Natural Soundscape Monitoring in Yellowstone National Park December 2004- March 2005

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Shan Burson/NPS Photo

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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 determine 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 seven sites in Yellowstone National Park during the winter use season 15 December 2004- 13 March 2005.

Oversnow vehicles were audible in the Old Faithful developed area an average of 69% of the day between 8 am and 4 pm. Oversnow vehicles were audible 29% (Old Faithful Upper Basin) and 47% (West Thumb Geyser Basin) of the day within geyser basins adjacent to developed areas. Along travel corridors the percent time audible ranged from 55% (West Yellowstone 3.1, but see text for details) to 61% during Presidents Day weekend (Madison Junction 2.3). The percent time audible in backcountry areas ranged from 4% (Lone Star Geyser) to 26% (Mary Mountain 8K). Sounds from oversnow vehicles were audible at least one mile adjacent to the main motorized routes at Mary Mountain 8K and Lone Star Geyser. Oversnow vehicles operating in the Gallatin National Forest on the west boundary of Yellowstone National Park were often audible at the West Yellowstone 3.1 monitoring site, three miles away. 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 West Yellowstone 3.1). Oversnow vehicle use was restricted on some road segments due to inadequate snowcover early and late in the winter use season. Consistent with acoustic data collected the previous winter season, the sound level and the percent time oversnow vehicles were audible remained substantially lower than oversnow vehicle sounds from the 2002- 2003 winter use season. The reduced sound and audibility levels were largely explained by the fewer numbers of snowmobiles used, the change from two to four- stroke engine technology and the guided group requirements.

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Introduction:

Natural soundscapes are a valued resource at national parks including Yellowstone National Park. The 2001 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 and wheeled vehicles, aircraft, and the sounds associated with other human activity and facility utilities 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 were invalidated by judicial decisions. Notwithstanding these legal decisions, these winter use plans concluded that historical oversnow use created unacceptable adverse impacts on natural soundscapes (and other resources). Therefore to manage the impact of sounds from oversnow vehicles (OSV) on the natural soundscape and other resources, the 2004 Temporary Winter Use Plans (WUP) Environmental Assessment defined acoustical impact definition thresholds within three natural soundscape management areas. This Temporary WUP was in effect during the winters of 2003- 2004 and 2004- 2005.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 2004- 2005 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. However, additional data from other human and natural sources were collected and summarized. This report also includes similar acoustical data collected during the winters of 2002- 2003 and 2003- 2004. See "Natural Soundscape Monitoring in Yellowstone National Park December 2003-March 2004" for additional soundscape information of previous winters, and the 2000 and 2003 Winter Use Plans for details of oversnow management during prior years.

Study Area:

Yellowstone National Park occupies the northwest corner of Wyoming and extends a short distance into Montana and Idaho on the north and west boundaries. 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 reduced to 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 simplistic categorization is generally maintained for habitat descriptions in this present study; however further work is needed to describe properly the natural acoustic zones. The major highways within YNP that are open to vehicles during the summer are groomed and available 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 15 December 2004 and 13 March 2005, 18,364 snowmobiles and 2,201 snowcoaches, totaling 20,565 oversnow vehicles, entered YNP (NPS unpublished data). The majority (19,665; 95.6%) of these oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful.

Instrumentation and Methods:

Automated acoustic monitors (developed by Skip Ambrose, retired NPS Natural Sounds and Mike Donaldson, Far North Aquatics) 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 event thresholds were generally set at 70 dBA and 1 second (fast) and 50 dBA and 10 seconds (slow), but were adjusted depending on location and wind exposure. In locations with frequent high winds, the slow sound level thresholds were increased to prevent recording thousands of wind events. Calibrated Type 1 Larson Davis (Provo, Utah) 824 sound level meters and 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 for the sampling period. SoundMonitor030101™ (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) using a precision microphone interface. 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 the dummy microphone) is the lowest sound level that the system can measure. During quiet periods the actual ambient sound level may be lower than the noise floor. Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) collected wind speed.

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 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 and height, and other factors are presented 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 sound monitoring locations (Fig. 1) were chosen among high use areas to represent the three natural soundscape management zones (Developed Area, Travel Corridor and Backcountry Area) and to permit comparisons to acoustic data collected previous winters. The specific placement relative to sound sources of interest was mainly determined by logistical constraints. These 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 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.

Old Faithful Upper Basin

Latitude:	44.46325
Longitude:	110.82740
Elevation:	7400 feet
Habitat:	60% open (wetlands, thermal area, boardwalk), 10% open (river), 30% forested (lodgepole pine),
Management Area:	Developed Area

The Old Faithful Upper Basin monitor was in a small group of lodgepole pines within the thermal area directly adjacent to a boardwalk. The microphone was located 15 feet off the boardwalk on Geyser Hill, 1050 feet from Old Faithful Geyser, 1650 feet from the Visitor Center and 1800 feet from the nearest motorized route (parking area). The monitor was powered directly from 12 volt batteries without solar panels.

Lone Star Geyser

Latitude:	44.41930
Longitude:	110.80482
Elevation:	7700 feet
Habitat:	75% forested (lodgepole pine), 25% open (thermal area)
Management Area:	Backcountry Area

The Lone Star monitor was located at the forest edge at the northeastern corner of the open thermal area surrounding Lone Star Geyser. The site was approximately 2.4 miles along a trail from the groomed Old Faithful- West Thumb Road and one mile in a straight line with intervening dense lodgepole forest and hills from the road. The microphones were located 200 feet from the periodically groomed ski trail, 525 feet from the geyser, and 25 feet from the edge of the open thermal area. The monitor was powered by 12 volt batteries charged by solar panels.

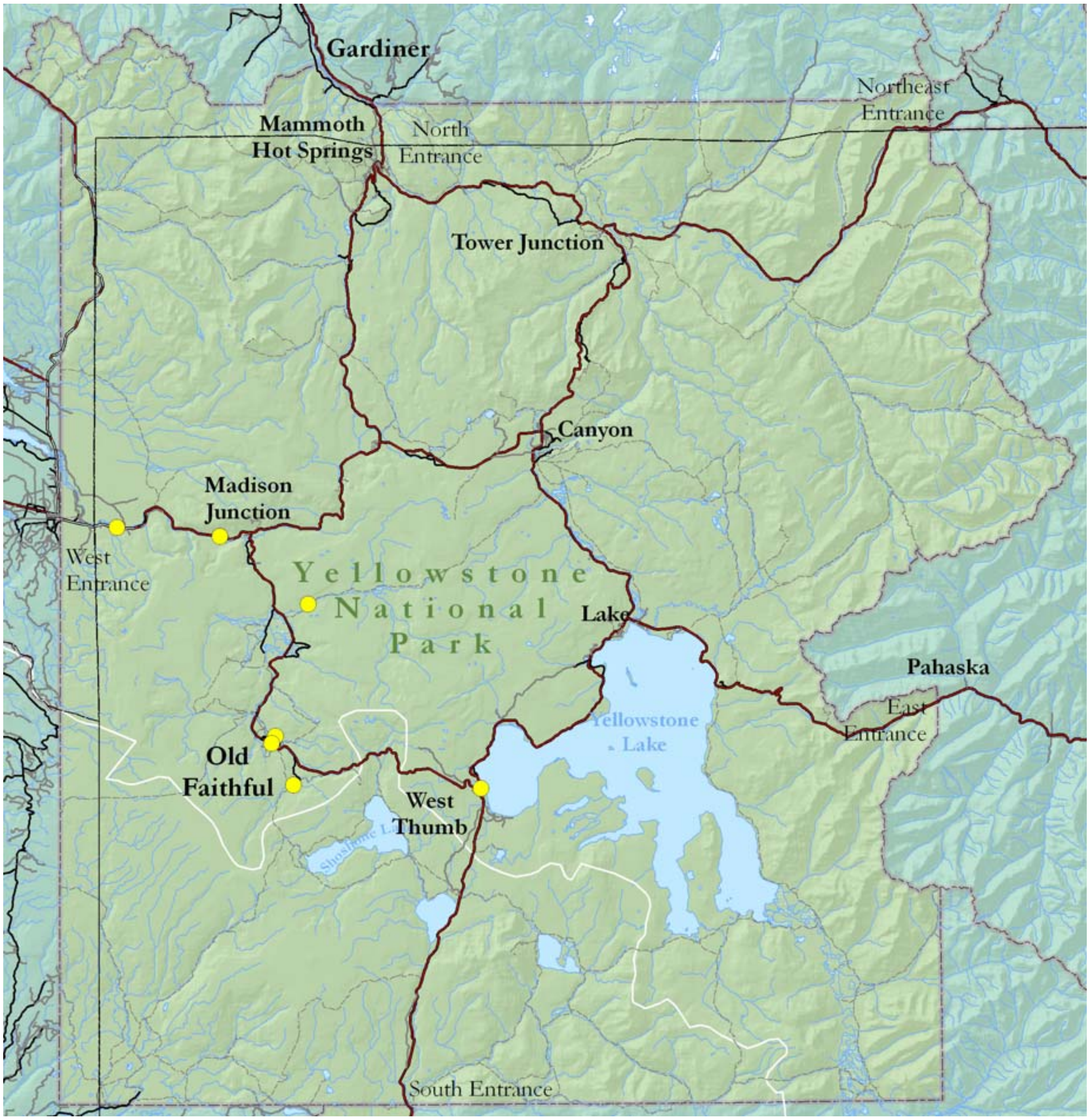

Figure 1. Locations of sound monitoring sites (yellow circles) within Yellowstone National Park, December 2004- March 2005. North to south: West Yellowstone 3.1, Madison Junction 2.3, Mary Mountain 8K, Old Faithful Upper Basin, Old Faithful Weather Station, Lone Star Geyser, and West Thumb.

Mary Mountain 8K
Latitude: 44.58153

Longitude: 110.78603
Elevation: 7200 feet
Habitat: 60% open (grassland), 10% open (river), 30% forested (lodgepole pine)
Management Area: Backcountry Area

The Mary Mountain 8K monitor was located adjacent to a downed tree on the edge of a meadow 8000 feet from the groomed Old Faithful- Madison Junction Road, 200 feet from the Nez Pierce River and 500 feet from the Mary Mountain Trail. The terrain was mostly open with pockets of lodgepole forests and two isolated hills between the monitor and the road. The monitor was powered by 12 volt batteries charged by solar panels.

West Yellowstone 3.1
Latitude: 44.65060
Longitude: 111.02554
Elevation: 6700 feet
Habitat: 15% open (road, river), 15% open (grassland), 70% forested (post- burn lodgepole pine)
Management Area: Travel Corridor

The West Yellowstone 3.1 monitor was located 100 feet south of the groomed Madison Junction- West Yellowstone Road 3.1 miles from the West Entrance within a post- burn lodgepole regrowth area. The nearby trees heights ranged from 5 to 15 feet. The Madison River was about 300 feet from the microphone north of the groomed road. The monitor was powered by 12 volt batteries charged by solar panels.

West Thumb
Latitude: 44.41589
Longitude: 110.57093
Elevation: 7900 feet
Habitat: 15% open (parking lot, road, boardwalk, buildings), 60% open (wetlands, thermal area, lake), 25% forested (lodgepole pine)
Management Area: Developed Area

The West Thumb monitor was located 10 feet from the most easterly boardwalk loop within the West Thumb geyser basin under a large single lodgepole pine 425 feet from the warming hut, 650 feet from Yellowstone Lake, 850 from the West Thumb to Canyon groomed road and 1800 feet from the South Entrance to West Thumb groomed road. The West Thumb monitor was powered directly from 12 volt batteries.

