# Natural Soundscape Monitoring in Yellowstone National Park December 2006-March 2007

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Shan Burson/NPS Photo

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Shan Burson
Division of Science and Resource Management
Grand Teton National Park
PO Drawer 170
Moose, Wyoming 83012
(307) 739-3584

**Abstract:**

Sounds associated with oversnow vehicles (snowmobiles and snowcoaches) are an important management concern at Yellowstone National Park. Acoustical standards and thresholds have been defined in park planning documents for the winter use season. The primary purpose of this study was to monitor the impact of oversnow vehicles on the natural soundscape. These data were then compared to the impact definition thresholds in the 2004 Yellowstone and Grand Teton National Park Temporary Winter Use Plans Environmental Assessment. Acoustical data were collected at five sites in Yellowstone National Park during the winter use season, 20 December 2006-11 March 2007.

Oversnow vehicles were audible in the Old Faithful developed area an average of 68% of the day between 8 am and 4 pm. At Old Faithful, oversnow vehicles were audible over the threshold of 75% for developed area for 9 of 35 days (26%) analyzed. Oversnow vehicles were audible 26% of the day adjacent to the road near Mud Volcano and 44% at Spring Creek 2. At Madison Junction 2.3 oversnow vehicles were audible for 59% of the day, exceeding the travel corridor threshold average of 50%. The maximum sound levels for oversnow vehicles exceeded 70 dBA at Old Faithful, along the groomed travel corridor between Madison Junction and the West Yellowstone entrance (Madison Junction 2.3) and between West Thumb and Old Faithful (Spring Creek 2). Sounds from both visitor and administrative oversnow vehicles were included in this study.

Although on average snowmobiles were audible for more time than snowcoaches, snowcoaches in general had higher sound levels, especially at higher speeds. The overall impact on the natural soundscape from oversnow vehicles was similar to the past two seasons, although there was increased audibility at two locations. The daily average number of oversnow vehicles that entered the park increased about 20% from last season. Consistent with acoustic data collected during the previous three winter seasons, the sound level and the percent time oversnow vehicles were audible remained substantially lower than during the 2002-2003 winter use season. The reduced sound and audibility levels were largely explained by fewer snowmobiles, the change from two to four-stroke engine technology, and the guided group requirements. The value of this monitoring study increases with each additional year because trends can begin to emerge in addition to detailed information about specific winters and locations.

## Table of Contents:

## Introduction:

Natural soundscapes are a valued resource at national parks including Yellowstone National Park. The 2006 National Park Service (NPS) Management Policies state that natural soundscapes (the unimpaired sounds of nature) are to be preserved or restored as is practicable. Natural soundscapes are intrinsic elements of the environment and are necessary parts of its ecological functioning and therefore associated with park purposes. The existing winter soundscape at Yellowstone consists of both natural and non-natural sounds. Common natural sounds include bird calls, mammal vocalizations, flowing water, wind, and thermal activity. Non-natural sounds include motorized sounds of snowmobiles, snowcoaches, snow-grooming, wheeled vehicles, aircraft, and the sounds associated with facility utilities and other human activity in destination and support areas.

The 2000 and 2003 Winter Use Plans Environmental Impact Statement of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway concluded that historical oversnow vehicle use created unacceptable adverse impacts on natural soundscapes (and other resources). To minimize the impact of sounds from oversnow vehicles (OSV) on the natural soundscape and other resources, the 2004 Temporary Winter Use Plans (WUP) Environmental Assessment established acoustical impact definition thresholds within three soundscape management areas. This Temporary WUP was in effect during the winters of 2004-2005 through 2006-2007 (a new winter use plan is currently in development). The impact definitions describing the acoustical thresholds of adverse major effects (Table 1) are compared to the acoustic field measurements collected in Yellowstone during the 2006-2007 winter use season. The primary purpose of this acoustical monitoring was to measure the impact of snowmobile and snowcoach sound on the park's natural soundscape. In general, sounds from both guided visitor and primarily unguided administrative oversnow vehicles were included in the study (but see Appendix E). For comparative purposes, this report also includes similar acoustical data collected during the winters of 2003-2004, 2004-2005, and 2005-2006 in Appendix F. See Burson (2004, 2005 and 2006) for additional information on park soundscapes during the previous winters, and the 2000 and 2003 Winter Use Plans for additional details of oversnow vehicle management.

## Study Area:

Yellowstone National Park occupies the northwest corner of Wyoming and extends a short distance into Montana and Idaho. The park is at high elevation and has extensive stands of lodgepole pine forests, grasslands, and open thermal areas. Large areas of Yellowstone are in early stages of lodgepole pine regrowth after the fires of 1988. The two million acre park was divided into two acoustic zone categories (open and forested) in a previous winter acoustical study (HMMH 2001) for the purpose of describing areas with similar natural acoustic properties. This categorization is generally maintained for habitat descriptions in this present study. The major roads within YNP that are open to vehicles during the summer are groomed for oversnow vehicle travel during the winter use season (December to March) with the exception of the road between Canyon and Tower and the plowed road between Mammoth and Cooke City along YNP's northern boundary. During the winter use season, between 20 December 2006 and 11 March 2007, 24,524 snowmobiles and 2,422 snowcoaches, totaling 26,946 oversnow vehicles, entered YNP (NPS unpublished data). The majority (25,979; 96.4%) of these oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. A total of approximately 174 snowmobiles and about 406 snowcoaches originated from Old Faithful and may not be included in the number of OSVs given elsewhere in this report.

**Instrumentation and Methods:**

Automated acoustic monitors (developed by Skip Ambrose, Sandhill Company, Castle Valley, UT and Mike Donaldson, Far North Aquatics, Fairbanks, AK) collected continuous one-second sound levels, digital recordings using a systematic sampling scheme (10 seconds every four minutes for a daily total of 360 samples), and 20-second recordings of sound events exceeding user-defined thresholds of sound level (decibel) and duration (seconds). These two event threshold triggers were set at 70 dBA and 1 second (fast) and 60 dBA and 10 seconds (slow). Calibrated Type 1 Larson Davis (Provo, Utah) 824 sound level meters, PRM902 microphone preamplifiers, and G.R.A.S. (North Olmsted, Ohio) 40AE microphones with windscreens were used to collect A-weighted wideband and 33 unweighted one-third octave band frequency (12.5-20,000 Hz) sound pressure levels each second during the sampling period. SoundMonitor051210 ™ (Far North Aquatics, Fairbanks, Alaska) software running on a Windows™-based Panasonic™ laptop computer controlled and stored the acoustical data. Each system collected high quality digital recordings (44.1 KHz, 16-bit). B&K (Naerum, Demark) Model 4231 and Larson Davis LD200 calibrators were used for field calibration. The sound level meters, microphone preamplifiers, microphones, and calibrators were tested and calibrated at a laboratory that conforms to and operates under the requirements of ANSI/NCSL Z540-1. During the initial deployment, the sound level meter noise floor was measured using a Larson Davis ADP005 dummy microphone. The actual system noise floor (3-7 dBA above the level measured with a dummy microphone) is the lowest sound level that the system can measure. During quiet periods the actual ambient sound level was often lower than the noise floor (Burson 2006). Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) and CV3F ultrasonic wind sensors (LCJ Capteurs, France) collected continuous wind speed data.

After the initial deployment, each monitor was visited at least biweekly. A field data sheet was completed during each visit. Basic site information, time arrive/time depart, latitude and longitude, habitat/vegetation types, equipment type and serial numbers, and software settings were documented. During each visit, time offsets were noted (global positioning system (GPS) time versus computer time), computer clocks were reset to GPS time, data were downloaded to a portable hard drive, and calibration levels were checked (differences from 94.0 dBA at 1000 Hz were noted and the system was recalibrated if >0.1 dBA).

The acoustic monitors, contained within weatherproof containers, were either plugged into electricity outlets (Old Faithful) or powered by 12-volt batteries with or without photovoltaic charging systems. Systems with solar panels or plugged into electrical outlets could operate continuously for weeks.

Specific methodologies (protocols) for equipment type, microphone placement, height, and other factors are summarized in Appendix A. These protocols followed guidance of Ambrose and Burson (2004) and were based on American National Standards Institute (ANSI) S12.9-1992, Part 2 (ANSI 1992), Federal Aviation Administration's "Draft Guidelines for the Measurement and Assessment of Low-level Ambient Noise" (Fleming et al. 1998), and "Methodology for the Measurement and Analysis of Aircraft Sound Levels within National Parks" (Dunholter et al. 1989). Appendix B contains a glossary of acoustical terms.

**Acoustic Measurement Locations:**

The 2006-2007 sound monitoring locations (Fig. 1) were chosen to include high, medium and no OSV use areas and represented three soundscape management zones (Developed Area, Travel Corridor and Backcountry). Locations that facilitated comparisons to acoustic data collected during previous winters were preferred. The specific placement relative to sound sources of interest was mainly determined by staffing and logistical constraints. The logistical constraints included open south facing sky for solar exposure for charging systems, proximity to electricity outlets, and placement of instrumentation in locations protected from large mammals. Habitat cover percentages listed below were measured in a 500 m radius of the sound monitor.

*Old Faithful Weather Station*

| | |
|---|---|
| Latitude: | 44.45688 |
| Longitude: | 110.83178 |
| Elevation: | 7400 feet |

| | |
|---|---|
| Habitat: | 50% open (parking lot, road, buildings), 30% open (wetlands, thermal area), 20% forested (sparse lodgepole pine) |
| Management Area: | Developed Area |

The Old Faithful Weather Station monitor was located within the fenced area of the weather station adjacent to the Ranger Station. The site and nearby motorized routes were in a mostly flat long wide valley. The microphones were located 40 feet from a walking/ski trail, 200 feet from the Ranger Station, 230 feet from the entrance road used by oversnow traffic, 300 feet from the large parking lot between the Ranger Station and the Visitors Center, 600 feet from the Old Faithful Inn, and 700 feet from the Snow Lodge. The monitor was powered by AC electricity.

*Madison Junction 2.3*

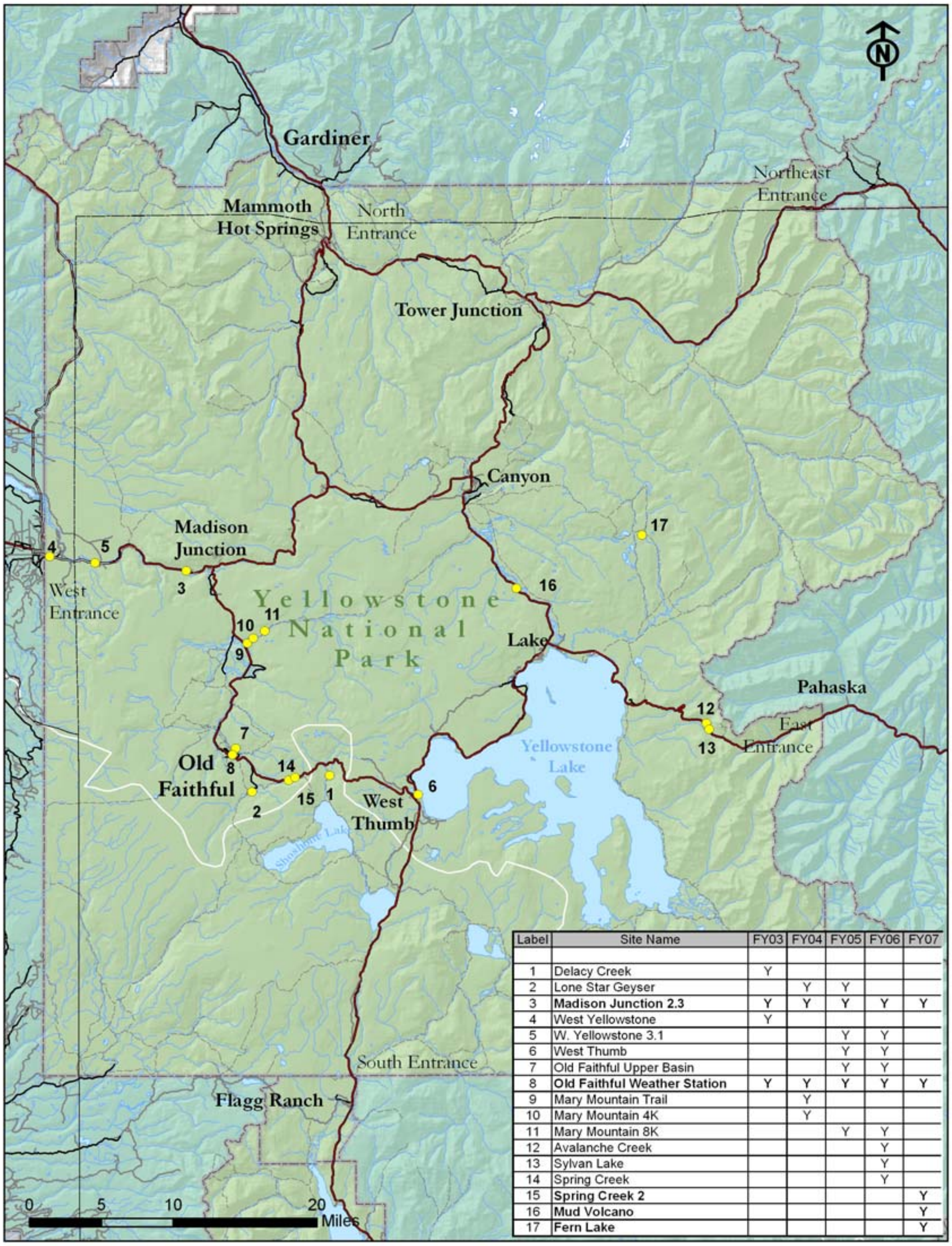
| | |
|---|---|
| Latitude: | 44.64253 |
| Longitude: | 110.89645 |
| Elevation: | 6800 feet |
| Habitat: | 80% forested (small post-burn lodgepole pines), 20% open (road, river). |
| Management Area: | Travel Corridor |

The Madison Junction 2.3 monitor was located 2.3 miles west of Madison Junction, 100 feet from the West Entrance-Madison Junction Road within a large area of small (4 to 8 feet) lodgepole pines, and 275 feet from the Firehole River. The site and nearby motorized route were in a long mostly flat valley, one mile wide, bounded on both sides by steep bluffs. The Madison Junction 2.3 monitor was powered from 12 volt batteries charged by solar panels.

*Spring Creek 2*

| | |
|---|---|
| Latitude: | 44.43100 |
| Longitude: | 110.75323 |
| Elevation: | 8000 feet |
| Habitat: | 95% forested, 5% open (road, river). |
| Management Area: | Travel Corridor |

The Spring Creek monitor was located about five miles east-southeast of Old Faithful, 100 feet from the Old Faithful- West Thumb Road within a forest of large lodgepole pines at the edge of a small south-facing open area. The site and nearby motorized route was on a slight incline approaching Craig Pass. The Spring Creek 2 monitor was powered from 12 volt batteries charged by solar panels.




| Label | Site Name | FY03 | FY04 | FY05 | FY06 | FY07 |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | Delacy Creek | Y | | | | |
| 2 | Lone Star Geyser | | Y | Y | | |
| 3 | **Madison Junction 2.3** | Y | Y | Y | Y | Y |
| 4 | West Yellowstone | Y | | | | |
| 5 | W. Yellowstone 3.1 | | | Y | Y | |
| 6 | West Thumb | | | Y | Y | |
| 7 | Old Faithful Upper Basin | | | Y | Y | |
| 8 | **Old Faithful Weather Station** | Y | Y | Y | Y | Y |
| 9 | Mary Mountain Trail | | Y | | | |
| 10 | Mary Mountain 4K | | Y | | | |
| 11 | Mary Mountain 8K | | | Y | Y | |
| 12 | Avalanche Creek | | | | Y | |
| 13 | Sylvan Lake | | | | Y | |
| 14 | Spring Creek | | | | Y | |
| 15 | **Spring Creek 2** | | | | | Y |
| 16 | **Mud Volcano** | | | | | Y |
| 17 | **Fern Lake** | | | | | Y |

**Figure 1**. Locations of sound monitoring sites (yellow circles) within Yellowstone National Park, December 2003-March 2007. See inserted table for key to year and map label. Only FY07 sampling locations are included in this report (but see Appendix F and Burson [2004], [2005] and [2006] for previous winters' sampling results).

*Mud Volcano*

| | |
|---|---|
| Latitude: | 44.46325 |
| Longitude: | 110.82740 |
| Elevation: | 7700 feet |
| Habitat: | 60% open (wetlands, thermal area, boardwalk), 10% open (river), 30% forested (lodgepole pine), |
| Management Area: | Travel Corridor |

The Mud Volcano monitor was placed within the branches of a fallen lodgepole pine across the groomed road from an extensive thermal area. The site and nearby motorized route were on a mostly flat plateau. The microphone was located 100 feet from the Grand Loop (Canyon to Lake) Road, 250 feet from the closest thermal activity and the Yellowstone River, and 500 feet from the Mud Volcano parking area. The monitor was powered from 12 volt batteries charged by solar panels.

*Fern Lake*

| | |
|---|---|
| Latitude: | 44.41589 |
| Longitude: | 110.57093 |
| Elevation: | 7900 feet |
| Habitat: | 40% open (meadow), 60% forested (lodgepole pine) |
| Management Area: | Backcountry Area |

The Fern Lake monitor was located about 8 miles from the nearest groomed roads (Grand Loop Road between Canyon and Fishing Bridge, and the East Entrance road) at the forested edge of a large meadow directly under a large lodgepole pine. The site was within an extensive area of rolling hills. The monitor was powered from 12 volt batteries charged by solar panels.

**Analyses:**

Audibility

The daily 360 10-second digital recordings were calibrated, combined, and replayed using Adobe's Audition™ software, Sound Devices USBPre™ acoustical interface, and professional grade headphones. The Soundscape Database software (Ric Hupulo, formerly of the Natural Sounds Program, Ft. Collins, CO) was used to analyze the audibility data. The entire 24 hour period was analyzed but the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here as prescribed in the 2004 Temporary Winter Use Plan.

When determining sound sources via playback of field recordings, the volume of the playback (after adjustment to the recorded calibration tone) was increased by 10 dBA to approximate field audibility. This value was determined from comparisons between field recordings and subsequent office playback. Humans have directional hearing and observers in the field can and do turn toward faint sounds and thus can hear those sounds better than when we cannot turn to face the sound, as in an office playback. This difference cannot be accounted for in an office environment. In addition, instrumentation used for recording and playback add artificial noise that may mask very quiet sounds that would be heard in the field. As a result, audibility determined through office playback of digital recordings likely represents a minimum assessment of time audible of various sound sources. All investigators had normal hearing as tested by certified audiologists. Investigators replayed the daily recordings and determined the source (snowmobile, animal, aircraft, wind, thermal activity, etc.) for each audible sound.

The percent time audible for each sound source was calculated using the combined 10-second samples as approximations of all periods of the day. For example, if a particular sound source was audible for half of the samples (180 of 360 samples) its percent time audible was calculated as 50%. Although any sampling scheme may miss a rare sound, comparison with attended logging, other sampling schemes and continuous recordings demonstrated that analyses using a 10 seconds/4 minute scheme closely approximate actual percent time audible of frequent sound sources (e.g., oversnow vehicles).

It was increasingly difficult to identify sound sources as distances increased from the recording location to the sound source. Therefore sound source codes are hierarchal (e.g., snowmobile; oversnow vehicle; motorized sound; non-natural sound; unknown). The most specific identification possible was used. Four-stroke snowmobiles were sometimes difficult to distinguish from snowcoaches. When the two categories could not be distinguished they were combined in the analyses (Fig. 3 and 6 provide examples of the relative proportions of snowmobiles, snowcoaches, and the combined category at two locations). When sound sources could only be identified as motorized vehicles they were not included in the oversnow vehicle category, although it is likely that many were oversnow vehicles.

Event Analysis

The event recordings of loud sounds were replayed and each sound source identified and tallied.

Sound levels

Sound pressure level data (decibels) were compiled and common acoustic metrics were calculated using HourlyMetrics™ software (Ric Hupalo, formerly of the NPS Natural Sound Program, Ft. Collins, CO). Wind contamination (distortion) causes false sound level data when wind speeds exceed the capacity of the microphone windscreens. Therefore, sound level data collected when wind speeds exceeded 11 mph were deleted from analyses. Strong wind is a natural phenomenon and deleting periods of time with strong winds would artificially lower estimates of natural ambient sound levels during these wind events. This potential bias is not a major concern because estimating natural ambient sound levels was not a primary objective of this study. Data influenced by visits to the monitoring site were also deleted from analyses.

This report relies on a number of common acoustical metrics for the sound level data and descriptive statistics, mostly medians, for the audibility data. The real distribution of data points is masked when only medians are displayed. A disadvantage of using only medians is that knowledge of these other values is often valuable for interpretation, therefore minimum and maximum values are also given. Although estimates of variability beyond the minimum and maximum values are also desirable no simple, yet informative, methods have been developed.

Results from this sound monitoring project can be compared to the soundscape impact thresholds in the 2004 Temporary Winter Use Plans Environmental Assessment (Table 1). The 2000 and 2003 WUP acoustic thresholds (Appendix C) contain previous standards and thresholds for further comparison.

**Table 1**. Impact definitions for the natural soundscape in the 2004 Temporary Winter Use Plans (WUP) Environmental Assessment. Also see Appendix C.

| **Impact Category Definition**[1] | **Management Area** | **Audibility**[2, 3] | **Maximum Sound Level**[3,4] |
|---|---|---|---|
| **No Effect** An action that does not affect the natural soundscape or the potential for its enjoyment. | Na | Na | Na |
| **Adverse Negligible Effect** An action that may affect the natural soundscape or potential for its enjoyment, but with infrequent occurrence and only for short duration at low sound levels. At this impact level, unique soundscape characteristics (such as bubbling hot springs or geysers are rarely affected). | Developed | Sound created by action is audible < 25% | Maximum sound level created by action is < 45 dBA |
| | Travel Corridor | <5% | < 40dBA |
| | Backcountry | <5% | <40 dBA |
| **Adverse Minor Effect** An action that may affect the natural soundscape or potential for its enjoyment. | Developed | >25% <45% | <60 dBA |
| | Travel Corridor | >15% <25% | <60 dBA |
| | Backcountry | >5% <10% | <40 dBA |
| **Adverse Moderate Effect** An action that may affect the natural soundscape or potential for its enjoyment. | Developed | >45% <75% | <70 dBA |
| | Travel Corridor | >25% <50% | <70 dBA |
| | Backcountry | >10% <20% | <45 dBA |
| **Adverse Major Effect** An action with an easily recognizable adverse effect on the natural soundscape and potential for its enjoyment. | Developed | >75% | >70 dBA |
| | Travel Corridor | >50% | >70 dBA |
| | Backcountry | >20% | >45 dBA |

[1]Thresholds are calculated using the period 8 am-4 pm. Measurements are at 100 feet from sound source in developed areas and travel corridors.
[2] Audibility is the ability of humans with normal hearing to hear a certain sound.
[3] To remain within impact category listed audibility and maximum sound level thresholds shall not be violated more than 15% of the measurement days.
[4]Typical natural soundscape sound levels on a calm winter day can range from 0-30 dBA. Snowmobile best available technology (BAT) sound level requirements of 73 dBA measured at 50 feet is roughly equivalent to 67 dBA at 100 feet. The maximum sound level for all non- natural sounds in national parks other than OSVs and motorboats is 60 dBA [36 CFR (2.12) (a)(1)(i)].

**Results and Discussion:**

Winter-long acoustical measurements were collected at Old Faithful Weather Station, Madison Junction 2.3 and Spring Creek 2. Additional data were collected for shorter time periods at Fern Lake and Mud Volcano (see previous section for site details). Data collection began on 20 December 2006 and continued throughout the winter use season (20 December 2006-11 March 2007). Selected data (Tables 2 and 3) were chosen for analysis based on visitor usage patterns, distribution of days of the week, month, and season, daily wind conditions, appropriate sample size, and timing of previous measurements. The WUP impact thresholds apply only to motorized oversnow vehicle sounds from 8 am-4 pm so for the audibility analyses generally only those periods are presented in this report. A wealth of biological data, as well as sound level data, is contained within this study's acoustic dataset. These additional data, substantially not yet analyzed, are available for future study. For comparative value the sound level data are presented for the 24 hour day although the WUP thresholds apply only to 8 am-4 pm.

A related, short-term study using specialized low noise instrumentation documented very low sound levels (as low as 0.7 dBA) near Craig Pass at Spring Creek 2 during February 2007. This was the second winter of low noise measurements and they reinforce the conclusions from Ambrose et al. (2006). The findings have implications for winter use monitoring. The very low natural ambient sound levels documented at these two Yellowstone National Park sites were not unlike some of the other locations used in this current study. Audibility of oversnow vehicles is determined, in part, by the natural ambient sound levels. Lower natural ambient sound levels result in higher OSV percent time audible. At several monitoring locations the lowest minimum sound levels were clearly below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum levels, and those that determine, in part, the audibility of oversnow vehicles, are therefore unknown. Because of this uncertainty, at the lowest sound levels the association between the number of OSVs, the natural sound levels, and the distances OSVs are audible remains ambiguous (see pg. 17-18 for more discussion).

Acoustic data were collected at Yellowstone National Park during the past five winter seasons. This dataset is beginning to provide information on trends, similarities among years and variability in time and location. Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore fail to describe or explain fully this inherent variability. This study suffers from this weakness; however, methods and techniques to address fully the soundscapes variability are currently unavailable. Attempts to draw tight correlations or associations between certain actions, such as the daily number of oversnow vehicles allowed and the percent time audible require more detailed analyses than are presented here. Nevertheless, the acoustic dataset that has been collected during the winter-use season and upon which this report is based is one of the most extensive national park acoustic datasets in existence and a substantial amount of useful information can be gathered from the data as presented.

See Appendix C for acoustical standards and thresholds of the 2000 and 2003 Winter Use Plans (WUP) of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway.

See Appendix D for a discussion and examples of a technique to visualize daily sound levels. This technique provides another avenue to understand the natural soundscape and the sound impact of oversnow vehicles.

See Appendix E for the results of an observational study designed to determine the proportion of several usage categories for oversnow vehicles (e.g., percent of total snowmobiles driven by park visitors).

See Appendix F for related sound monitoring data from previous winter seasons.

Perhaps the most intuitive and easily understandable results come from the digital recordings and audibility analyses. These results will be presented first followed by the sound level analyses.

**Table 2**. Dates used for audibility analyses at five locations in Yellowstone National Park, December 2006-March 2007. Daily average number of snowmobiles was 299/day for the winter use season. Total number of days analyzed, 140.

| Old Faithful Weather Station | Madison Jnct. 2.3 | Spring Creek 2 | Fern Lake | Mud Volcano |
|---|---|---|---|---|
| 35 days | 35 days | 35 days | 21 days | 14 days |
| 25-Dec-06 | 25-Dec-06 | 25-Dec-06 | 21-Jan-07 | 13-Feb-07 |
| 26-Dec-06 | 26-Dec-06 | 26-Dec-06 | 22-Jan-07 | 14-Feb-07 |
| 27-Dec-06 | 27-Dec-06 | 27-Dec-06 | 23-Jan-07 | 15-Feb-07 |
| 28-Dec-06 | 28-Dec-06 | 28-Dec-06 | 24-Jan-07 | 16-Feb-07 |
| 29-Dec-06 | 29-Dec-06 | 29-Dec-06 | 25-Jan-07 | 17-Feb-07 |
| 30-Dec-06 | 30-Dec-06 | 30-Dec-06 | 26-Jan-07 | 18-Feb-07 |
| 31-Dec-06 | 31-Dec-06 | 31-Dec-06 | 27-Jan-07 | 19-Feb-07 |
| 8-Jan-07 | 8-Jan-07 | 5-Jan-07 | 3-Feb-07 | 1-Mar-07 |
| 9-Jan-07 | 9-Jan-07 | 6-Jan-07 | 4-Feb-07 | 2-Mar-07 |
| 10-Jan-07 | 10-Jan-07 | 7-Jan-07 | 5-Feb-07 | 3-Mar-07 |
| 11-Jan-07 | 11-Jan-07 | 8-Jan-07 | 6-Feb-07 | 4-Mar-07 |
| 12-Jan-07 | 12-Jan-07 | 9-Jan-07 | 7-Feb-07 | 5-Mar-07 |
| 13-Jan-07 | 13-Jan-07 | 10-Jan-07 | 8-Feb-07 | 7-Mar-07 |
| 14-Jan-07 | 14-Jan-07 | 16-Jan-07 | 9-Feb-07 | 8-Mar-07 |
| 27-Jan-07 | 27-Jan-07 | 20-Jan-07 | 13-Feb-07 | |
| 28-Jan-07 | 28-Jan-07 | 21-Jan-07 | 16-Feb-07 | |
| 30-Jan-07 | 30-Jan-07 | 22-Jan-07 | 17-Feb-07 | |
| 31-Jan-07 | 31-Jan-07 | 23-Jan-07 | 18-Feb-07 | |
| 1-Feb-07 | 1-Feb-07 | 1-Feb-07 | 19-Feb-07 | |
| 2-Feb-07 | 2-Feb-07 | 2-Feb-07 | 21-Feb-07 | |
| 3-Feb-07 | 3-Feb-07 | 3-Feb-07 | 22-Feb-07 | |
| 13-Feb-07 | 13-Feb-07 | 4-Feb-07 | | |
| 14-Feb-07 | 14-Feb-07 | 5-Feb-07 | | |
| 15-Feb-07 | 15-Feb-07 | 6-Feb-07 | | |
| 16-Feb-07 | 16-Feb-07 | 7-Feb-07 | | |
| 17-Feb-07 | 17-Feb-07 | 24-Feb-07 | | |
| 18-Feb-07 | 18-Feb-07 | 25-Feb-07 | | |
| 19-Feb-07 | 19-Feb-07 | 26-Feb-07 | | |
| 1-Mar-07 | 1-Mar-07 | 1-Mar-07 | | |
| 2-Mar-07 | 2-Mar-07 | 2-Mar-07 | | |
| 3-Mar-07 | 3-Mar-07 | 3-Mar-07 | | |
| 4-Mar-07 | 4-Mar-07 | 4-Mar-07 | | |
| 6-Mar-07 | 6-Mar-07 | 6-Mar-07 | | |
| 7-Mar-07 | 7-Mar-07 | 7-Mar-07 | | |
| 8-Mar-07 | 8-Mar-07 | 8-Mar-07 | | |
| Daily # of snowmobiles entering Yellowstone NP during sampling days.[1] | | | | |
| 316/day | 316/day | 306/day | 306/day | 302/day |

[1]Listed at bottom of table are daily snowmobile averages for the days included in the analysis. Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Daily average number of snowcoaches for the winter use season was 30/day. See text for further details.

**Table 3**. Dates used for sound level analyses at five locations in Yellowstone National Park, December 2006-March 2007. Total hours, 6,569.

| | |
|---|---|
| Old Faithful (1,621 hours)<br>20-22 December 2006<br>4 January-11 March 2007 | Madison Jct 2.3 (1,875 hours)<br>20 December 2006-11 March 2007 |
| Spring Creek 2 (1,531 hours)<br>21 December 2006-11 March 2007 | Mud Volcano (723 hours)<br>9 February-11 March 2007 |
| Fern Lake (819 hours)<br>20 January-23 February 2007 | |

Audibility:

The source of each sound (snowmobile, animal, aircraft, wind, thermal activity, etc.) that was audible was identified from the 120 10-second digital recording samples each day during 8 am-4 pm. The proportion of each sound source sample out of the possible 120 was used to calculate the percent time audible for each sound source; however, only the snowmobile, snowcoach and wind percent time audible is presented. Oversnow vehicles were often audible outside the 8 am- 4 pm time period, but these data are generally not presented. Often multiple snowmobiles or snowmobiles and snowcoaches were audible simultaneously, but other times one masked the sound of the other so all percent time audible statistics should be considered minimum values. The average number of snowcoaches entering YNP during the winter season was 30/day (range 16-52). The average number of snowmobiles entering YNP during the winter season was 299/day (range 105-542). See Table 2 for further details. The percent time audible calculations were based on days throughout the entire winter use season.

An important question is the relationship between the number of snowmobiles and snowcoaches entering YNP and the percent of time that they are audible. At first glance this appears an easily answered question. It seems intuitively obvious that more snowmobiles and snowcoaches would make more sound and that they would be heard a greater proportion of the day. This is true in general and is obvious in some of the acoustic data collected during the past five winters. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are NPS and concession snowmobiles and snowcoaches used within the park, especially in destination areas such as Old Faithful (see Appendix E). Therefore the number of snowmobiles entering the park is not directly related to the number passing any particular section of the road and hence their impact on the natural soundscape of that area. Second, as the numbers of visitors entering the park increases, additional snowmobiles are often added to existing groups enlarging group size, but not creating additional groups. The percent time that snowmobiles are audible is more closely associated with the number and distribution of groups rather than the number of individual snowmobiles. Third, audibility also depends on environmental conditions, such as temperature, wind conditions, inversions, the natural ambient sound level and other factors (as discussed in the next paragraph) that vary spatially and temporally, further complicating the relationship between the number of visitor snowmobiles and their percent time audible.

A related issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow vehicles were audible. Using logic and common sense, the number and distribution of oversnow vehicles largely determine the NFI. Given the same number of oversnow vehicles, NFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases OSVs would likely be heard at increasing distances). A particular percent time audible can have varying NFIs. For example, if oversnow vehicles were audible for 50% of an hour, depending on the distribution of these vehicles they could all be audible in the first 30 minutes and not audible the remaining 30 minutes. Or oversnow vehicles could be audible every other 10 minute period during the hour. The NFI of the first scenario would be 30 minutes but only 10 minutes for the second. Groups of guided snowmobiles have increased the NFIs at YNP compared to unguided snowmobiles (personal observation, and Appendix D; Fig. D-7 and D-8).

