hz) can be attributed to wind noise on the microphone diaphragm. Deltas at higher frequency bands (bands 37 through 43, or 5 through 20 kHz) can be attributed to differences in the frequency response of each system's respective microphone.

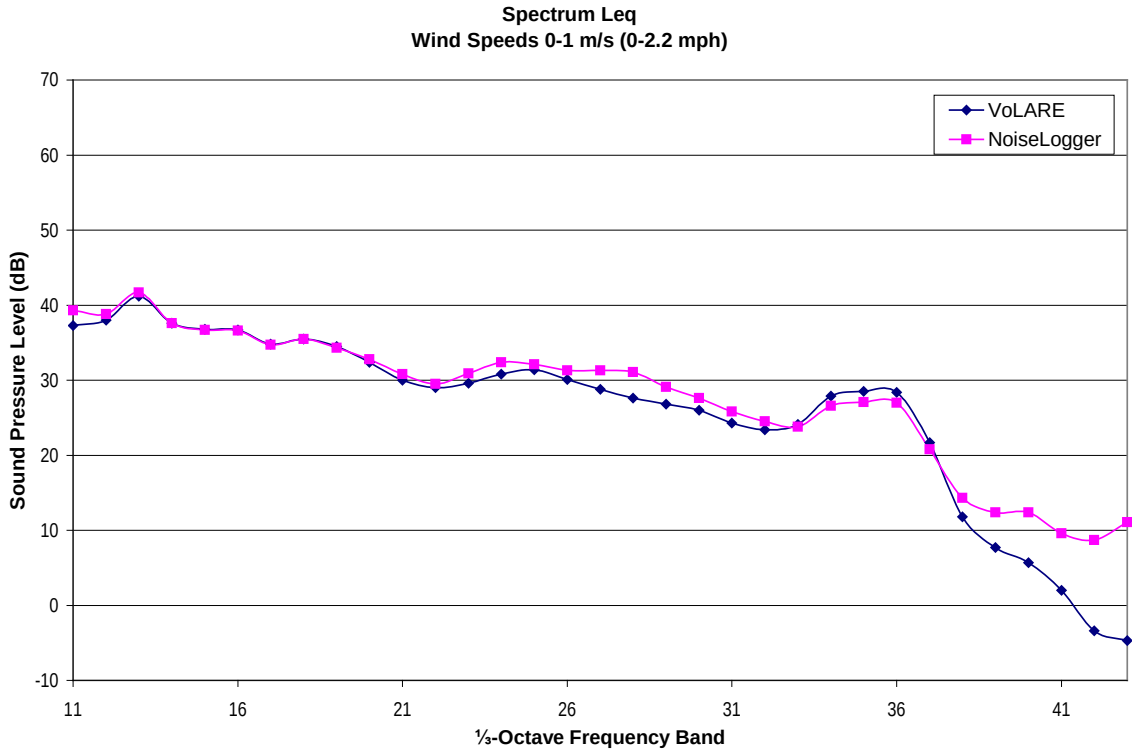


Figure 176. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 0-1 m/s.

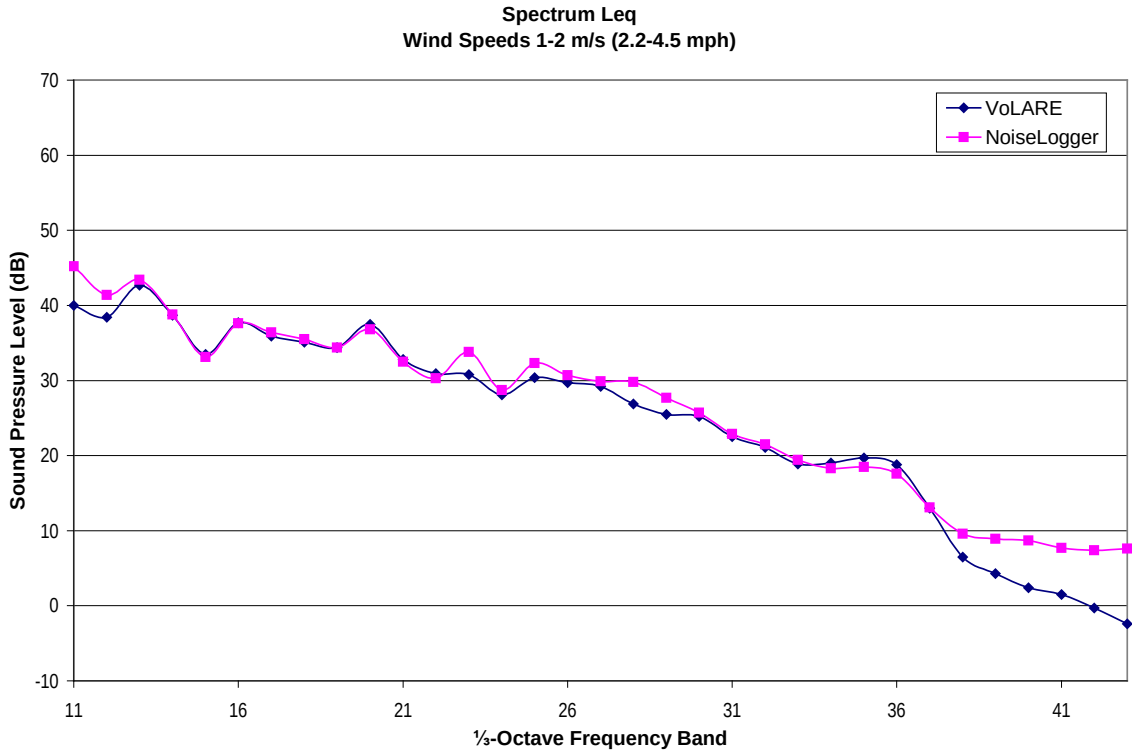


Figure 177. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 1-2 m/s.