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 6 feet) lodgepole pines, and 275 feet from the Firehole River. The Madison Junction 2.3 monitor was powered directly from 12 volt batteries.

Analyses:

<u>Audibility</u>

The daily 360 10- second digital recordings were calibrated and replayed using Adobe's Audition™ software, Sound Devices USBPre™ acoustical interface and professional headphones. 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) has to be increased by 10 dB to approximate field audibility. This value was determined from comparisons between field recordings with sound sources identified and subsequent office playback. An additional factor in field listening is that 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. 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 a sampling scheme may miss a rare sound, testing 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 (Figs. 4 and 18 provide examples of the relative proportions of snowmobiles, snowcoaches and the combined category at two locations).

Event Analysis

The event recordings of loud sounds were replayed and each sound source identified and tallied. The events caused by wind were not included in these analyses.

Sound levels

Sound pressure level data (decibels) were reduced and common acoustic metrics were calculated using the analytical software, HourlyMetrics™ (Ric Hupalo, 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 objective of this study. Data influenced by visits to the monitoring site were also deleted. Although historically, arithmetic averages were generally used to aggregate hourly summary metrics, decibels are logarithmic and therefore logarithmic averages are more appropriate. The hourly sound level data presented here for comparative purposes from 2003/2004 were calculated using logarithmic averages. However, sound levels collected over long time intervals in national parks are rarely normally distributed (there are many more low levels than high levels) therefore median values provide better estimates of central tendencies and are used for the analysis of 2004/2005 data.

This report relies on a number of common acoustical metrics for the sound level data and descriptive statistics, mostly medians, for the audibility data. It should be recognized that high and low data points are masked when medians are calculated. A disadvantage of using medians is that knowledge of these high values is often valuable for proper interpretation. These missing elements are included when their absence may lead to misinterpretation. Estimates of variability beyond the minimum and maximum values are also desirable. A statistician from Montana State University is conducting additional detailed statistical analyses of these acoustic data and will report on his findings by the spring 2006.

Results from this sound monitoring project can be compared to the 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: Ch. 1 (2.12) p.21- 22. 1 July 2003).

Results and Discussion:

Long- term acoustical measurements were made at four primary sites, Old Faithful Weather Station, Lone Star Geyser, Mary Mountain 8K, and West Yellowstone 3.1. Additional data were collected at one site (Madison Junction 2.3) over Presidents Day Weekend and two weeklong sites (Old Faithful Upper Basin and West Thumb) during January and February 2005 (see previous section for site details). Data collection began on 10 December 2004 and continued throughout the winter, although only data collected during the winter use season (15 December 2004- 13 March 2005) are presented. Selected data (Tables 2 and 3) were chosen for analysis based on visitor usage patterns, distribution over days of the week, month and season, daily wind conditions, timing of previous measurements, and availability of time for analysis. 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.

Oversnow travel was prohibited on particular road segments due to lack of adequate snowcover early and late in the 2004/2005 winter use season. Travel by snowmobile from the West Entrance to Madison Junction began 1 January and ended 9 March 2005. Therefore fewer snowmobiles traveled to Old Faithful during the early and late season and this was reflected in the acoustic data.

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

See Appendix D for 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).

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 seven locations in Yellowstone National Park, December 2004- March 2005. Daily average number of snowmobiles was 206/day for the winter use season and 239/day for January and February. Daily average number of snowmobiles during days used for analysis are listed at bottom of table. Daily average number of snowcoaches for the winter use season was 25/day. See text for further details and the dates of restricted oversnow travel (page 14). Total number of days analyzed, 99.

Old Faithful Weather Station <u>25 days</u>	West Yellowstone 3.1 <u>22 days</u>	Lone Star Geyser <u>18 days</u>	Mary Mnt 8K <u>18 days</u>	Old Faithful Upper Basin <u>8 days</u>	West Thumb <u>6 days</u>	Madison Jnct. 2.3 <u>2 days</u>
16- Dec- 04	17- Dec- 04	19- Jan- 05	10- Jan- 05	25- Jan- 05	5- Feb- 05	19- Feb- 05
17- Dec- 04	22- Dec- 04	21- Jan- 05	11- Jan- 05	26- Jan- 05	6- Feb- 05	20- Feb- 05
18- Dec- 04	23- Dec- 04	24- Jan- 05	16- Jan- 05	27- Jan- 05	7- Feb- 05	
24- Dec- 04	24- Dec- 04	27- Jan- 05	27- Jan- 05	28- Jan- 05	8- Feb- 05	
25- Dec- 04	25- Dec- 04	29- Jan- 05	28- Jan- 05	29- Jan- 05	9- Feb- 05	
26- Dec- 04	28- Jan- 05	30- Jan- 05	29- Jan- 05	30- Jan- 05	10- Feb- 05	
28- Dec- 04	29- Jan- 05	2- Feb- 05	31- Jan- 05	31- Jan- 05		
1- Jan- 05	30- Jan- 05	6- Feb- 05	2- Feb- 05	1- Feb- 05		
10- Jan- 05	31- Jan- 05	7- Feb- 05	6- Feb- 05			
25- Jan- 05	1- Feb- 05	10- Feb- 05	10- Feb- 05			
26- Jan- 05	7- Feb- 05	18- Feb- 05	18- Feb- 05			
27- Jan- 05	11- Feb- 05	22- Feb- 05	19- Feb- 05			
29- Jan- 05	18- Feb- 05	26- Feb- 05	24- Feb- 05			
1- Feb- 05	19- Feb- 05	3- Mar- 05	2- Mar- 05			
7- Feb- 05	20- Feb- 05	4- Mar- 05	4- Mar- 05			
18- Feb- 05	21- Feb- 05	5- Mar- 05	5- Mar- 05			
19- Feb- 05	26- Feb- 05	12- Mar- 05	8- Mar- 05			
20- Feb- 05	2- Mar- 05	13- Mar- 05	11- Mar- 05			
21- Feb- 05	4- Mar- 05					
24- Feb- 05	7- Mar- 05					
25- Feb- 05	10- Mar- 05					
3- Mar- 05	13- Mar- 05					
4- Mar- 05						
5- Mar- 05						
13- Mar- 05						
Average # of snowmobiles during sampling days*						
204/day	110/day	228/day	140/day	232/day	72/day	253/day

* Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone with the exception of only West Yellowstone Entrance snowmobiles were used for West Yellowstone 3.1, Madison Junction 2.3 and Mary Mountain 8K, and only South Entrance snowmobiles were use for West Thumb. Up to 30 snowmobiles/day may have originated at Old Faithful and were not included in the totals here.

Table 3. Dates used for sound level analyses at seven locations in Yellowstone National Park, December 2004- March 2005. Total hours, 6,869.

Old Faithful (1,996 hours) 15 December 2004- 13 March 2005	Old Faithful Upper Basin (280 hours) 25 January 2004- 2 February 2005
Lone Star Geyser (1,673 hours) 15 December 2004- 3 January 2005 18 January- 13 March 2005	West Thumb (172 hours) 4- 11 February 2005
West Yellowstone 3.1 (1,363 hours) 14 January- 13 March 2005	Madison Jct 2.3 (47 hours) 19- 20 February 2005
Mary Mnt. 8K (1,338 hours) 7 January 2004- 13 March 2005	

Audibility:

We determined the source of each sound (snowmobile, animal, aircraft, wind, thermal activity, etc.) that was audible each day during 8 am- 4 pm from the 120 10-second (for a daily total of 20 minutes) digital recording samples. We then used the proportion of each sound source sample out of the possible 120 to calculate the percent time audible for each sound source; however, only the snowmobile and snowcoach percent time audible is presented here. Oversnow vehicles were often audible outside the 8 am – 4 pm time period, but this data is generally not presented here. 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 25/day (range 7- 52). The average number of snowmobiles entering YNP during the winter season was 206/day (range 43- 424). See Table 1 and Appendix D for further details.

The percent time audible calculations were based on the entire winter use season unless otherwise noted, including the periods with restricted oversnow vehicle use. The resulting percent time audible values are therefore lower than they would be if the early and late season periods had been eliminated from the analysis. However, days with high winds were generally not analyzed for percent time audible due to the occasional wind contamination of the recording and the masking effects of wind turbulence. If days with high winds had been included, the overall percent time oversnow vehicles were audible would likely have been slightly lower.

An important question is what is the relationship between the number of snowmobiles and snowcoaches entering YNP and the percent time 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 apparent in the some of the acoustic data collected during the past three winters (see early and late season 2004/2005 at Old Faithful Weather Station [Fig. 2]). Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are NPS and concession snowmobiles used within the park, especially in destination areas such as Old Faithful (Appendix D). 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 audibility. 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 and other factors (next paragraph) that vary spatially and temporally, further complicating the relationship between the number of visitor snowmobiles and their percent time audible. Studies are planned for the upcoming winter to address these issues.

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 would be the times when no oversnow vehicles were audible. Using common sense and logic, 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).

Audibility depends on the sound level of and distance from the sound source as well 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 location. No two days were identical, but patterns were regularly observed and differences among monitoring locations are demonstrated.

Old Faithful Weather Station

Within the developed area at Old Faithful, the average daily percent time audible for snowmobiles and snowcoaches was 69% (Fig. 2). This compares to 61% during the previous winter use season (Fig. 3). The increase in audibility may be explained in part by the addition of contractors commuting to work at the Old Faithful Inn, 600 feet from the monitor. Contractors comprised 11% of the total number of groups and 5% of the total number of snowmobiles audible in the Old Faithful area during 13 hours of observation (see Appendix D). Oversnow vehicles traveling on the main route and within the Old Faithful developed area were audible at this site. The 2004/2005 daily percent time audible values reflect the restricted oversnow road use periods during the early and late season (Fig. 2). Figure 2 also shows the percent time that wind was audible. Wind, depending on direction and speed, can increase the distance sounds are audible or mask other sounds. Unlike at the backcountry sites, the association between wind and oversnow vehicle percent time audible at Old Faithful is negligible (Fig. 2).

Percent time audible can be calculated by hour to understand the pattern of oversnow vehicle use between 8 am and 4 pm (Fig. 4, compare to previous season Fig. 5). Figures 4 and 5 also show the relative proportion of snowmobiles and snowcoaches in the overall oversnow vehicle category, and Figure 4 shows the maximum and minimum percent time oversnow vehicles were audible from each hour used to calculate the average values. (E.g., during the winter season, oversnow vehicles were audible for an average of 81% of the 1100 hour. Oversnow vehicles were audible for 100% of the 1100 hour on 25 January and 20 February and a low of 53% of the 1100 hour on 26 December). The three hours, 11 am to 1 pm exceeded the average percent time audible impact definition threshold of 75% of the 2004 Temporary WUP (e.g., exceeded 75% on 15 of 25 days at the 1100 hour). The analyses for the WUP measurement period are restricted to 8 am- 4 pm but oversnow vehicle sounds beyond that time were common, especially later in the day (e.g., Fig. 6). For comparative purposes, Figures 6, 7 and 8 show days with the maximum percent time audible for the past three seasons. Figure 6 also shows the increased snowmobile use during the late night and early morning hours compared to previous years. This unexplained increased use was a general trend for the winter of 2004/2005.