Audibility depends on the sound level of and distance from the sound source as well as the presence of natural sounds, and non-sound source variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover. These various factors influenced day to day audibility at any given location including the sound monitoring sites. In general, distant oversnow vehicles were masked by wind. The presence or absence of wind made the most appreciable difference in the percent time that OSVs were audible at sites where OSVs could be heard at low sound levels during calm wind conditions. All audibility results reported here are from the analyses of actual field recordings from the monitoring sites. Therefore, all sounds, both natural and non-natural influenced the reported audibility of OSVs. No two days were identical, but patterns were regularly observed and differences among monitoring locations are apparent.

*Old Faithful Weather Station*

Acoustic data were collected at this site for the fifth winter. Even though this site was in a very busy developed area many natural sounds were present, including wind, snow, wolves, coyotes, bison, red squirrels, ravens, ducks and geese. Non-natural sounds of building utilities, construction activities, and people's voices were frequently audible along with oversnow vehicles. The average daily percent time audible for snowmobiles and snowcoaches was 68% within the developed area at Old Faithful, (Fig. 2). This compares to 67% during the previous winter use season and 69% during 2004-2005 (see Appendix F). The average daily percent time audible of OSVs during the last three winter use seasons was essentially the same. During the winter of 2006-2007 the daily OSV percent time audible was consistently between 50% and 80% on all but two days (Fig. 2). Nine (26%) of the 35 days analyzed exceeded the WUP audibility threshold of 75% for developed areas. This doubled the number of days that exceeded the audibility threshold compared to last year, but there were also more days at lower percent time audible compared to the previous year (Fig. 2).

Oversnow vehicles traveling on the main road and within the Old Faithful developed area were audible at this site. Wind, depending on direction and speed, can increase the distance sounds are audible or mask other sounds. However, with all else equal OSVs are heard at greater distances during calm wind conditions, and there appears to be no strong association between wind and oversnow vehicle percent time audible at Old Faithful (Fig. 2). This is logical because the higher ambient sound levels at Old Faithful mask distant OSV sounds.

Percent time audible can be calculated by hour to understand the pattern of oversnow vehicle use between 8 am and 4 pm (Fig. 3). Early in the day (8 am and 9 am) snowcoaches were audible for more time than snowmobiles. On average, however, snowmobiles were audible for 61% more time than snowcoaches (Fig. 3). Oversnow vehicles were audible on average over 75% of the time during each of the three mid-day hours (11 am, 12 pm and 1 pm). Oversnow vehicles were audible up to a maximum of 100% of the hour during 8 am, 11 am, 12 pm and 1 pm during some days of the winter season (Fig. 3).

The analyses for the WUP measurement period are restricted to 8 am-4 pm but oversnow vehicle sounds were commonly audible outside that time period (e.g., Fig. 4). Many of these OSVs were driven by employees.

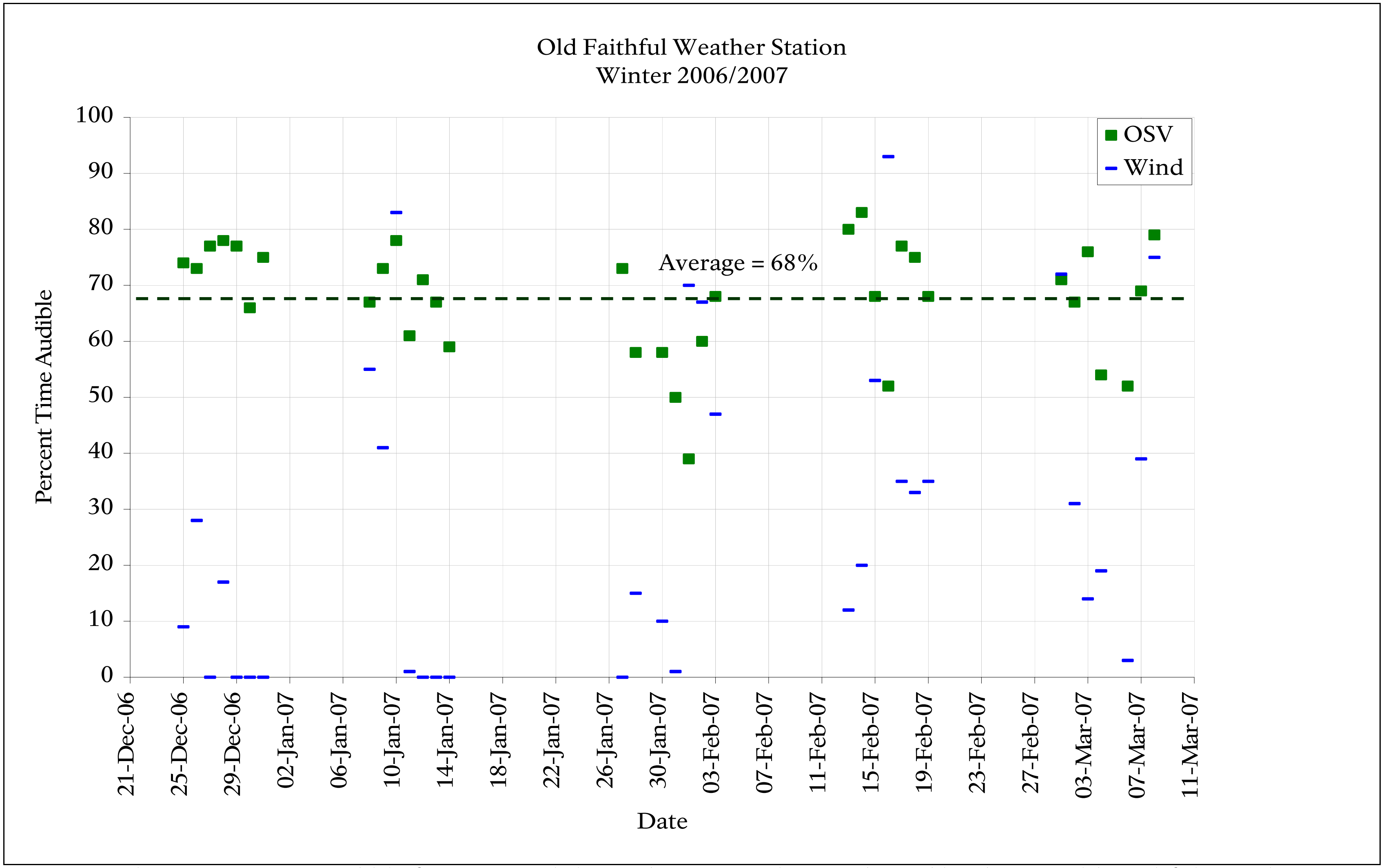



**Figure 2**. The percent time audible for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 20 December 2006 to 11 March 2007.

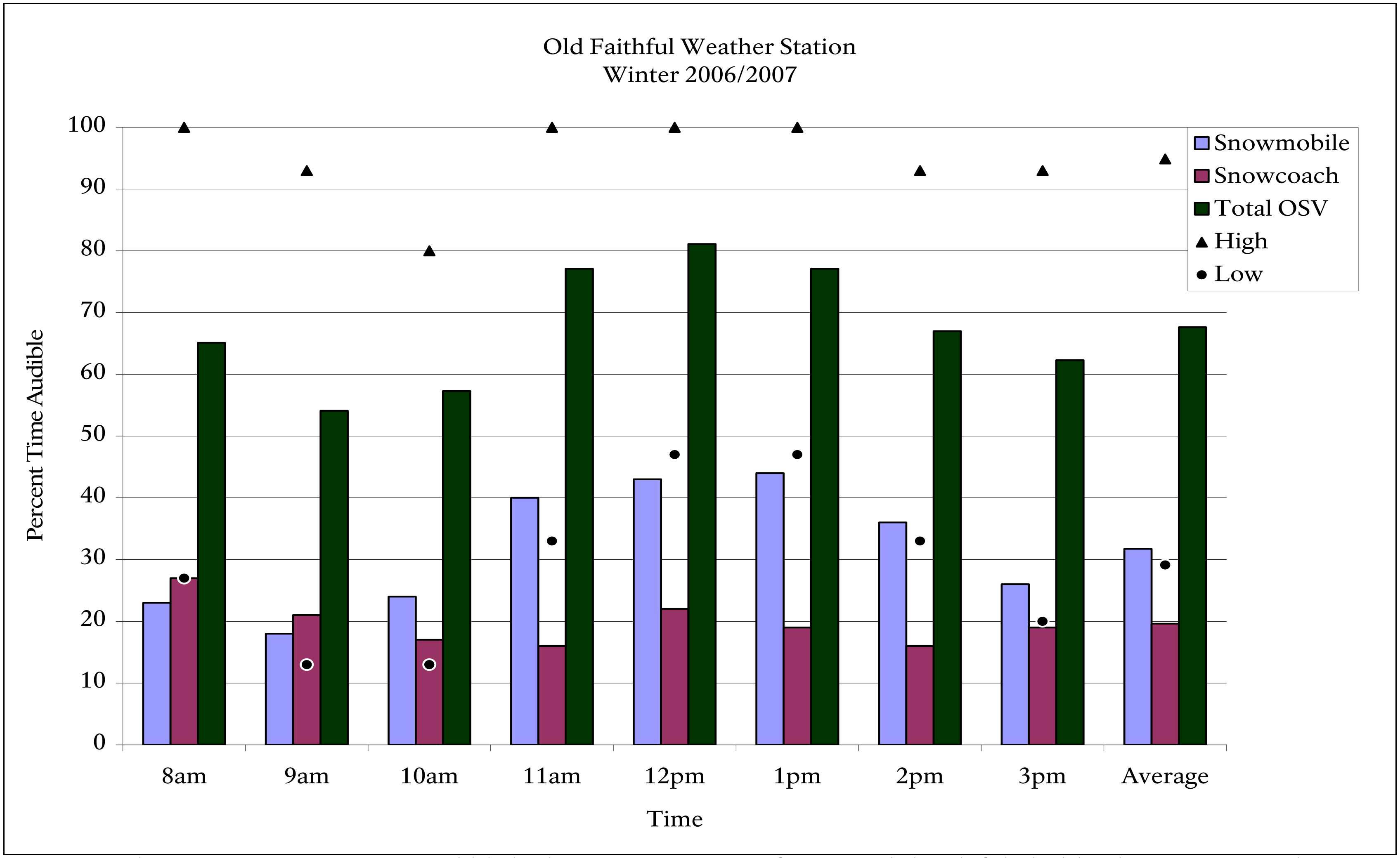



**Figure 3**. The average percent time audible by hour (8 am-4 pm) of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 20 December 2006 to 11 March 2007.

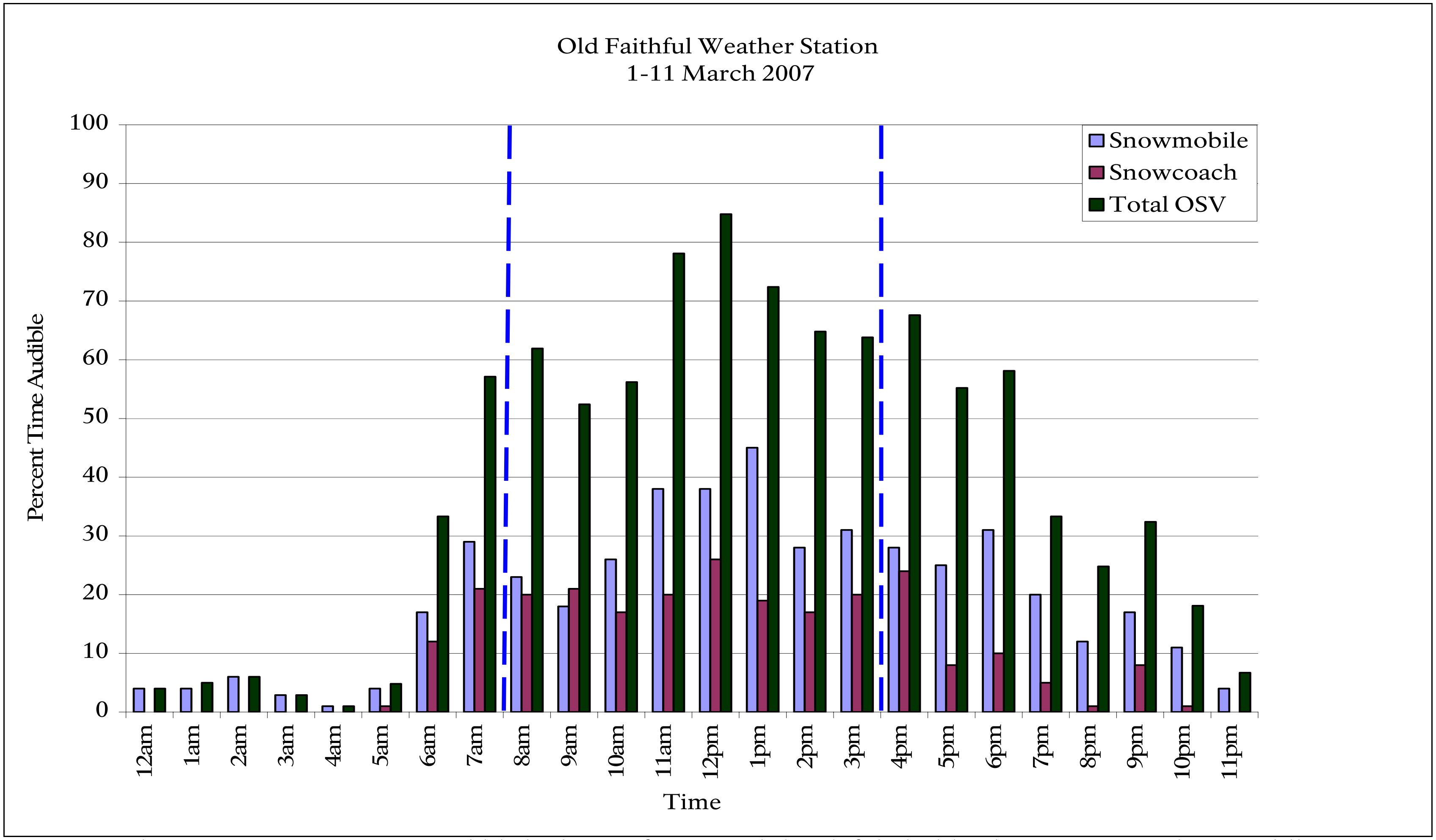



**Figure 4**. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar) at Old Faithful Weather Station, Yellowstone National Park 1-11 March 2007. The winter use analysis time period is between the vertical dashed lines. Note OSVs were audible during every hour of the average 24 hour day.

*Madison Junction 2.3*

Madison Junction 2.3 monitoring site was located 100 feet off the West Entrance Road 2.3 miles west of Madison Junction in a travel corridor soundscape management zone. Acoustic data were collected over the entire winter use season of 2006-2007 (Fig. 5) and 2005-2006, and during the Presidents Day Weekends of 2005, 2004, and 2003 (Appendix F). Quiet riffles of the Madison River were constantly audible when not masked by the sounds of wind, swans, coyotes, wolves, ducks, geese, ravens, and oversnow vehicles. Snowmobiles and snowcoaches were audible for an average of 59% of the time during the entire winter use season (Fig. 5). This compares to 55% last winter. The audibility of OSVs during the last two winters exceeded the WUP audibility threshold of 50% for travel corridors (Table 1). The OSV percent time audible exceeded 50% for 25 (71%) of 35 days analyzed during the winter 2006-2007 (Fig. 5). Wind speed was associated with the audibility of OSVs at this site. OSVs were less audible on days with more wind due to the masking effect of wind on the distant and faint OSV sounds.

Oversnow vehicles were audible for 71% of the day during Presidents Day Weekend (Fig. 5). The variable OSV audibility during Presidents Day Weekend during the past five years is a result of the very small sample size of two days.

The hourly pattern follows a bimodal distribution (Fig. 6) documenting the pulse of OSVs passing by the site in the morning on the way into the park and in the afternoon on the way back to West Yellowstone. Figure 6 also shows that many of the OSVs cannot be distinguished as a snowmobile or a snowcoach. This indicates that many OSVs were audible over long distances because nearby OSVs can usually be identified.

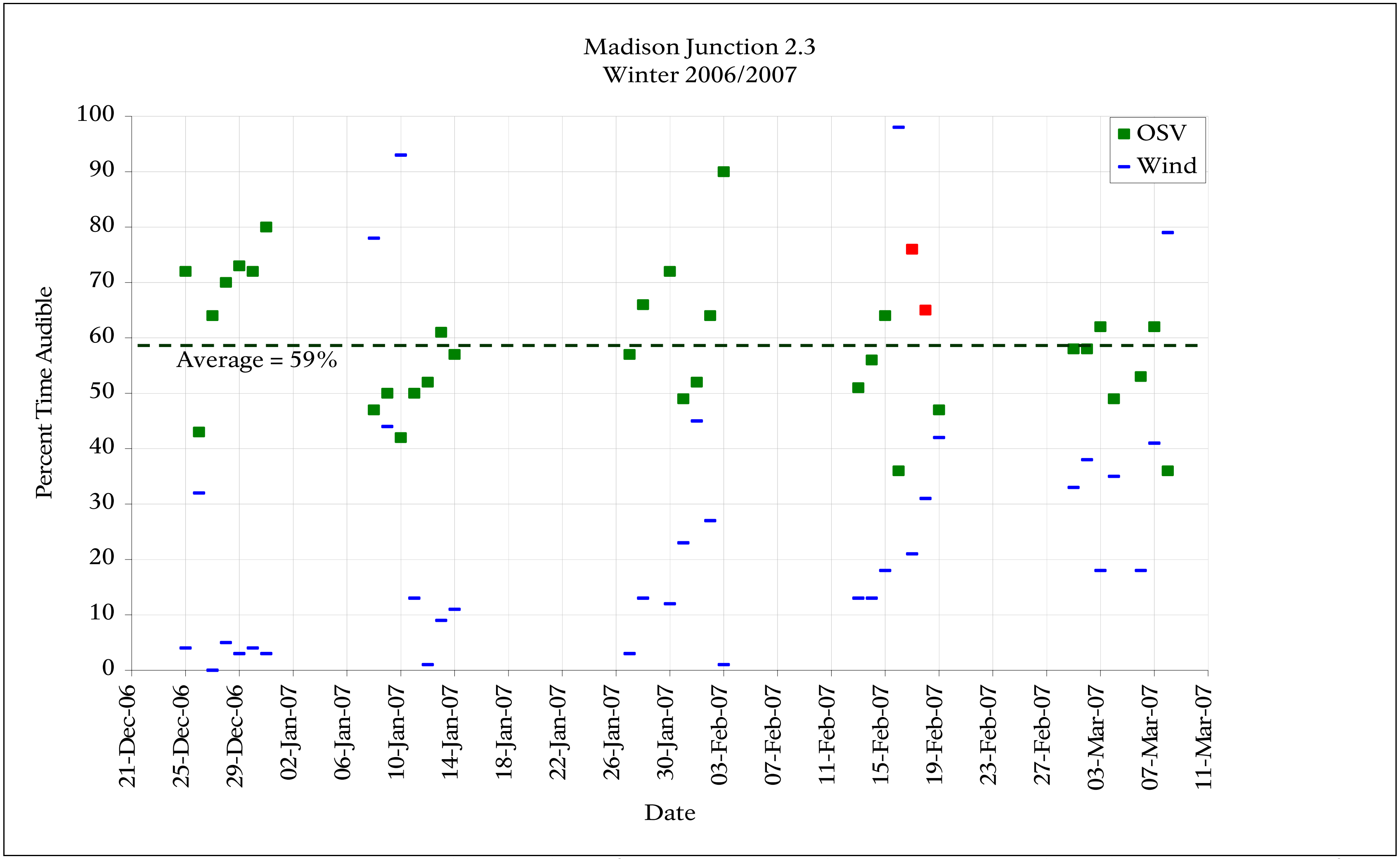



Figure 5. The average percent time audible by date of snowmobiles and snowcoaches, and wind at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 20 December 2006-11 March 2007. Red squares indicate OSV numbers over Presidents Day Weekend for 2007.

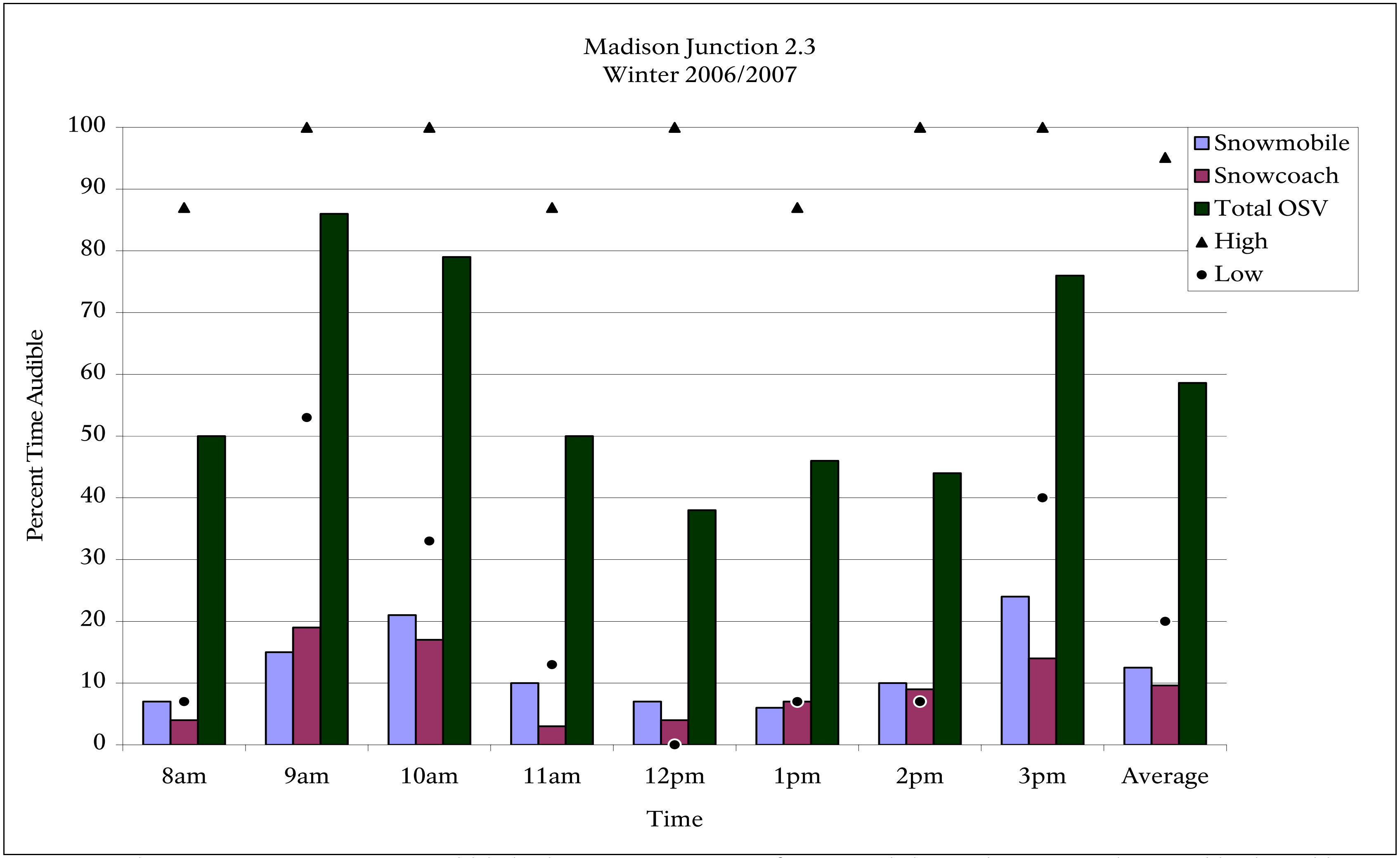



**Figure 6**. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches, and high and low OSV values at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 20 December 2006- 11 March 2007.

*Spring Creek 2*

Spring Creek 2 monitoring site was chosen to represent a travel corridor between the south entrance and Old Faithful. This site was ½ mile from the Spring Creek location monitored last season. Contrary to the site name, no creek sounds were audible at Spring Creek 2. Popping trees, coyotes, wolves, many chickadees and other birds, wind, and snowfall were audible along with oversnow vehicles. The average percent time audible for all OSVs was 44% (Fig. 9). There was a high degree of variability among days at this site mainly a result of a strong association with wind. Days with little wind had high OSV audibility and days with considerable wind masked distant, but otherwise audible OSVs. This site experienced considerable wind during a higher proportion of days than any of the other four monitoring sites (Fig. 9).

The expected travel corridor bimodal pattern is again shown by the hourly percent time audible (Fig. 10). This pattern is weaker at locations farther from the originating areas at the park's entrances and stronger nearer the park entrances. The site also demonstrates the distance that OSVs were audible as shown by the large proportion of OSVs that could not be more specifically identified due to the distance. OSVs are audible at greater distances at sites with the lowest ambient sound levels.

See Appendix D for additional information about the soundscape at this and other sites.

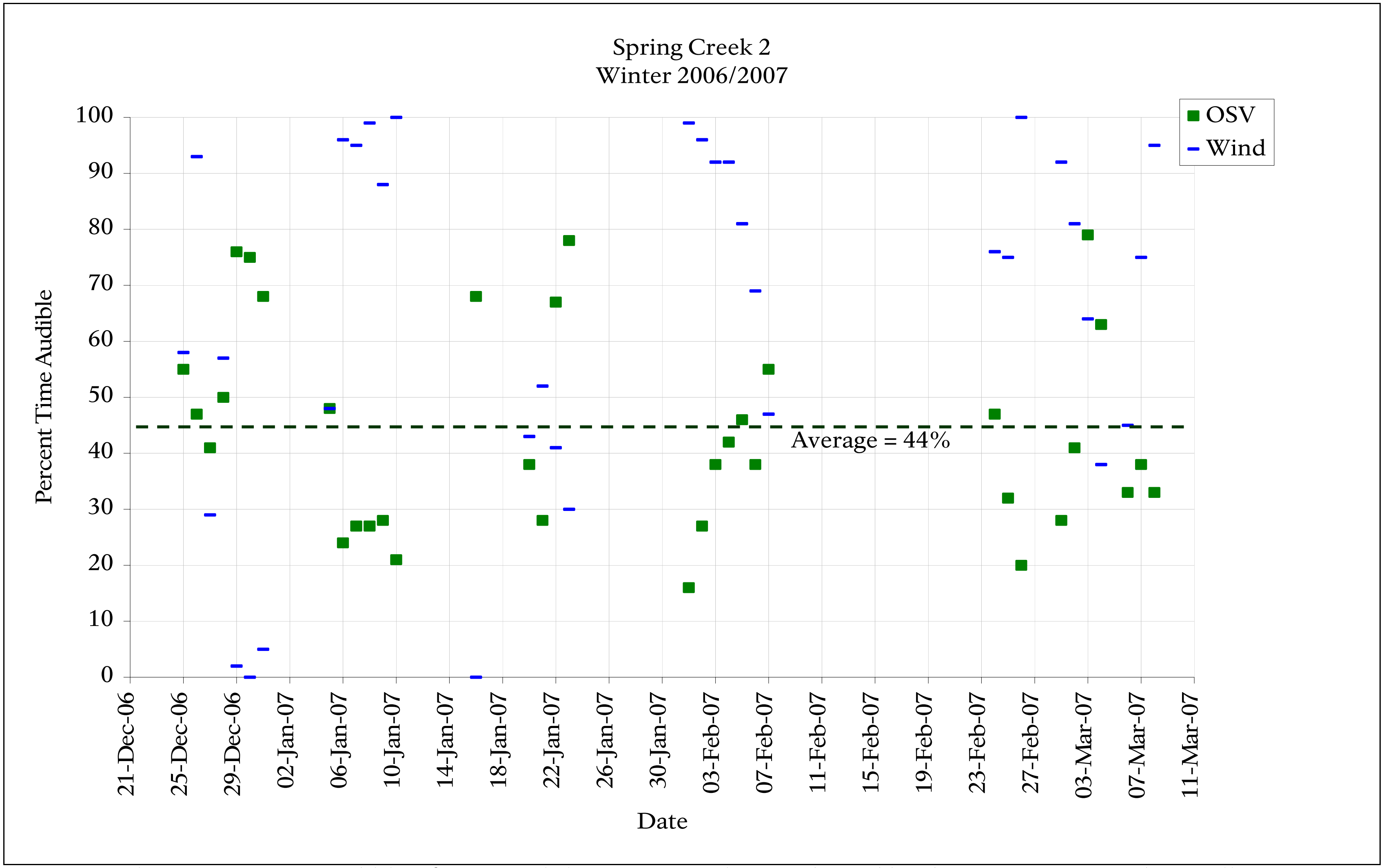



**Figure 9.** The percent time audible of snowmobiles, snowcoaches, and wind by date at Spring Creek 2, Yellowstone National Park, (8 am-4 pm), 20 December 2006-11 March 2007.

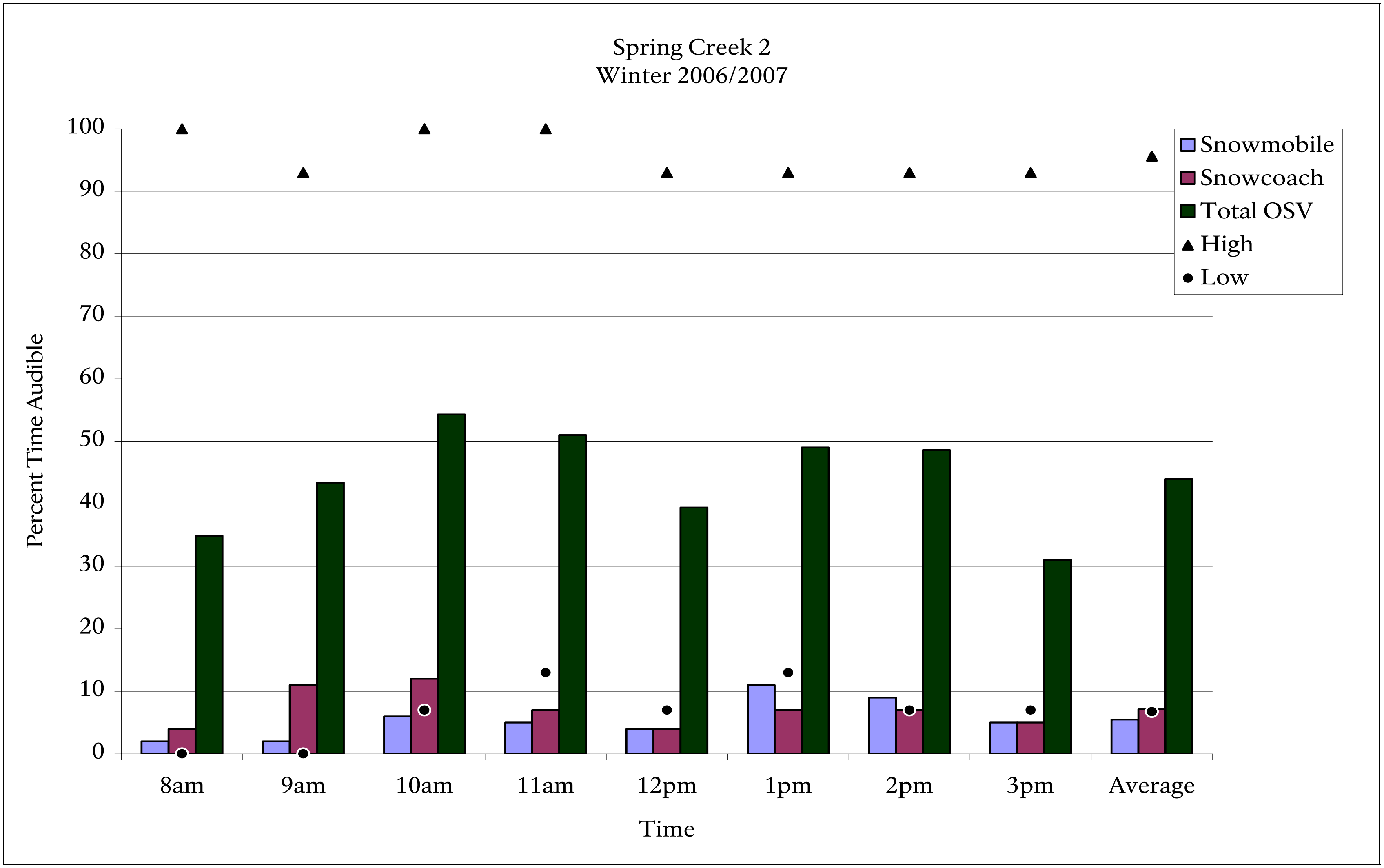



**Figure 10.** The percent time audible of snowmobiles, snowcoaches by date at Spring Creek 2, Yellowstone National Park, (8 am-4 pm), 20 December 2006-11 March 2007.

*Mud Volcano*

Although this site was located 100 feet from the groomed road along a travel corridor near Mud Volcano, natural sounds defined the soundscape. Rapids of the Yellowstone River and geothermal activity were constantly heard unless masked by wind, ravens, coyotes, people's voices, or oversnow vehicles. The natural ambient sound level was about 30 dBA, about twice as loud as at all other sites. These river and geothermal sounds masked distant OSV sounds that would have otherwise been audible. Oversnow vehicles were audible 26% of the time between 8 am and 4 pm (Fig. 7) at the Mud Volcano monitoring site. Mud Volcano is a destination for guided snowmobile groups that travel to the less visited segments of the Grand Loop Road. Few snowcoaches were audible at this site (Fig. 7).

The percent time audible by hour had a distribution with an audibility peak at the noon hour (Fig. 8). This is consistent with locations far from a park entrance.