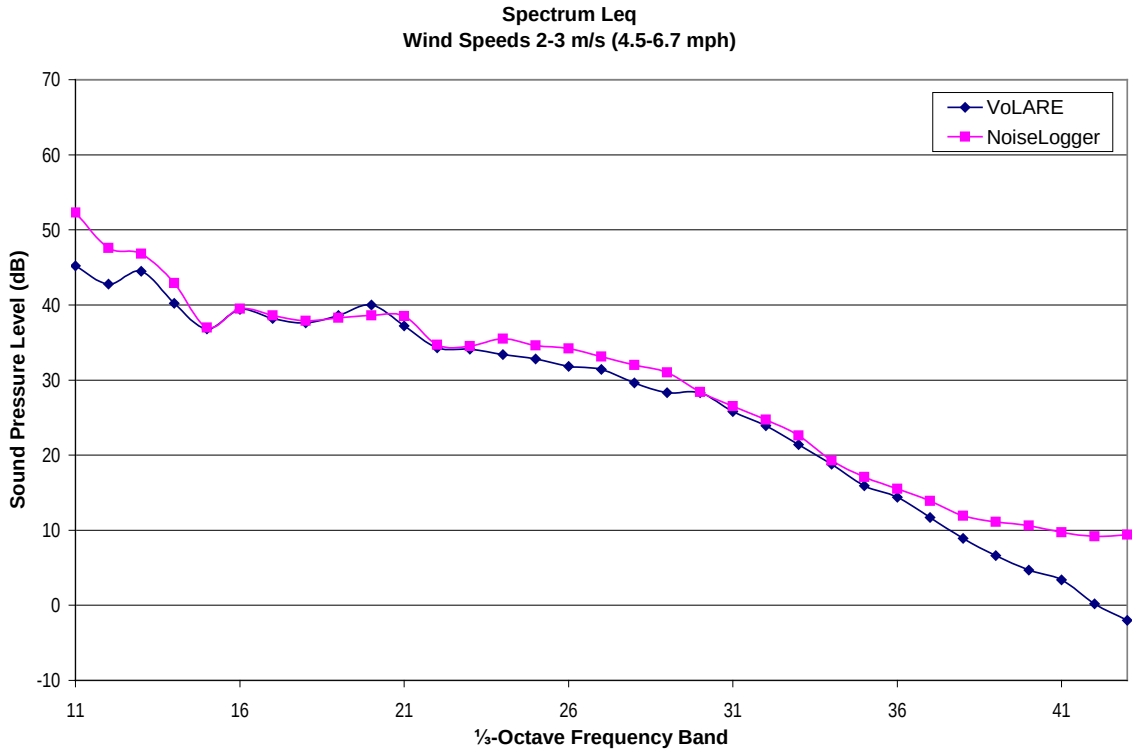


Figure 178. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 2-3 m/s.

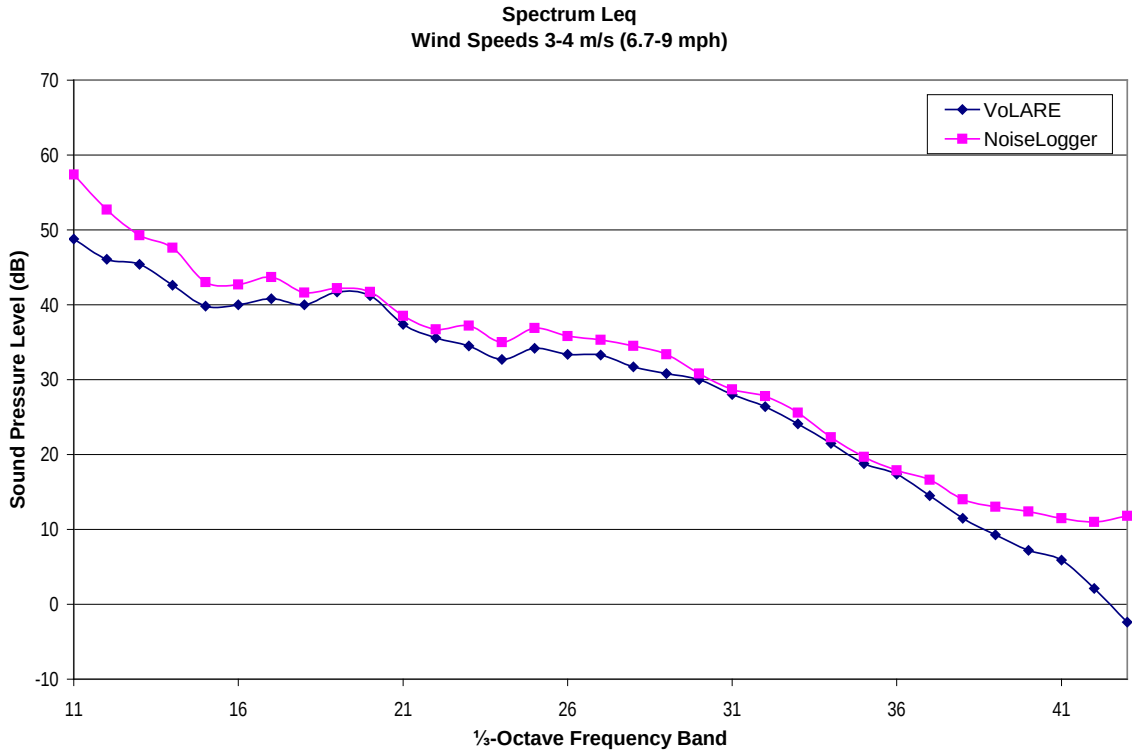


Figure 179. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 3-4 m/s.