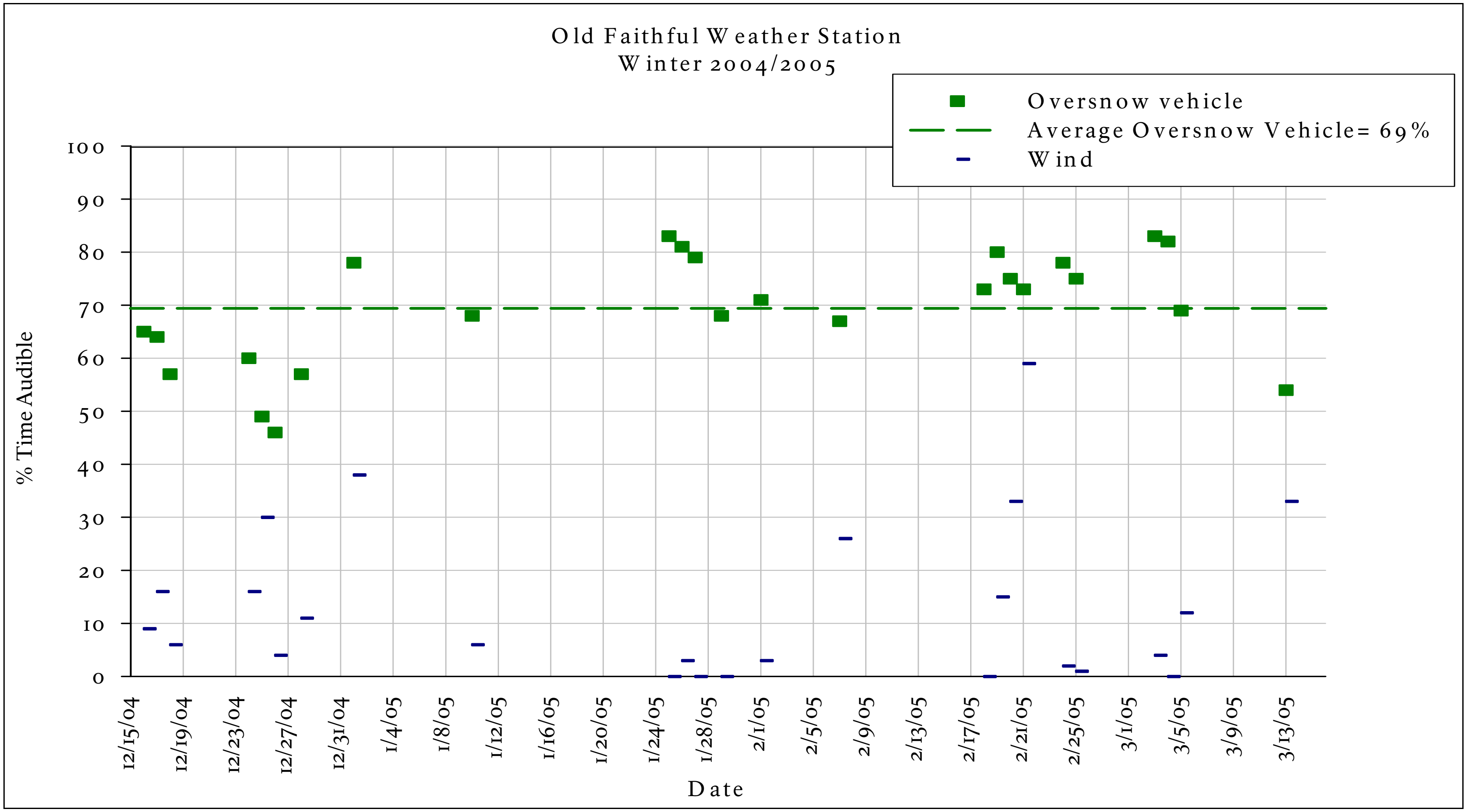

Figure 2. The percent time audible for snowmobiles and snowcoaches, and wind (dashes) by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March 2005. Compare to Fig. 3.

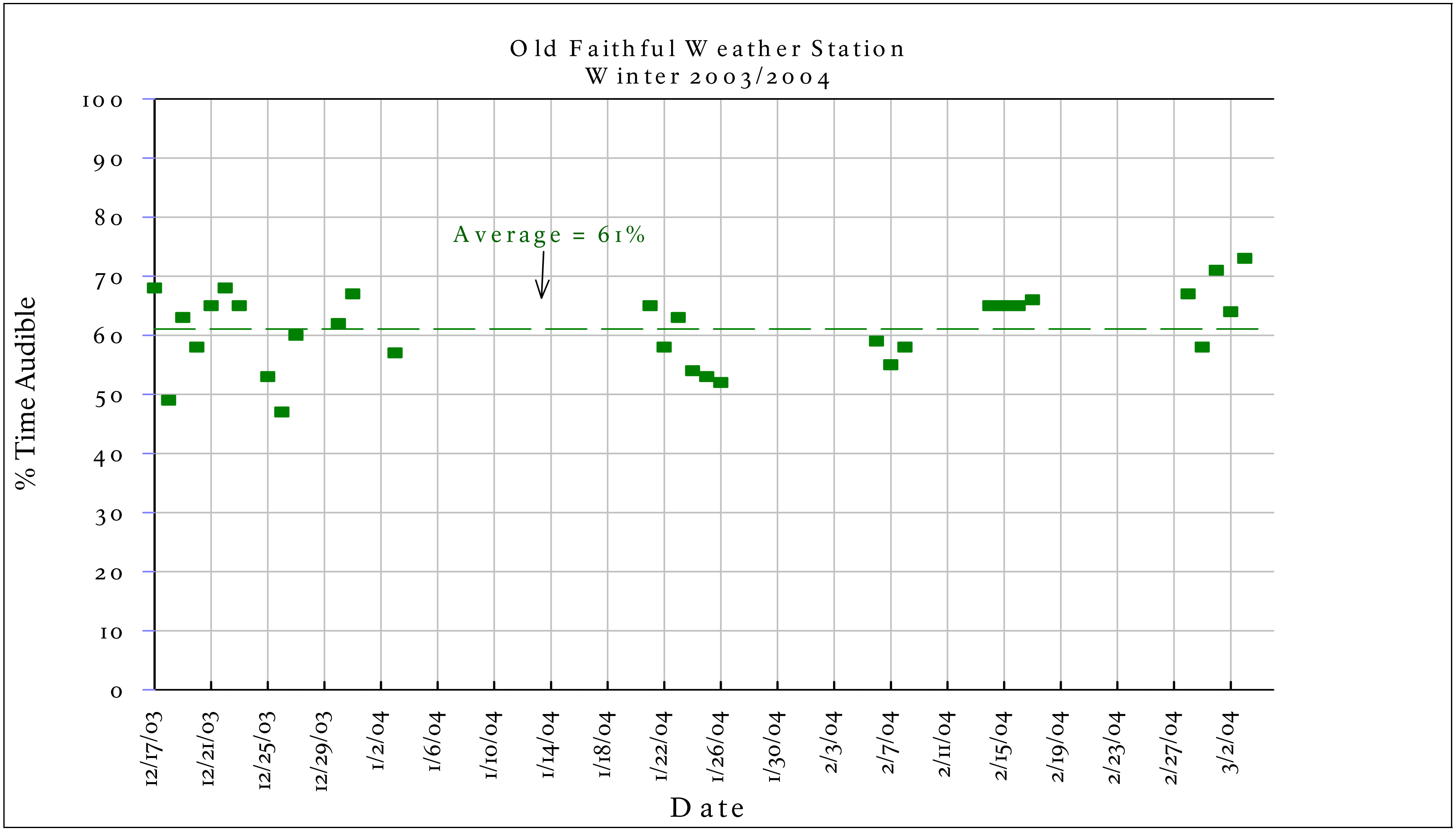

Figure 3. The percent time audible by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 3 March 2004. Compare to Fig. 2.

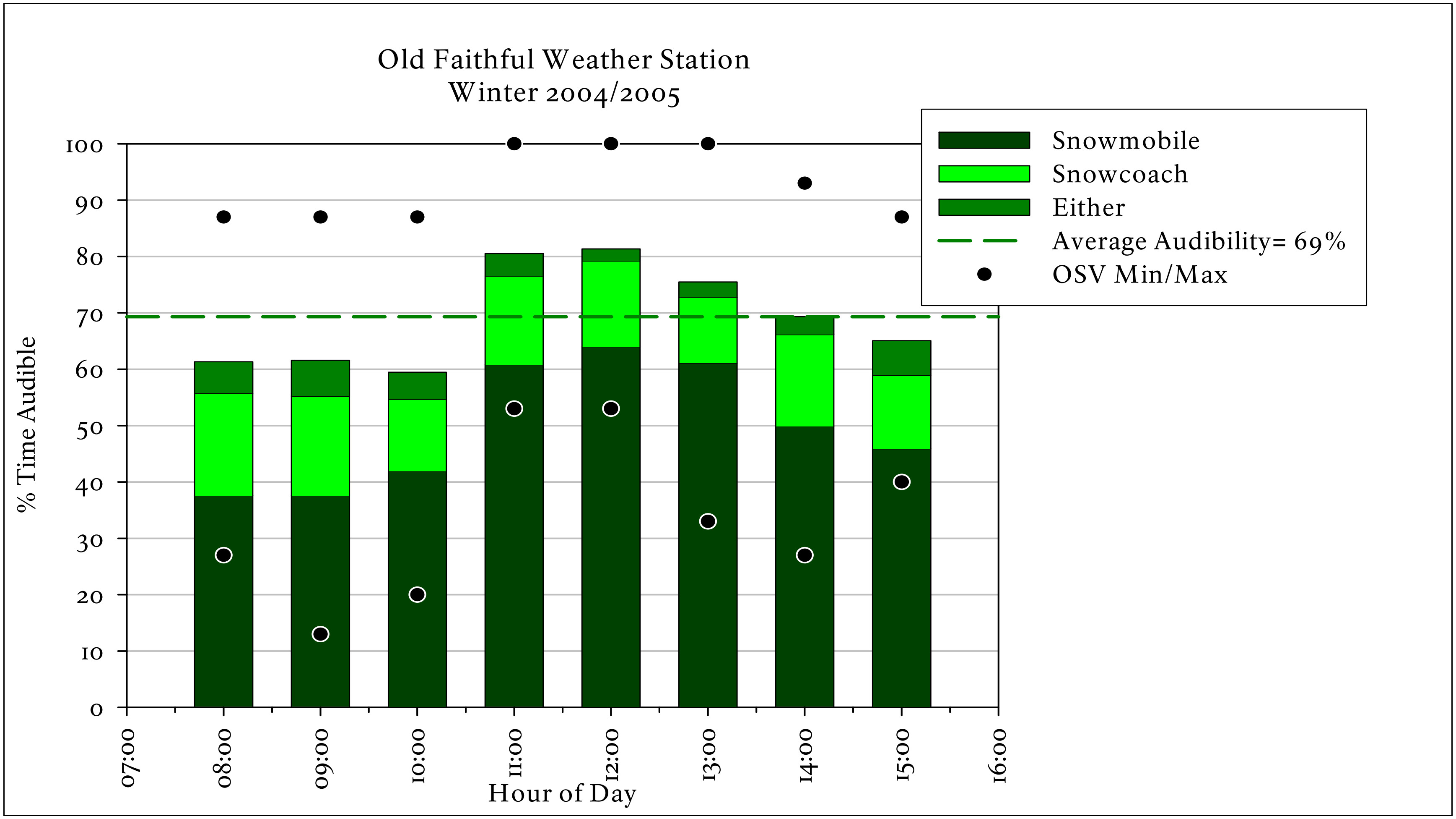

Figure 4. The average percent time audible by hour (8 am- 4 pm) of snowmobiles (bottom bar category) and snowcoaches (middle bar category) and combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March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