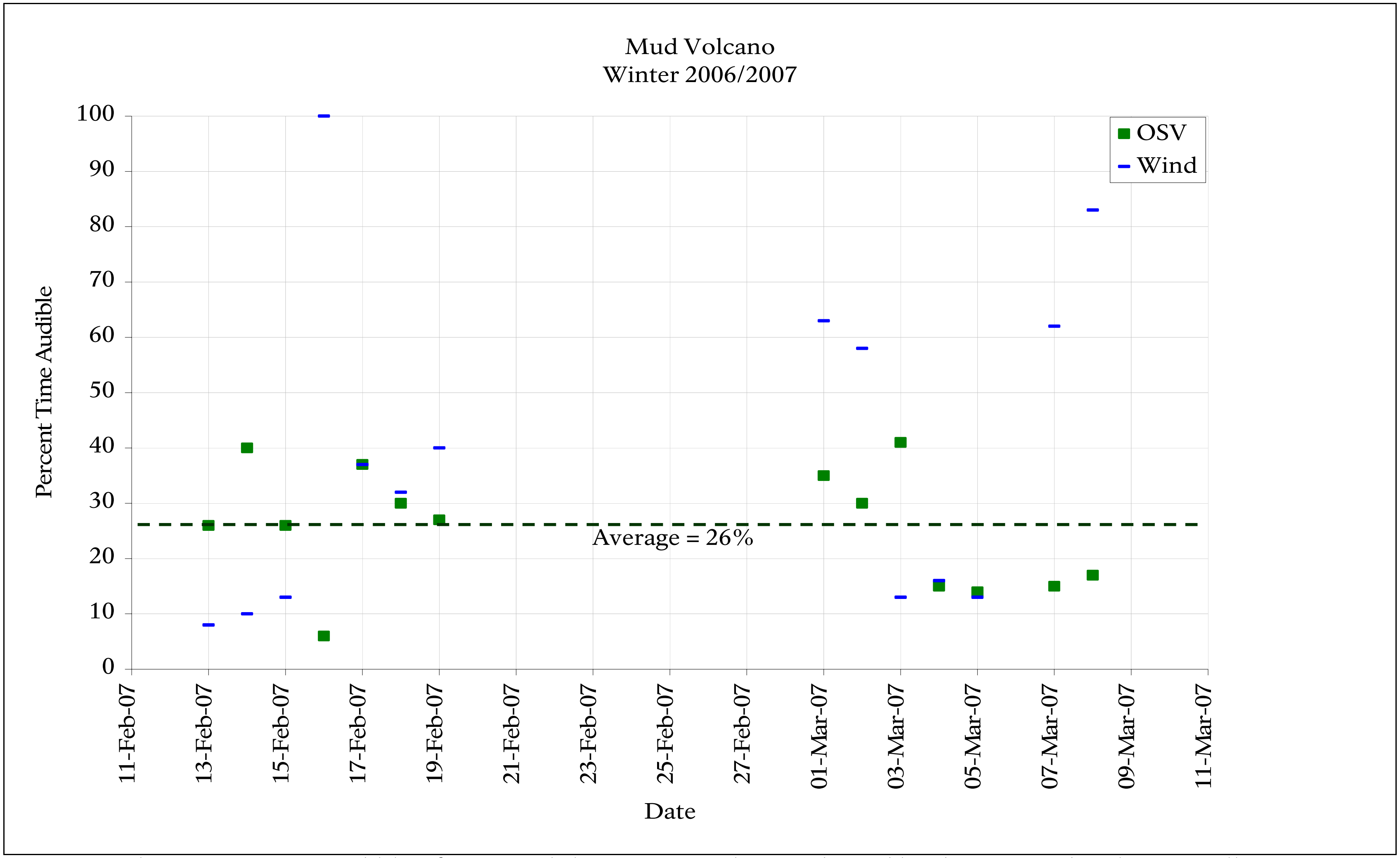



**Figure 7.** The percent time audible of snowmobiles, snowcoaches, and wind by date at Mud Volcano, Yellowstone National Park, (8 am-4 pm), 9 February-11 March 2007.

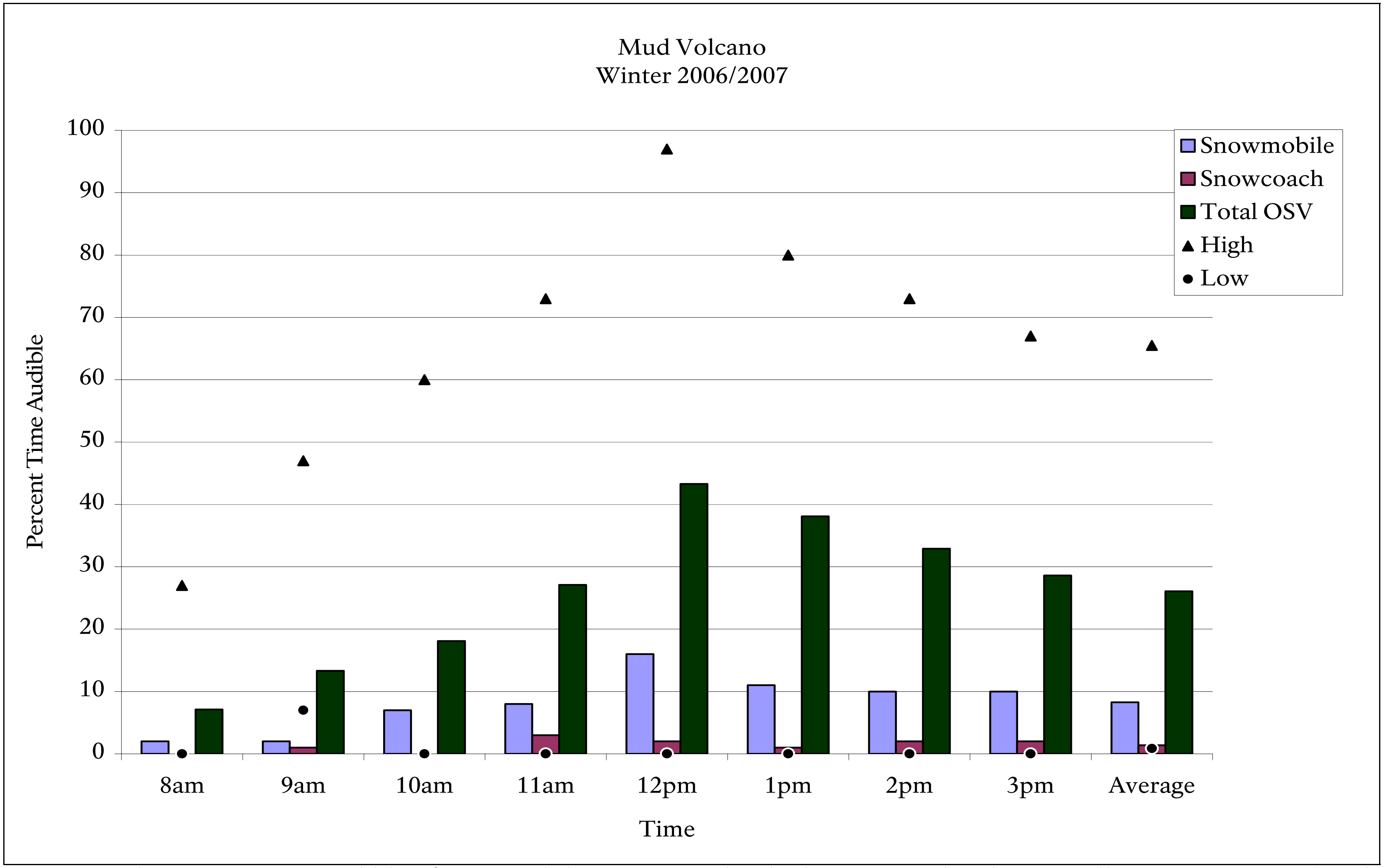



**Figure 8.** The percent time audible of snowmobiles, snowcoaches by hour at Mud Volcano, Yellowstone National Park, (8 am-4 pm), 9 February-11 March 2007.

*Fern Lake*

The sound monitor at Fern Lake was in the backcountry northeast of Lake about 8 miles from the nearest OSV corridor (the road between Lake and Canyon) (Fig 1, #17). No OSV sounds were audible at this site, but wind, snowfall, ducks, magpies, ravens, geese, and other birds were frequently audible and several coyotes and wolves were recorded. The only non-natural sound sources were aircraft. Jets and propeller planes were audible on average for 6% of the period 8 am-4 pm during the winter use period.

Event Analysis:

The loudest sound events at each site were recorded and later identified. NPS snow groomer events were often one of the loudest events, but mainly occurred outside the WUP day (8 am to 4 pm). Event threshold triggers were maintained just above the level that prevented wind from creating the majority of the events. Event analysis augments audibility analysis by distinguishing the loudest sound sources from those less loud. Table 4 lists the loudest sound sources by number of occurrences and percent of all loud sources. Madison Junction 2.3 was 100 feet from a 35 mph zone and Spring Creek 2 a 45 mph zone; both in travel corridors. The Spring Creek 2 monitoring site recorded many of the loud Bombardier snowcoaches at cruising speed. The Madison Junction 2.3 monitor recorded several 2 stroke snowmobiles. Few to no loud motorized events occurred at the Mud Volcano and Fern Lake monitoring sites and therefore are not included here. The Old Faithful Weather Station site was 230 feet from the nearest motor route. The distance and slow OSV speeds caused few loud events to be recorded there.

**Table 4**. The number and percentage of sound events exceeding user-defined thresholds of sound level and duration at two locations in Yellowstone National Park (8 am to 4 pm). These represent the loudest sounds recorded at these locations during the 2006-2007 winter use season.

| | Spring Creek 2[1] | | Madison Junction 2.3[1] | |
|---|---|---|---|---|
| Sound Source | Number | % | Number | % |
| Snowmobile | 2 | 0.6 | 11 | 11.5 |
| Snowcoach | 346 | 99.1 | 81 | 84.3 |
| Oversnow Vehicle | 1 | 0.3 | | |
| Snow Groomer | | | 2 | 2.1 |
| Natural | | | 2 | 2.1 |
| Total | 349 | 100 | 96 | 100 |

[1] Thresholds were set at 70 dBA/1 second or 60 dBA/10 seconds

Sound Levels:

Sound level analysis is not as easily understood as audibility analysis. The WUP thresholds apply only to oversnow vehicles (snowmobiles and snowcoaches), but occasional natural sounds (wind, bird vocalizations, etc.) and other motorized sounds (aircraft, snow groomer, etc.) may be as loud as oversnow vehicle sounds during some periods and in some locations. Therefore the sound levels for oversnow vehicles should be separated from other sounds before evaluating them against sound level thresholds. Unfortunately there is yet no automated process for separating different sound sources from the sound level data and the manual separation of oversnow vehicles sound levels during the nearly 24 million seconds of data collected in this study this past winter is practically impossible. Therefore the interpretation of sound levels becomes more difficult. In the developed areas and along travel corridors the loudest sounds during 8 am-4 pm were almost always from oversnow vehicles, but as distance increased from these motorized areas natural sounds were sometimes louder than oversnow vehicle sounds.

The 2004 Temporary Winter Use Plans Environmental Assessment defined oversnow vehicles having maximum sound levels greater than 70 dBA in developed areas and travel corridors and greater than 45 dBA in backcountry areas as a major adverse effect (Table 1). To compare to previous winter use plans' standards and thresholds see Appendix C. To introduce decibel levels Table 5 has typical sound levels of some common sound sources.

In addition to maximum sound levels ($L_{max}$) other common acoustical metrics such as the energy level equivalent or energy average ($L_{eq}$) and the $L_{50}$ and $L_{90}$ sound level exceedance metrics are useful to provide a better understanding of the soundscape. See Appendix B for a glossary of acoustic terms.

$L_{eq}$ is the level (in decibels) of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. $L_{eq}$ depends heavily on the loudest periods of a time-varying sound. $L_{eq}$ of an intruding source, though, is inadequate to fully characterize the intrusiveness of the source. The effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the sound level of the "background", usually the natural ambient sound levels.

$L_{50}$ and $L_{90}$ are the sound levels (L), in decibels, exceeded *x* percent of the time. The $L_{50}$ value represents the sound level exceeded 50 percent of the measurement period. $L_{50}$ is the same as the median; the middle value where half the sound levels are above and half below. The $L_{90}$ value represents the sound level exceeded 90 percent of the time during the measurement period. $L_{90}$ is a useful measure of the natural sounds because in park situations, away from developed areas, the lowest 10 percent of sound levels are less likely to be affected by non-natural sounds. Put another way, non-natural sounds in many park areas are likely to affect the measured sound levels for less than 90 percent of the time. The $L_{50}$ or the median is also not affected by a few loud sounds as is the $L_{eq}$ and therefore provides another useful measure of the sound environment.

Returning to the complications of evaluating these sound level results, the $L_{90}$ is the NPS (and other organizations) standard for use as an analog to the natural ambient sound level in locations other than those most heavily impacted from non-natural sounds. However, using $L_{90}$ or other $L_x$ metrics as the natural ambient sound level is inappropriate in locations with constant non-natural sounds such as at the Old Faithful Weather Station monitoring site. In very quiet areas the $L_{90}$ may overestimate the true natural ambient sound level because of limitations of the instrument noise floor threshold. The noise floor, the lowest level the acoustic equipment could measure, was approximately 19-20 dBA (see Table 5 for reference levels). The quietest sound levels in YNP are below this noise floor (Burson 2006) so the lowest documented measurements in this report likely overestimate the actual minimum sound levels. While there is no easy solution to these problems, the disadvantages of any one metric can be reduced by using multiple sound level metrics.

Sound levels depend on the distance from the sound source, the presence of natural sounds, as well as non-sound source variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover. These various factors influenced day to day sound levels measured at each sound monitoring location. No two days were identical, but patterns were regularly observed and differences among monitoring locations are apparent.

**Table 5**. Approximate decibel levels of commonly known sound sources. Note that decibels are logarithmic and a difference of 10 decibels is perceived as a doubling or halving of loudness. The range of audible sound levels for humans is generally considered from 0 – 130 dBA. Sound sources in the table below that have no associated distance listed are at typical operational distances.

| dBA | Perception | Outdoor Sounds | Indoor Sounds |
|---|---|---|---|
| 130 | Painful | | |
| 120 | Intolerable | Jet aircraft at 50 ft | Oxygen torch |
| 110 | Uncomfortable | Turbo-prop at 200 ft | Rock Band |
| 100 | | Jet flyover at 1000 ft | Blood-curdling scream |
| 90 | Very noisy | Lawn mower/Nearby Thunder | Hair dryer |
| 80 | | Diesel truck 50 mph at 50 ft | Food blender |
| 70 | Noisy | 2-stroke snowmobile 30 mph at 50 ft | Vacuum cleaner |
| 60 | | 4-stroke snowmobile 30 mph at 50 ft | Conversation |
| 50 | Moderate | Croaking Raven flyover at 100 ft | Office |
| 40 | | Snake River at 100 ft | Living room |
| 30 | Quiet | Summer backcountry | Quiet bedroom |
| 20 | Very quiet | Winter backcountry | Recording studio |
| 10 | Barely audible | Below standard noise floor | |
| 0 | Limit of audibility | Quiet winter wilderness | |

*Old Faithful Weather Station*

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 9-12 for the winter 2006-2007. The Old Faithful monitor was 230 feet from the entrance/exit road used by oversnow vehicles. The 2004 WUP impact definition thresholds assume a distance of 100 feet from the sound source in developed areas. In a free-field, sound levels decrease by approximately 6 dBA for every doubling of the distance from the source to the receiver. Therefore to compensate for the additional distance from the sound monitor using the reasonable assumption that the maximum sound levels originate from oversnow vehicles traveling 230 feet from the sound monitor, adding an additional 6 dBA to the maximum sound levels shown in the following figures would approximate the levels at 100 feet. This assumption is reasonable for only $L_{max}$ because it is likely that lower sound levels commonly originate from areas other than the exit road such as the parking lot, the main road, the other sources near the sound monitor, etc. and therefore the distance is unknown and thus the correction factor is also unknown.

Because the loudest sounds have the most influence on $L_{eq}$ values, oversnow vehicle sounds largely determined the $L_{eq}$ value at Old Faithful. Oversnow vehicles were often used outside the period covered by the WUP measurement periods, even in the middle of the night (Fig. 4).

The lowest sound levels (about 25 dBA) were determined by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 9, 10, 11, and 12).

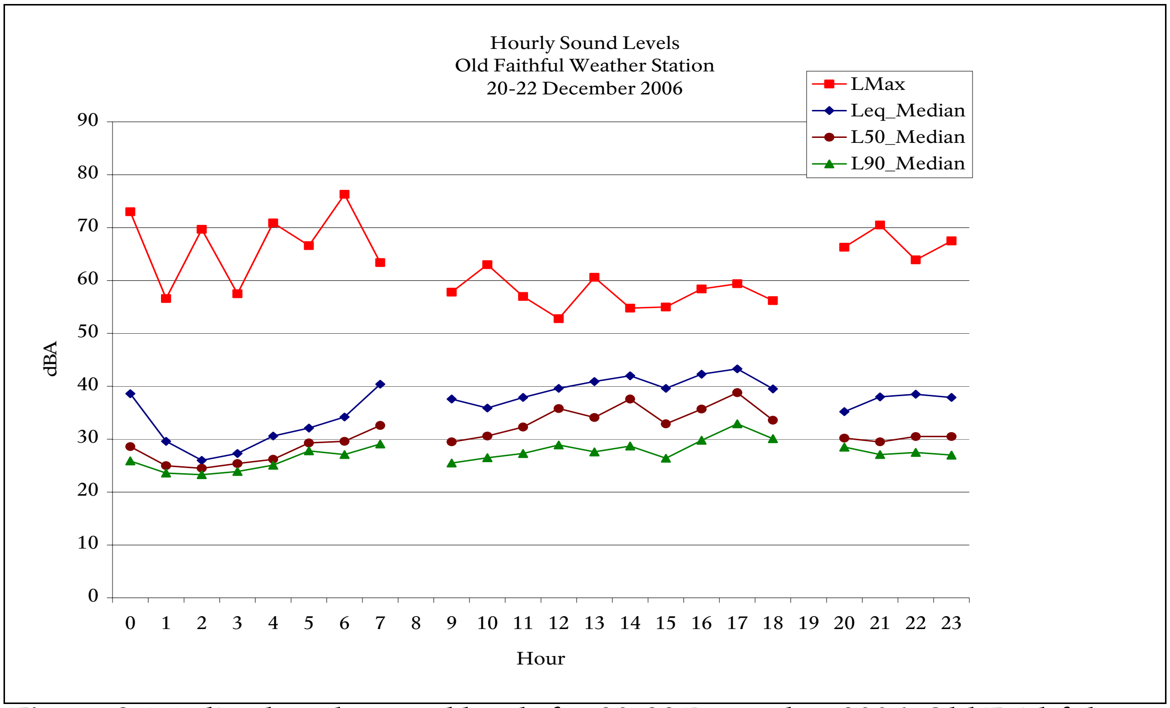



**Figure 9**. Median hourly sound levels for 20-22 December 2006, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. $L_{max}$ is the highest sound level measured during the measurement period. Missing hours are due to site visits and those with too few seconds. (n=55 hours)

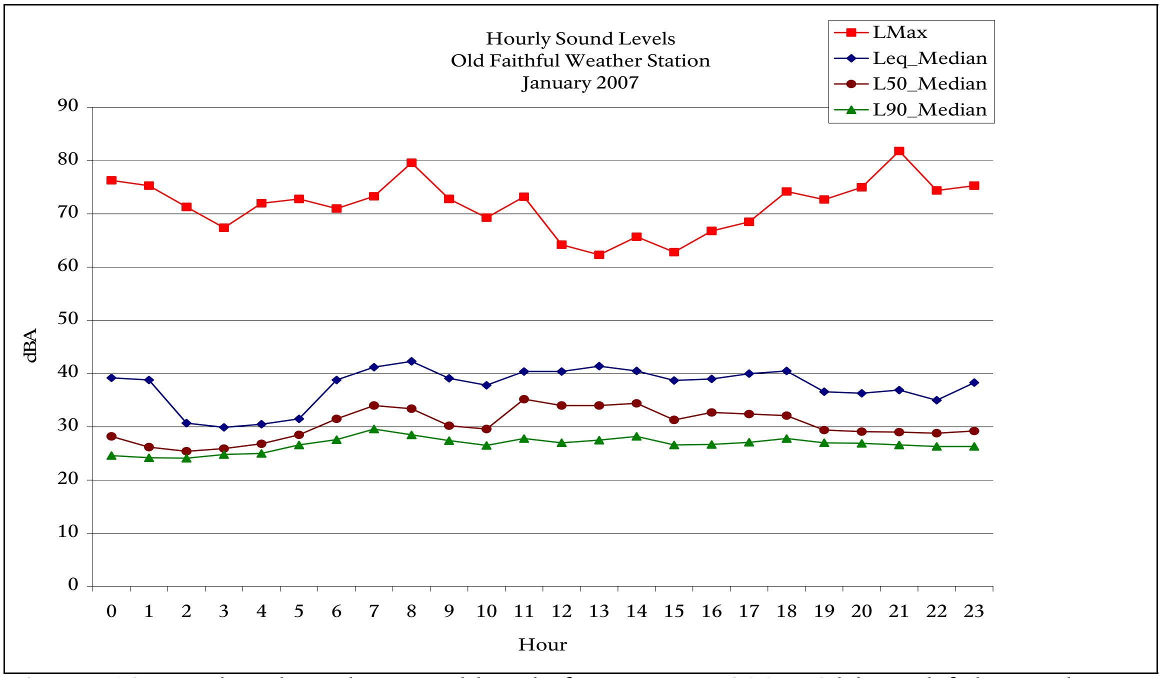



**Figure 10**. Median hourly sound levels for January 2007, Old Faithful Weather Station, Yellowstone National Park. See Fig. 9 caption for more details. (n=637 hours)

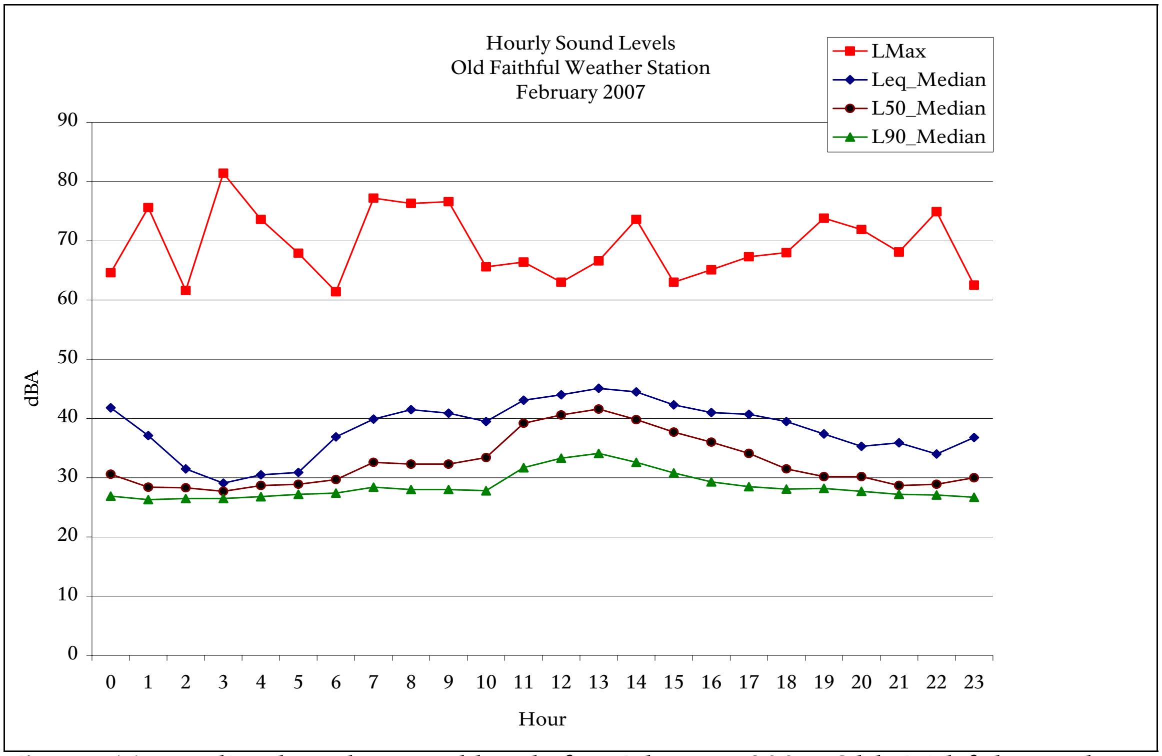



**Figure 11**. Median hourly sound levels for February 2007, Old Faithful Weather Station, Yellowstone National Park. See Fig. 9 caption for more details. (n=666 hours)

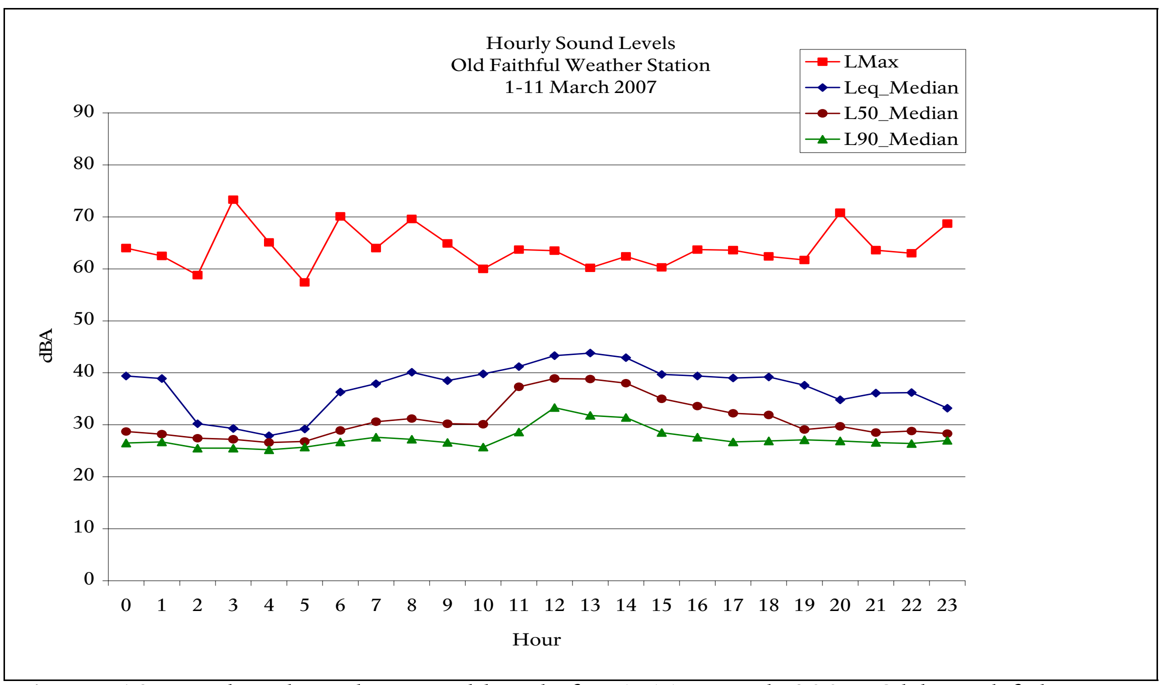



**Figure 12**. Median hourly sound levels for 1-11 March 2007, Old Faithful Weather Station, Yellowstone National Park. See Fig. 9 caption for more details. (n=262 hours)

*Madison Junction 2.3*

Consistent with previous seasons, the median hourly sound levels from oversnow vehicles at Madison Junction 2.3 exceeded the 2004 WUP maximum sound level impact definition threshold (70 dBA) during most of the hours of the measurement day (8 am-4 pm) in 2006-2007 (Fig. 13-16). The median hourly $L_{eq}$ (the average sound energy) follows the predictable bimodal pattern with peaks mid-morning and late afternoon consistent with OSV traffic patterns (Fig. 13-16). The lowest median hourly $L_{90}$ values are constrained by riffles of the nearby Madison River (Fig. 13-16). Wind generally increases during the afternoons and this is reflected in the median hourly $L_{50}$ and $L_{90}$ values (Fig. 13-16).

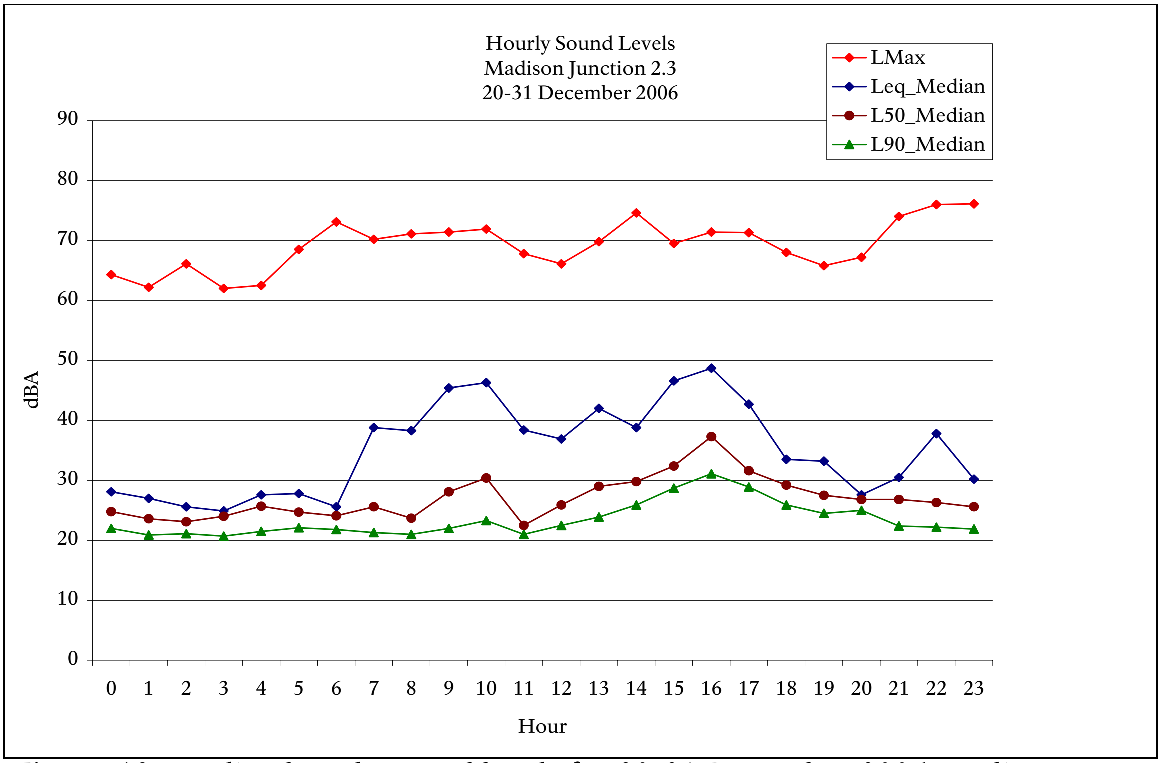



**Figure 13**. Median hourly sound levels for 20-31 December 2006 Madison Junction 2.3, Yellowstone National Park. See Fig. 9 caption for more details. (n=263 hours)

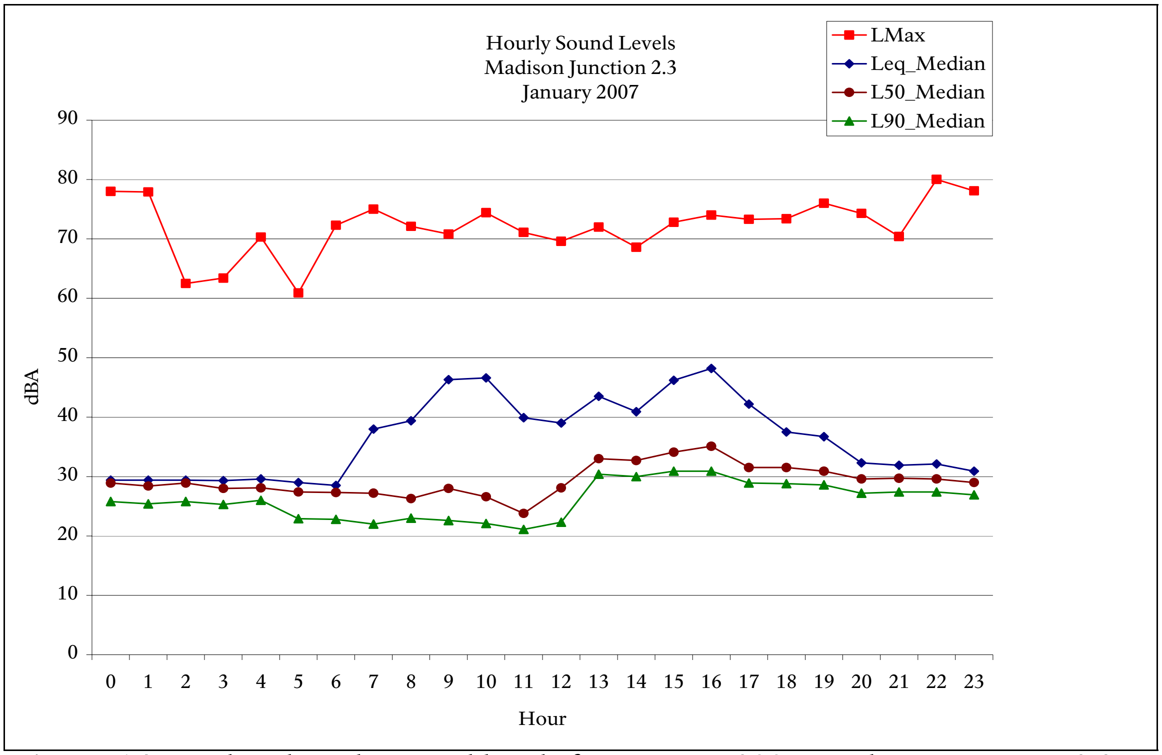



**Figure 14**. Median hourly sound levels for January 2007 Madison Junction 2.3, Yellowstone National Park. See Fig. 9 caption for more details. (n=714 hours)