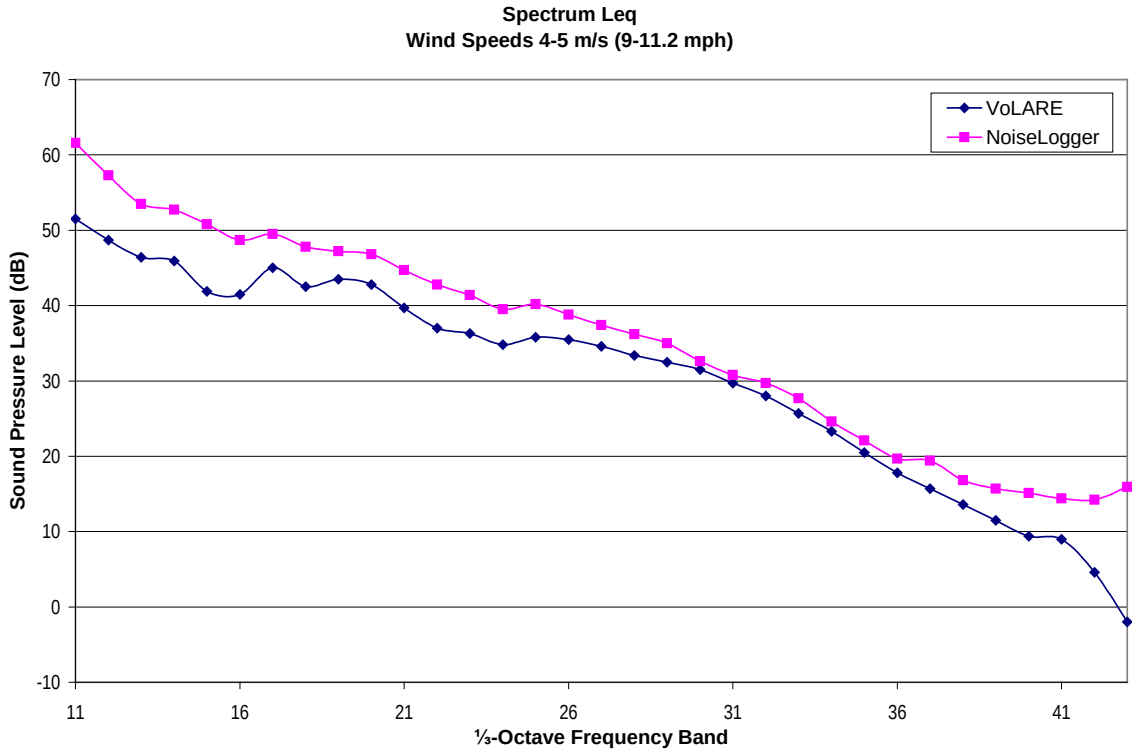


Figure 180. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 4-5 m/s.

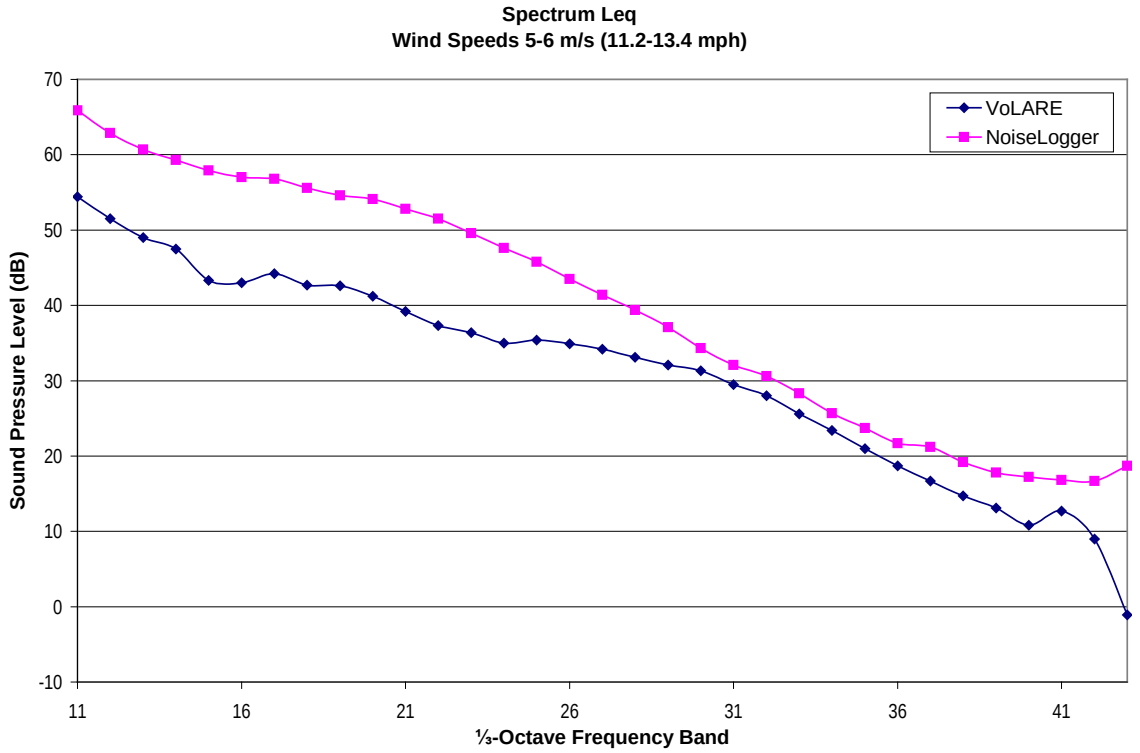


Figure 181. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 5-6 m/s.