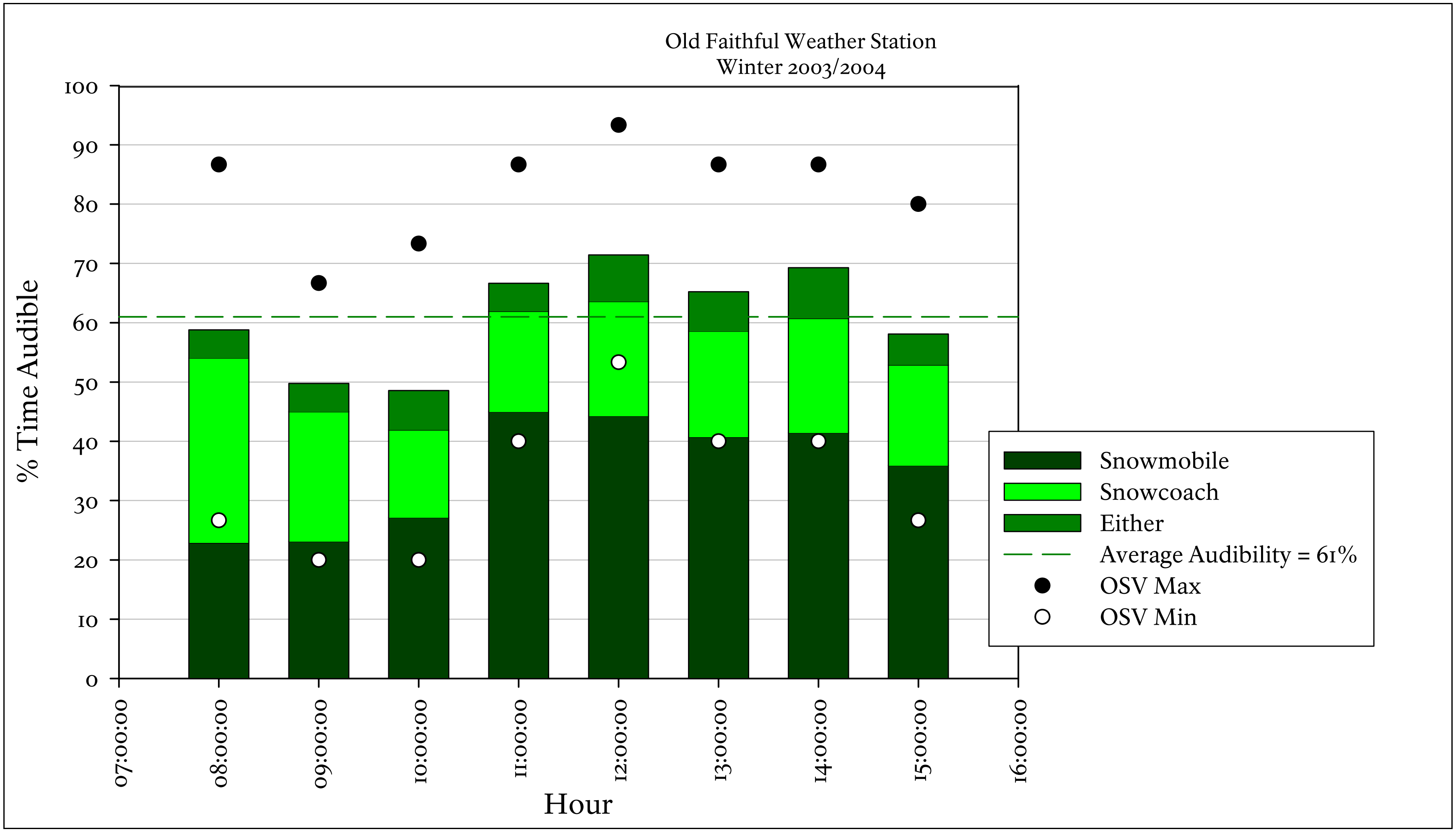

Figure 5. The average percent time audible by hour (8 am- 4 pm) of snowmobiles (bottom bar category) and snowcoaches (middle bar category) and combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 14 March 2004. Compare to Fig. 4.

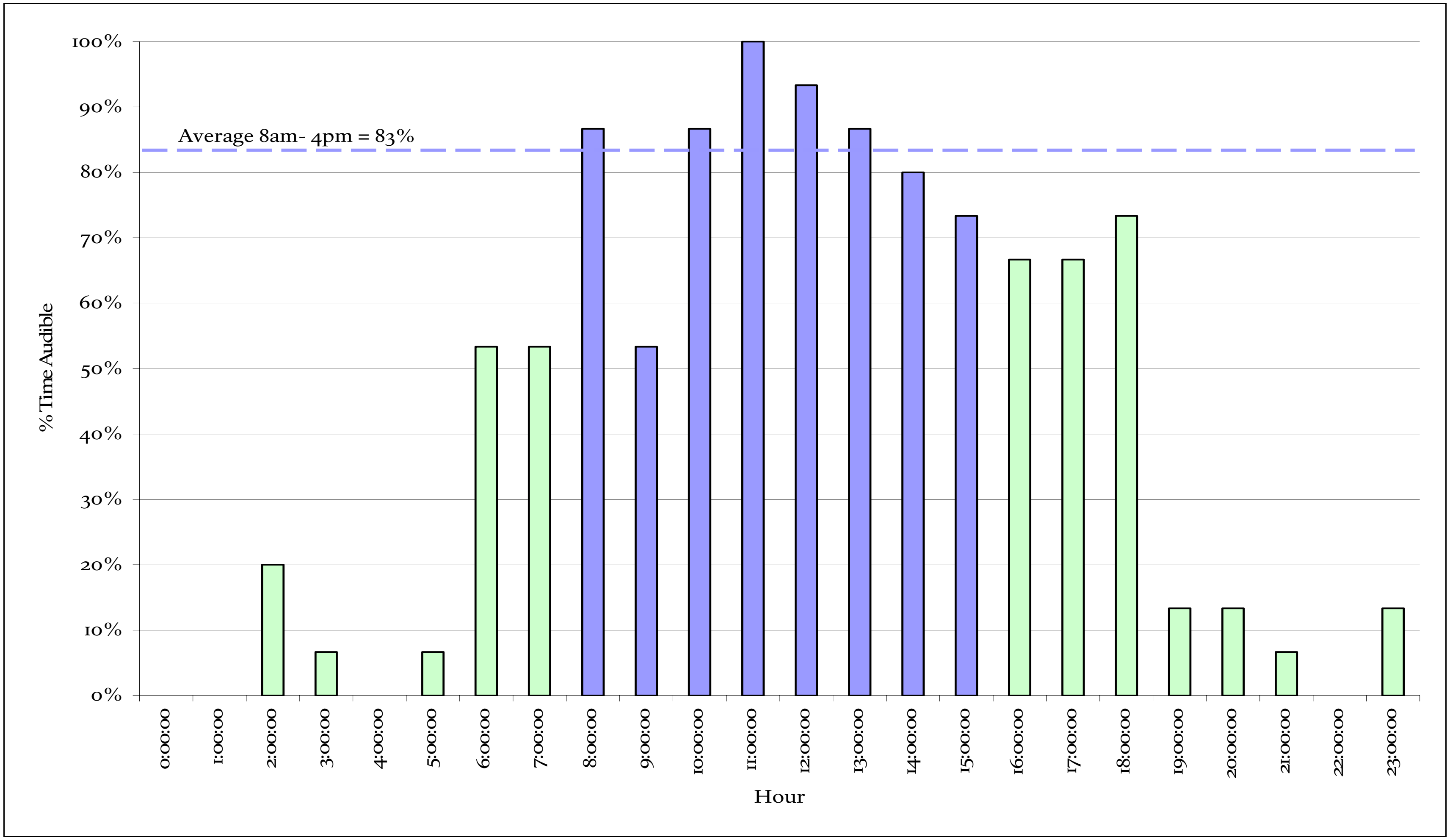

Figure 6. The percent time audible by hour (12am- 11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 25 January 2005, the day with the highest average audibility. The green histograms are outside the WUP measurement period (8 am- 4 pm) and are shown for comparative purposes. Compare to Figs. 7 and 8.

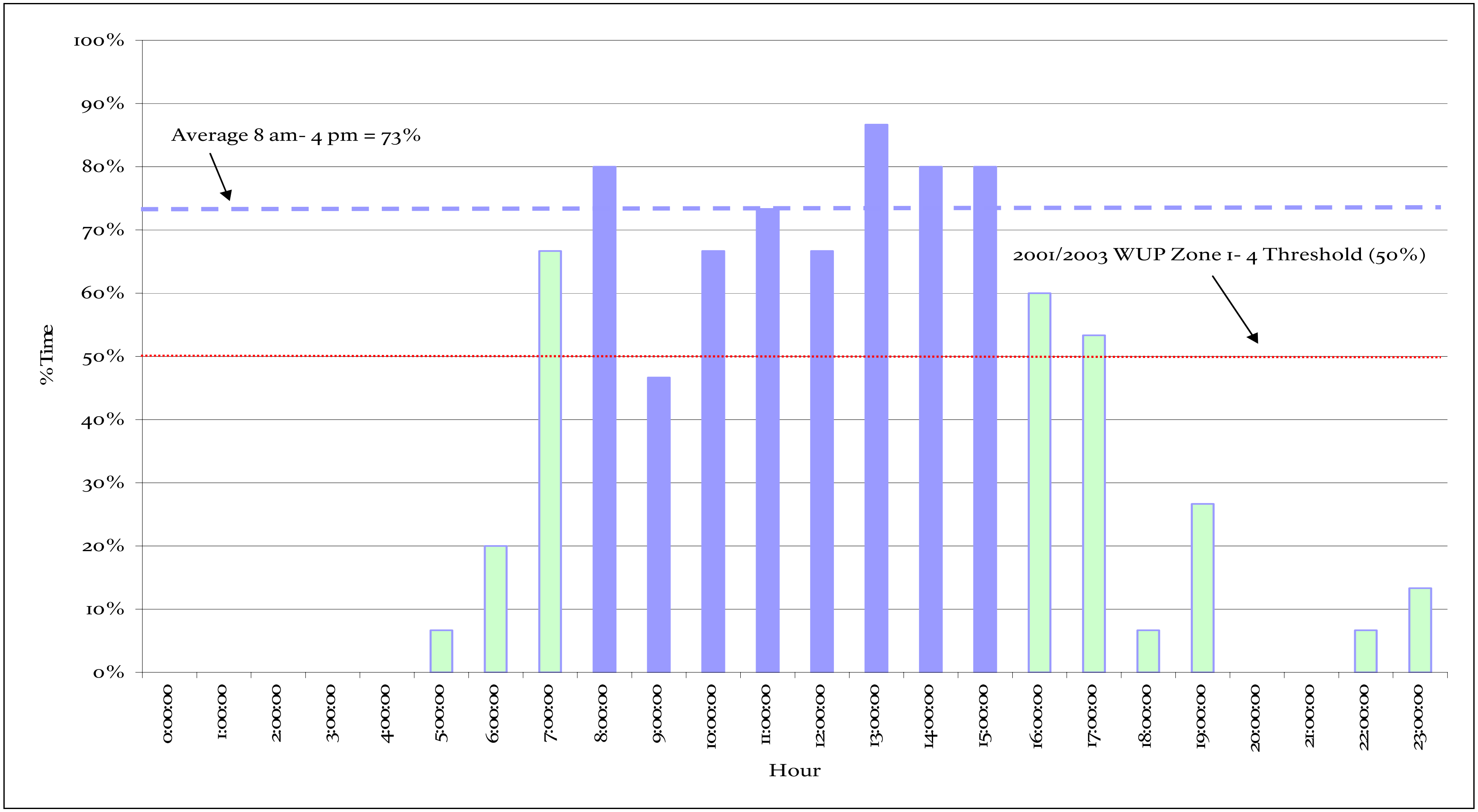

Figure 7. The percent time audible by hour (12am- 11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 3 March 2004, the day with the highest average audibility. The green histograms are outside the WUP measurement period (8 am- 4 pm) and are shown for comparative purposes. Compare to Figs. 6 and 8.