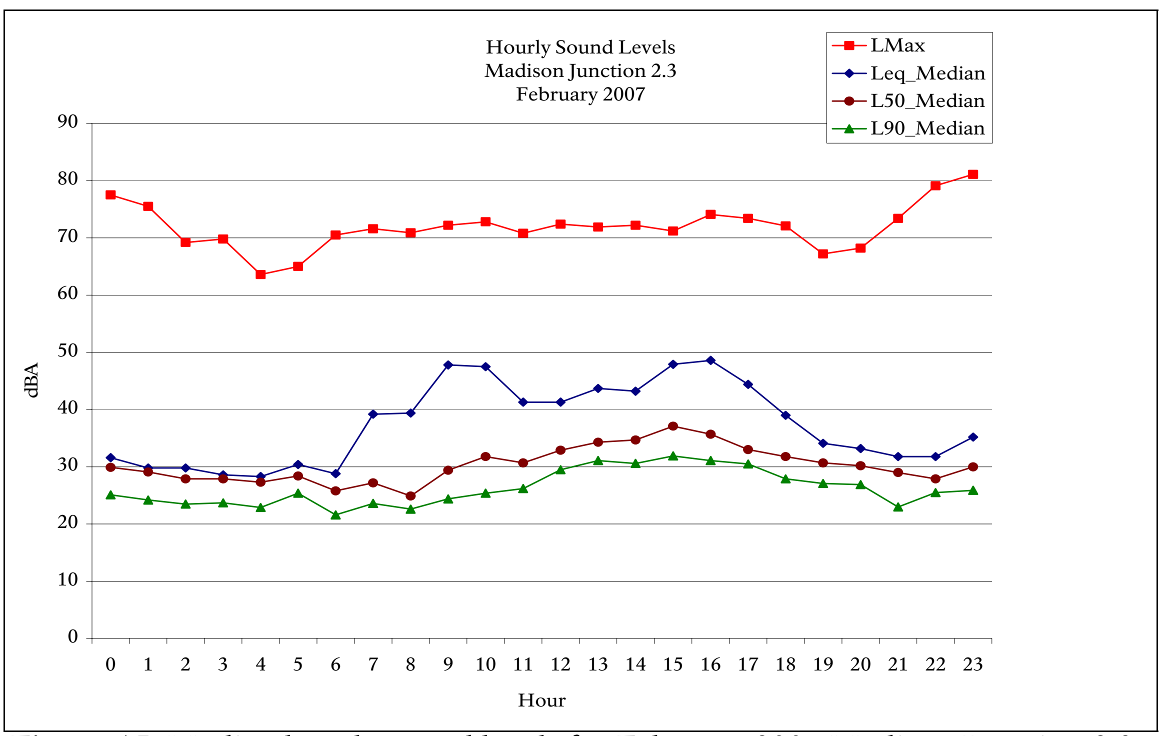



**Figure 15**. Median hourly sound levels for February 2007 Madison Junction 2.3, Yellowstone National Park. See Fig. 9 caption for more details. (n=653 hours)

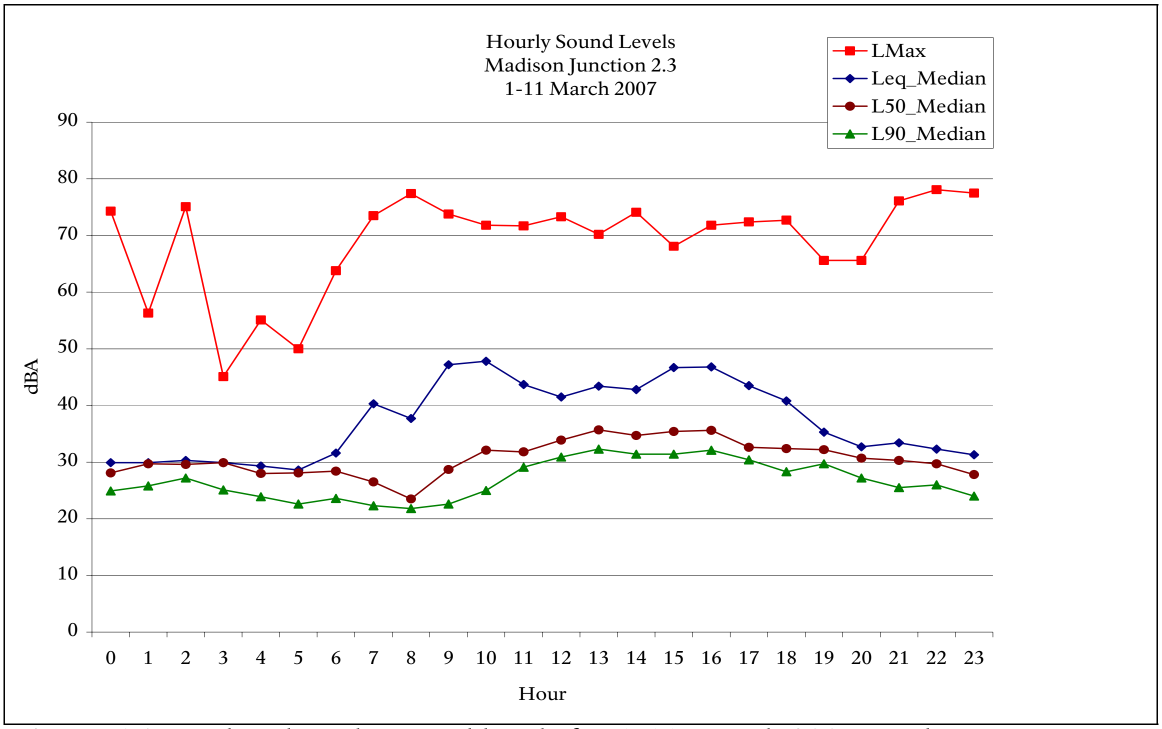



**Figure 16**. Median hourly sound levels for 1-11 March 2007 Madison Junction 2.3, Yellowstone National Park. See Fig. 9 caption for more details. (n=245 hours)

*Spring Creek 2*

The Spring Creek 2 monitoring site was along a travel corridor east-southeast of Old Faithful and away from any developed areas. It was within a forest of large lodgepole pines ½ mile east of last season's Spring Creek in an area that had sun exposure to charge solar panels.

The tight clustering of $L_{90}$, $L_{50}$, and $L_{eq}$ during the night indicates that this area was consistently very quiet with few loud events (Fig. 17-20). Wind and oversnow vehicles increased the sound levels during the day (Fig. 17-20). High exhaust Bombardier snowcoaches and conversion van snowcoaches traveled at cruising speeds passed this monitoring site. The Bombardiers were generally loudest, but most snowcoaches had higher sound levels than snowmobiles. Overall, snowcoaches were the loudest non-natural sources of sound during the day and snow groomers were the loudest non-natural source of sound outside the WUP period, 8 am – 4 pm.

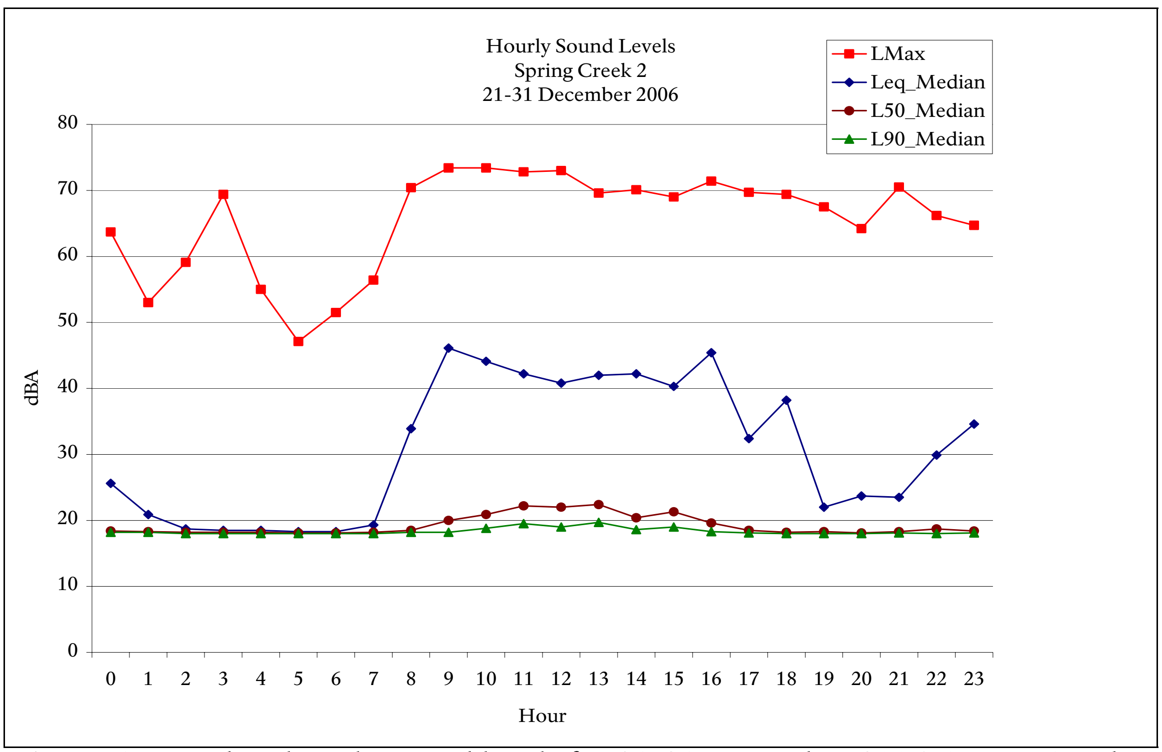



**Figure 17**. Median hourly sound levels for 21-31 December 2006, Spring Creek 2, Yellowstone National Park. See Fig. 9 caption for more details. (n=246 hours)

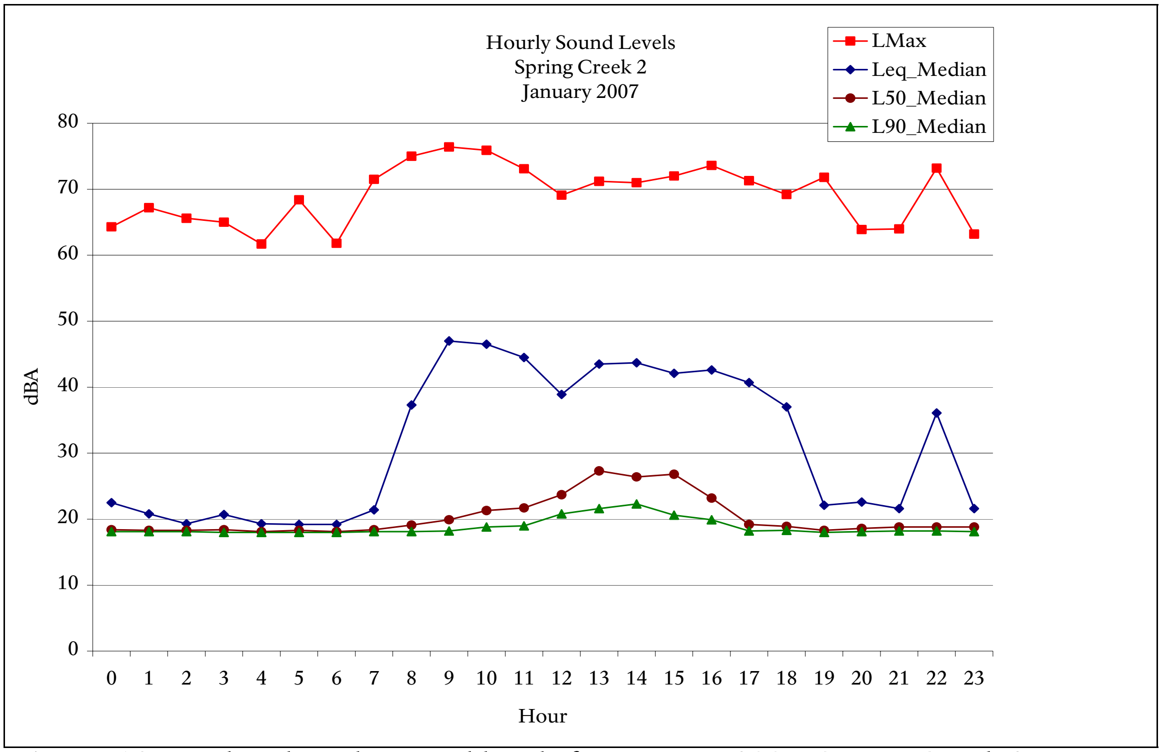



**Figure 18**. Median hourly sound levels for January 2007, Spring Creek 2, Yellowstone National Park. See Fig. 9 caption for more details. (n=639 hours)

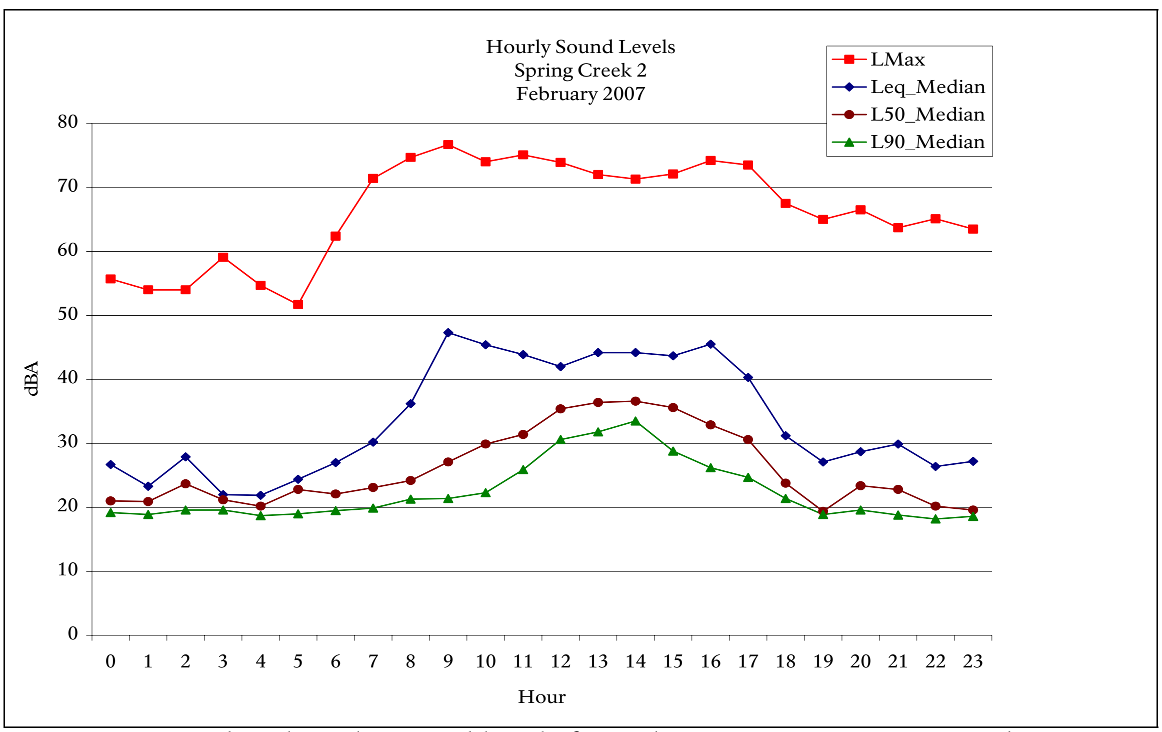



**Figure 19**. Median hourly sound levels for February 2007, Spring Creek 2, Yellowstone National Park. See Fig. 9 caption for more details. (n=384 hours)

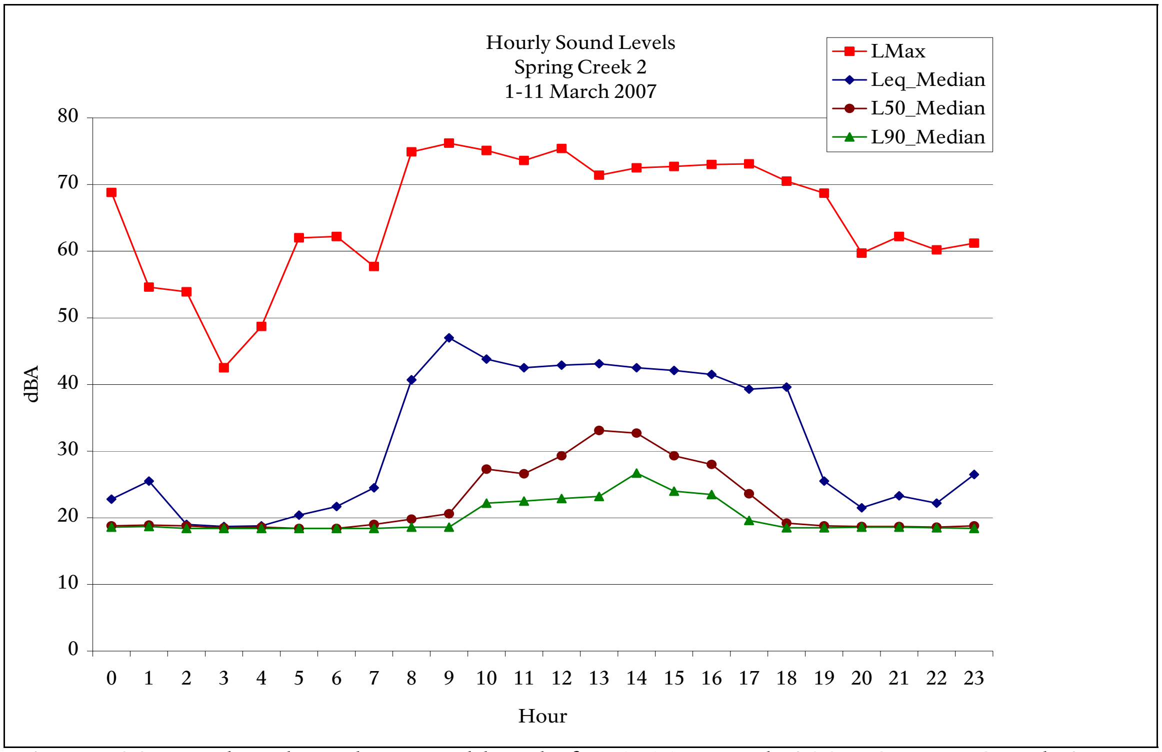



**Figure 20**. Median hourly sound levels for 1-11 March 2007, Spring Creek 2, Yellowstone National Park. See Fig. 9 caption for more details. (n=262 hours)

*Mud Volcano*

The Mud Volcano monitoring site was located across the road from the parking area at Mud Volcano. Thermal activity and Yellowstone River sounds were constantly present.

The tight clustering of the median hourly $L_{90}$, $L_{50}$, and $L_{eq}$ during the night indicates that not many sounds were present other than the river and thermal sounds around 30 dBA (Fig. 21-22). The increase in the median hourly sound levels during the day reflects the increased afternoon wind speed.

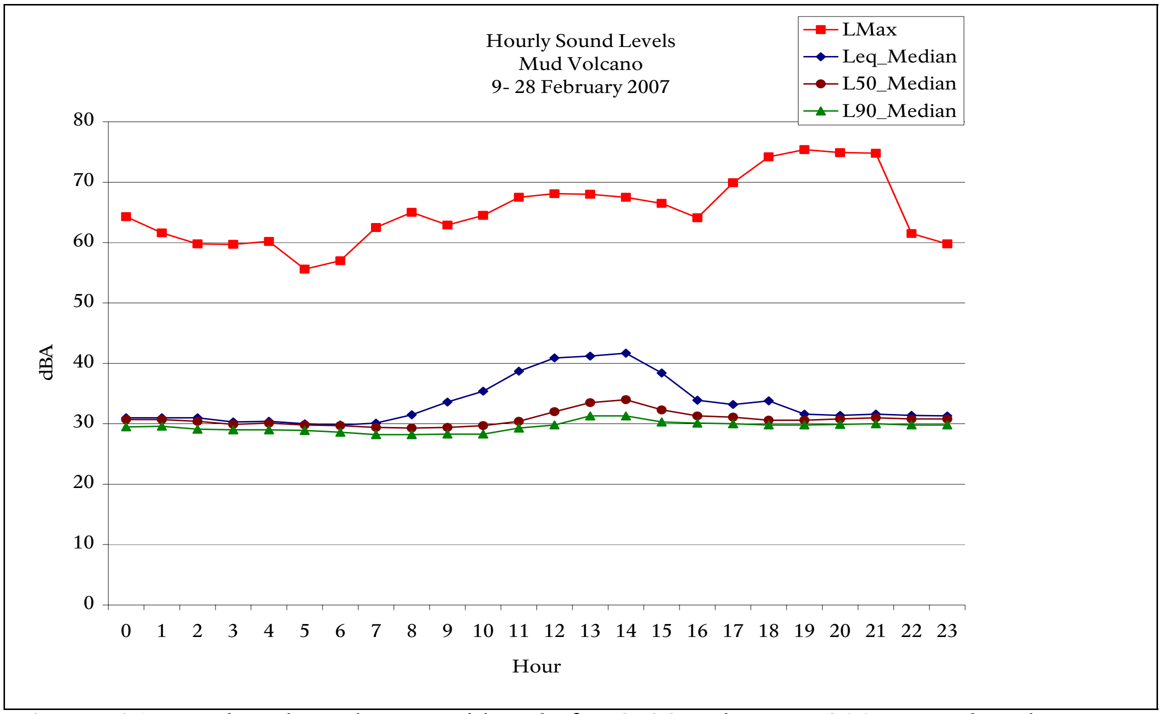



**Figure 21**. Median hourly sound levels for 9-28 February 2007, Mud Volcano, Yellowstone National Park. See Fig. 9 caption for more details. (n=462 hours)

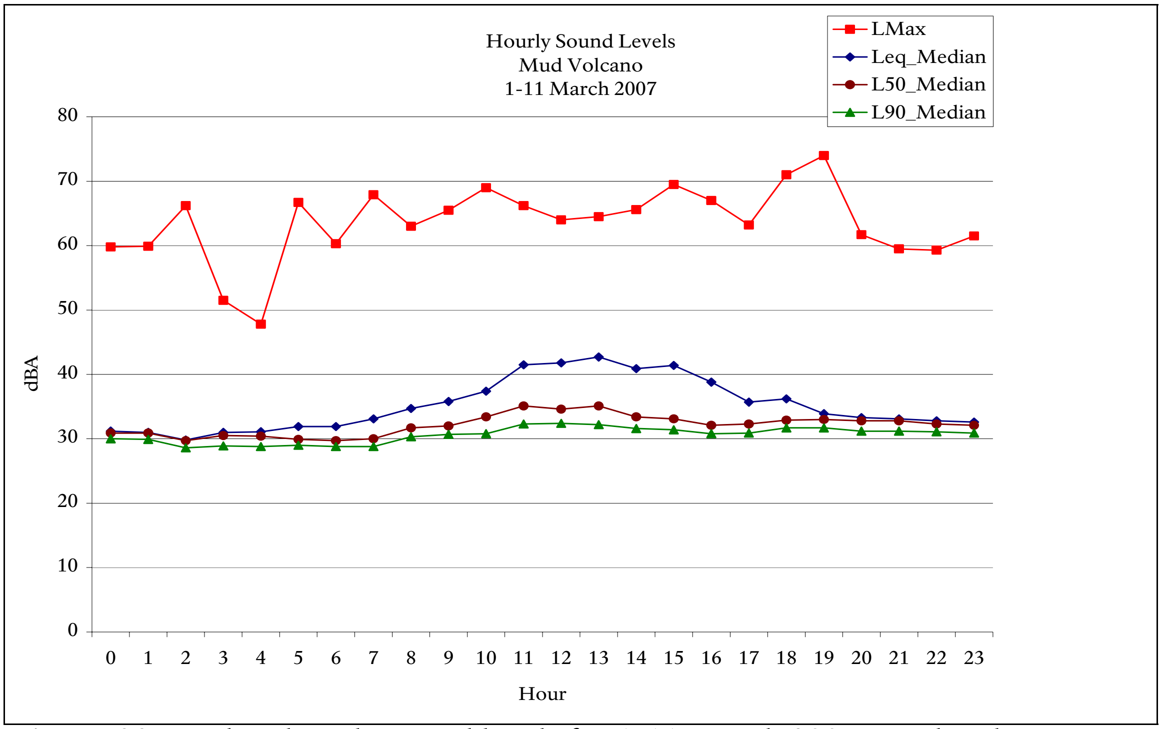



**Figure 22**. Median hourly sound levels for 1-11 March 2007, Mud Volcano, Yellowstone National Park. See Fig. 9 caption for more details. (n=261 hours)

*Fern Lake*

The sound monitor at Fern Lake was in the backcountry northeast of Fishing Bridge about 8 miles from the nearest OSV corridor (the road between Fishing Bridge and Canyon) (Fig 1, #17). No OSV sounds were audible at this site. The only non-natural sound sources were aircraft. The tight clustering of $L_{90}$, $L_{50}$, and $L_{eq}$ during most of the day indicates that this area was consistently very quiet with few loud events (Fig. 23-24). Wind, bird vocalizations, and aircraft increased the sound levels during the day (Fig. 23-24).

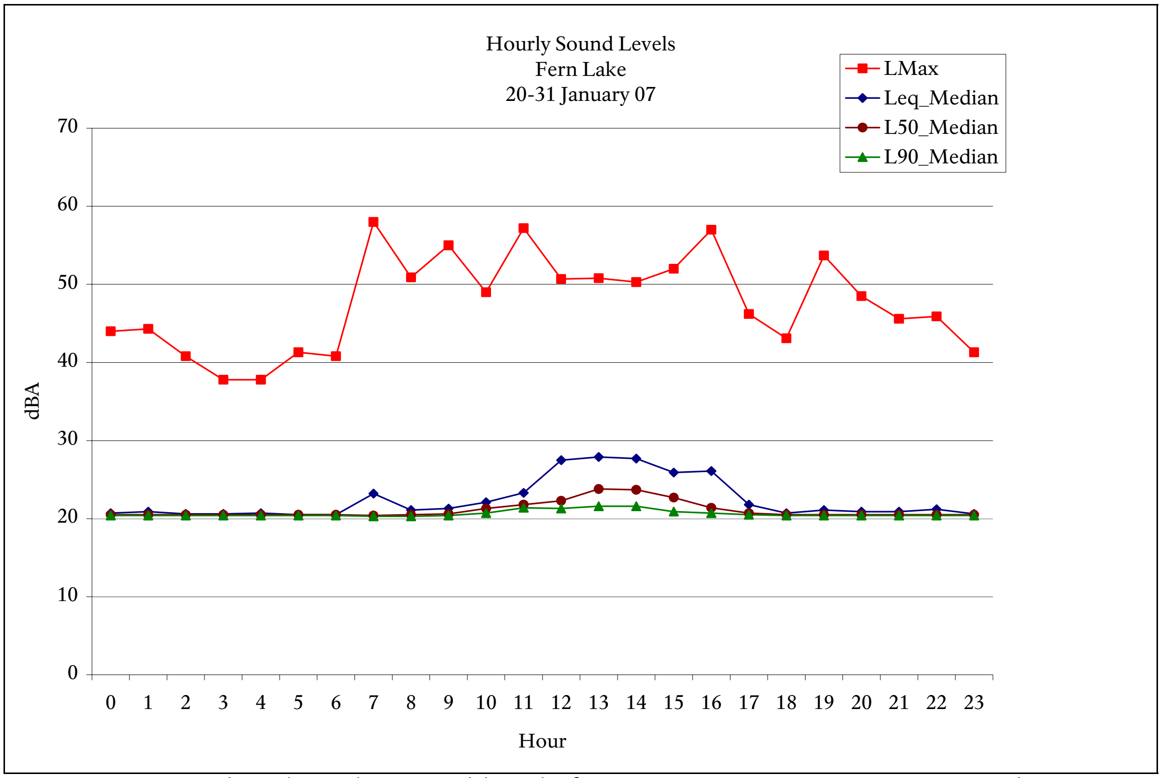



**Figure 23**. Median hourly sound levels for 20-31 January 2007, Fern Lake, Yellowstone National Park. See Fig. 9 caption for more details. (n=272 hours)

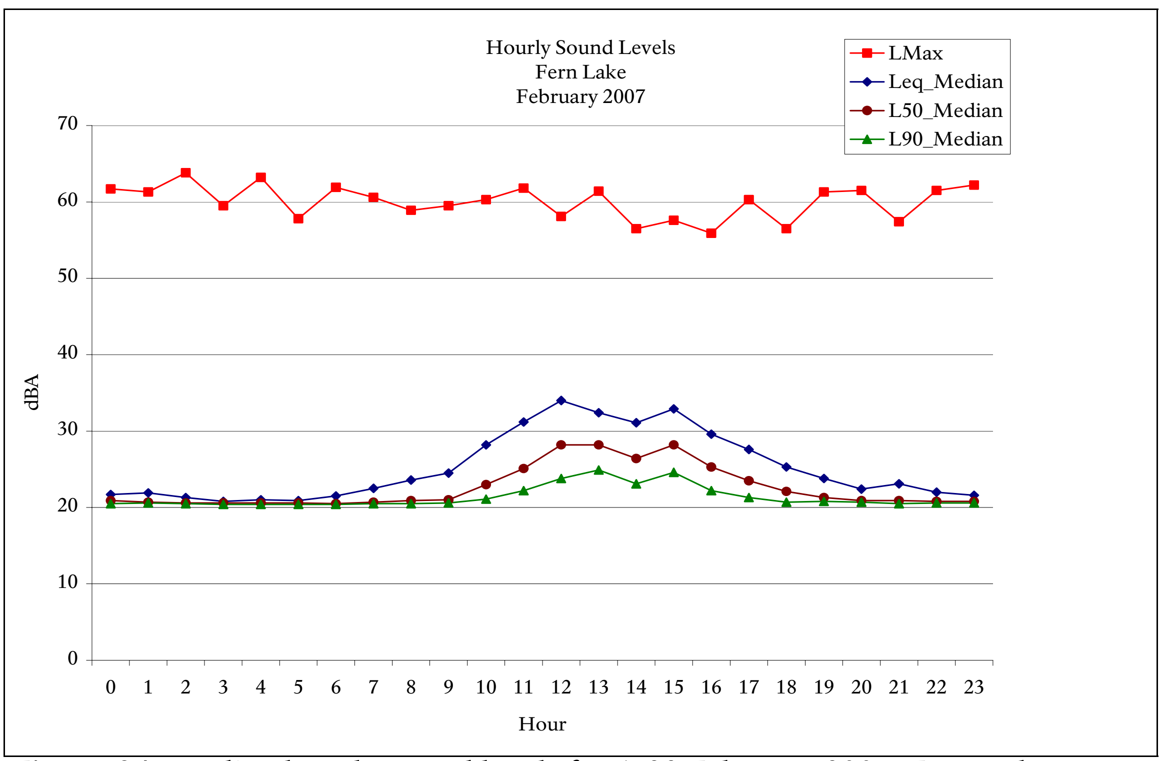



**Figure 24**. Median hourly sound levels for 1-23 February 2007, Fern Lake, Yellowstone National Park. See Fig. 9 caption for more details. (n=547 hours)

**Recommendations:**

1- Sound levels and audibility from motorized oversnow vehicles should be reduced.

Although substantial improvements have been made by the switch from 2-stroke to 4-stroke snowmobiles and by the guiding requirement, the WUP $L_{max}$ sound levels and audibility thresholds are being exceeded at developed areas and travel corridors. Improvements to snowcoach sound emissions should be made, especially to the older and louder Bombardier snowcoaches. Phasing out 2-stroke snowmobiles used by employees, contractors, and concessionaires would reduce the sound levels and audibility of those user groups. Minimizing administrative OSV use at all times, especially during the night, would minimize impacts to the natural soundscape.

Sound levels and audibility from motorized oversnow vehicles also can be reduced by lowering speed limits, especially in popular areas for visitors such as near thermal features and around Old Faithful. Decreasing the speed limit on all roads would reduce oversnow vehicle impacts on the natural soundscape and would have the added benefit of encouraging sightseeing while traveling. Reducing unnecessary idling and rapid acceleration, and other driver behavior modifications would also minimize sound impacts from oversnow vehicles. Reducing the total number and reducing single and small groups of OSVs operating on YNP roads would also minimize their impact to natural soundscapes. Soundscape awareness training should be developed and presented to operators of motorized oversnow vehicles. The NPS should work with manufacturers, equipment operators, and concessionaires to reduce further sound levels of oversnow vehicles.

2- Audibility and sound level metrics standards and thresholds should continue to be used for impact definitions in planning documents. These standards should include percent time audible and maximum sound level. A new acoustical metric should be developed to improve impact assessment.

The ability to determine if the acoustic impacts of winter oversnow use are meeting the management objectives require that quantitative acoustical standards and thresholds are defined. Acoustical monitoring and the understanding of natural soundscapes in parks are rapidly improving. The requirements for specific impact definitions and associated standards parallel these changes. It is essential to use easily understood, and more importantly, measurable and meaningful standards and thresholds (such as percent time audible and maximum sound levels). A new metric that combines percent time audible, sound energy and percent of park area impacted by a sound source should be pursued.

3- Continue to monitor both audibility and sound levels.

The combined sound level and audibility data gathered for this study provide useful acoustical information about YNP's soundscapes and the level of impact from oversnow vehicles. Collecting audibility data and identifying sources of sounds is important to characterize natural soundscapes and the non-natural acoustical impacts. Evaluating oversnow impacts on the natural soundscape requires sound source identification. In addition to information on audibility, the sound level of intruding non-natural sounds is an important aspect of soundscape monitoring. Collecting continuous 1/3 octave band frequency sound levels allows all standard acoustical metrics to be calculated. Collecting acoustical data provides the means to validate results from computer acoustical modeling.