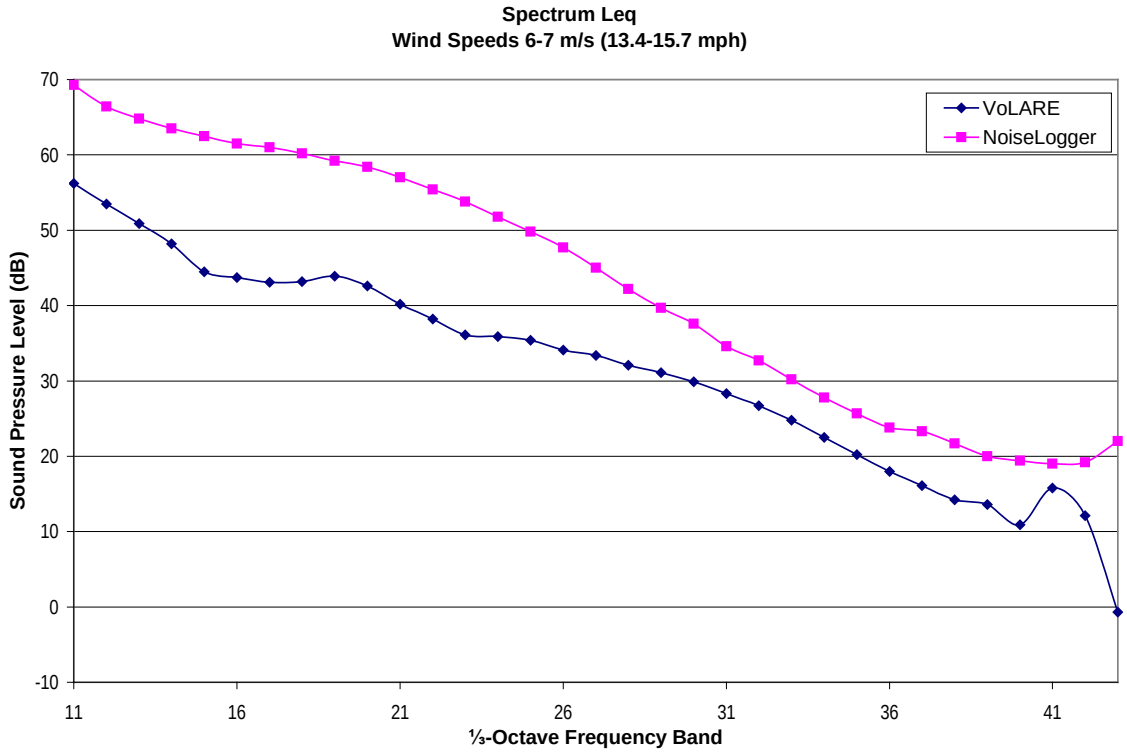


Figure 182. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 6-7 m/s.

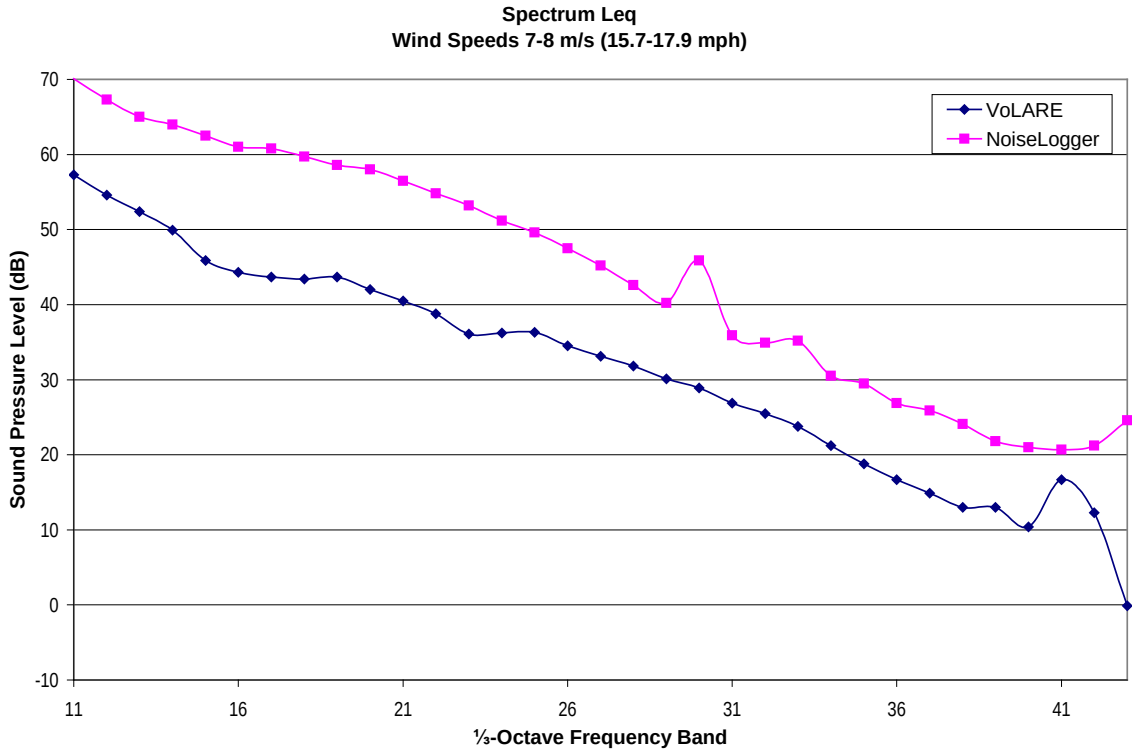


Figure 183. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 7-8 m/s.