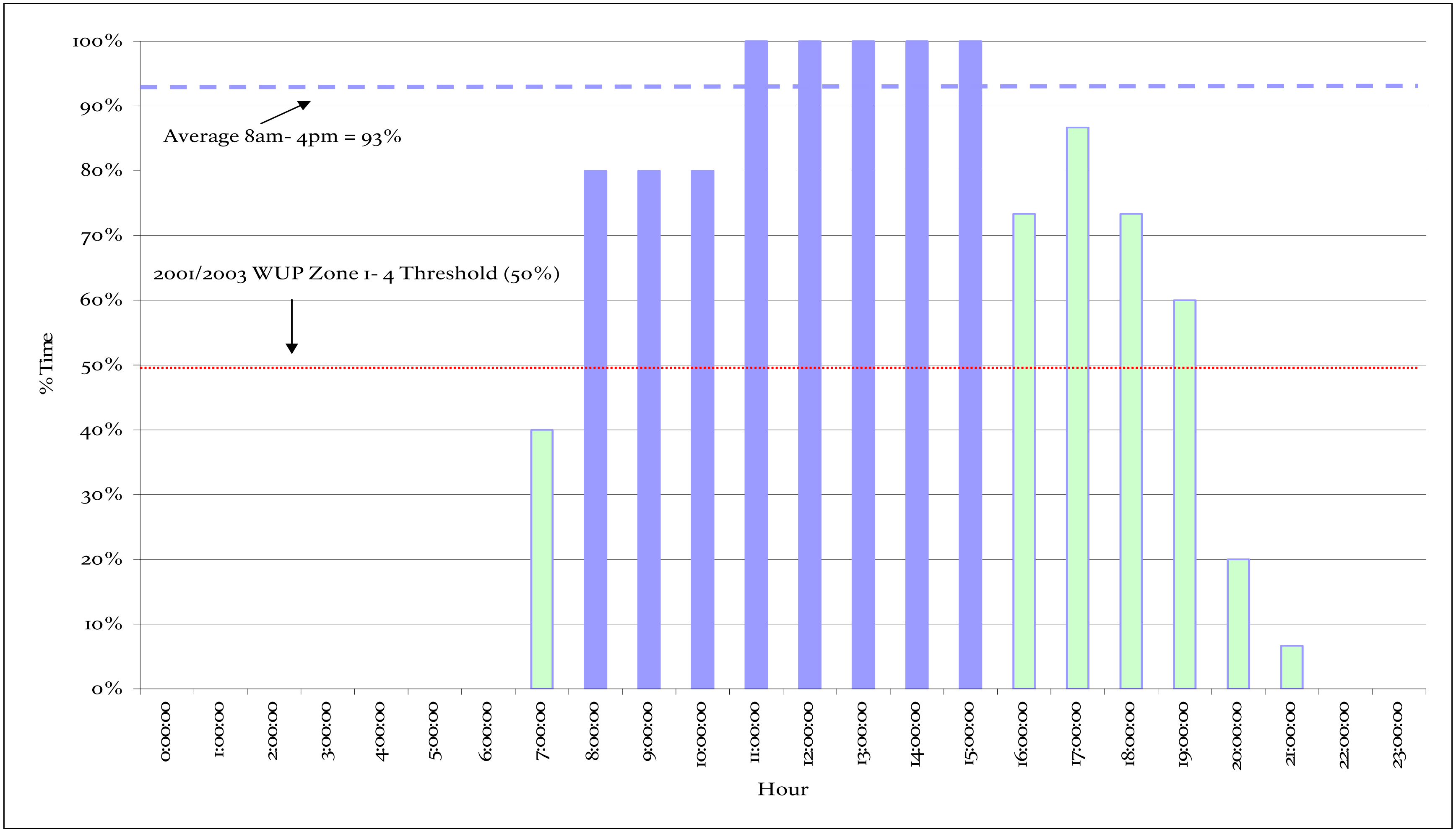

Figure 8. The percent time audible by hour (12am- 11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 14 February 2003. The green histograms are outside the WUP measurement period (8 am- 4 pm) and are shown for comparative purposes. Compare to Figs. 6 and 7.

Old Faithful Upper Basin

Acoustic data were collected for eight days at a location in the developed area of the Old Faithful Upper Basin to estimate the percent time oversnow vehicles were audible (Figs. 9 and 10). This monitor was located adjacent to a boardwalk within a popular thermal area about 1800 feet (1/3 mile) from the nearest motorized route from 25 January to 1 February 2005. These data provide a useful comparison to data collected at the Old Faithful Weather Station about 2600 feet (1/2 mile) away near the center of motorized activity (Figs. 2- 8). Audibility data was analyzed at both sites for five of the same days. For those days the percent time audible at the Upper Basin was 30% compared to 76% at the Weather Station. Oversnow vehicles that were audible at the Upper Basin site were often approaching or departing the Old Faithful area along the roads leading north or south and were not within the developed area itself.

The comparisons between these two Old Faithful sites also illustrates that as the distance increases between the sound source and the measurement location it becomes more difficult to assign specific sounds to their sources and categories begin to be combined. A larger proportion of audible sounds at the Upper Basin were coded as snowmobile or snowcoach rather than one or the other (Fig. 10).

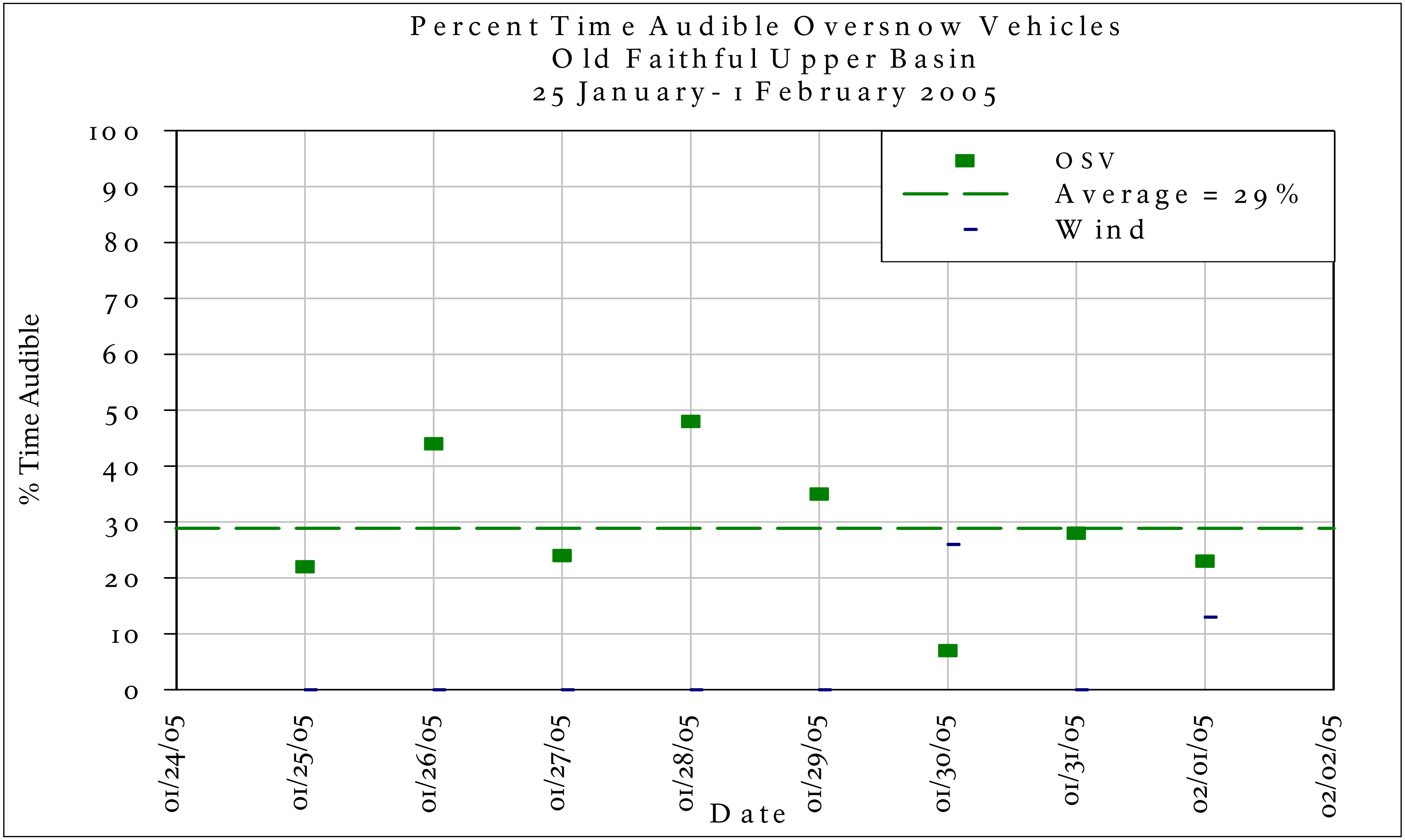

Figure 9. The average percent time audible of snowmobiles and snowcoaches and wind by date at Old Faithful Upper Basin, Yellowstone National Park, (8 am- 4 pm), 25 January- 1 February 2005. Compare to Fig. 2.