4- Conduct acoustical experiments to fill in gaps to better understand the impacts of oversnow vehicles on the natural soundscape.

YNP can better manage the impacts of oversnow vehicles on the natural soundscape with answers to specific questions such as how group size and type of oversnow vehicle affects sound levels and audibility, what is the distance to limits of audibility in different habitat types (acoustic zones) and weather conditions, the effects of road surface on sound levels and audibility, how speed influences percent time audible and sound levels, and other currently unanswered questions. Acoustic computer modeling can begin to answer some of these questions but needs to be validated by actual field data collection. Studies are ongoing that provide information to better understand the relationship between oversnow vehicle numbers and their impact on the natural soundscape.

5- Increase the number of sampling locations and sample duration, and continue sampling beyond the winter season.

The representativeness of the acoustical dataset will improve as the number of sampling locations is increased within and among management zones. A full range of locations provides a more comprehensive evaluation of YNP's natural soundscape and the impacts from oversnow vehicles. The need for additional sites should be tempered by the disadvantages of short data collection periods. That is, it is usually preferable to gather multiple weeks of data at one location rather than shorter duration periods at multiple locations. Data collected during non-winter seasons allow comparisons to other seasons and provides additional information of YNP's natural and non-natural soundscapes. Year-round data collection started during the spring of 2005 and should be continued.

## Acknowledgements:

Skip Ambrose (NPS Natural Sound Program-retired) developed an initial study plan that led to this project. Thanks to the generosity of Mary Hektner, Mary Kay Woodin was able to cheerfully brave the winter conditions and conduct and enter into a computer database most of the 2007 OSV observational classification sessions. I thank Brian Teets and Mary Donovan for adding a number of OSV classification sessions to their already busy schedule. The Old Faithful Ranger staff, especially Bonnie Schwartz, and the Old Faithful Maintenance staff provided logistical and much appreciated help on this project. Robin Long expertly coded most of the digital recordings. Her assistance was invaluable. Skip Ambrose and Chris Florian provided ongoing assistance on many aspects of this project, including help on the low noise measurements. Mike Donaldson provided computer software. The NPS Natural Sound Program also provided analysis software. This report heavily relies on last year's report and John Sacklin, Denice Swanke, Mike Yochim, Robin Long, and Margaret Wilson provided valuable editorial comments on one or both reports. Last year's report also was improved by a technical review by the Office of the Governor, State of Wyoming.

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Harris Miller Miller and Hanson, Inc. 2002. Draft supplemental technical report on noise: winter use plan final supplemental environmental impact statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr. Memorial Parkway. Report No. 295860.360. October 2002.

## Appendix A: Instrument and Setup Protocol

AC Output Weighting
For digital recordings using the AC output of the SLM, the AC output weighting shall be set to Flat, with appropriate gain setting for SLM or recording device in use

Attended Data Logging
Observers will conduct attended data logging approximately 50 m (150 feet) from the sound level meter, microphone, and/or tape recorder to ensure that field personnel can move about and conduct whispered conversations without influencing the measured sound. Observations during attended logging will be recorded on a standardized NPS data sheet.

Bird Spike
Spikes made of wire or hard plastic which prevents birds from perching on microphones and windscreens shall be used.

Cables and Wiring
All cables and wiring shall be secured to prevent any sound which might be created in windy conditions (due to wiring hitting other objects).

Calibrator
A calibrator whose performance is essentially independent of off-reference atmospheric conditions (such as the B & K Model 4231) is to be used.

Instrument Clocks
All clocks associated with the sound measurement effort shall be coordinated with GPS (Global Positioning System) time. This includes sound level meters, data loggers (notebook computer, Personal Digital Assistant-PDA), and all digital watches used during data logging. For long-term measurements, all clocks will be synchronized with GPS time at the beginning of the measurement period, and time differences with GPS time will be noted at the end of the measurement period. Acoustic data collected during the measurement period will be adjusted to correspond with GPS time.

Microphone type
A Type 1 random incidence microphone is recommended for acoustic measurements in wilderness settings. Microphones can be either polarized or pre-polarized.

Monitor Location
The microphone/pre-amplifier/windscreen shall be placed in a location representative of the habitat/acoustic zone under study. The microphone diaphragm should be placed 1.1 m to 1.5 m above the ground surface and

oriented vertically (microphone grid facing the sky).

Solar Panels
All solar panels should be placed in a location with as little shading as possible and at least .3 m (12 inches) above the ground.

Sound Level Meter
Sound level meters shall be Type I or better and should perform true numeric integration and averaging in accordance with ANSI S1.4-1983.

Time Weighting
Sound level meters shall be set to fast exponential time weighting.

Windscreen
Windscreens which are effectively acoustically transparent (less than +/- 0.5 dB effect over the frequency span of interest) shall be used.

## Appendix B: Glossary of Acoustic Terms

**Acoustics**
The science of sound.

**Ambient Sound, Existing**
All sounds in a given area (includes all natural and all non-natural (human-caused) sounds).

**Ambient Sound, Natural**
The natural sound conditions found in a given area, including all sounds of nature. The natural ambient sound level of a park is comprised of the natural sound conditions which exist in the absence of mechanical, electrical, and other non-natural sounds. Some generally unobtrusive non-natural sounds (talking quietly, walking) may be part of the natural soundscape, but not those generated by mechanical, electrical, or motorized means. Natural ambient sounds are actually composed of many natural sounds, near and far, which often are heard as a composite, not individually. In an acoustic environment subjected to high levels of non-natural sounds, natural sounds may be masked. Natural ambient sound is considered synonymous with the term "natural quiet," although "natural ambient sound is more appropriate because nature is not always quiet.

**Ambient Sound, Non-natural**
Ambient sounds attributable to non-natural sources (mechanical, electrical, and other non-natural sources). In a national park setting, these sounds may be associated with activities that are essential to the park's purpose, they may be a by-product of park management activities, or they may come from outside the park.

**Appropriate Sounds**
Sound conditions defined as appropriate for an area in national parks, such as a specific management zone. Other appropriate sounds, not natural in origin, are those types of sounds which are generated by activities directly related to the purposes of a park, including resource protection, maintenance, and visitor services. Natural sounds are not only appropriate, but are part of the park's resource base to be protected and enjoyed by the visiting public.

**Appropriate Sound Level**
Appropriate sound levels in a given area of a park are determined based on mandates in the Organic Act, establishment legislation, or other laws pertinent to the specific purposes and values associated with the park. This determination takes the form of management zone objectives for soundscape, as well as measurable indicators and standards for sound.

**Attenuation**
The reduction of sound intensity by various means (e.g., air, humidity and porous materials).

**Area of Audibility**
The area within which a specific sound or sounds is audible.

**Audibility**
Audibility is the ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, other simultaneous interfering sounds or stimuli, and by the frequency content and amplitude of the sound.

**Decibel**
A logarithmic measure of any measured physical quantity and commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic unit Pascal. The difference between the sound pressure for silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels. See also, Sound Level.

Doubling of Sound Pressure = 6 dB
Doubling of Sound Power = 3 dB
Doubling of Perceived Sound Level = 10 dB (approximately)

**Doppler Effect (or Shift)**
The apparent upward shift in frequency of a sound as a noise source approaches the receiver or the apparent downward shift when the noise source recedes.

**Energy Equivalent Sound Level (**$L_{eq}$**)**
The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. $L_{eq}$ depends heavily on the loudest periods of a time-varying sound. $L_{eq}$ of an intruding source by itself, though, is inadequate for fully characterizing the intrusiveness of the source. Research has shown that judgments of the effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the sound level of the "background," in this case, the sound level of the non-intruding sources, usually the natural ambient sound levels. $L_{eq}$ must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels (gusts of wind, birds, insects) may heavily influence (increase) its value, even though the sound levels are typically lower.

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

**Hearing Range (human)**
An average healthy young person can hear frequencies from approximately 20 Hz to 20000 Hz, and sound pressure levels from 0 dB to 130 dB or more (threshold of pain). The smallest perceptible change is 1 dB.

**Impact**
For environmental analysis, an impact is defined as a change at a receptor that is caused by a stimulus, or an action. In accordance with the CEQ regulations (40 CFR 1500-1508), direct and indirect impacts (environmental consequences) are to be described in an environmental document by assessing their type, magnitude, intensity, and duration. The significance of an impact is to be determined specifically in view of criteria provided in 40 CFR 1508.27, based on the outcome of these assessments. An assessment will take account of the short or long term nature of the impact, the extent to which it is either beneficial or adverse, whether it is irreversible or irretrievable, and, finally, its geographic and societal extent. Lastly, a resource impact is put in the context of all other past, present or reasonably foreseeable actions which affect the same resource, and its contribution to the total cumulative effect is to be disclosed. Under CEQ regulations, the term “impact” is synonymous with “effect” (40 CFR 1508.8).

**Loudness**
The subjective judgment of intensity of a sound by humans. Loudness depends upon the sound pressure and frequency of the stimulus. Loudness was defined by Fletcher and Munson (1933) as a physiological description of the magnitude of an auditory sensation.

**Masking**
The process by which the threshold of audibility for a sound is raised by the presence of another (masking) sound. A masking noise is one that renders inaudible or unintelligible another sound that is also present.

**Noise**
Traditionally, noise has been defined as unwanted, undesired, or unpleasant sound. This makes noise a subjective term. Sounds that may be unwanted and undesired by some may be wanted and desirable by others. Noise is sound, as defined in this document: a pressure variation, etc. In order to keep terms used in soundscape management as non-subjective as possible, sounds should be classified as either appropriate or inappropriate, rather than as “noise.” or “sound.” The appropriateness of any sound in a given area of a park will depend on a variety of factors, including the management objectives of that area.

**Noise-free Interval**
The period of elapsed time between human-caused sounds. The length of the continuous period of time during which only natural sounds are audible. Though

little research has been conducted to relate how this measure correlates with ecological functioning, visitor judgments or with common experiences in park settings, it should provide a reasonable measure of the existence and availability of periods with only natural sounds. It is also a metric that requires no acoustics knowledge to be meaningful.

**Octave**

The interval between two frequencies having a ration of 2 to 1. For acoustic measurements, the octaves start a 1000 Hz center frequency and go up or down from that point, at the 2:1 ratio. From 1000 Hz, the next filter's center frequency is 2000 Hz, the next is 4000 Hz, etc., or 500 Hz, 250 Hz, etc. Octave filtering is usually referred to as the class of octave filters typically 1, 3 or 12, thus creating full octaves, one-third octaves, or one-twelve octaves.

**Octave Band**

The segment of the frequency spectrum centered on an octave center frequency bounded by the midpoint between the next lower and higher octave.

**Percent Exceedance ($L_x$)**

These metrics are the sound levels (L), in decibels, exceeded *x* percent of the time. The $L_{50}$ value represents the sound level exceed 50 percent of the measurement period. $L_{50}$ is the same as the median. The $L_{90}$ value represents the sound level exceeded 90 percent of the time during the measurement period. $L_{50}$ and $L_{90}$ are useful measures of the natural sounds because in park situations, away from developed areas, they are less likely to be affected by non-natural sounds. Put another way, non-natural sounds in many park areas are likely to affect the measured sound levels for less than 50% of the time, and almost certainly for less than 90% of the time. $L_{50}$ is used when there is high probability that no non-natural sounds affect the measurements. $L_{90}$ is used when human-produced sounds are present much of the time during measurements. Common sounds that could be present for more than 50% of the time include road traffic sounds and, in some areas, high altitude jet aircraft.

**Percent Time Above Natural Ambient**

The amount of time that sound levels from non-natural sound(s) are greater than sound levels of natural ambient sound levels in a given area. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long non-natural sound levels exceed natural ambient sound levels.

**Percent Time Audible**

The amount of time that various sounds are audible to animals, including humans, with normal hearing (hearing ability varies among animals). A specific sound may be below the natural ambient sound level, but still be audible to some animals. This information is essential for measuring and monitoring non-natural sounds in national parks. These data can be collected by either a trained observer (attended logging) or by making high-quality digital recordings (for later playback). Percent Time Audible is useful because it is a measure that is understandable without any acoustics knowledge. It is a metric that correlates well with park visitor judgments of annoyance and with visitor reports of interference from certain sound sources with the sounds of nature.

**Spectrum (Frequency Spectrum)**
The amplitude of sound at various frequencies. It is given by a set of numbers that describe the amplitude at each frequency or band of frequencies.

**Sound**
A wave motion in air, water, or other media. It is the rapid oscillatory compressional changes in a medium that propagate to distant points. It is characterized by changes in density, pressure, motion, and temperature as well as other physical properties. Not all rapid changes in the medium are sound (such as wind distortion on a microphone diaphragm).

**Sound Impacts**
Sound impacts are effects on a receptor caused by the physical attributes of sound emissions. In national parks, non-natural sounds cause physical changes in the soundscape that can be detected and measured. The fact that a sound can be measured does not equate immediately to whether the impact of that sound is adverse, inconsequential, or beneficial, or whether there are adverse secondary impacts on wildlife, cultural values, or visitors. Levels of impact and impact significance are policy determinations.

**Soundscape**
Soundscape refers to the total acoustic environment associated with a given area. In a national park setting, soundscapes can be composed of natural sounds, or it can be composed of both natural and non-natural sounds.

**Soundscape, Natural**
Natural soundscapes consist of sounds associated with nature: wind, water flow, rain, surf, wildlife, thermal activity, lava flows, or other sounds not generated by non-natural means.

**Sound Level**
The *weighted* sound pressure level obtained by frequency weighting, generally A-weighting (dBA).

**Sound Level Floor (Noise Floor)**
The lowest amplitude measurable by sound monitoring equipment. Most commercially available sound level meters and microphones can detect sound levels down to about 15 to 20 dBA; however, there are microphones capable of measuring sound levels below 0 dBA.

**Sound Pressure Level (SPL)**
The logarithmic form of sound pressure. In air, 20 times the logarithm (to the base 10) of the ratio of the actual sound pressure to a reference sound pressure (which is 20 micropascals, and by convention has been selected to be equal to the assumed threshold of human hearing). It is also expressed by attachment of the word decibel to the number.

**Windscreen**
A porous device used to cover the microphone of a sound level measurement system. Windscreens are designed to minimize the effects of wind disturbance on the sound levels being measured while minimizing the attenuation of the signal.

These definitions were derived from several sources, including:

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## Appendix C. Acoustic standards and thresholds in previous winter use plans

**Table C-1**. Management zones and soundscape thresholds in 2000 Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Environmental Impact Statement Winter Use Plan.

| Zone | Management Zone | Maximum Audibility[1] of motorized sound during the hours of 8 am-4 pm |
|---|---|---|
| 1 | Destination or Support Area | Audibility: NTE 50%<br>(anywhere within area boundary) |
| 2 | Plowed Road<br>(within 100 feet either side of road) | Audibility: NTE 50%<br>at 100 feet |
| 3 | Groomed Motorized Route Clean and Quiet<br>(within 100 feet either side route) | Audibility: NTE 50%<br>at 100 feet |
| 4 | Groomed Motorized Route<br>(within 100 feet either side route) | Audibility: NTE 50%<br>at 100 feet |
| 5 | Groomed Motorized Trail Clean and Quiet<br>(within 100 feet either side of trail) | Audibility: NTE 25%<br>at 100 feet |
| 6 | Groomed Motorized Trail<br>(within 100 feet either side of trail) | Audibility: NTE 25%<br>at 100 feet |
| 7 | Ungroomed Motorized Trail<br>(within 100 feet either side of trail) | Audibility: NTE 25%<br>at 100 feet |
| 8 | Groomed Non-motorized Trail | Audibility: NTE 10%<br>at 500 feet |
| 9 | Ungroomed Non-motorized Trail or Area | Audibility: NTE 10%<br>at 500 feet |
| 10 | Backcountry non-motor trail or area | Audibility: NTE 10% at 500 feet<br>Audibility: NTE 0% at 1000 feet |

[1] Audibility- the ability of a person with normal hearing to hear a given sound

**Table C-2**. Management zones and soundscape thresholds in 2003 Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Supplemental Environmental Impact Statement Winter Use Plan.

| Zone | Management Zone | Maximum Audibility[1], Max. dBA[2], and Hourly $L_{eq}$ [3] of oversnow vehicle sounds during hours of 8 am-4 pm |
|---|---|---|
| 1 | Destination or Support Area (anywhere within area boundary) | Audibility: NTE[4] 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45dBA |
| 2 | Plowed Road (within 100 feet either side of road) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 3 | Groomed Motorized Route (within 100 feet either side route) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 4 | Groomed Motorized Trail (within 100 feet either side route) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 5 | Ungroomed Motorized Trail or Area (within 100 feet either side of trail) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 6 | Groomed Non-motorized Trail (within 100 feet either side of trail) | Audibility: NTE 25%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 7 | Ungroomed Nonmotorized Trail or Area (within 100 feet either side of trail) | Audibility: NTE 20%<br>dBA: NTE Lnat[5] - 6 dBA<br>$L_{eq}$: NTE to Lnat |
| 8 | Backcountry Nonmotorized Area (anywhere within area >1,000 feet from motorized area) | Audibility: NTE 20%<br>dBA: NTE Lnat - 6 dBA<br>$L_{eq}$: NTE to Lnat |
| 9 | Sensitive Area (no winter use) | |

[1] Audibility- the ability of a person with normal hearing to hear a given sound
[2] dBA- weighted sound level in decibels
[3] $L_{eq}$ - The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.
[4] NTE- not to exceed
[5] Lnat- The natural sound conditions found in a given area, including only sounds of nature.

## Appendix D. Visualizations of one-third octave band frequency sound levels

The NPS Natural Sound Program in Ft. Collins, CO developed a technique for plotting each of the 33 one-third octave band frequency decibel levels for each second of the day (ex. Fig. D-1). The major sources of sound at each monitoring location can be "seen" in these visualizations. Viewing the pictures in color is essential. Each figure is one day, 24 hours from midnight to midnight. Each row contains two hours starting with the first hours of the day, labeled with white two digit numbers. The site and date is the title on top. The frequency is plotted on a logarithmic scale as indicated in the left margin. The right margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest.

Figures D-1-D-5 show example days from each of this study's monitoring sites. Determining the common sound sources signatures from the 1/3 octave band frequencies is not difficult, but takes a bit of experience. A brief introduction follows. Oversnow vehicle signatures are narrow yellow marks that extend from high to low frequency. Louder sounds are brighter yellow as shown in hour 09 in Fig. D-1. Snow groomers are the brighter broader marks with the extended light blue before and after trails in hours 18 and 19 (Fig. D-1). During the hours 01, 02, 03, and others, a jet appears as a slanting haystack from the Doppler Effect of decreasing frequency as the jet travels away from the monitoring location (Fig. D-1). The Doppler Effect is also evident with propeller planes (double declining lines) during the 14 and 16 hours (D-1). Building utility sounds and wind create the extensive pale blue at Old Faithful Weather Station (Fig. D-2). Strong wind was present for the first 4 hours of the day at Mud Volcano (Fig. D-3). The sounds of riffles on the Madison River are shown especially during the early morning hours and extended coyote choruses during the hours of 19, 20 and 22 (Fig. D-4). Aircraft, wind gusts and bird vocalizations are the only sounds at Fern Lake (Fig. D-5). A day of using specialized low sound level equipment at Spring Creek 2 is shown (Fig. D-6) for comparative purposes.

Figures D-7 and D-8 compare the sound levels during Saturday of Presidents Day Weekend at Madison Junction 2.3 during 2003 (1,679 snowmobiles during Saturday and Sunday) and 2006 (674 snowmobiles during Saturday and Sunday). One can readily see the yellow spikes of OSVs passing the monitoring site beginning earlier in the day in 2003 and with shorter time intervals between OSVs. This comparison illustrates the difference in noise-free interval, sound level, distribution, and number of OSVs between years. See figure D-4 for another example of OSV activity at this site during the most recent winter season.

Not only can specific sound sources be identified from these visualizations, but patterns and the variability in number, timing, and sources of sounds can be deciphered. This technique will likely be refined and perhaps will lead to an automated, quantified process to characterize soundscapes in the future.

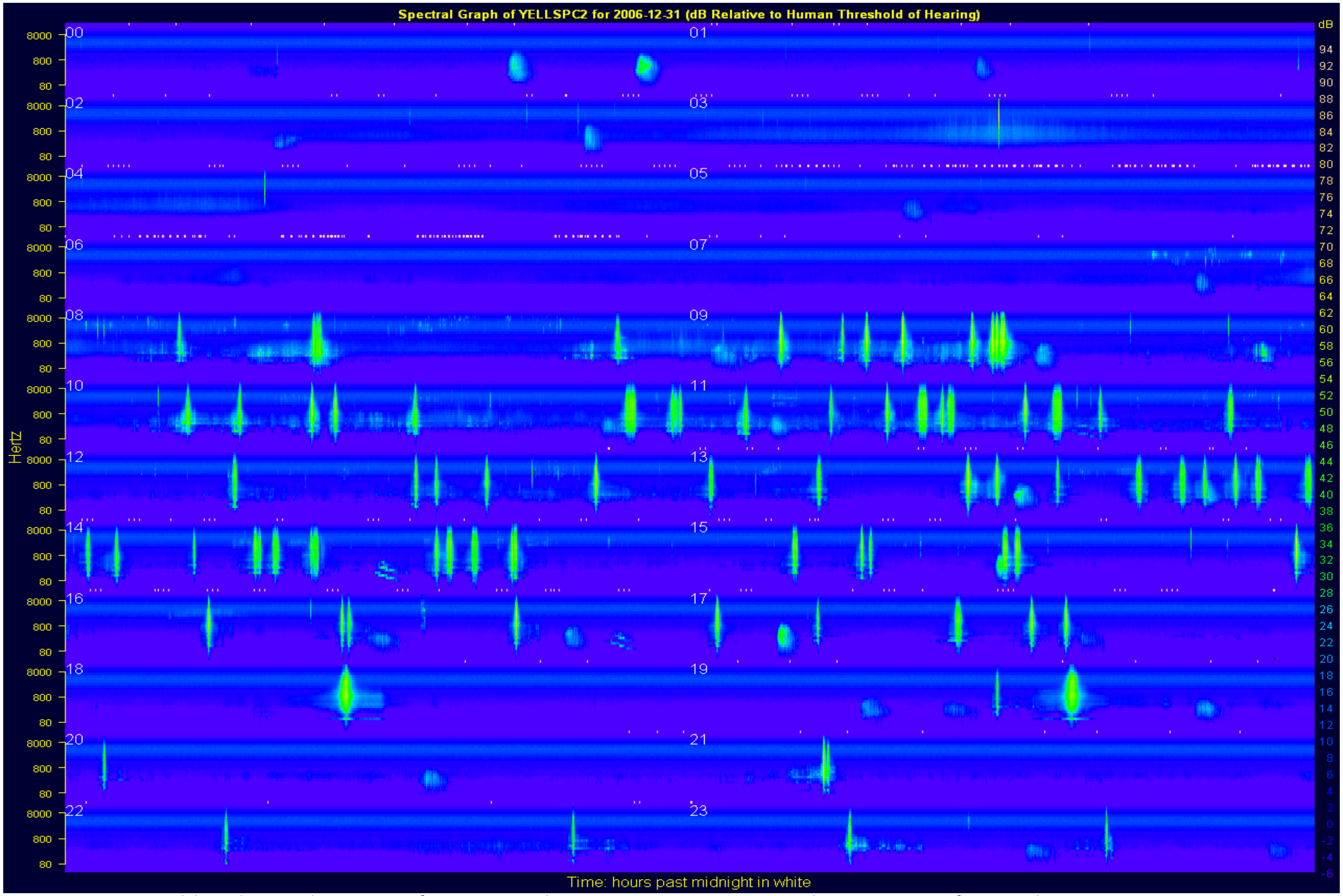

Figure D-1. Sound level visualization of 31 December 2006 at Spring Creek 2. See text for explanation.

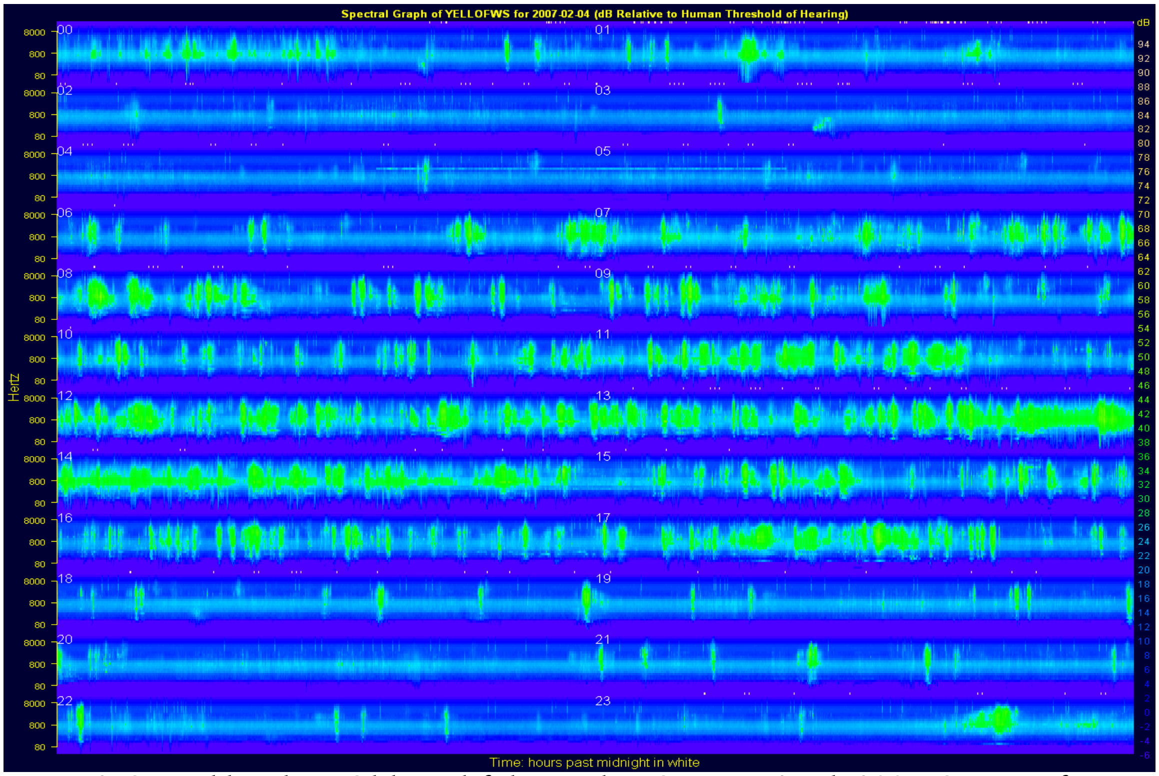

Fig D-2. Sound levels at Old Faithful Weather Station, 4 Feb 2007. See text for explanation.

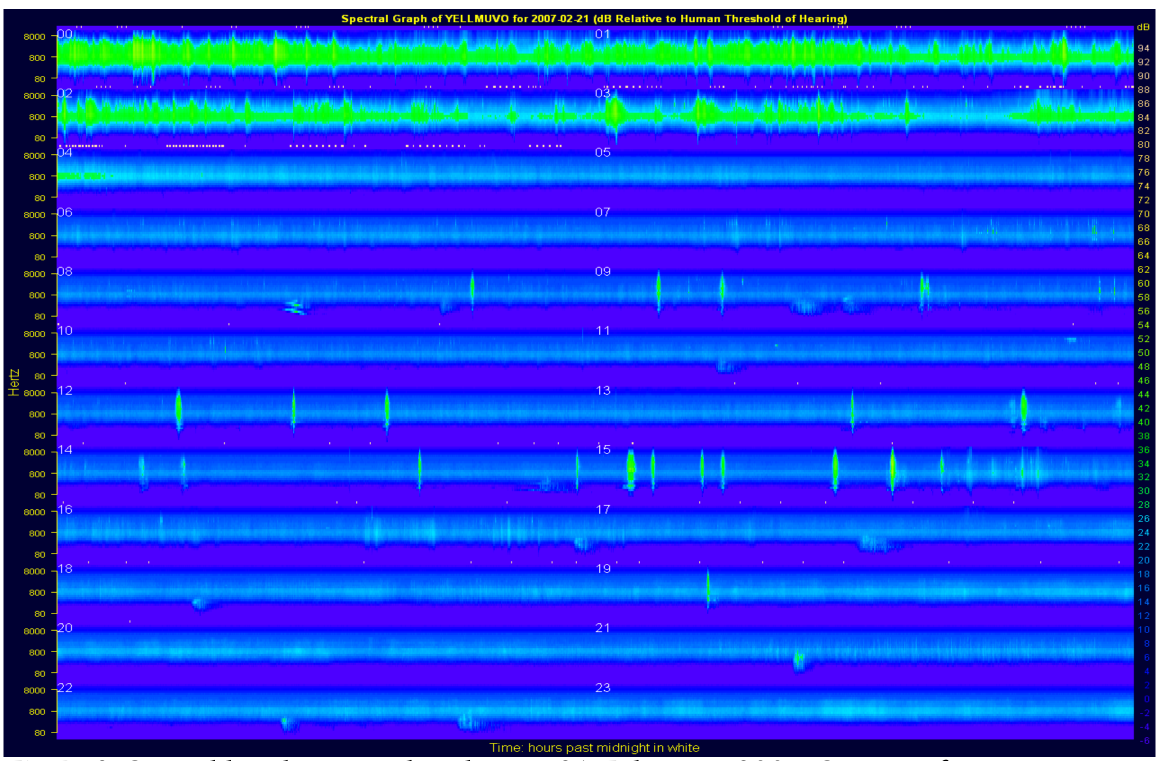

Fig D-3. Sound levels at Mud Volcano, 21 February 2007. See text for explanation.

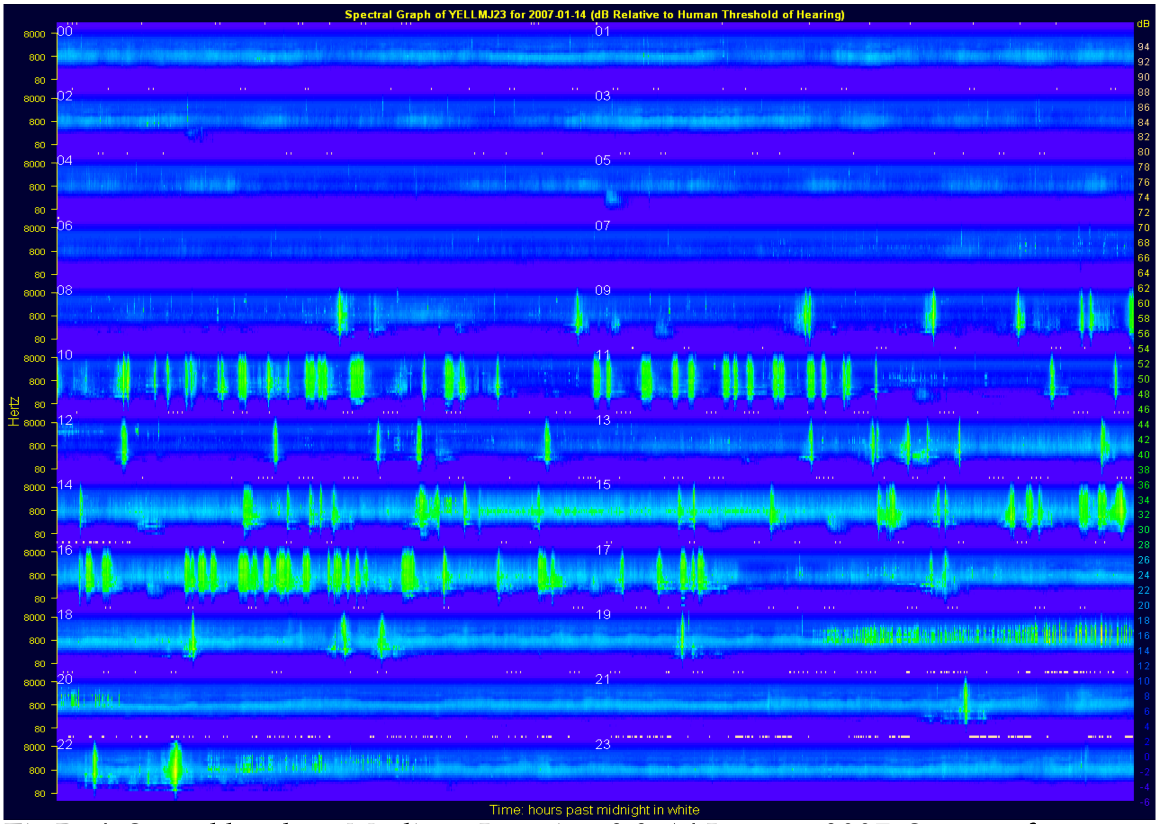

Fig D-4. Sound levels at Madison Junction 2.3, 14 January 2007. See text for explanation.