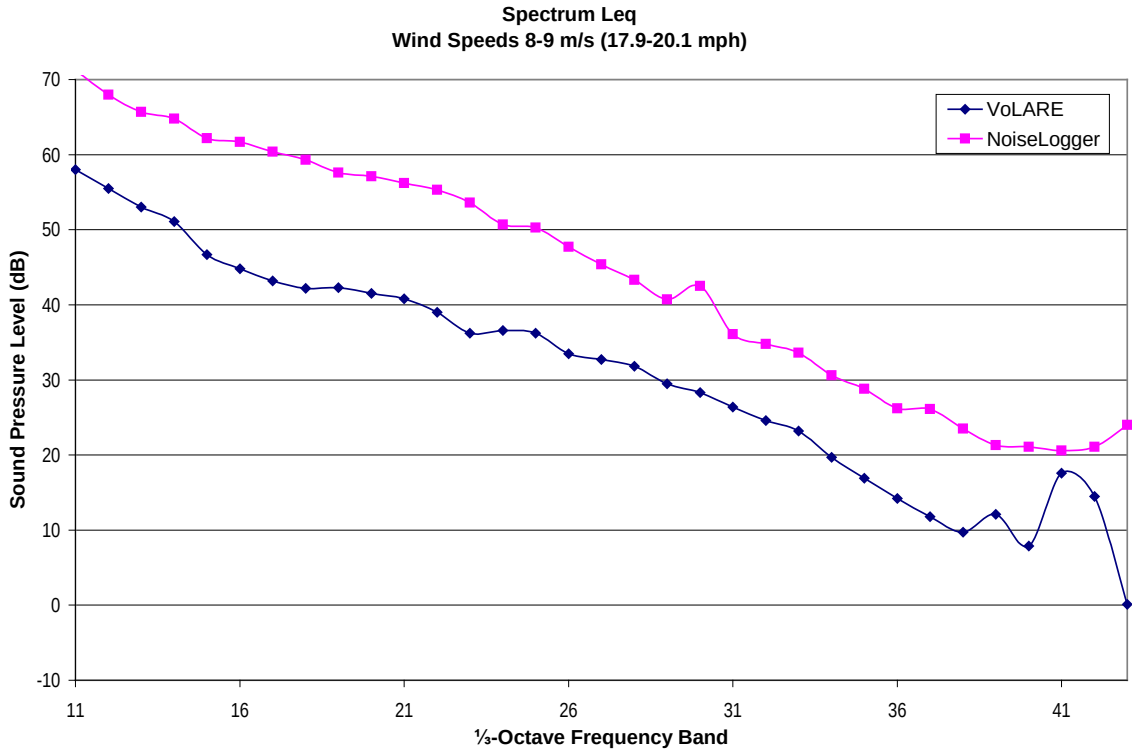


Figure 184. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 8-9 m/s.

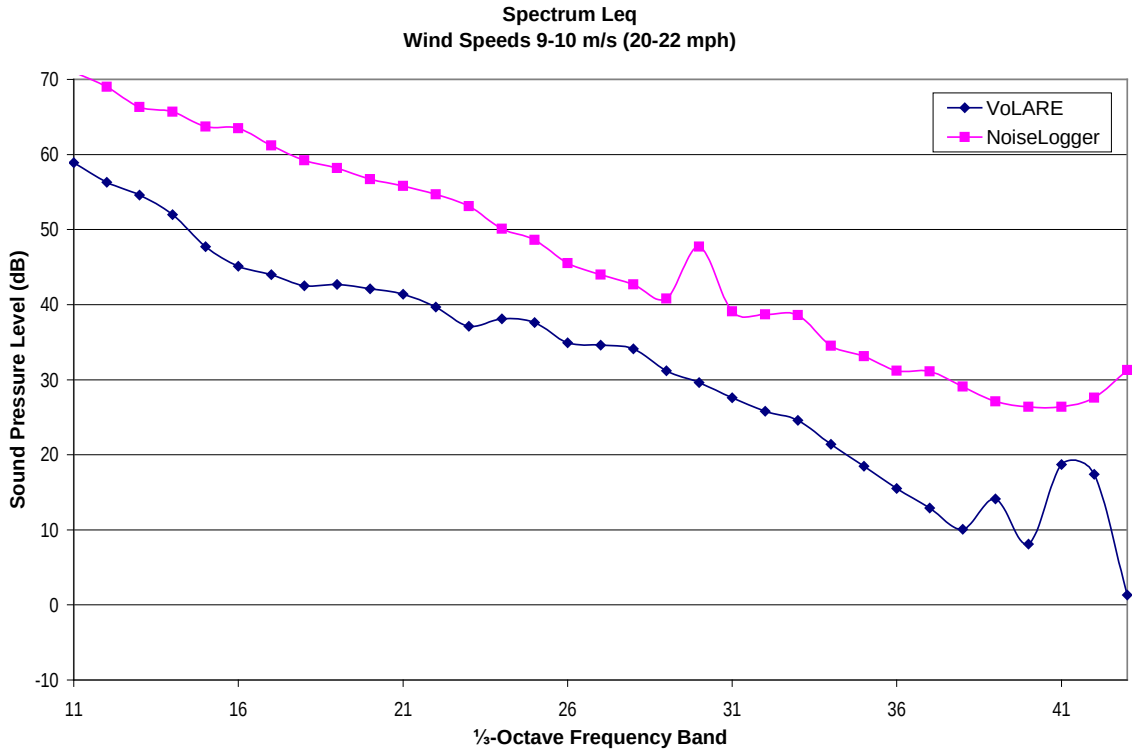


Figure 185. NoiseLogger™ versus VoLARE spectrum L_{eq}'s for wind speeds 9-10 m/s.