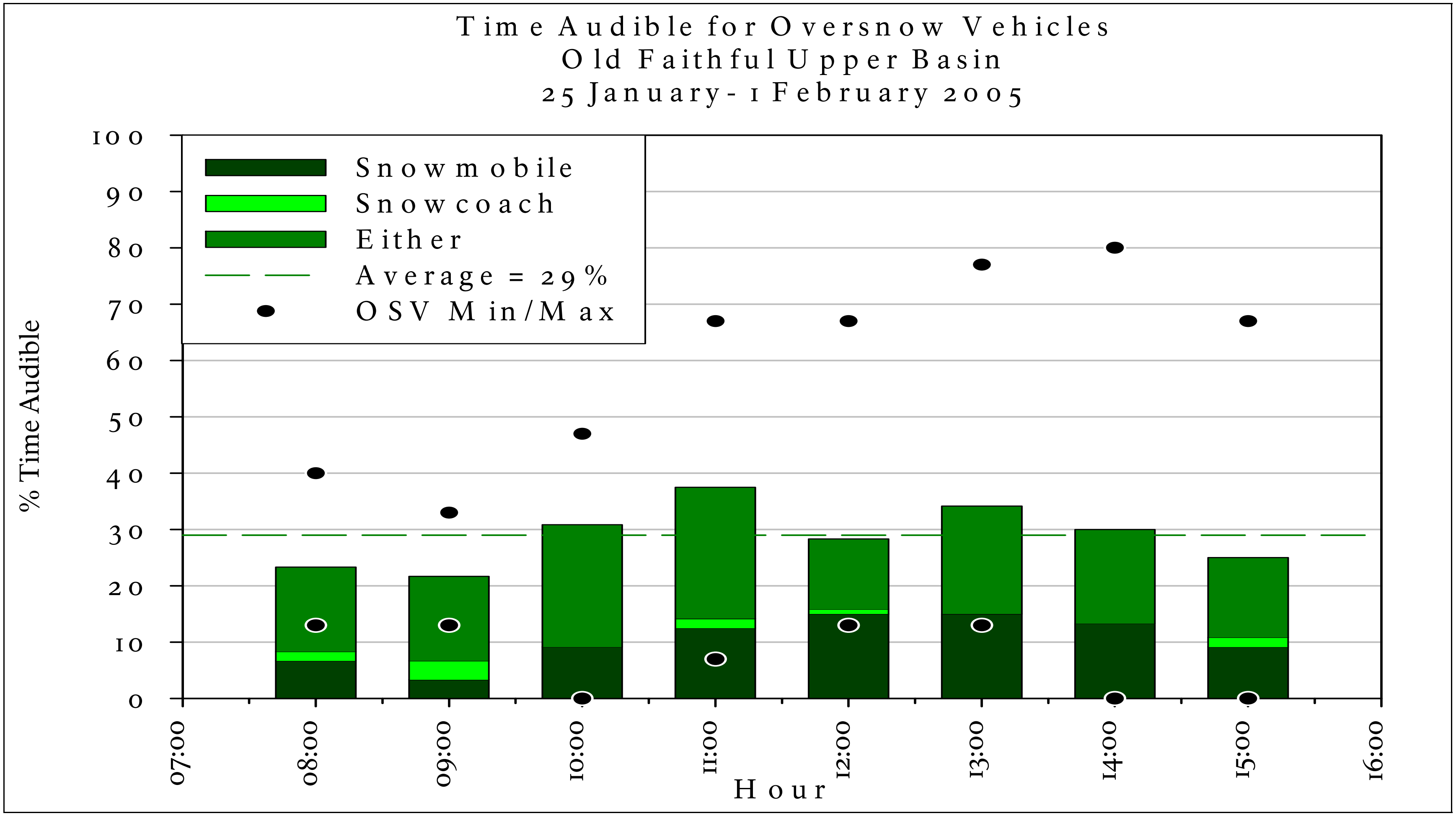

Figure 10. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at Old Faithful Upper Basin, Yellowstone National Park, 25 January- 1 February 2005. Compare to Fig. 4.

Lone Star Geyser

The Lone Star Geyser monitoring site was near a popular ski trail and geyser basin and was in a backcountry area acoustic zone. The site was one mile from the nearest groomed road, though occasionally the ski trail was groomed using a snowmobile. Snowmobiles and snowcoaches were audible 13 of 18 days and an average of 4% during all analyzed days (Figs. 11 and 13). This was nearly identical to the previous season (Figs. 12 and 14).

The Lone Star Geyser itself was audible on regular 3 hour intervals. Skiers and other visitors to the geyser were increasingly audible as the season progressed. More aircraft (jets and propeller planes) were audible [an average of 6% (2- 10%) of the time between 8 am- 4 pm] than over oversnow vehicles at this backcountry monitoring site.

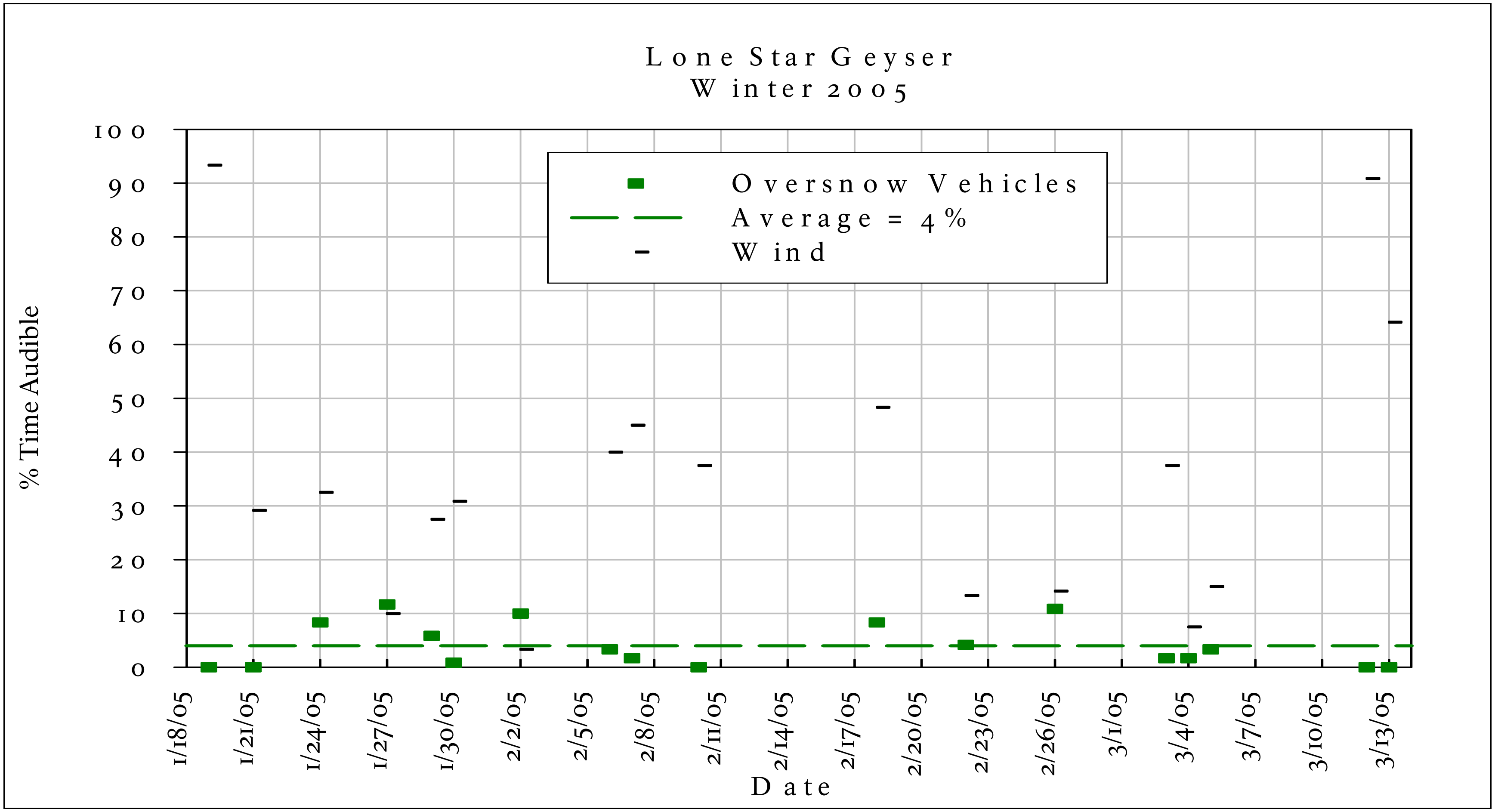

Figure 11. The average percent time audible of snowmobiles and snowcoaches and wind by date at Lone Star Geyser, Yellowstone National Park, (8 am- 4 pm), January- March 2005. Compare to Fig. 12.

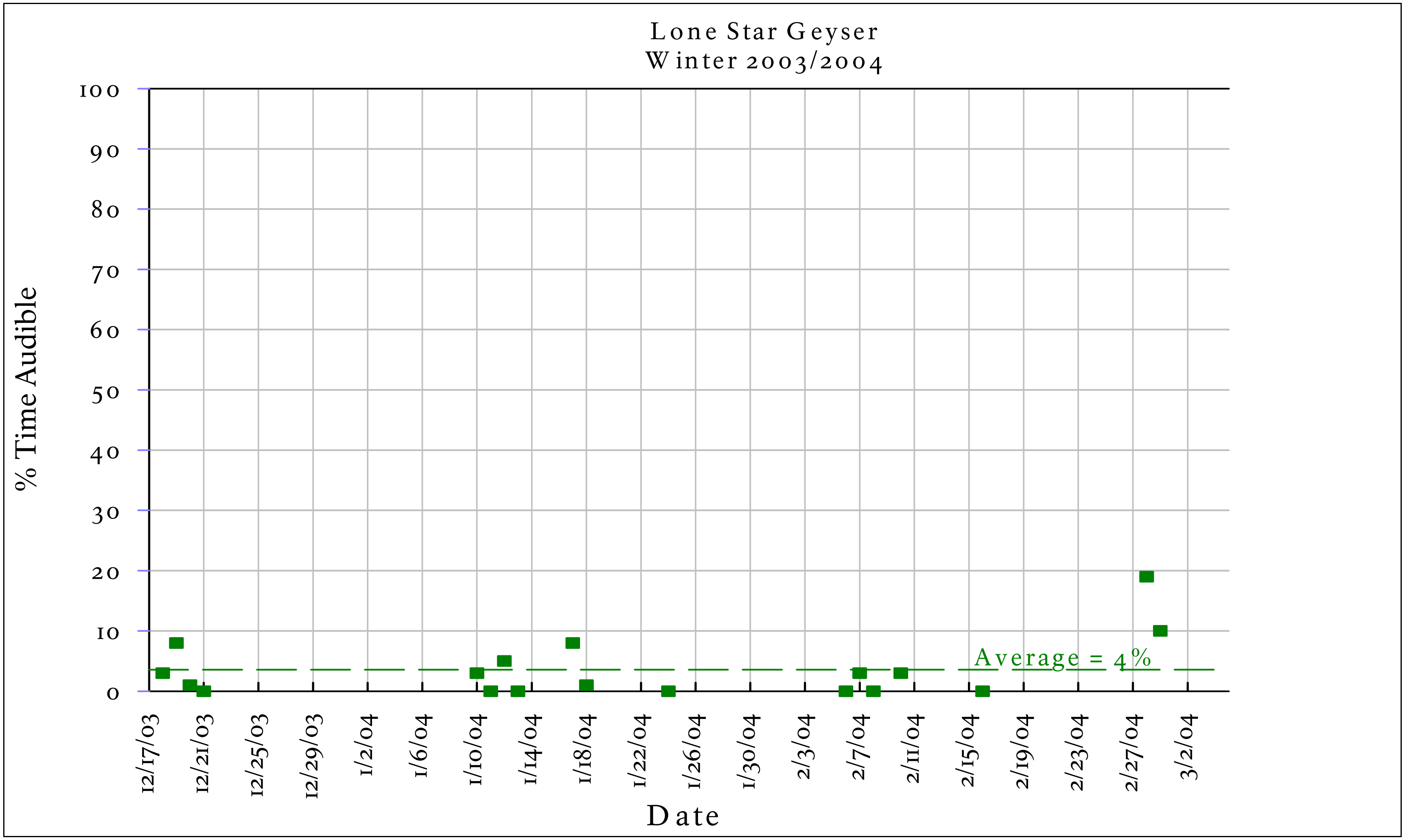

Figure 12. The percent time audible (green squares) (8 am- 4 pm) of snowmobiles and snowcoaches by date at Lone Star Geyser, Yellowstone National Park, December 2003- March 2004. Compare to Fig. 11.