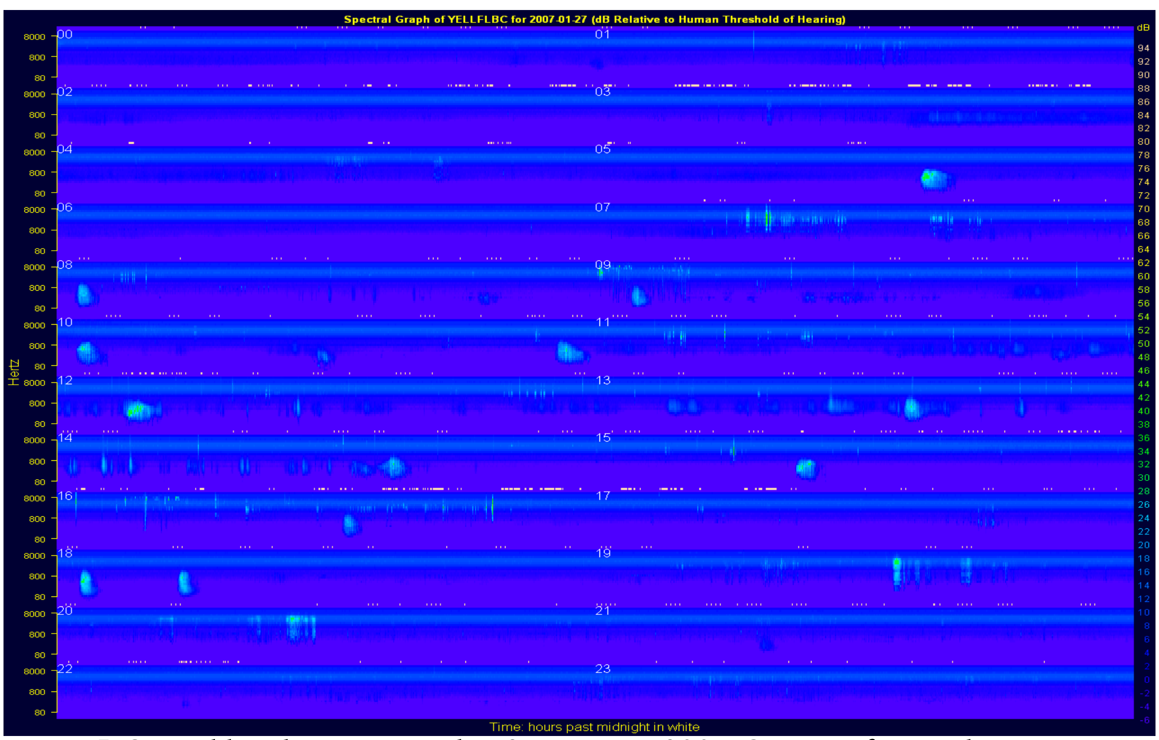

Fig D-5. Sound levels at Fern Lake, 27 January 2007. See text for explanation.

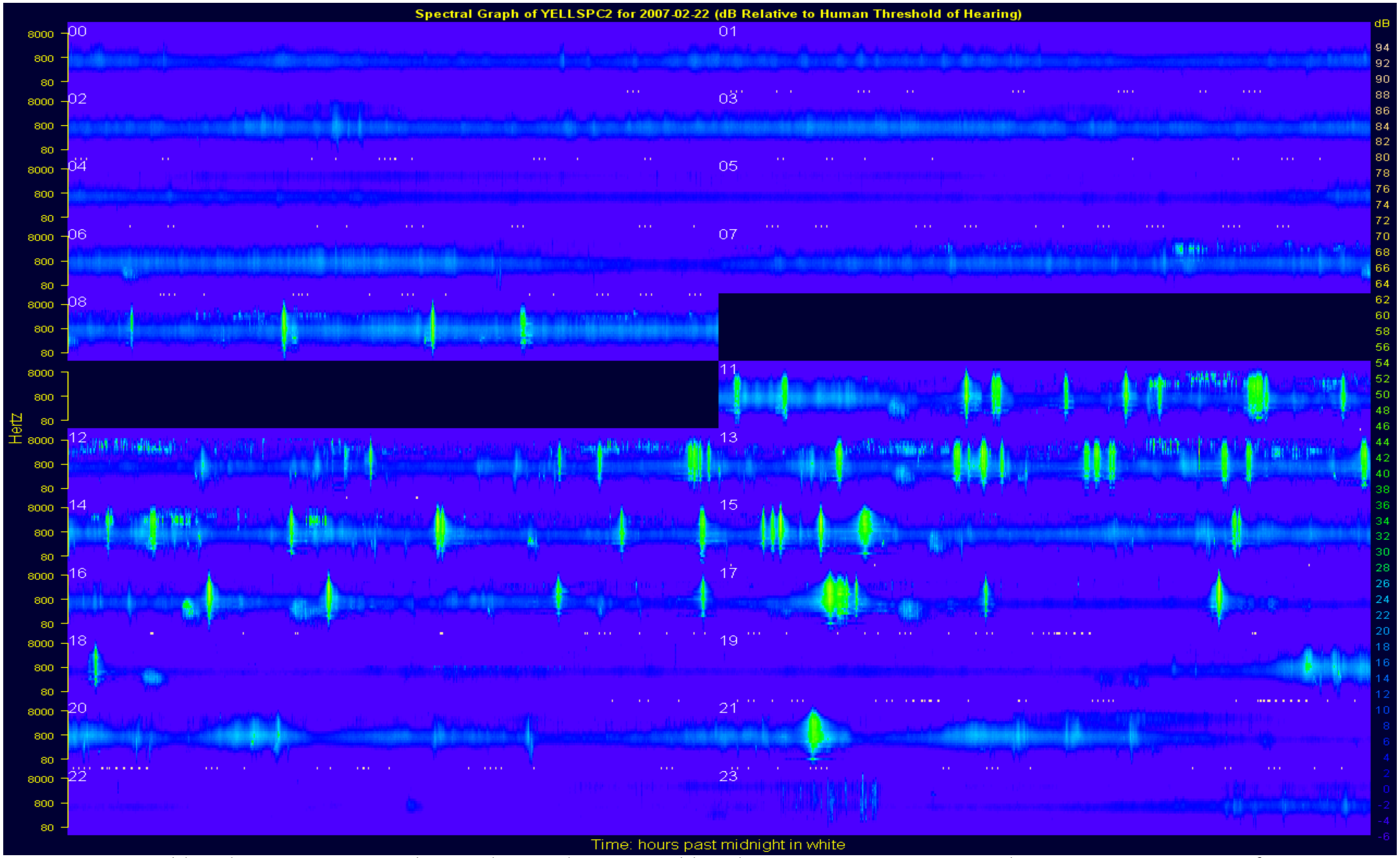


Fig D-6. Sound levels at Spring Creek 2 with very low sound level instrumentation, 22 February 2007. See text for explanation of this visualization.

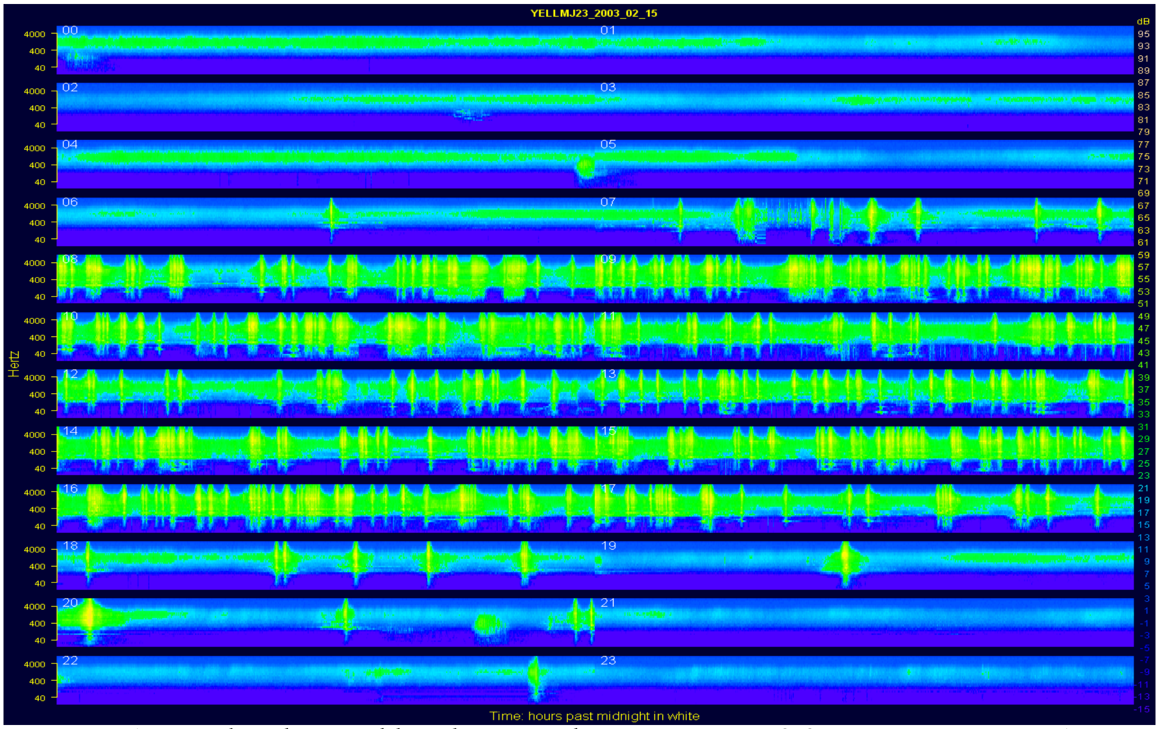


Fig D-7. A-weighted sound levels at Madison Junction 2.3 monitoring site, 15 February 2003. Compare to Fig. D-8 for number and timing of OSVs. See text for explanation.

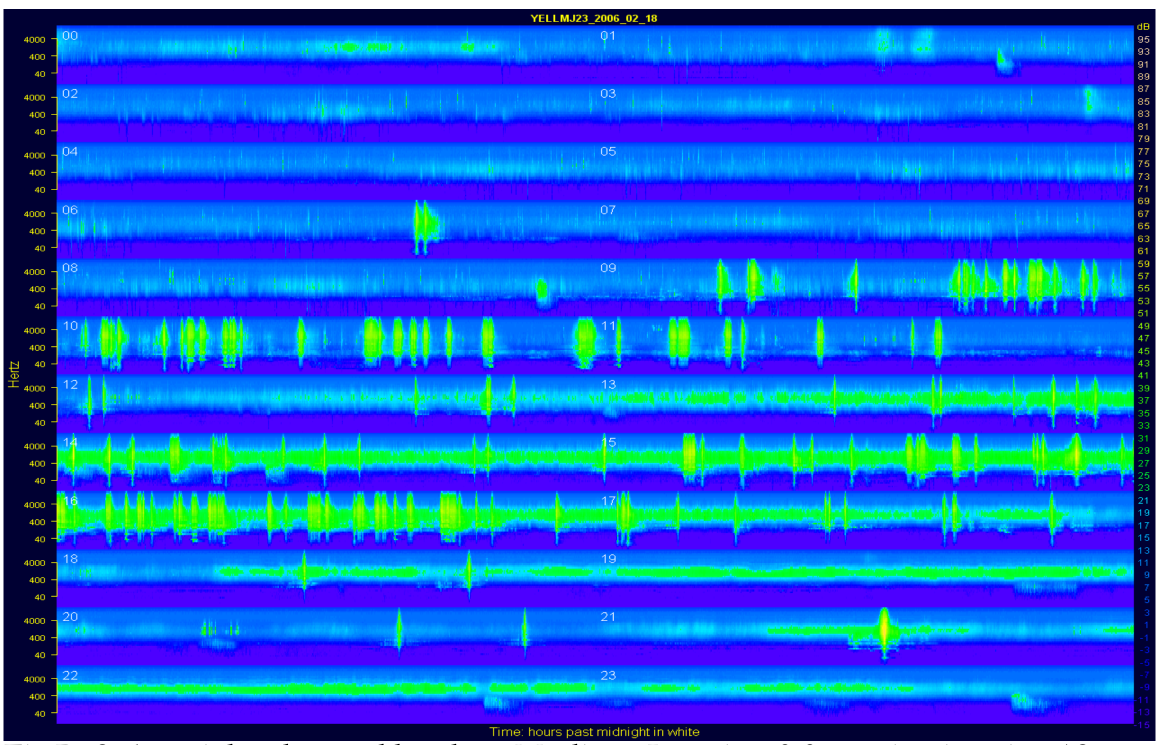


Fig D-8. A-weighted sound levels at Madison Junction 2.3 monitoring site, 18 February 2006. Compare to Fig. D-7 for number and timing of OSVs. See text for explanation.

## Appendix E. Observational study of oversnow vehicle usage

The audibility analysis using unattended sound monitoring equipment estimated the percent time all sounds were audible at those locations. Unfortunately, it was not able to provide the identity of the user type of oversnow vehicles. To determine the type and proportion of oversnow vehicle usage a separate observational study was conducted during the three winters of 2005-2007. Observers were positioned within view of travel routes at a number of key locations and documented the time audible and type of usage for each oversnow vehicle observed. The data were collected during 85 logging periods at locations within the Old Faithful and Canyon developed area and along the travel corridor mainly between Kepler Cascades and West Yellowstone and Bridge Bay and Cygnet Lake (Table E-1), 17 February-5 March 2005, 20 January-9 March 2006, and 26 December 2006-5 March 2007. The total observer logging time was 110 hr 54 min 58 sec, 7am to 5pm, split between morning and afternoon.

Table E-1. Locations used for observational study of oversnow usage patterns during winters 2005-2007 in Yellowstone National Park.

| Developed Area | Travel Corridor |
|---|---|
| Old Faithful Entrance Road | Kepler Cascades Pullout |
| Old Faithful Parking Lot | Daisy Trailhead |
| Old Faithful Ranger Station | Mallard Lake Trailhead |
| Old Faithful Main Road | Midway Geyser Basin |
| Canyon Junction | Mary Mountain Trailhead |
| | Madison Junction 2.3 |
| | West Yellowstone 3.1 |
| | Bridge Bay Area |
| | Talus Slopes |
| | Tuff Cliff Pullout |
| | Cygnet Lake Trailhead |

Oversnow usage types included guided visitors, NPS administrative use, contractors, and Xanterra administrative use, (see sample data sheet Table E-2). These data were then transferred to an MS Access™ database for summary and analysis. Tables E-3 to E-5 present these summary analyses.

The number and proportion of snowmobiles was analyzed by group (Table E-3) and by individual machine (Table E-4). Oversnow vehicles that were not seen, but only heard, were not included in these results because the user group could not be determined. The developed area, travel corridor, and combined totals are summarized in both tables. To understand snowmobile usage patterns within

Yellowstone NP it is necessary to assess both group and individual patterns. A total of 1,701 groups of oversnow vehicles were documented, including 911 snowmobile groups (E-3). Group size ranged from 1-23. Average size for all snowmobile groups was just over four snowmobiles per group; seven snowmobiles per guided group and just over one snowmobile per administrative group. A total of 4,732 individual oversnow vehicles were tallied, including 4,015 snowmobiles (E-4).

Of all individual snowmobiles observed, guided visitors (recreational use) accounted for 92% along travel corridors and 80% at Old Faithful (Table E-4). Guided visitors comprised 69% of all groups documented along travel corridors (Table E-3). As would be expected, more administrative travel occurred in the Old Faithful developed area than along travel corridors between developed areas (Tables E-3 and E-4). Contractors working on the Old Faithful Inn comprised 7% of all groups of snowmobiles documented in developed areas (Table E-3). Other administrative travel totaled 51% of the total number of groups observed in developed areas (Table E-3).

Guided snowmobiles comprised 47% of all snowmobiles audible. All oversnow vehicles were audible for 58% of the study period and comprised 88% of the motorized sounds audible (Table E-5). Snowmobiles were audible for 46 hours 47 minutes and 14 seconds (42%) of the 110 hours 54 minutes and 58 second study period (Table E-5). No motorized sounds were audible for 34% of the time during the study period (Table E-5).

**Table E-2**. Field data sheet for logging oversnow usage type in Yellowstone National Park, during the winters of 2005-2007.

| | | |
|---|---|---|
| Date: | Time: Start/End | Page of |
| Name, Address, Telephone: | Shan Burson Grand Teton National Park 307 739 3584 | |
| Location Description: | Latitude: | |
| | Longitude: | |
| | Elevation (ASL, feet): | |
| Habitat types (up to three, include percentage) and Terrain within .5 km: | | |

| | | |
|---|---|---|
| Weather | Temperature (F): | Cloud cover (%): |
| | Wind (MPH/from): | Precipitation: |

| Time Start: | Source*: | Time Stopped: | Location: | Remarks: |
|---|---|---|---|---|
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| | | | | |
| 10:41:05 | 4.2 | 10:46:08 | Eastbound | Yellow Bombardier |
| 10:45:12 | 4.1 | 10:48:50 | Out headed south | 8 in guided group leaving OF |

24 hr. time. Include exact Obs.Time Start and End

| | | | | |
|---|---|---|---|---|
| *Source: 0 | None audible | 8 | People | Instructions |
| 1.1 | Aircraft, jet | 10 | Building sounds | Record when non-natural sounds are audible. Give priority to oversnow. |
| 1.2 | Aircraft, propeller | 11 | Construction | Record other non-natural sounds as possible. Note when ignoring them. |
| 1.3 | Aircraft, helicopter | 19 | Non-natural other | Record time in hours, minutes and seconds. Try to use GPS time (that is. |
| 2 | Vehicle (type) | 20 | Non-natural unk. | accurate time). Record stop time as well as start time. |
| 3 | Watercraft (type) | | | Record oversnow type (4.1, 4.2, 4.3, 4.4) and number making up group. |
| 4 | Oversnow Vehicle | | | Record type of user (contractor, Xanterra, NPS researcher, Ranger, admin, |
| 4.1 | Snowmobile | | | snowcoach or guided snowmobile group) in Remarks column. |
| 4.2 | Snowcoach | | | Note type of snowcoach (Mattrax, Red or Yellow Bomb, Yellow Bus, etc.) |
| 4.3 | Snowmobile or Snowcoach | | | Record type of snowmobile if not 4 stroke. |
| 4.4 | Snow Groomer | | | Record anything else that would improve understanding of circumstances. |
| 6 | Motors | | | Record direction of travel in Location column |

**Table E-3**. Number and proportion of snowmobile groups by usage type traveling within Yellowstone National Park, winters 2005-2007.

| Location | Guided Snowmobiles | Contractor | NPS Maintenance | Ranger | Research | NPS Other/Unknown | Concession Admin | Unknown Admin | Xanterra Admin | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Developed Area | 168 | 30 | 29 | 43 | 7 | 54 | 3 | 4 | 65 | 403 |
| | 42% | 7% | 7% | 11% | 2% | 13% | 1% | 1% | 16% | 100% |
| | | | | NPS-All[a] | 133 | | | | | |
| | | | | | 33% | | | | | |
| | | | | Admin-All[b] | 205 | | | | | |
| | | | | | 51% | | | | | |
| Travel Corridor | 349 | 6 | 9 | 31 | 27 | 60 | 15 | 0 | 11 | 508 |
| | 69% | 1% | 2% | 6% | 5% | 12% | 3% | 0% | 2% | 100% |
| | | | | NPS-All | 127 | | | | | |
| | | | | | 25% | | | | | |
| | | | | Admin-All | 153 | | | | | |
| | | | | | 30% | | | | | |
| All Areas | 517 | 36 | 38 | 74 | 34 | 114 | 18 | 4 | 76 | 911 |
| | 57% | 4% | 4% | 8% | 4% | 13% | 2% | 0% | 8% | 100% |
| | | | | NPS-All | 260 | | | | | |
| | | | | | 29% | | | | | |
| | | | | Admin-All | 358 | | | | | |
| | | | | | 39% | | | | | |

[a]NPS-All Includes maintenance, rangers, research and NPS others/unknown

[b]Admin-All Includes all but guided snowmobiles, contractors and unknowns

**Table E-4.** Number and proportion of individual snowmobiles by usage type traveling within Yellowstone National Park, winters 2005-2007.

| Location | Guided Snowmobiles | Contractor | NPS Maintenance | Ranger | NPS Research | NPS Other/Unknown | Concession Admin | Unknown Admin | Xanterra Admin | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Developed Area | 1118 | 46 | 39 | 42 | 9 | 59 | 3 | 5 | 69 | 1390 |
| | 80% | 3% | 3% | 3% | 1% | 4% | 0% | 0% | 5% | 100% |
| | | | | NPS-All[a] | 149 | | | | | |
| | | | | | 11% | | | | | |
| | | | | Admin-All[b] | 226 | | | | | |
| | | | | | 16% | | | | | |
| Travel Corridor | 2320 | 16 | 13 | 30 | 32 | 68 | 24 | 0 | 12 | 2515 |
| | 92% | 1% | 1% | 1% | 1% | 3% | 1% | 0% | 0% | 100% |
| | | | | NPS-All[a] | 143 | | | | | |
| | | | | | 6% | | | | | |
| | | | | Admin-All[b] | 179 | | | | | |
| | | | | | 7% | | | | | |
| All Areas | 3438 | 62 | 52 | 72 | 41 | 127 | 27 | 5 | 81 | 3905 |
| | 88% | 2% | 1% | 2% | 1% | 3% | 1% | 0% | 2% | 100% |
| | | | | NPS-All[a] | 292 | | | | | |
| | | | | | 7% | | | | | |
| | | | | Admin-All[b] | 405 | | | | | |
| | | | | | 10% | | | | | |

[a]NPS-All Includes maintenance, rangers, research and NPS others/unknown

[b]Admin-All Includes all but guided snowmobiles, contractors and unknowns

**Table E-5.** Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2007, Yellowstone National Park. Totals may not appear correct due to rounding errors.

| **Snowmobiles Only** | | | |
|---|---|---|---|
| **User Group** | **Elapsed Time** | **Percentage** | **Combined Total** |
| **Guided Snowmobile** | 21:59:24 | 47% | 47% |
| **Contractor** | 0:43:28 | 2% | 2% |
| **NPS-Maintenance** | 1:13:03 | 3% | |
| **NPS-Ranger** | 2:45:53 | 6% | |
| **NPS-Research** | 0:49:44 | 2% | |
| **NPS Other/Unknown** | 3:41:55 | 8% | 18% |
| **Admin-Concession** | 2:27:48 | 5% | |
| **Administrative-Xanterra** | 1:38:04 | 3% | |
| **Administrative-Unknown** | 0:02:20 | 0% | 9% |
| **Unknown User** | 11:24:35 | 24% | 24% |
| | **46:46:14** | | |
| **All Motorized Sounds** | | | |
| **Jets** | 3:20:18 | 5% | |
| **Props** | 1:27:41 | 2% | |
| **Helicopters** | 0:30:00 | 1% | 7% |
| **Snowmobile** | 46:46:14 | 64% | |
| **Snowcoach** | 14:24:16 | 20% | |
| **Snowmobile or Snowcoach** | 1:35:03 | 2% | |
| **Unknown Oversnow Vehicle** | 3:47:17 | 2% | 88% |
| **Groomer** | 2:03:00 | 2% | 2% |
| **Unknown/Other Motorized** | 1:17:15 | 3% | 3% |
| | **72:39:48** | | |
| **Total Observation Time** | 110:54:58 | | |
| **Motorized Sounds** | 72:39:48 | 65% | |
| **Oversnow Vehicles** | 64:03:49 | 58% | |
| **Snowmobiles** | 46:46:14 | 42% | |
| **No Motorized Sounds** | 38:16:10 | 35% | |

## Appendix F. Monitoring results from the winters of 2003-2006

The following figures include monitoring results from previous winters. These figures are useful for comparison to the analysis presented for the 2006-2007 winter season in the body of this report.

Two differences between the analyses of the winters 2003-2004 and the following three winters should be noted. The hourly sound levels by month are calculated using median values for the $L_{eq}$, $L_{50}$, and $L_{90}$ values for 2004-2005, 2005-2006, and 2006-2007. The same metrics were calculated as log means for winter 2003-2004. All sound levels collected when the wind speed was greater than 11 mph were deleted from the analysis in 2004-2005, 2005-2006, and 2006-2007. During 2003-2004 some data were retained with wind speeds higher than 11 mph. These differences among years would tend to increase the $L_x$ values for the winter 2003-2004 during those periods with high wind and at sites with few loud events. The log means are more influenced by higher values than is the median and the retention of high wind speeds would also have increased the $L_x$ values. However, at the YNP monitoring sites there would be generally less then 5% difference between the metrics calculated using the two methodologies (Mike Donaldson, pers. comm.).

*Old Faithful Weather Station*

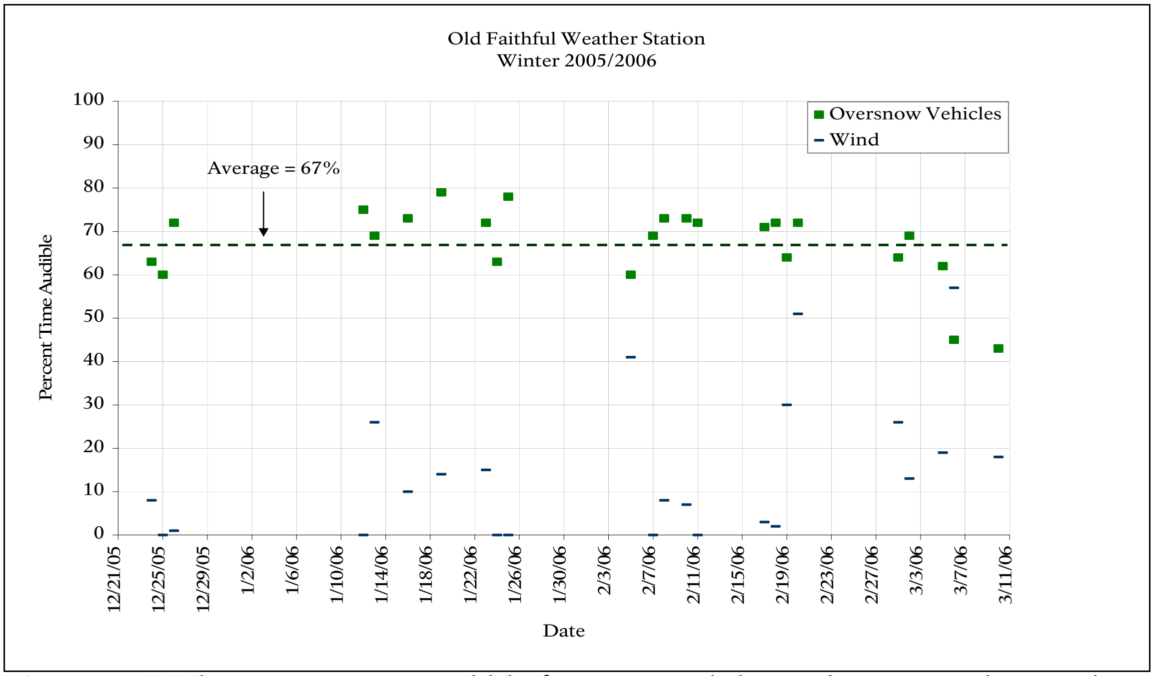


**Figure F-1**. The percent time audible for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 21 December 2005 to 12 March 2006.

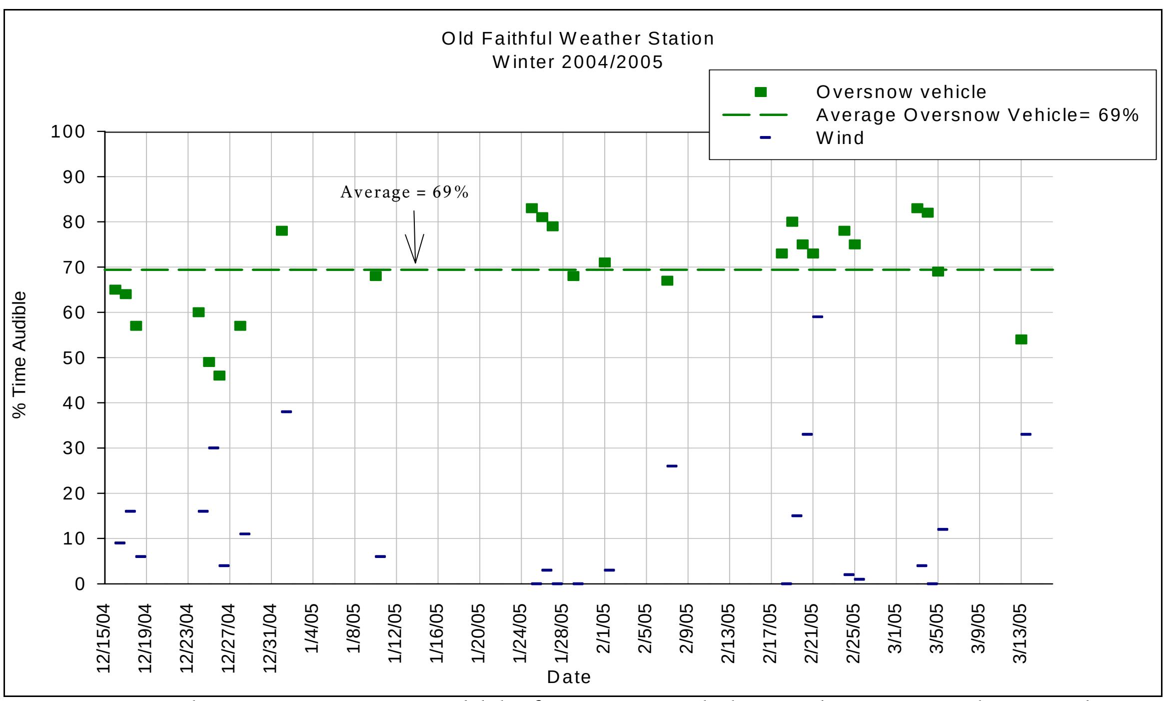


Figure F-2. The percent time audible for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March 2005.

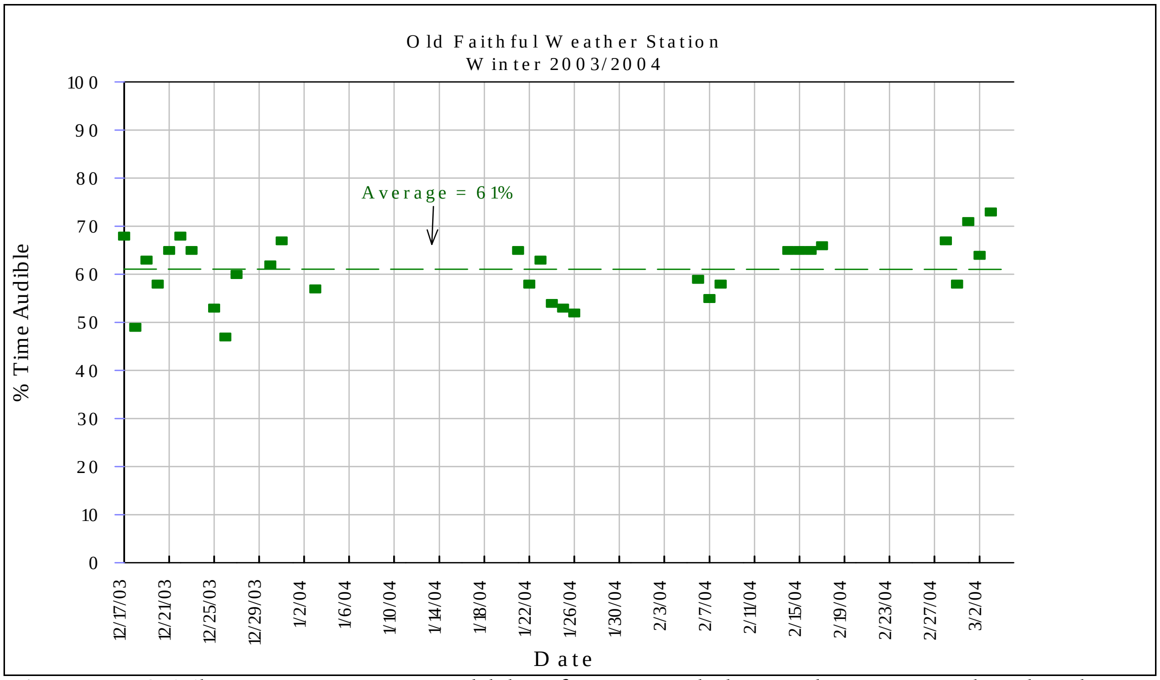


**Figure F-3**. The percent time audible of snowmobiles and snowcoaches by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 3 March 2004.

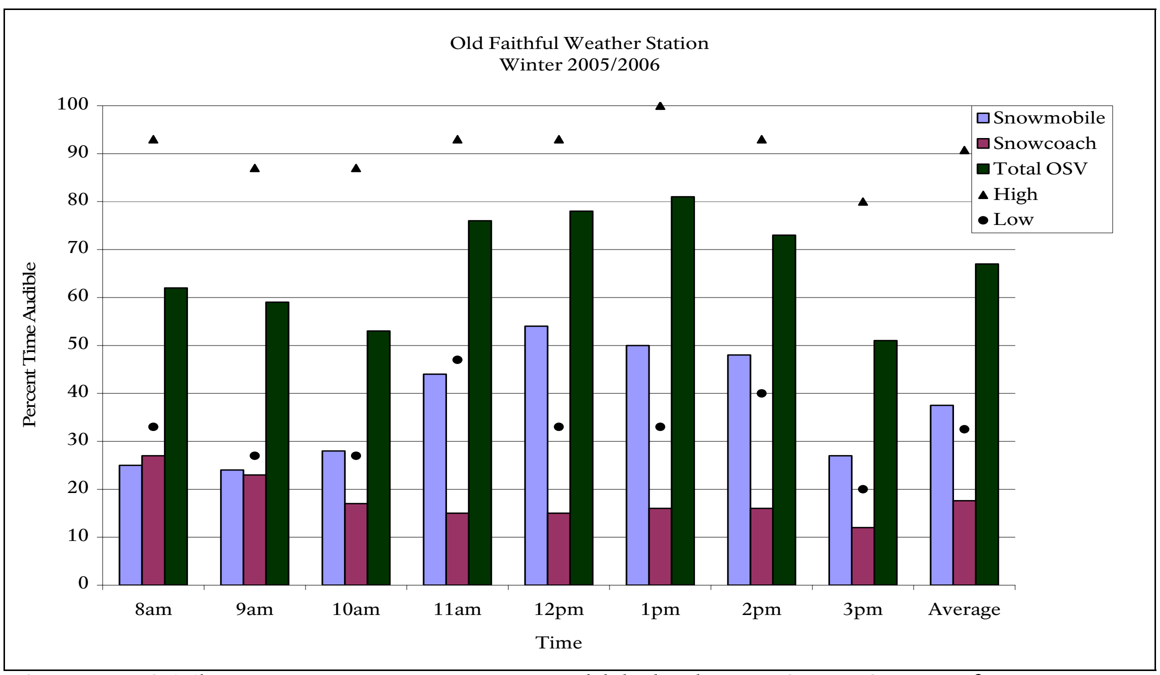


**Figure F-4**. The average percent time audible by hour (8 am-4 pm) of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 21 December 2005 to 12 March 2006.