The above figures verify that a wind filter would be highly beneficial to the analysis and minimize the deltas seen between NoiseLogger™ and VoLARE data. They further indicate that this wind filter should be for wind speeds between 5 m/s and 7 m/s (11 – 15.7 mph). Consequently, a conservative 5 m/s (11.2 mph) wind cutoff filter was applied to all data. It is important to also reiterate that removing all data measured for wind speeds greater than this wind cutoff criterion did not result in a significant loss of data – approximately 90 percent of the originally measured data were retained.

APPENDIX F. ACOUSTIC ZONE ANALYSIS

Many parks, particularly those within similar ecosystems have similar physical, biological and meteorological parameters – including land cover, wildlife activity, visitor-use, wind and seasonality. Therefore, one would expect that their baseline ambient sound levels would also be similar, thus, allowing for the potential transferability of baseline ambient data within large, homogeneous regions of a particular park and possibly between similar regions in other parks.

An area of justified concern is the reliability of transferred ambient data in the dynamic outdoor environment of a national park - be it data from one area of a park to another area within the same park, or data from one park to a completely different park. It is presently hypothesized that after a critical mass of baseline ambient sound level data have been collected, it will be statistically viable to begin generalizing data measured in one park to regions possessing similar attributes in other parks. What is not currently known, however, is how many park measurement studies will be needed to achieve statistical reliability and scientific defensibility of ambient data as this type of effort has never been attempted before. The transferability hypothesis, if proven sound, will not preclude measurements entirely in other parks, but it should greatly reduce the scope of required measurements. It is anticipated that some baseline ambient sound level measurements will be necessary in all parks. The purpose of a limited measurement campaign (probably a few days in even the later parks included in the ATMP and VA program) is to statistically prove the hypothesis of transferability of baseline ambient sound level data on a park-by-park basis, and, as important, secure public acceptance of the environmental compliance documents prepared for individual parks.

In developing acoustic zones within a national park,[*] land cover (Section F.1) and climate/ ecological domain (Section F.2) are the two most important technical factors influencing ambient sound levels as they are the two most significant factors affecting how sound waves propagate from source to receiver.[41]

[*] The number of initial acoustic zones within a particular park are primarily determined by land cover and climate regions within that park, and not park size. Acoustic zones may then be further subdivided based on factors such as park management zones, visitor-use, and wildlife habitats. For example, Hawai`i Volcanoes National Park is approximately 400 square miles with an estimated 9 acoustic zones based on land cover and topographical information. Badlands, a slightly larger park at almost 500 square miles possessed uniformity of land cover and topography over much of the park, but was divided into 3 acoustic zones based on park management zones.

F.1 Land Cover

The vegetative land cover within a park is one of the key attributes affecting the acoustics. Land cover directly affects how sounds propagate from a source to a receiver. Sounds typically propagate with little attenuation over acoustically hard surfaces (e.g., bare rocks or water) as opposed to acoustically soft surfaces (e.g., grassy fields or dense trees). With the goal of potentially facilitating future data transferability between parks, all baseline acoustic data collected thus far have been organized/classified in accordance with the National Land Cover Database (NLCD). Developed by the U.S. Geological Survey (USGS), the NLCD is the only nationally consistent land cover data set in existence and is comprised of twenty-one NLCD subclass categories for the entire U.S. (see Table 56).[42] Hawai`i Volcanoes' land cover distribution using the NLCD categories is shown in

Table 57. This classification approach has been closely coordinated with NPS personnel.*

Table 56. National Land Cover Database (NLCD) characterization classes/subclasses.

Land Cover Class	Land Cover Subclass	Description
Water	11 Open Water	All areas of open water, generally with less than 25% cover of vegetation/land cover.
Water	12 Perennial Ice/Snow	All areas characterized by year-long surface cover of ice and/or snow.
Developed	21 Low Intensity Residential	All areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80% of the cover. Vegetation may account for 20 to 70% of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
Developed	22 High Intensity Residential	Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20% of the cover. Constructed materials account for 80 to100% of the cover.
Developed	23 Commercial/Industrial/ Transportation	Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.
Barren	31 Bare Rock/Sand/ Clay	Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.
Barren	32 Quarries/Strip Mines/Gravel Pits	Areas of extractive mining activities with significant surface expression.
Barren	33 Transitional	Areas of sparse vegetative cover (less than 25% of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clearcuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.).
Forested Upland	41 Deciduous Forest	Areas dominated by trees where 75% Or more of the tree species shed foliage simultaneously in response to seasonal change.
Forested Upland	42 Evergreen Forest	Areas dominated by trees where 75% or more of the tree species maintain their leaves all year. Canopy is never without green foliage.
Forested Upland	43 Mixed Forest	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the cover present.
Shrubland	51 Shrubland	Areas dominated by shrubs; shrub canopy accounts for 25-100% of the cover. Shrub cover is generally greater than 25% when tree cover is less than 25%. Shrub cover may be less than 25% in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25% and shrubs cover exceeds the cover of the other life forms.
Non-Natural Woody	61 Orchards/Vineyards/ Other	Orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals.
Herbaceous Upland Natural/Semi-natural Vegetation	71 Grasslands/ Herbaceous	Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25%, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

* It should be noted that there is currently no standard vegetation classification system in the NPS. However, several classification systems, including NLCD and NatureServe described in this document, are being reviewed by the NPS for use in grouping NPS park units by common vegetation, topography, and habitat.