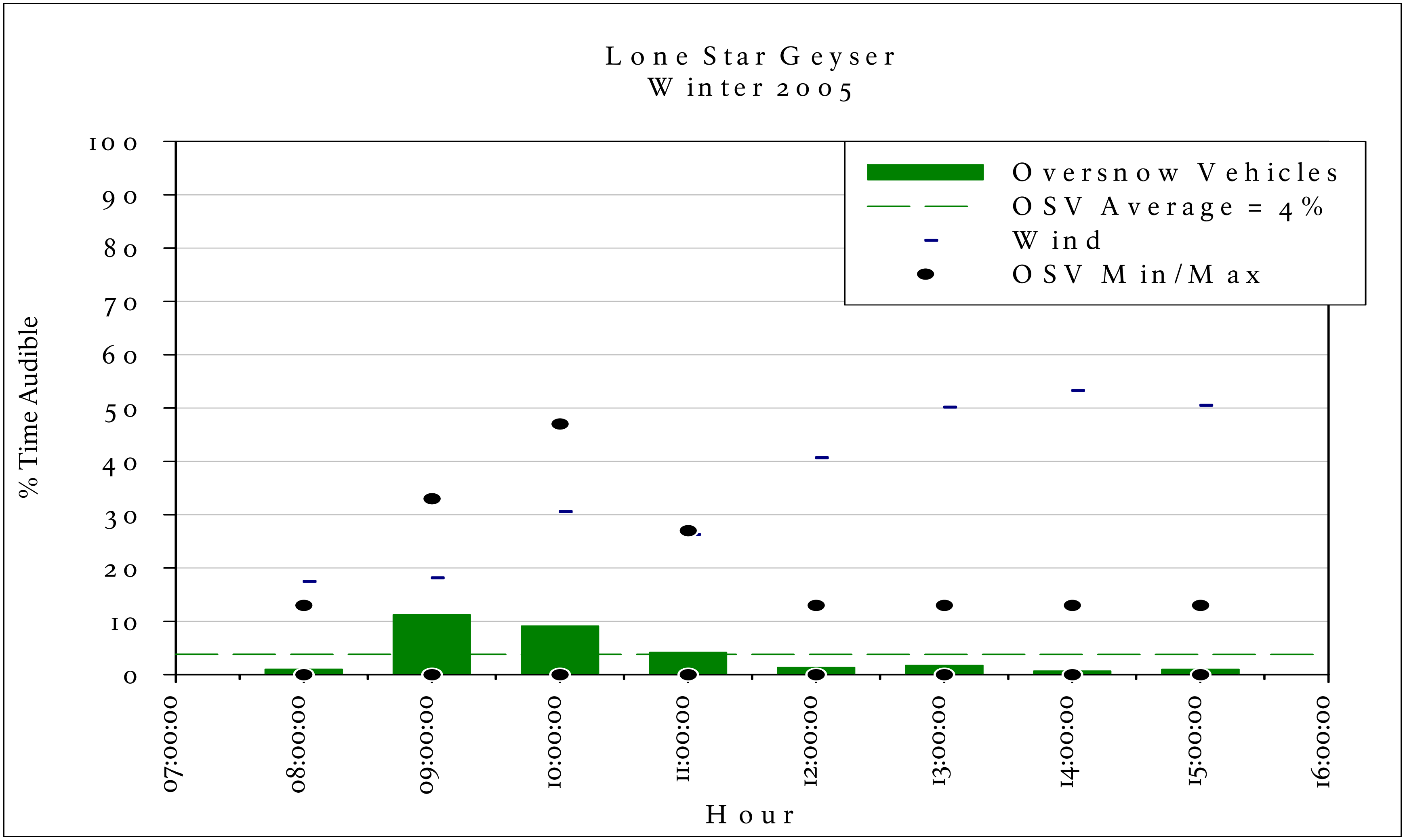

Figure 13. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at Lone Star Geyser, Yellowstone National Park, January- March 2005. Compare to Fig. 14.

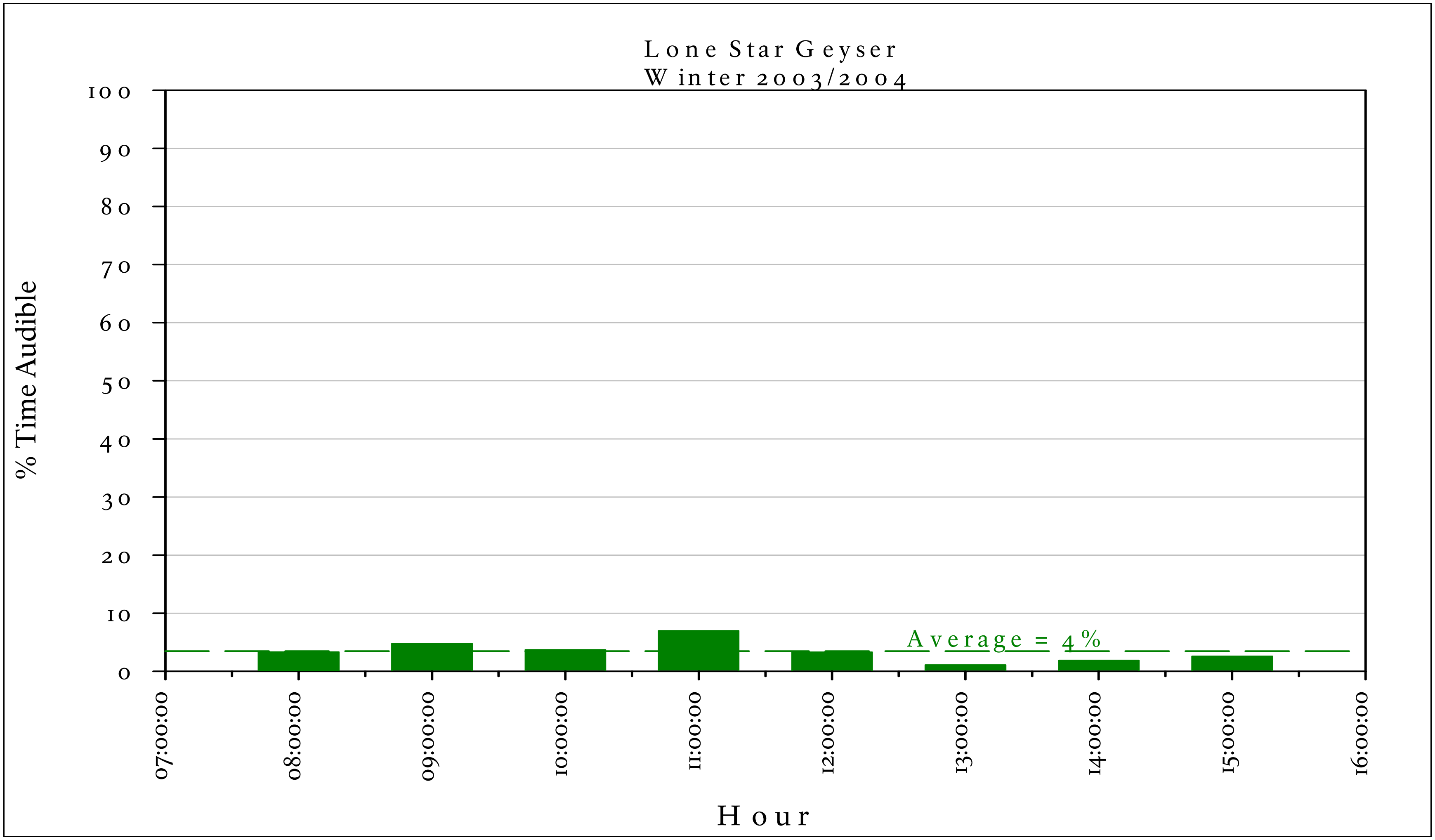

Figure 14. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at Lone Star Geyser, Yellowstone National Park, December 2003 to February 2004. Compare to Fig. 13.

Mary Mountain 8K

Mary Mountain 8K site was in a backcountry area acoustical zone, but Figures 15 and 16 indicate that oversnow vehicles on the groomed Old Faithful- Madison Junction Road 8000 feet away were audible. All days analyzed had oversnow vehicles audible at least 10% of the time. The average percent time audible for all days analyzed was 26% (9 of 18 days exceeded 20%). The audibility impact definition threshold for a major adverse effect in the 2004 WUP was 20% in backcountry areas (Table 1).

Wind commonly masks motorized sound, especially at greater distances from travel corridors. This is likely reflected in the hourly patterns of audibility at Mary Mountain 8K. As wind increased in the afternoon, oversnow vehicles one and a half miles away were heard less often (Fig. 16). The only non- natural sounds other than oversnow vehicles at this backcountry site were aircraft (jets and propeller planes). They were audible for 5% (range 3%- 8%) of the day from 8 am- 4 pm.