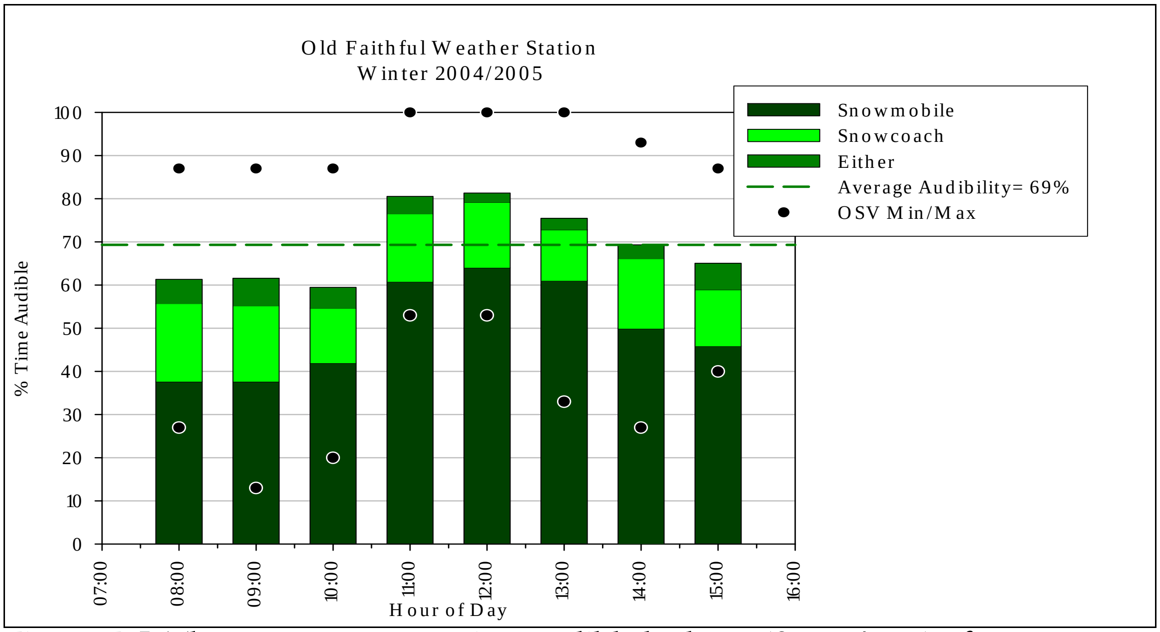

Figure F-5. The average percent time audible by hour (8 am-4 pm) of snowmobiles (bottom bar category), snowcoaches (middle bar category), combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March 2005.

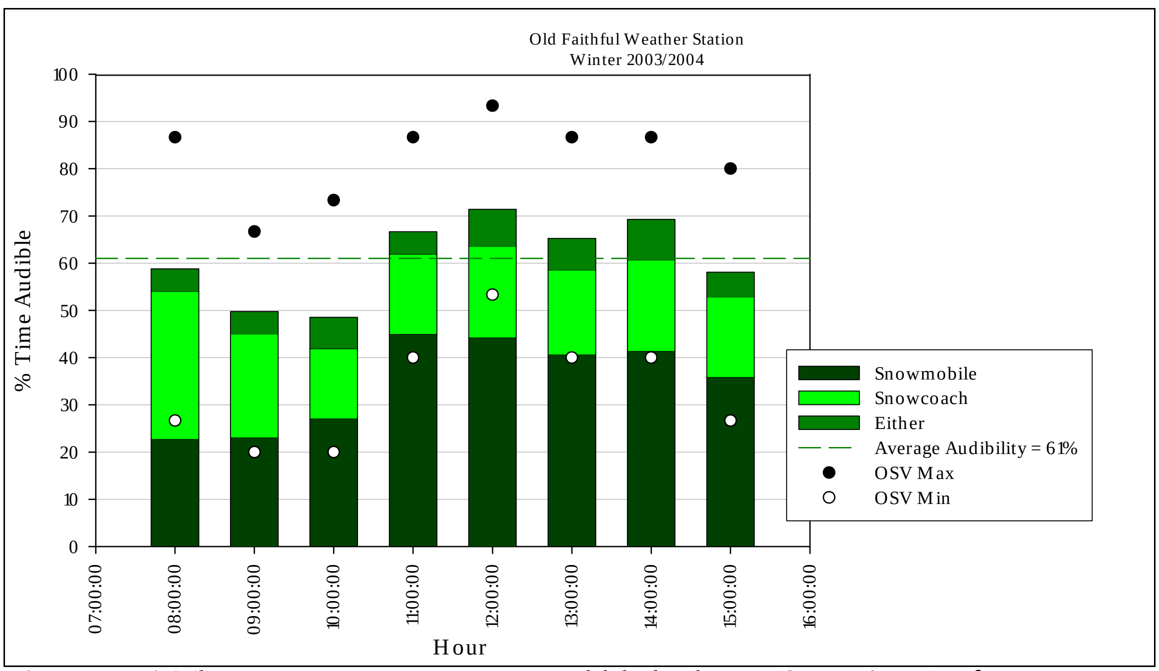

**Figure F-6**. The average percent time audible by hour (8 am-4 pm) of snowmobiles (bottom bar category), snowcoaches (middle bar category), combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 14 March 2004.

*Madison Junction 2.3*

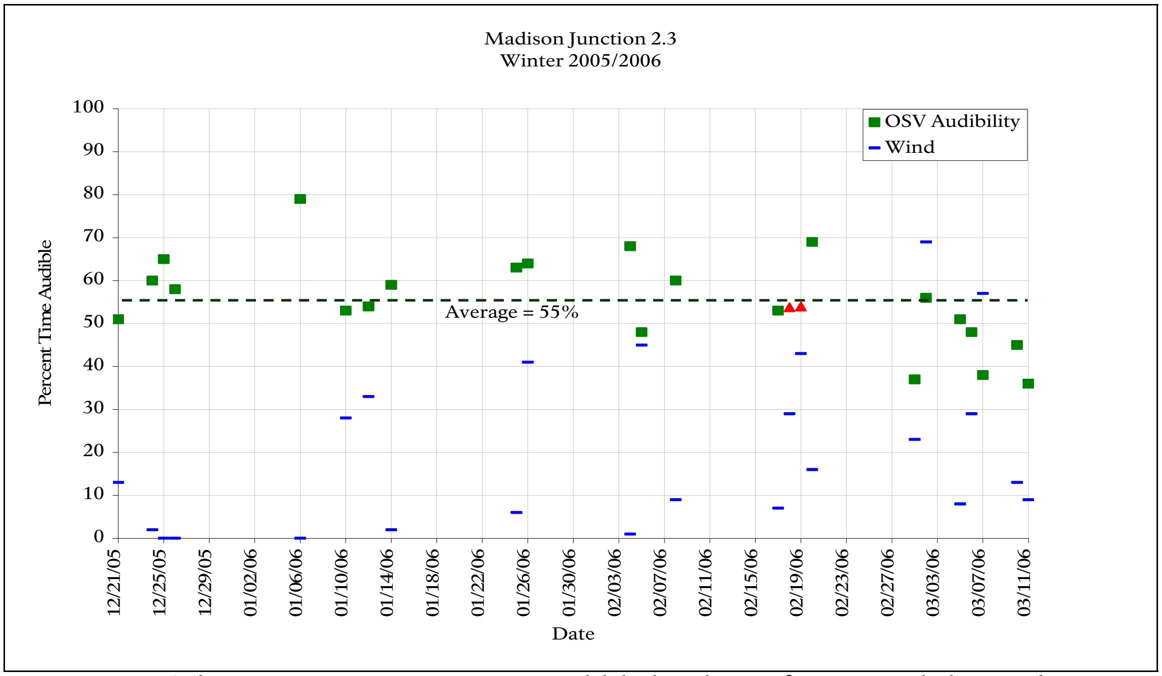


Figure F-7. The average percent time audible by date of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 21 December 2005-12 March 2006. Red triangles indicate Presidents Day Weekend for 2006 (54%) for comparison to prior years.

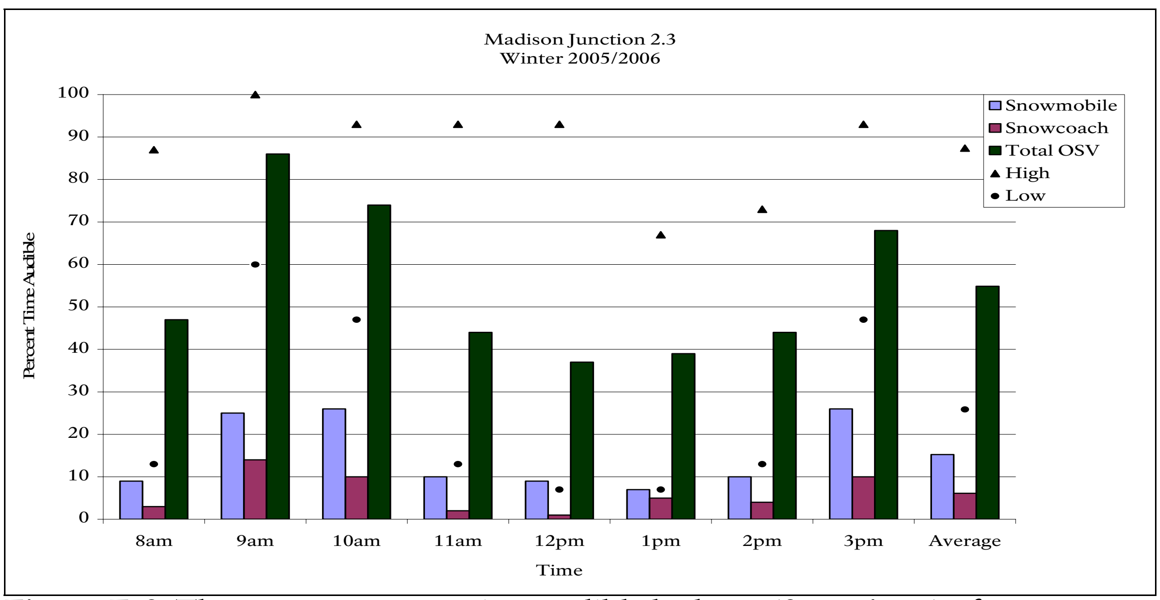


**Figure F-8**. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 21 December 2005- March 2006.

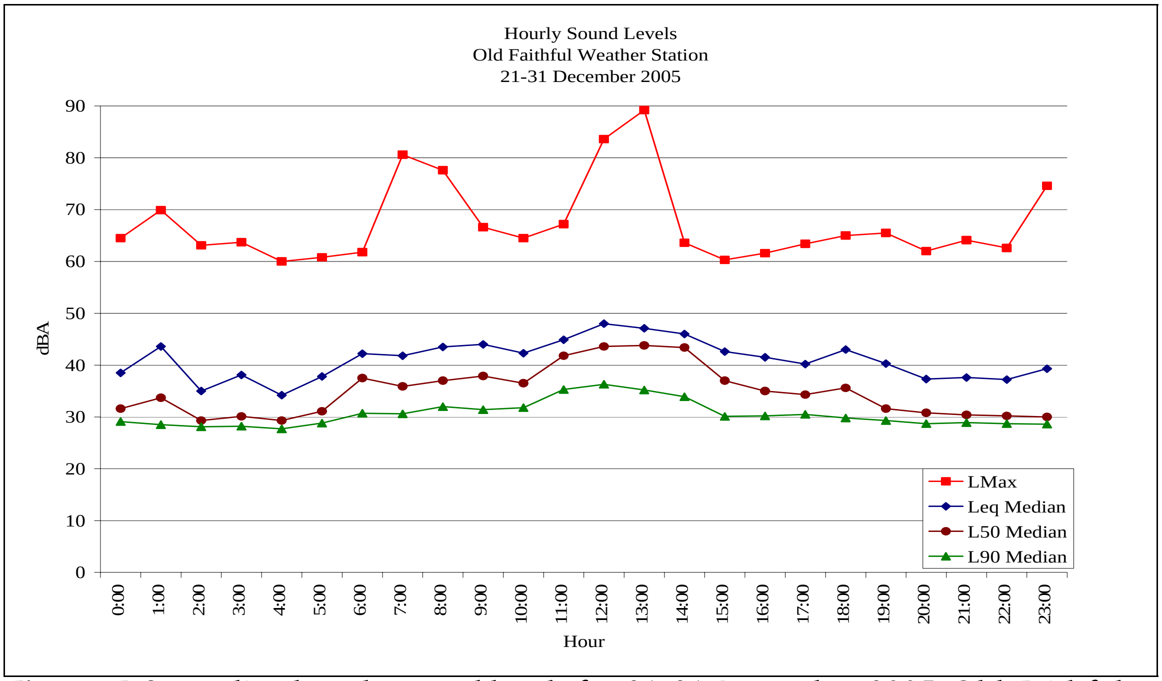


**Figure F-9**. Median hourly sound levels for 21-31 December 2005, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. $L_{max}$ is the highest sound level measured during the measurement period. (n=258 hours)

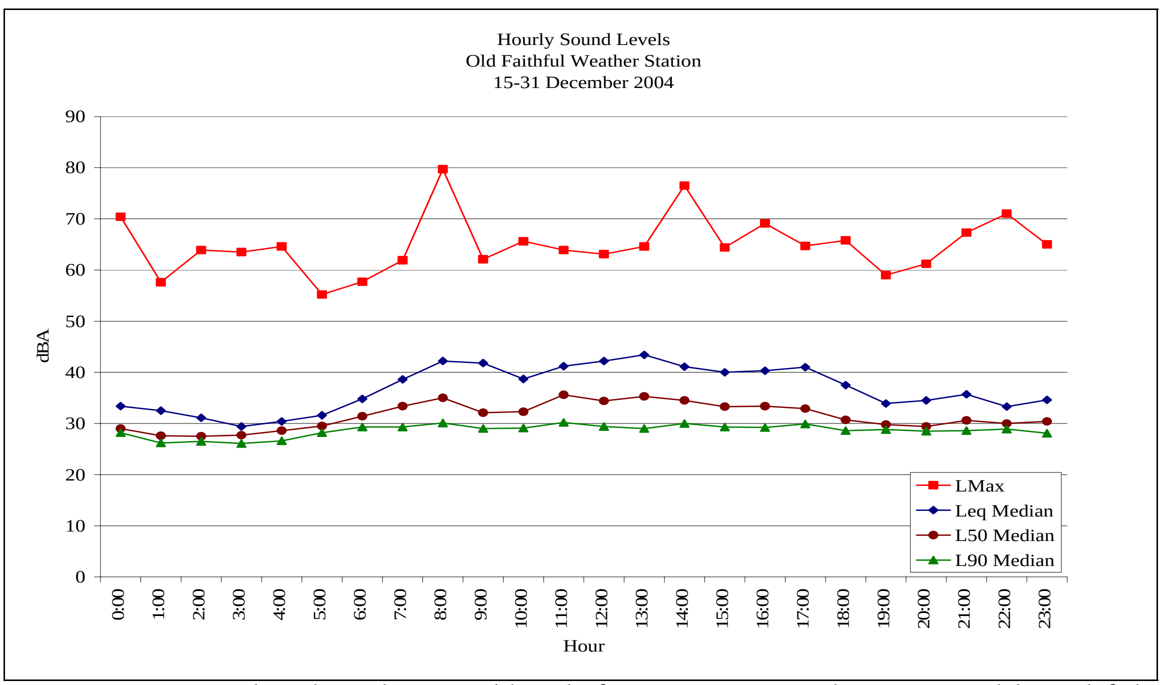


**Figure F-10**. Median hourly sound levels for 15-31 December 2004, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. (n=370 hours)

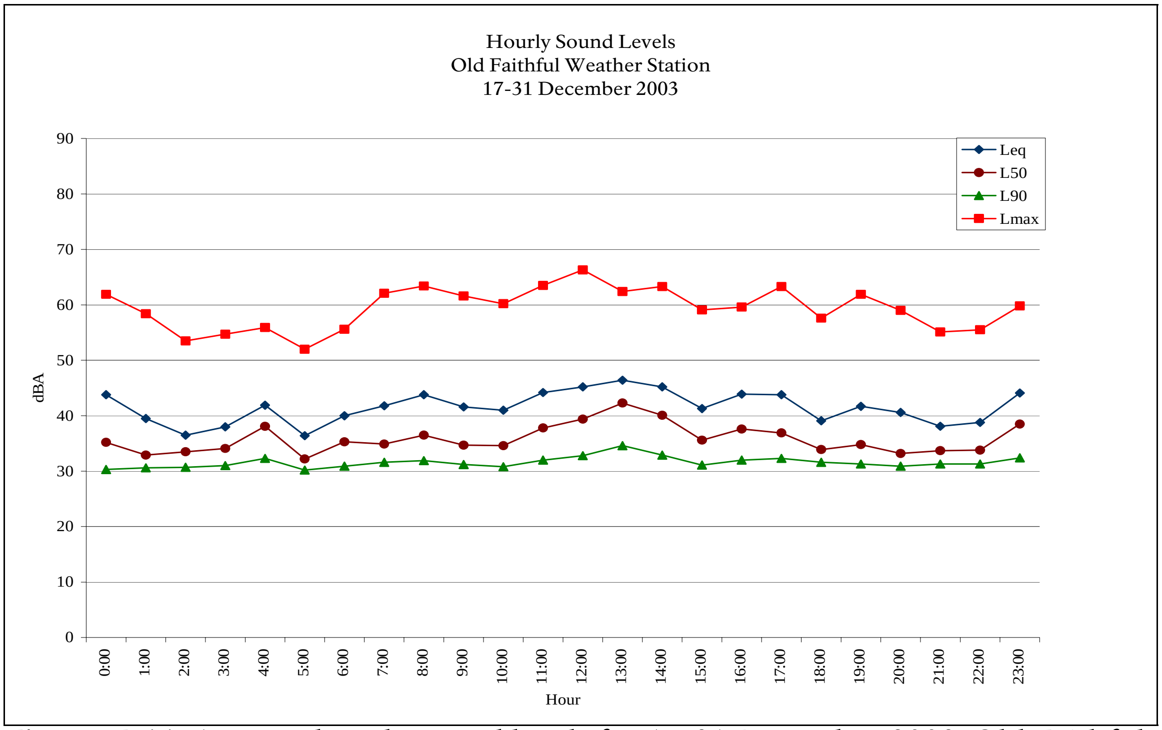


**Figure F-11**. Average hourly sound levels for 17-31 December 2003, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. (n=358 hours)

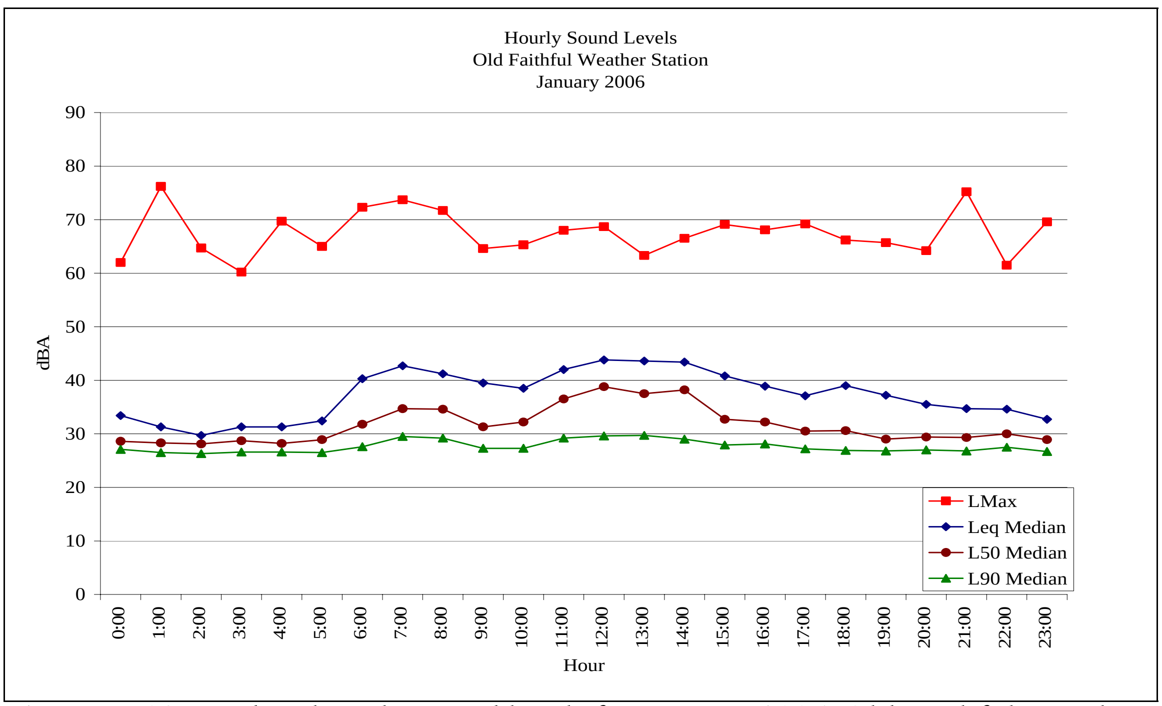


**Figure F-12**. Median hourly sound levels for January 2006, Old Faithful Weather Station, Yellowstone National Park. (n=728 hours)

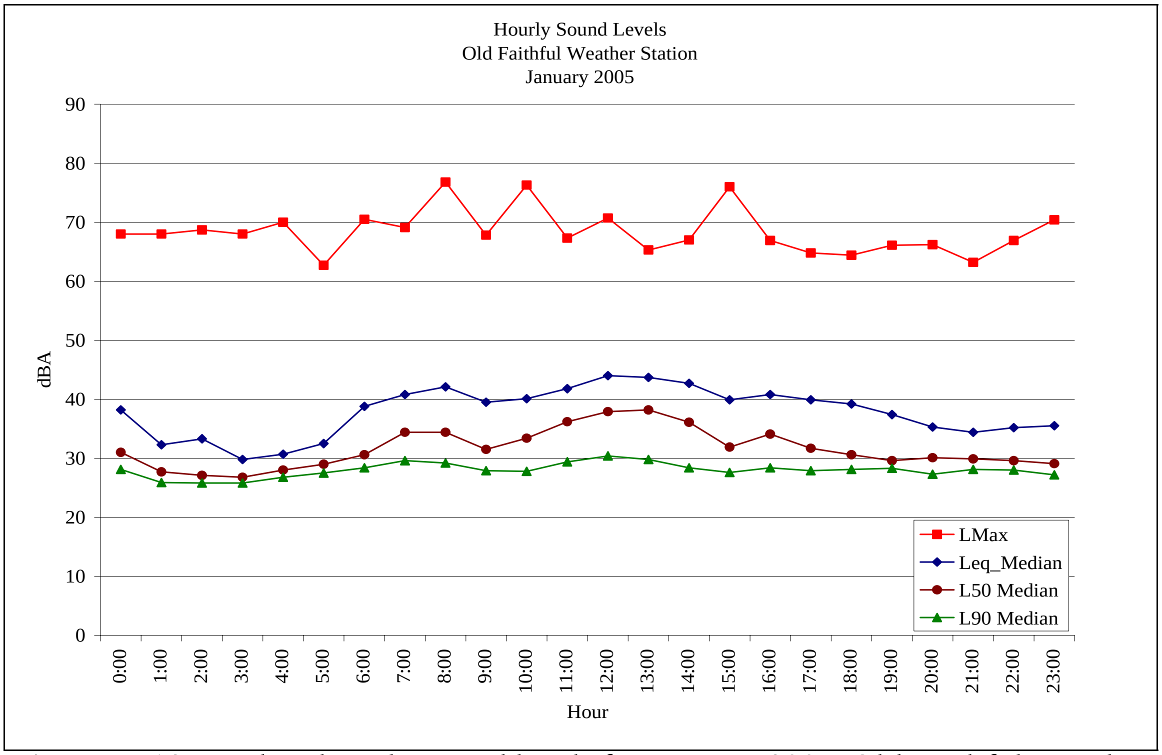


**Figure F-13**. Median hourly sound levels for January 2005, Old Faithful Weather Station, Yellowstone National Park. (n=736 hours)

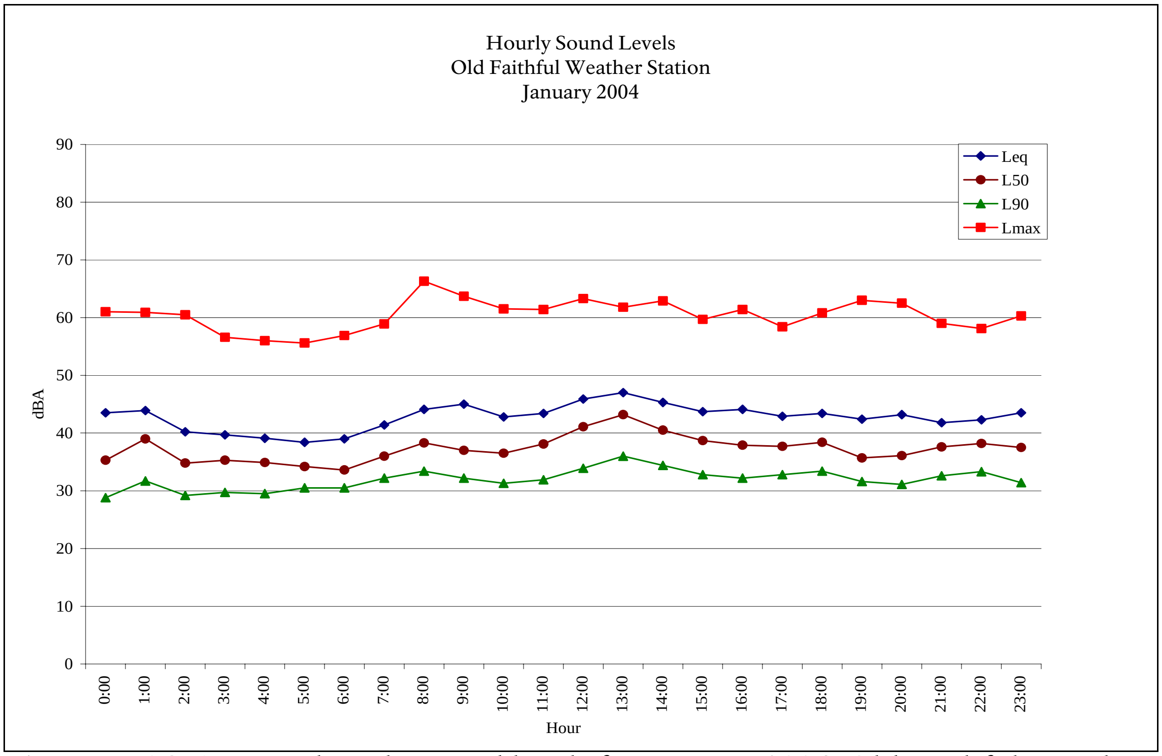


**Figure F-14**. Average hourly sound levels for January 2004, Old Faithful Weather Station, Yellowstone National Park. (n=735 hours)

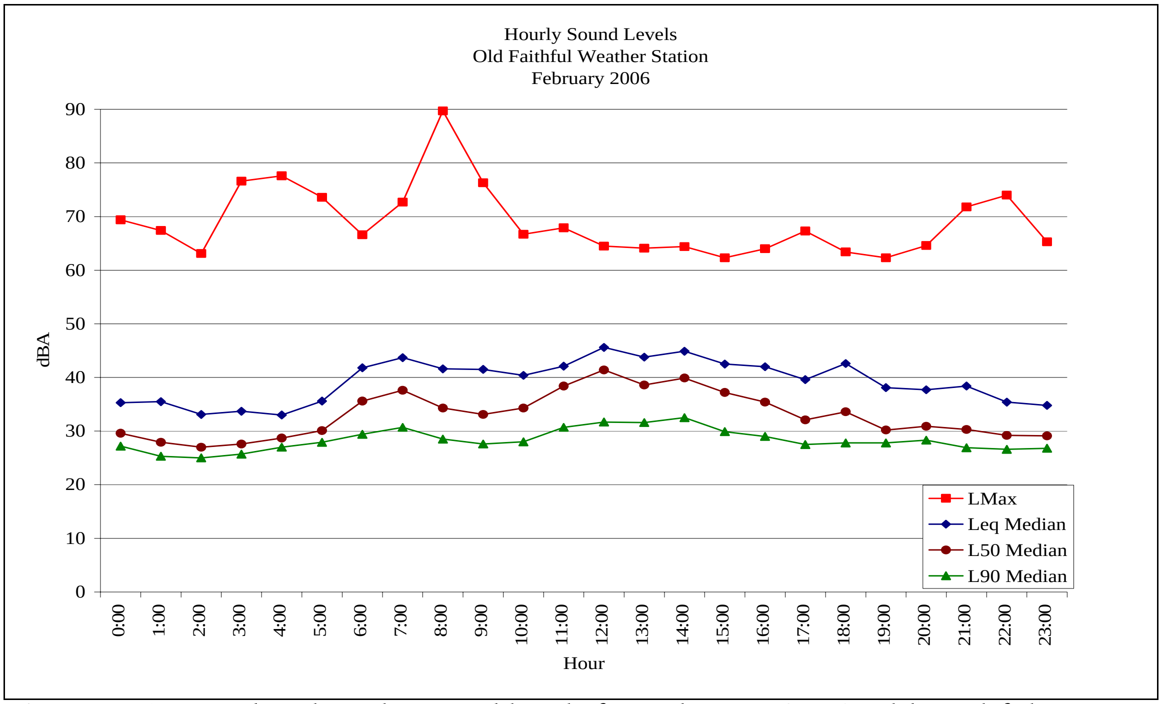


**Figure F-15**. Median hourly sound levels for February 2006, Old Faithful Weather Station, Yellowstone National Park. (n=637 hours)

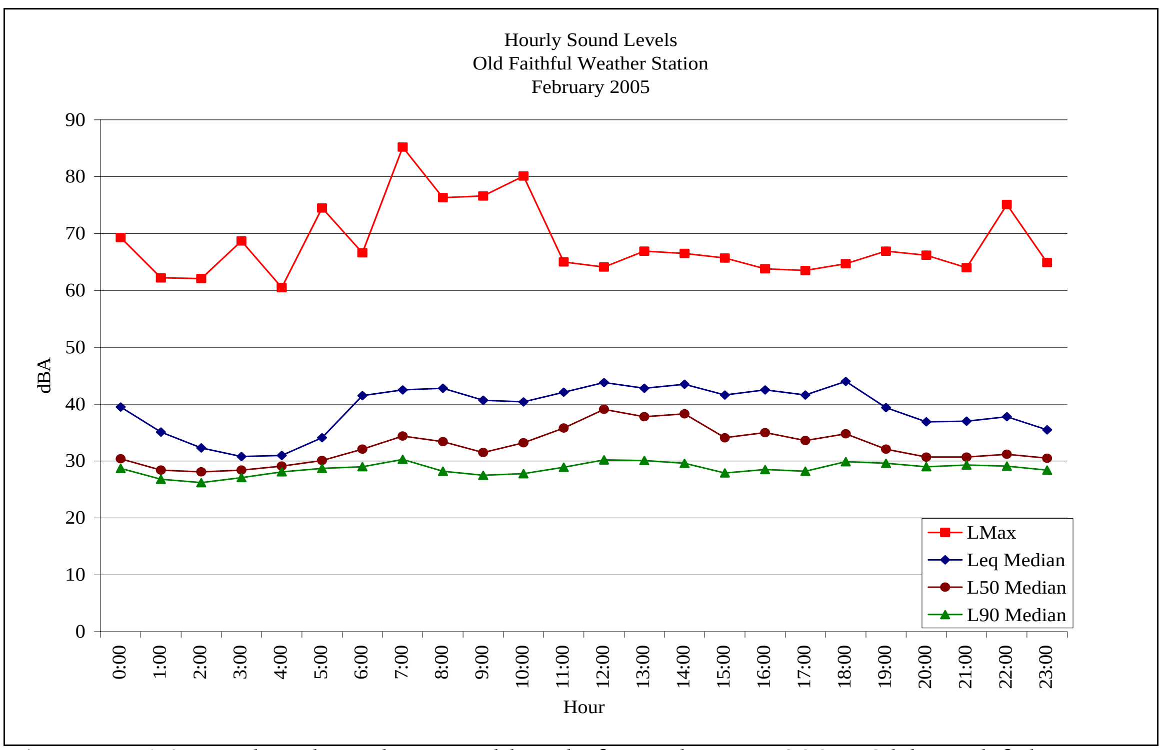


**Figure F-16**. Median hourly sound levels for February 2005, Old Faithful Weather Station, Yellowstone National Park. (n=609 hours)