Land Cover Class	Land Cover Subclass	Description
Herbaceous Planted/Cultivated	81 Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of se-ed or hay crops.
Herbaceous Planted/Cultivated	82 Row Crops	Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.
Herbaceous Planted/Cultivated	83 Small Grains	Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.
Herbaceous Planted/Cultivated	84 Fallow	Areas used for the production of crops that do not exhibit visible vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage.
Herbaceous Planted/Cultivated	85 Urban/Recreational Grasses	Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses.
Wetlands	91 Woody Wetlands	Areas where forest or shrubland vegetation accounts for 25-100% of the cover and the soil or substrate is periodically saturated with or covered with water.
Wetlands	92 Emergent Herbaceous Wetlands	Areas where perennial herbaceous vegetation accounts for 75-100% of the cover and the soil or substrate is periodically saturated with or covered with water.

Table 57. Land cover subclass distribution in Hawai`i Volcanoes.

Land Cover Class	Land Cover Subclass	Area (Sq. Mi.)
Water	11 Open Water	0.0
Water	12 Perennial Ice/Snow	0.0
Developed	**21 Low Intensity Residential**	**0.1**
Developed	22 High Intensity Residential	0.0
Developed	23 Commercial/Industrial/Transportation	0.0
Barren	**31 Bare Rock/Sand/Clay**	**224.7**
Barren	32 Quarries/Strip Mines/Gravel Pits	0.0
Barren	33 Transitional	0.0
Forested Upland	41 Deciduous Forest	0.0
Forested Upland	**42 Evergreen Forest**	**60.1**
Forested Upland	43 Mixed Forest	0.0
Shrubland	**51 Shrubland**	**67.7**
Non-Natural Woody	61 Orchards/Vineyards/Other	0.0
Herbaceous Upland Natural/Semi-natural Vegetation	**71 Grasslands/Herbaceous**	**47.5**
Herbaceous Planted/Cultivated	81 Pasture/Hay	0.0
Herbaceous Planted/Cultivated	82 Row Crops	0.0
Herbaceous Planted/Cultivated	83 Small Grains	0.0
Herbaceous Planted/Cultivated	84 Fallow	0.0
Herbaceous Planted/Cultivated	85 Urban/Recreational Grasses	0.0
Wetlands	91 Woody Wetlands	0.0
Wetlands	92 Emergent Herbaceous Wetlands	0.0
	Total*	**400.1**

F.2 Climate and Ecological Domain

Climatology can also affect baseline ambient sound levels, as sound propagates differently in cold dry regions as opposed to warm humid regions; and substantial differences in wildlife activity can also be expected with varying climatology. Thus, different climate regions (or ecological domains) of the U.S. have to be considered. The organization, NatureServe, and its natural heritage program members, with funding from The Nature Conservancy, have completed the first working classification of terrestrial ecological systems in the United States, southern Alaska, and adjacent portions of Mexico and Canada. The ecological divisions of North America used in association with NatureServe are shown in Figure 186.[43] Note: Hawai`i is not shown in this figure. Its ecological division is #412 (Hawaiian Highlands). With the goal of

* Because the NPATMA applies to all commercial air tour operations within the ½-mile outside the boundary of a national park, these numbers include these areas. Therefore, the total area of all land cover types is larger than the total area of the park.

potentially facilitating future data transferability between parks, all baseline acoustic data collected thus far have been organized by ecological division. This approach has been closely coordinated with NPS personnel.[*]

[*] It should be noted that there is currently no standard vegetation classification system in the NPS. However, several classification systems, including NLCD and NatureServe described in this document, are being reviewed by the NPS for use in grouping NPS park units by common vegetation, topography, and habitat.

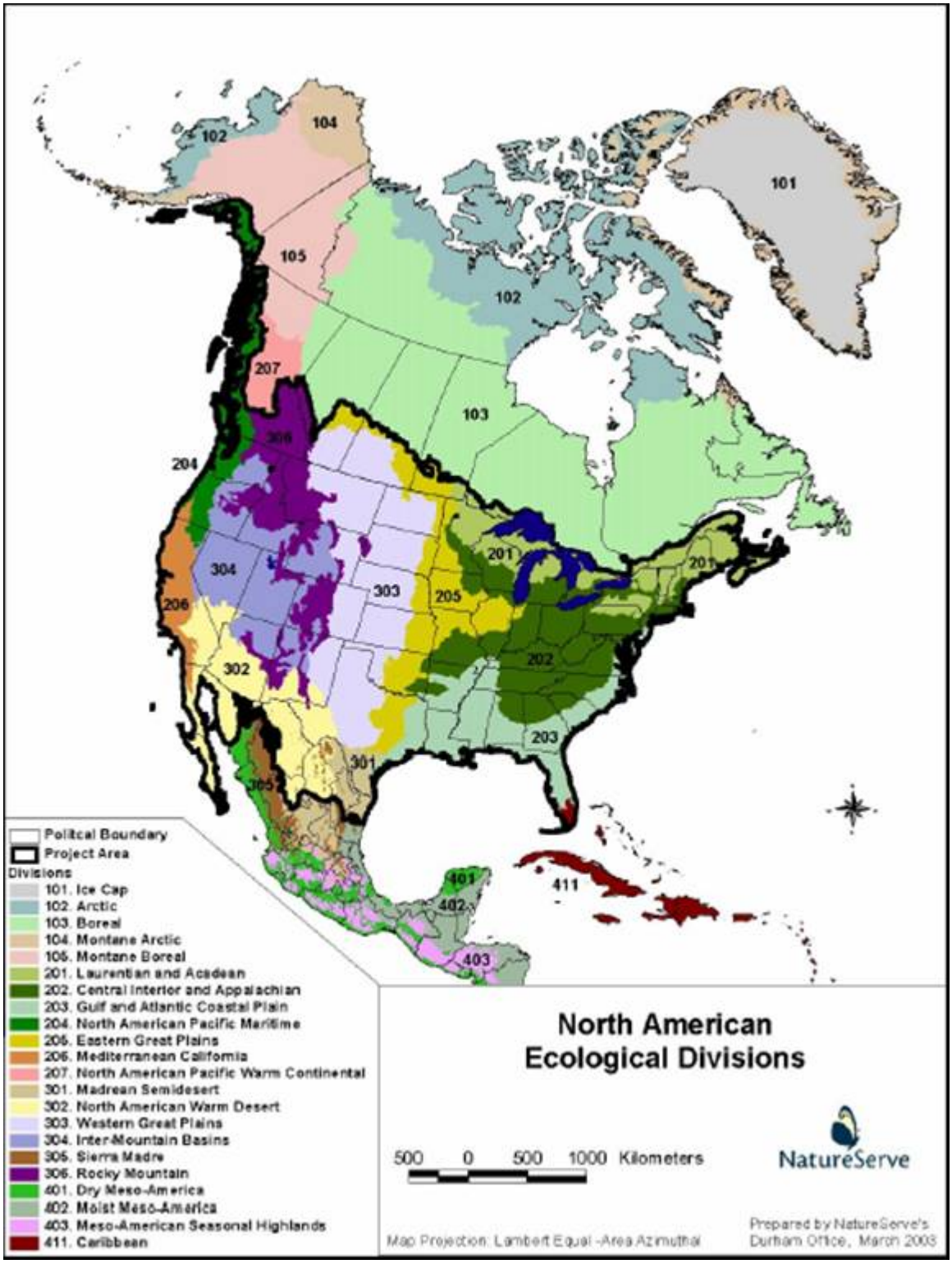


Figure 186. NatureServe ecological divisions of North America.[*]

[*] Hawai`i is not shown in this figure. Its ecological division is #412 (Hawaiian Highlands).

F.3 Statistical Tests for Data Transferability

The site transferability hypothesis seeks to show that similar locations within a national park have similar acoustic features. This provides a means to estimate ambient acoustic features of large regions of a national park that are economically infeasible to monitor with sound level equipment. Two statistical methods were used to evaluate the site transferability hypothesis: Regression Analysis (see Section E.3.1) and the Kolmogorov-Smirnoff (K-S) Statistic (see Section E.3.2). These two methods were used in tandem to assess acoustic similarity. If a site combination passed both methods it was considered strong evidence that the sites were similar. If a site combination failed both methods, it was an indication the sites were different. Cases where one method indicated similarity and the other method was contradictory were evaluated individually and a final decision was made after review of the results and pertinent site information.

F.3.1 Regression Analysis

Although sound-level data, whose associated wind speed was greater than 5 m/s (see Section 5.5.1), were not used in data analyses, it was still considered likely that wind speed would affect the hourly L_{50} sound levels. An analysis of the Pearson Correlations confirmed this, indicating that the correlation between hourly L_{50} and hourly average wind speed is significant at the majority of sites.

Because sound levels at each site were found to be dependent upon wind speed, any attempt to find statistical similarity between sites needs to take the wind variable into consideration. Therefore, site comparisons were conducted by regressing L_{50} on wind speed using a third order polynomial, fitted with a weighted, least-squares regression,[*] and including a dummy site variable. The significance of this site variable was then used to answer the question, "Can the variation in hourly L_{50} be explained, not only by wind speed, but also by site-specific characteristics?" If the site variable was not significant, it can be said that none of the variation in L_{50} can be explained by site. If none of the

[*] This regression was also conducted taking into account the fact that the hourly L_{50} data is also highly correlated over time. In other words, a sample from the 10:00 hour is highly correlated with a sample from the 9:00 hour and from the 11:00 hour. Due to this correlation, the number of degrees of freedom used in this regression was not based on the number of hourly L_{50} data points, which were measured. Rather, the number of degrees of freedom was based on the number of days over which the measurements were conducted

variation can be explained by site, then there is statistically no difference between sites. The site variable was considered statistically significant if its p-level was 0.05 or less. The p-level represents the probability of error in accepting the observed result as valid.

F.3.2 Kolmogorov-Smirnoff (K-S) Statistic

The Kolmogorov-Smirnoff (K-S) method evaluates two different cumulative distribution functions (cdf) and computes the probability that they are the same distribution.[44] This test is a nonparametric alternative to the t-test for independent samples. The implementation of this method uses the overall, hourly distributions of the measured sound pressure levels. The K-S statistic was computed for each daytime hour. If a majority (more than 50 percent) of the daytime hours pass the K-S test, then the sites were considered equivalent.

Using the above tests, the following comparisons were performed to statistically assess ambient data collected at a pair of sites within Hawai`i Volcanoes that were: (1) located in the same acoustic zone, (2) had the same land cover class/subclass (per NLCD), or (3) experienced similar levels of visitor-use. Section 6.2 presents the results.

As new ambient data are collected in parks with additional land cover types and within other ecological divisions, it is anticipated that the analysis of acoustic zones may be expanded to a larger scale, possibly nationwide.

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