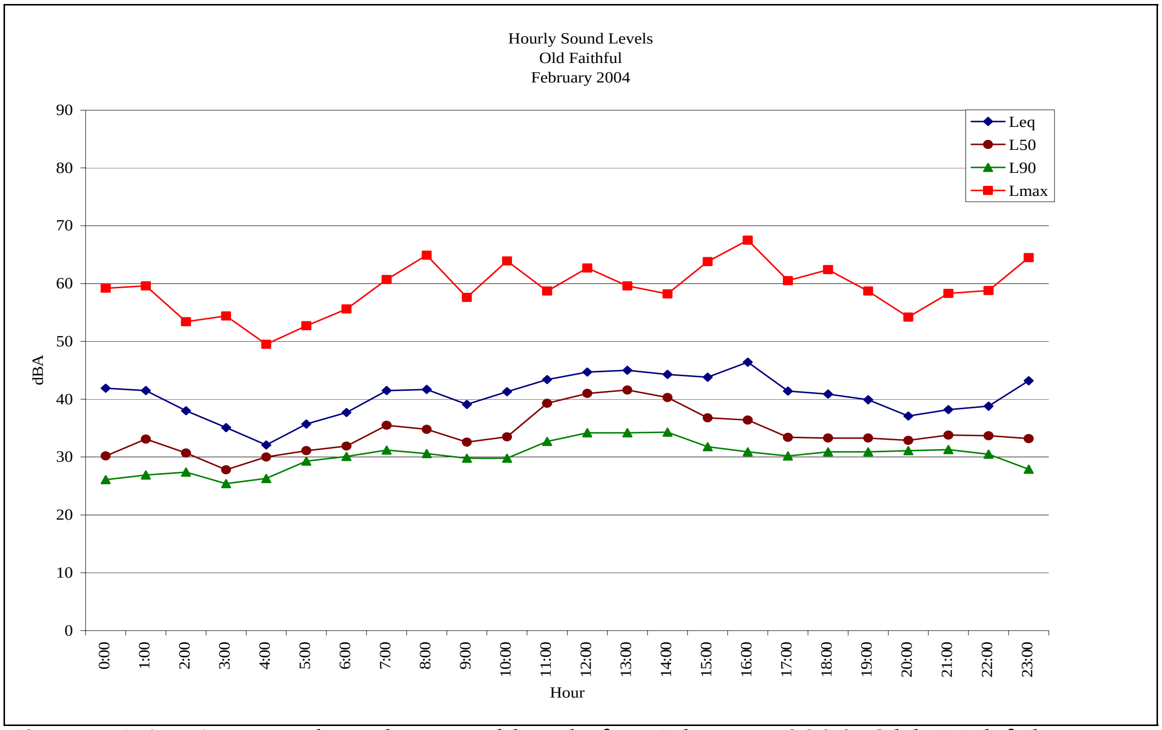


**Figure F-17**. Average hourly sound levels for February 2004, Old Faithful Weather Station, Yellowstone National Park. (n=435 hours)

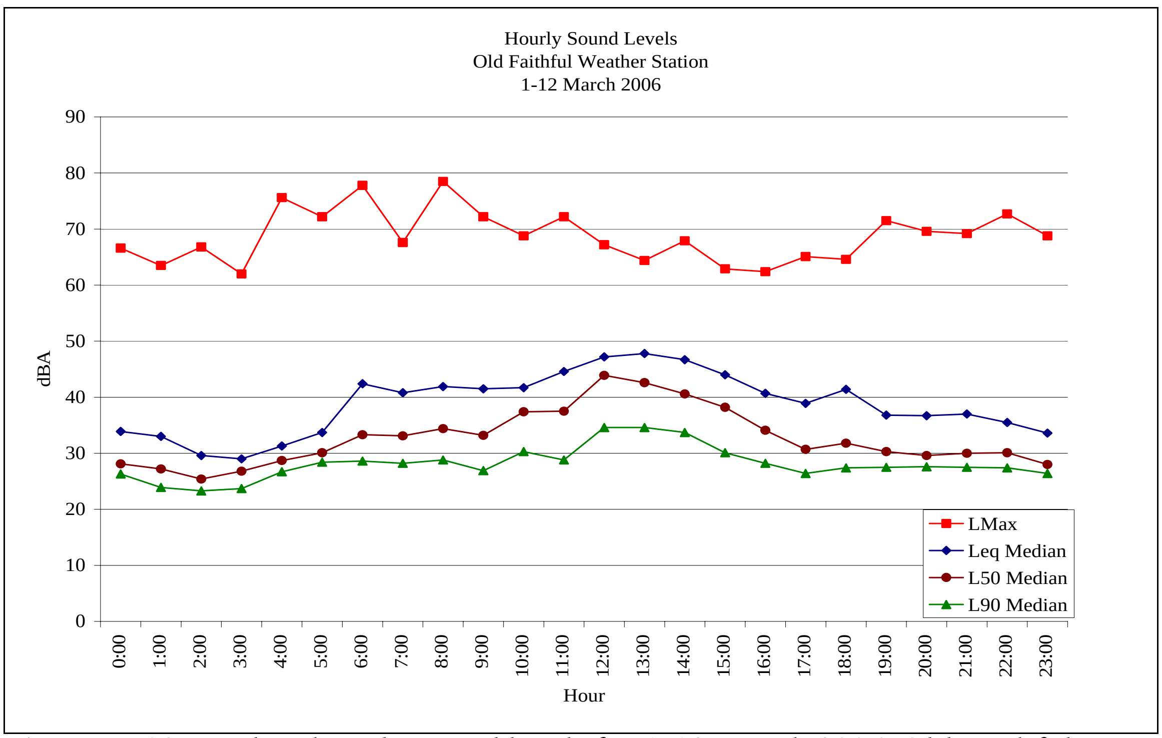


**Figure F-18**. Median hourly sound levels for 1-12 March 2006, Old Faithful Weather Station, Yellowstone National Park. (n=281 hours)

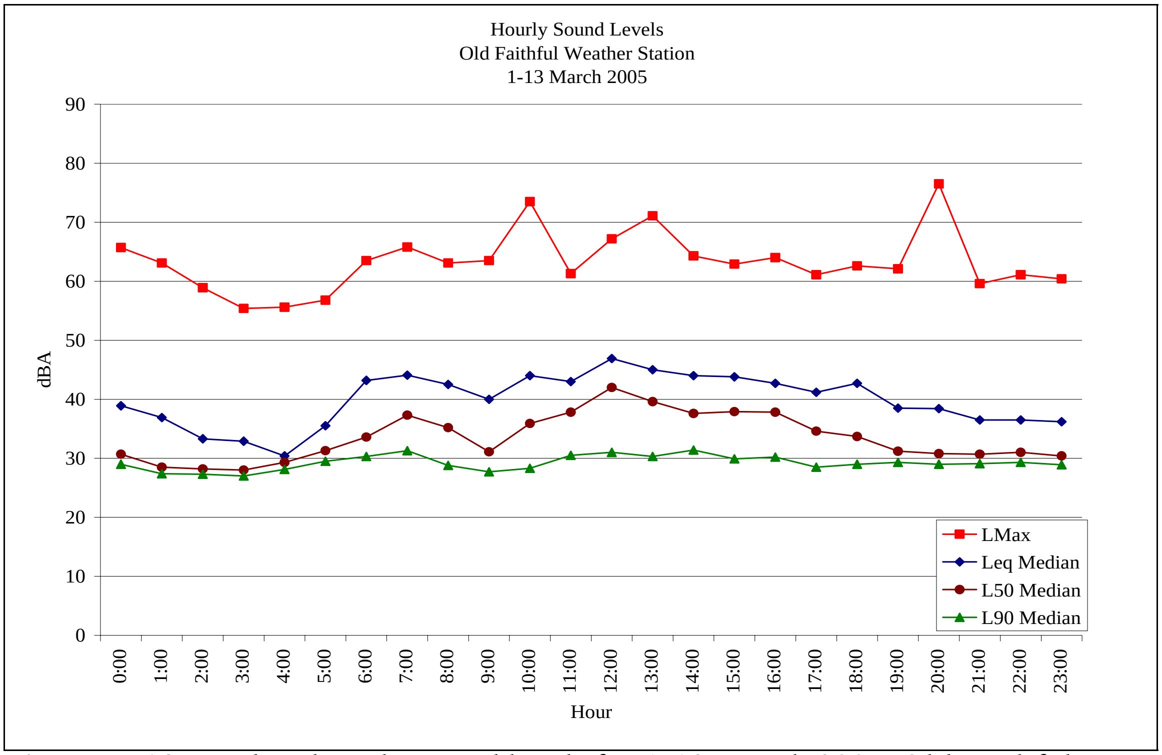


**Figure F-19**. Median hourly sound levels for 1-13 March 2005, Old Faithful Weather Station, Yellowstone National Park. (n=281 hours)

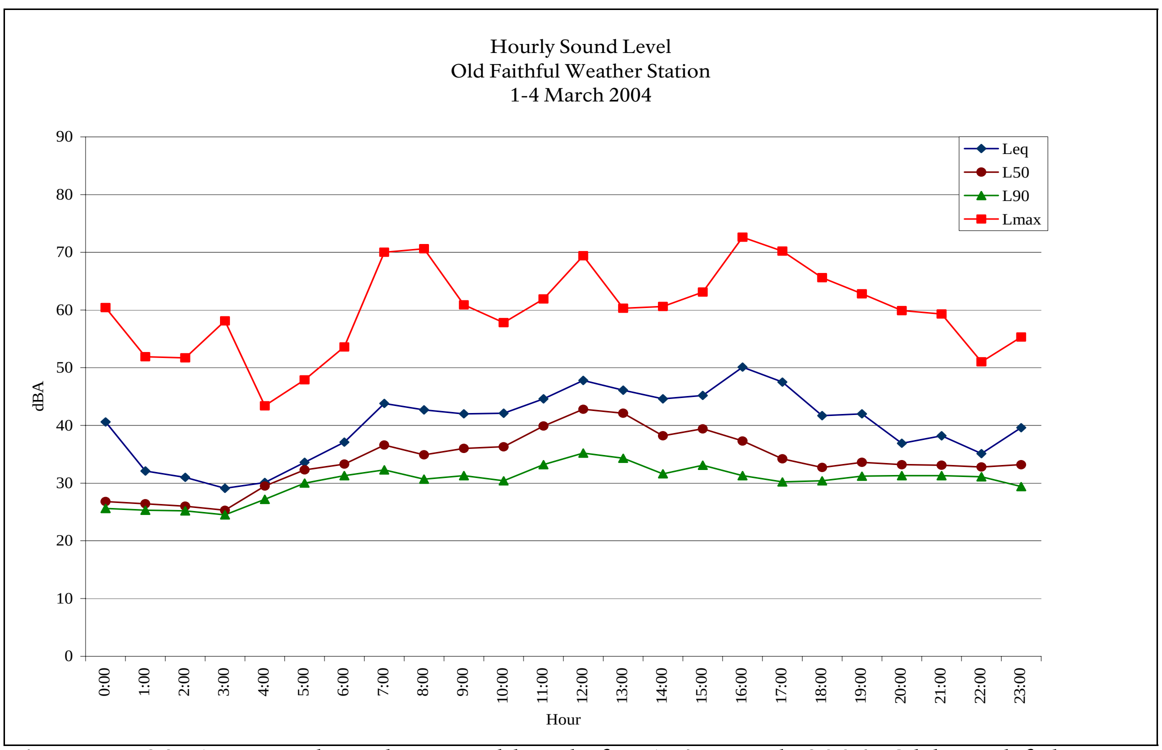


**Figure F-20**. Average hourly sound levels for 1-4 March 2004, Old Faithful Weather Station, Yellowstone National Park. (n=82 hours)

*Madison Junction 2.3*

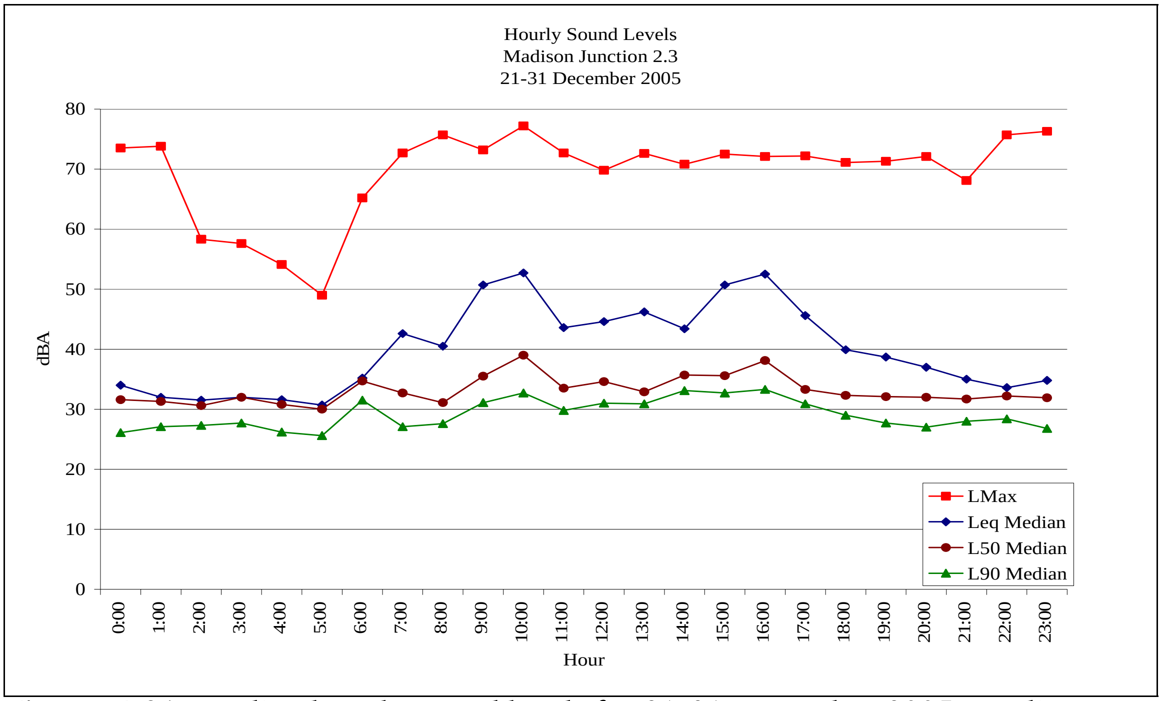


**Figure F-21**. Median hourly sound levels for 21-31 December 2005, Madison Junction 2.3, Yellowstone National Park. (n=259 hours)

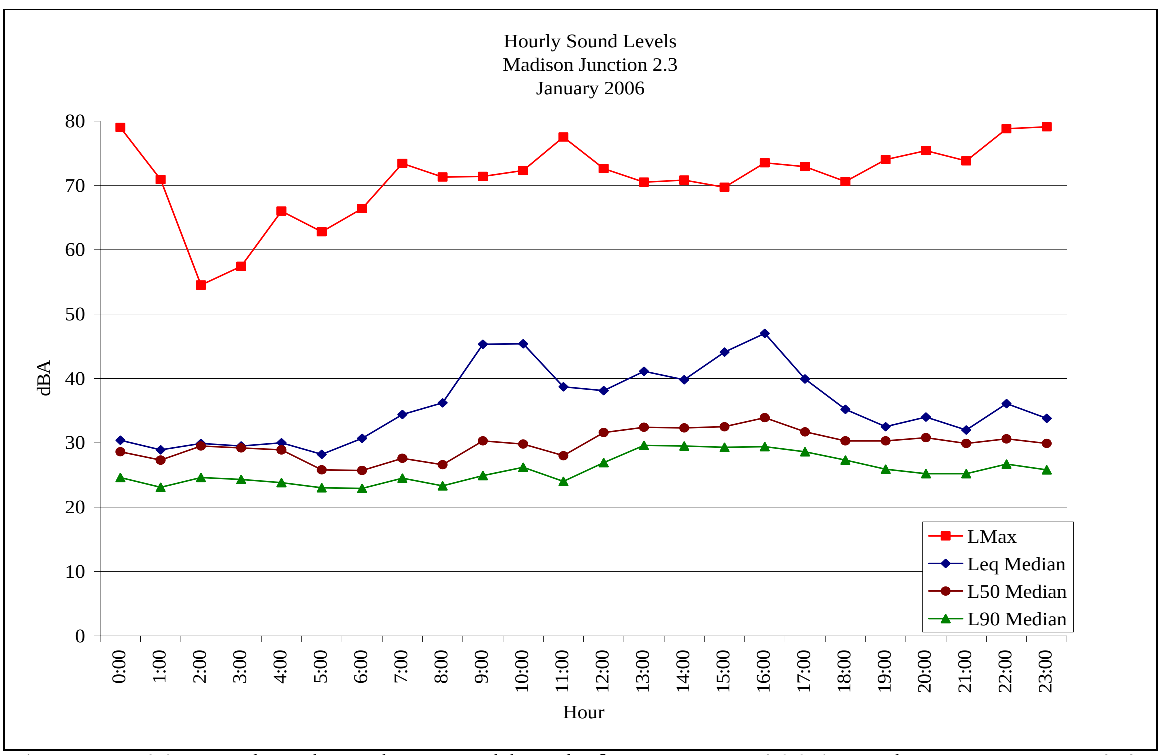


**Figure F-22**. Median hourly sound levels for January 2006 Madison Junction 2.3, Yellowstone National Park. (n=729 hours)

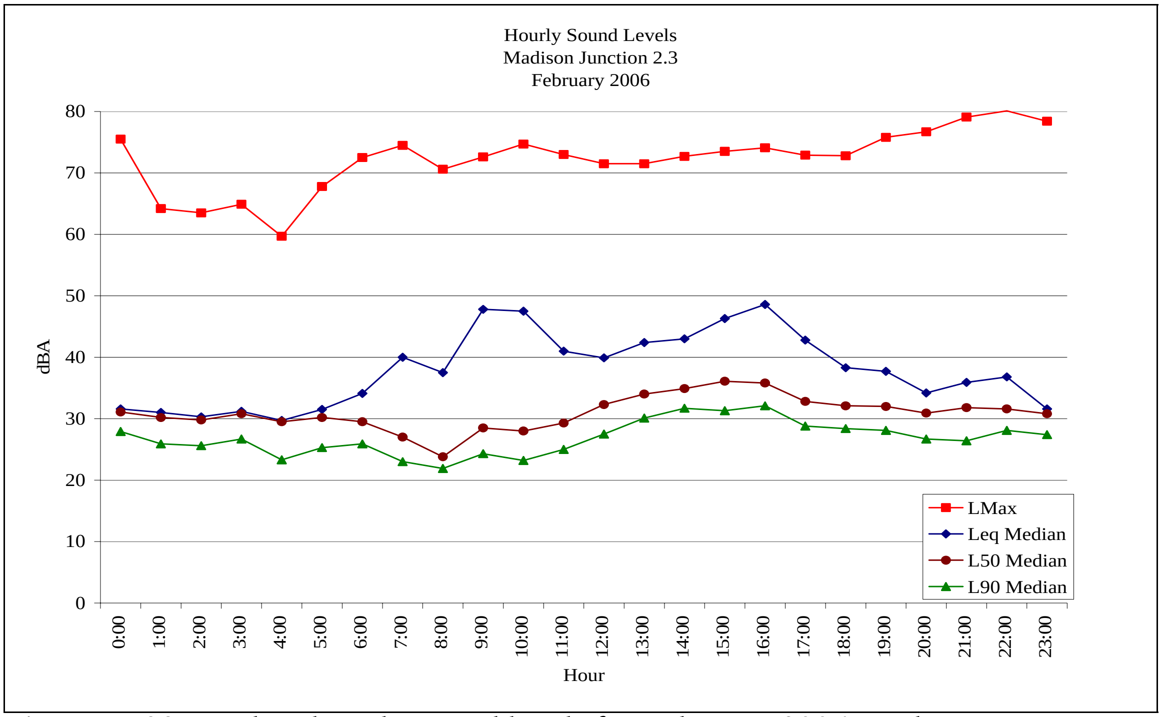


**Figure F-23**. Median hourly sound levels for February 2006 Madison Junction 2.3, Yellowstone National Park. (n=666 hours)

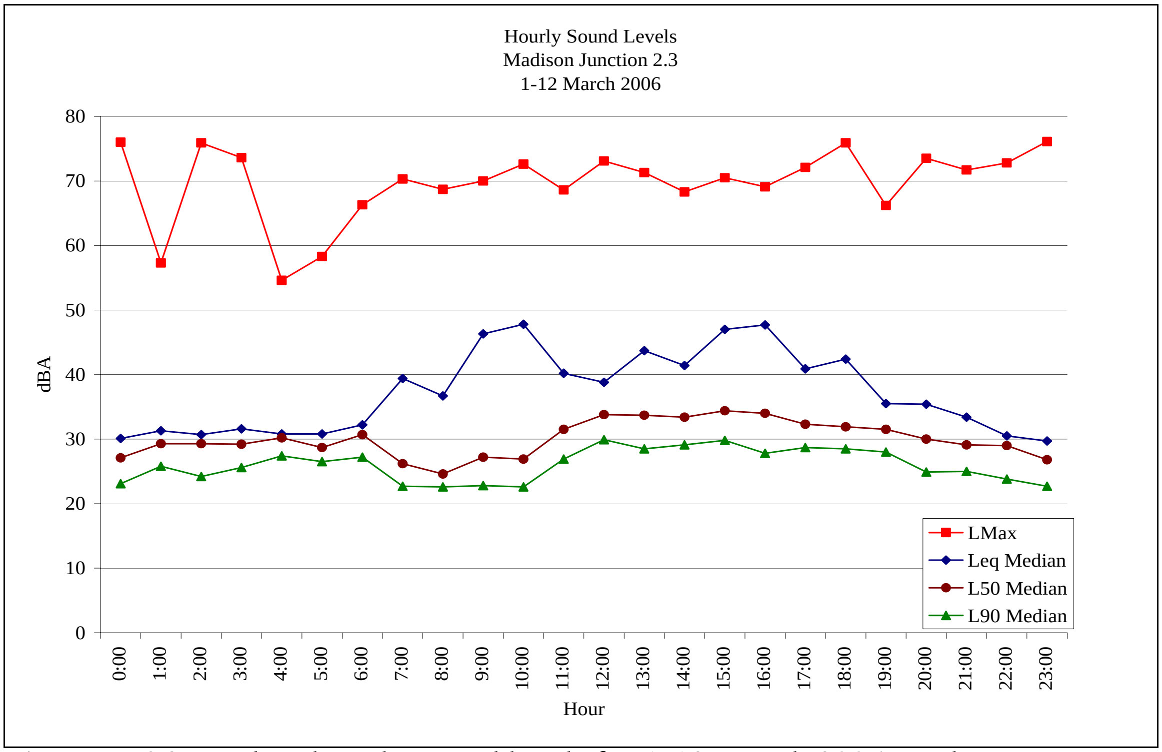


**Figure F-24**. Median hourly sound levels for 1-12 March 2006 Madison Junction 2.3, Yellowstone National Park. (n=286 hours)

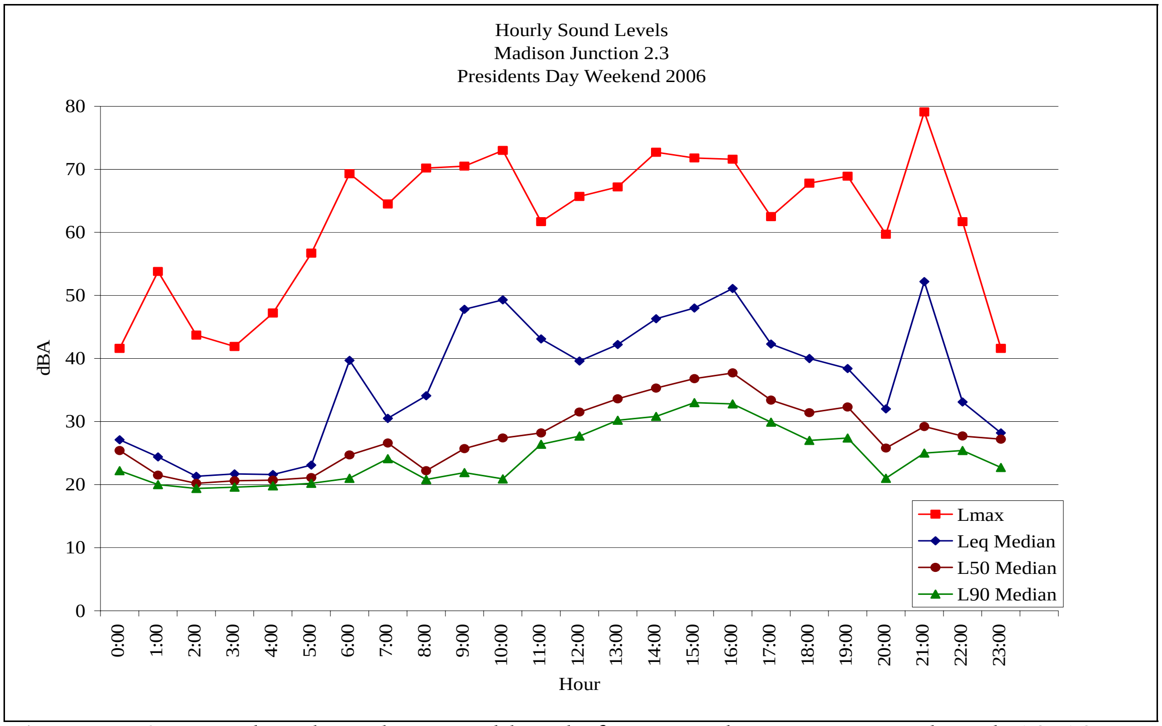


**Figure F-25**. Median hourly sound levels for Presidents Day Weekend, 18-19 February 2006, Madison Junction 2.3, Yellowstone National Park. (n=48 hours)

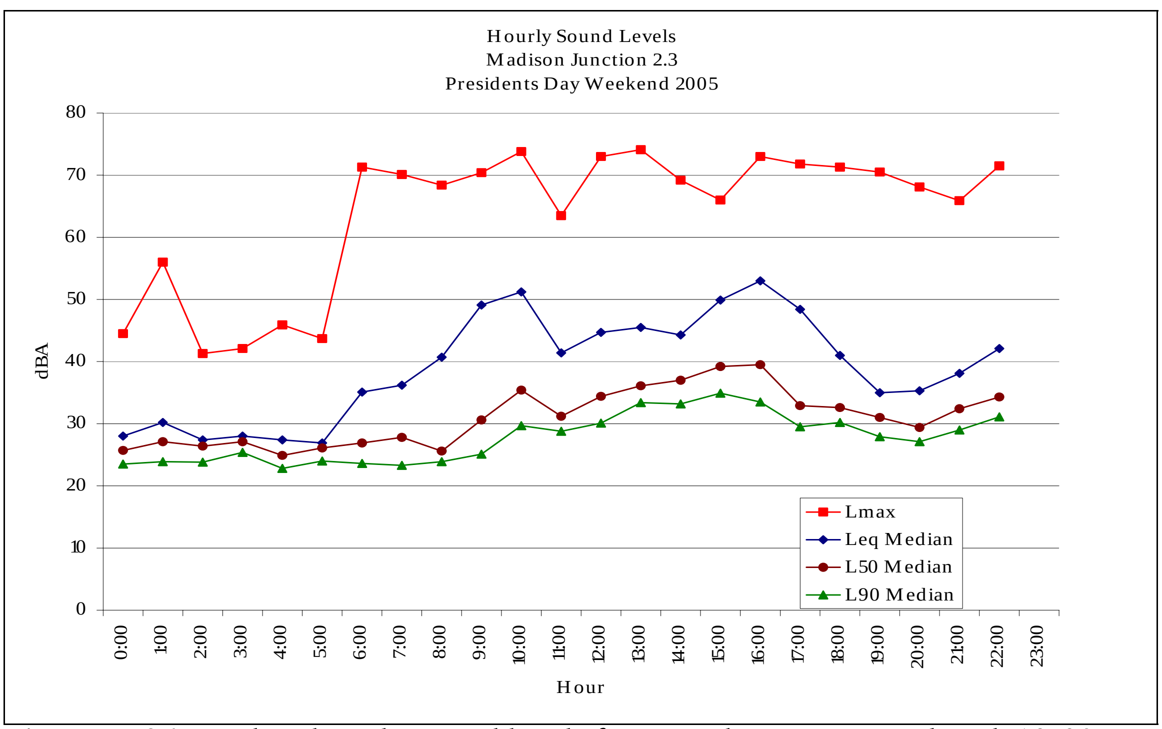


**Figure F-26**. Median hourly sound levels for Presidents Day Weekend, 19-20 February 2005, Madison Junction 2.3, Yellowstone National Park. (n=46 hours)

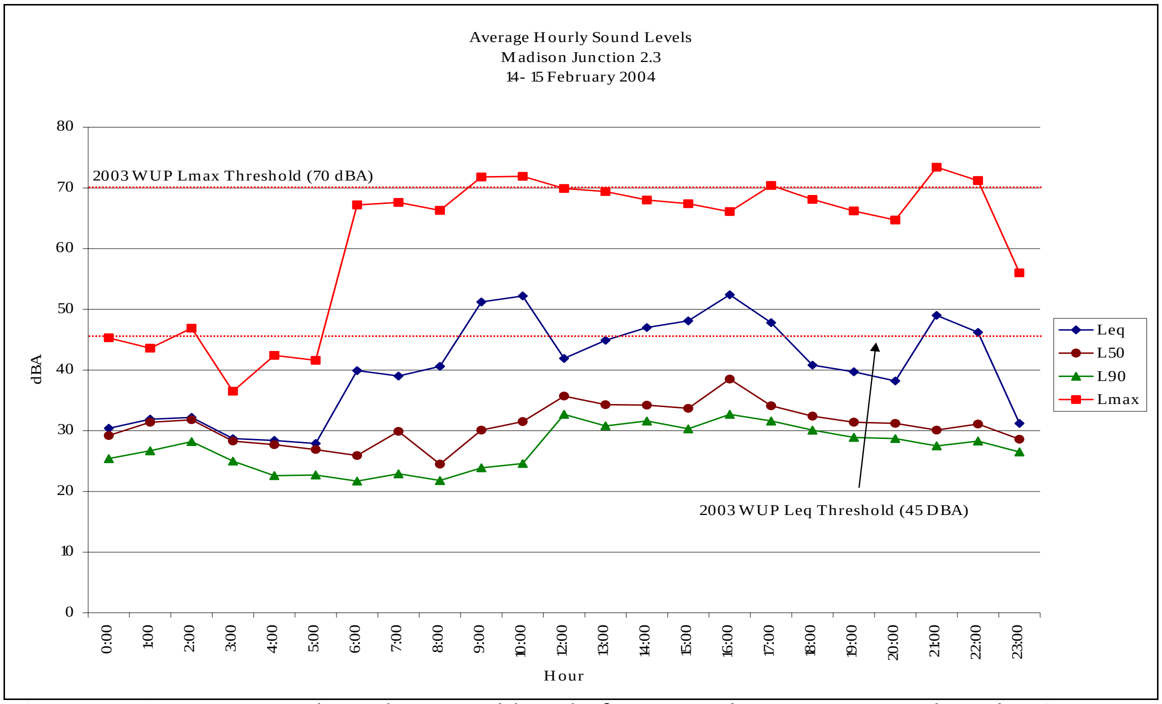


**Figure F-27**. Average hourly sound levels for Presidents Day Weekend, 14-15 February 2004, Madison Junction 2.3, Yellowstone National Park. (n=47 hours)

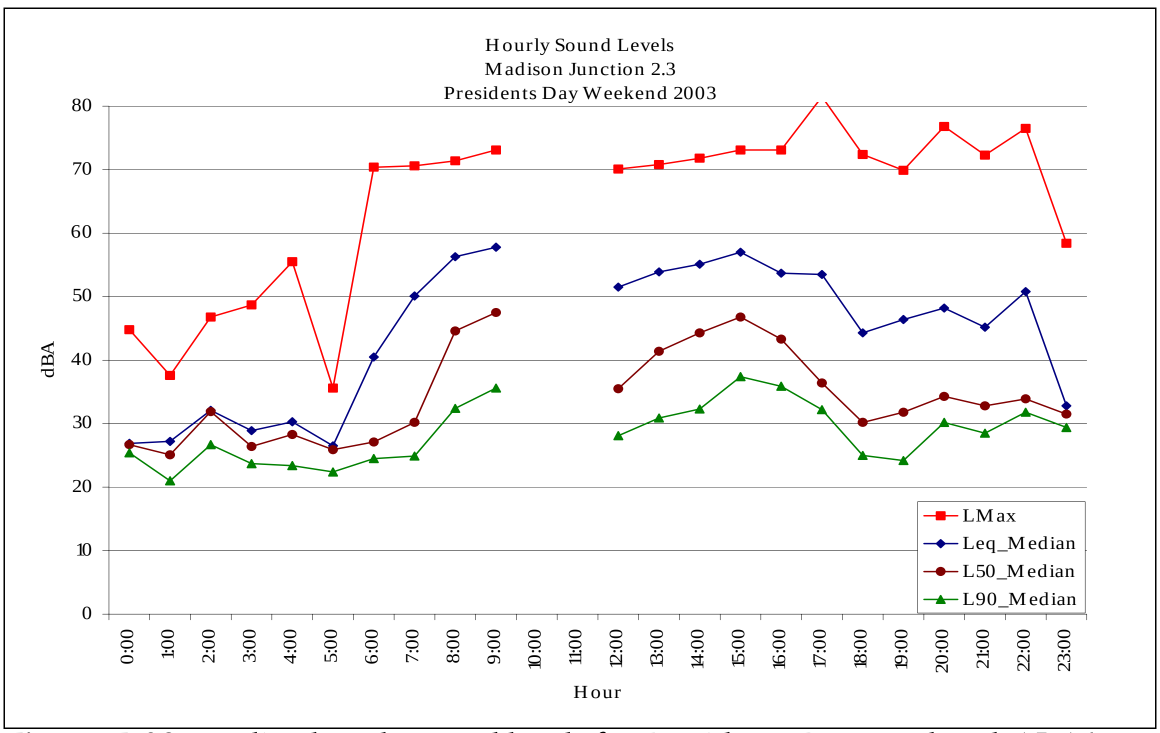


**Figure F-28**. Median hourly sound levels for Presidents Day Weekend, 15-16 February 2003, Madison Junction 2.3, Yellowstone National Park. Missing hours are due to site visits. (n=44 hours)