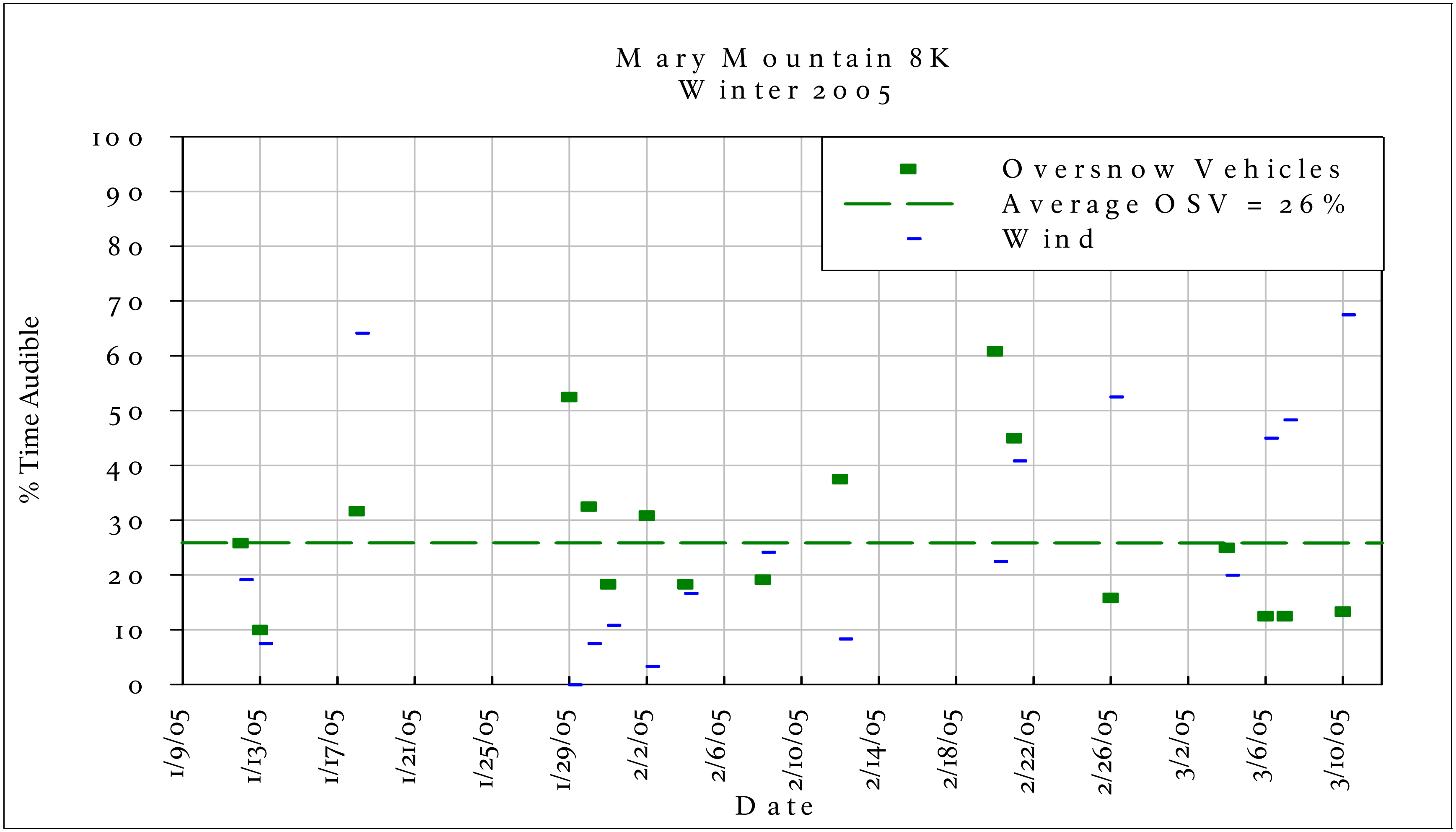

Figure 15. The percent time audible of snowmobiles and snowcoaches and wind (8 am- 4 pm) by date 8000 feet from the Madison Junction- Old Faithful Road near Mary Mountain Trail, January –March 2005.

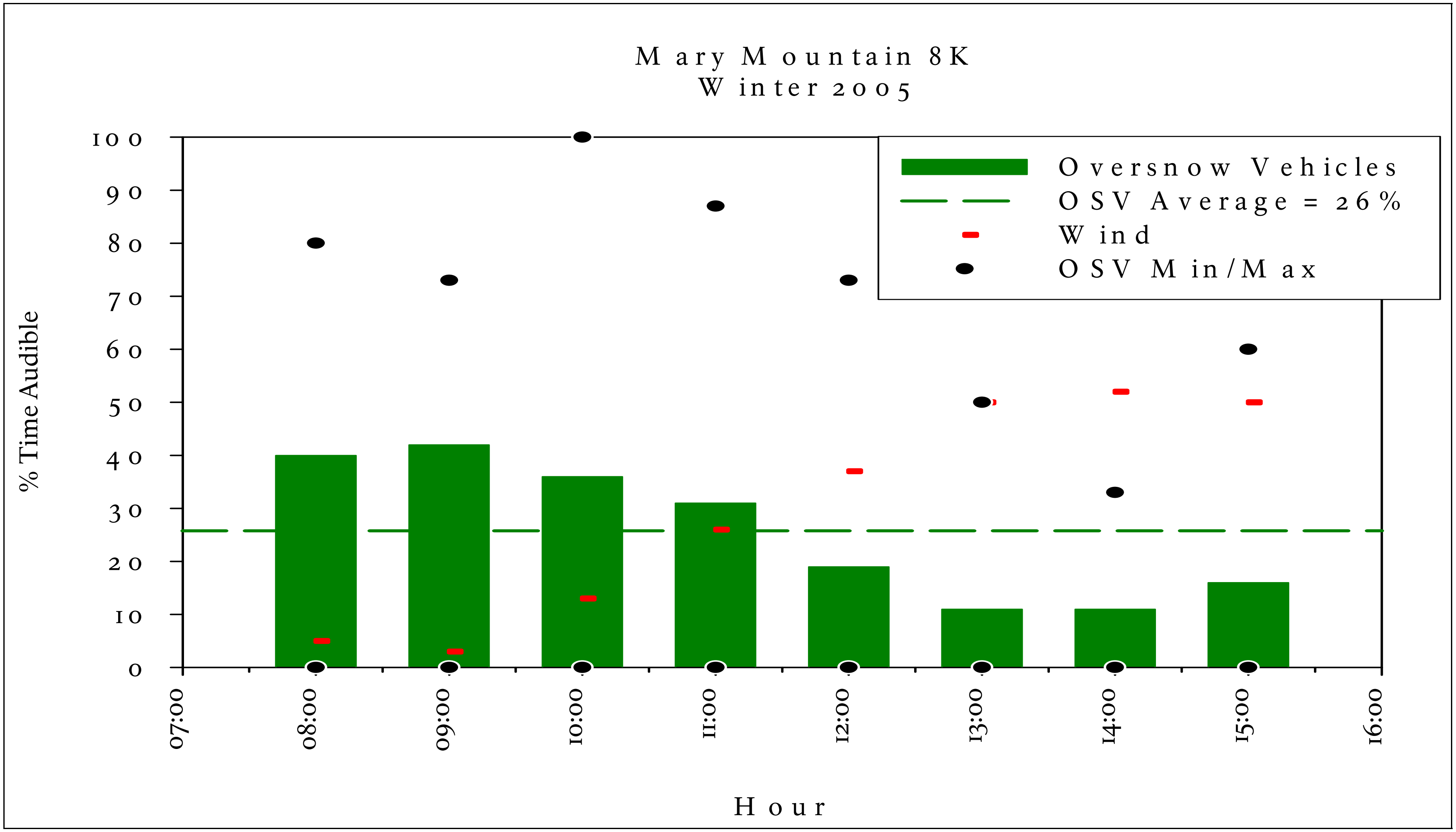

Figure 16. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches, and wind 8000 feet from the Madison Junction- Old Faithful Road near Mary Mountain Trail, Yellowstone National Park, January- March 2005.

West Yellowstone 3.1

West Yellowstone 3.1 monitor was located 100 feet south of the West Entrance-Madison Junction Road 3.1 miles east of the west entrance station in a travel corridor acoustic zone. The site was 900 feet from a turnout overlooking the Madison River. Voices were occasionally audible from parties that stopped at the turnout. Because engines were turned off while parked it is unlikely that the turnout had much effect on the percent time oversnow vehicles were audible at this monitoring site. The results indicate the restricted use of the road during the early and late season (Fig. 17). The oversnow vehicles audible in December and after 9 March were either snowcoaches or distant snowmobiles outside the park (Figs. 17). Oversnow vehicles were audible for an average of 55% during the entire winter season and an average of 66% during the peak season (1 January – 9 March). An unanticipated finding was that snowmobiles operating outside Yellowstone's western boundary in Gallatin National Forest and possibly within West Yellowstone, MT were commonly audible at the West Yellowstone 3.1 site (Fig. 19). The distinctive sounds of two- stroke snowmobiles over three miles away were clearly distinguishable on the recordings and while visiting the site. Snowmobiles operating outside the park also were often commonly heard late into the night. The percent time audible using only oversnow vehicles that traveled the groomed road between West Entrance and Madison Junction was 36%, calculated for a subset of days (Fig. 19).

The percent time audible of OSVs traveling into the park during morning peak would have been more pronounced if only OSVs passing the monitoring site were counted rather than both those on the park road and those audible from the Gallatin National Forest (Fig. 18). Most of the guided groups of snowmobiles returned to West Yellowstone and passed the monitoring site after 4 pm, outside the measurement period for this analysis (OSV percent time audible 54% 4- 5 pm and 52% 5- 6 pm).

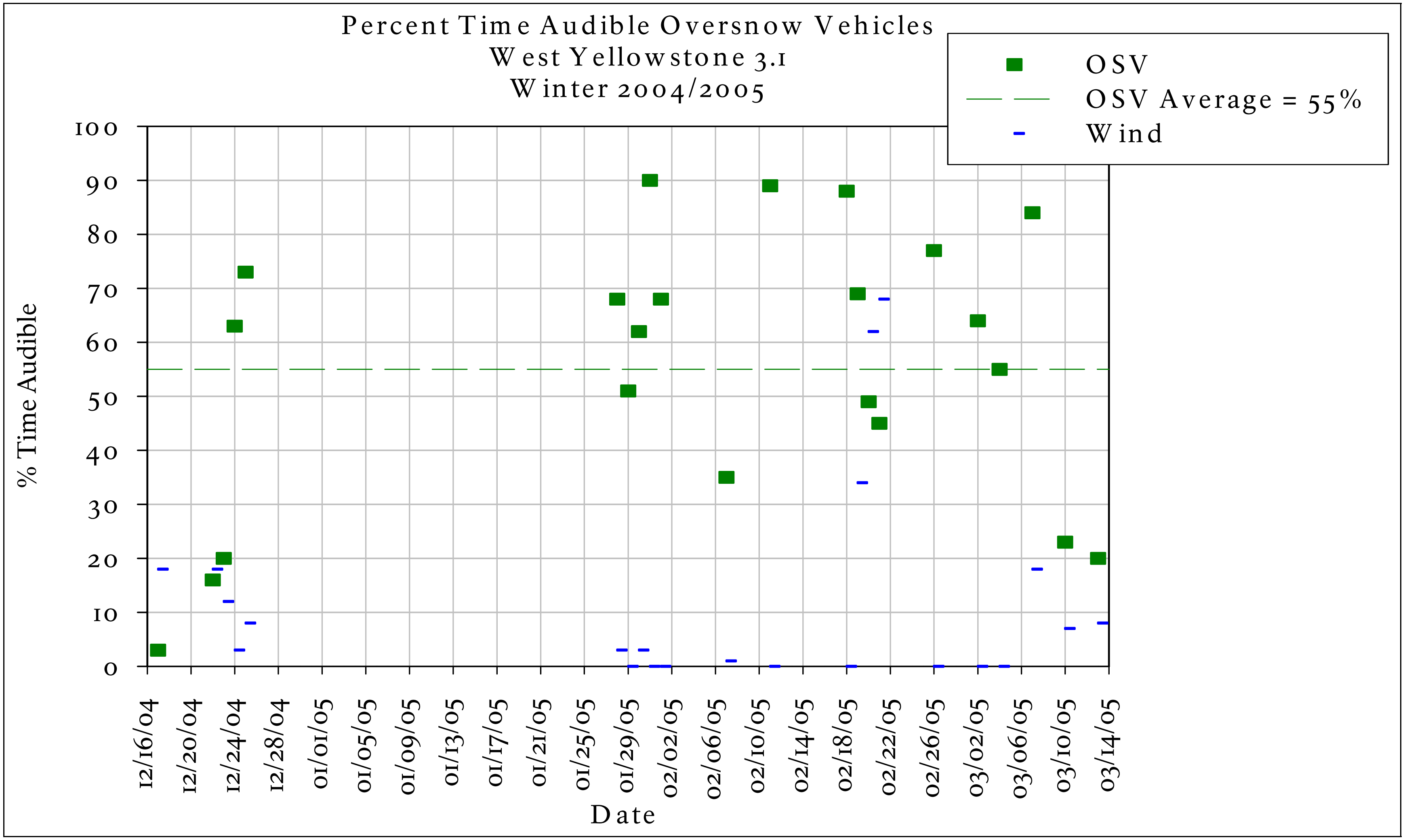

Figure 17. The percent time audible of snowmobiles and snowcoaches and wind by date at West Yellowstone 3.1, Yellowstone National Park, (8 am- 4 pm), December 2004- March 2005.

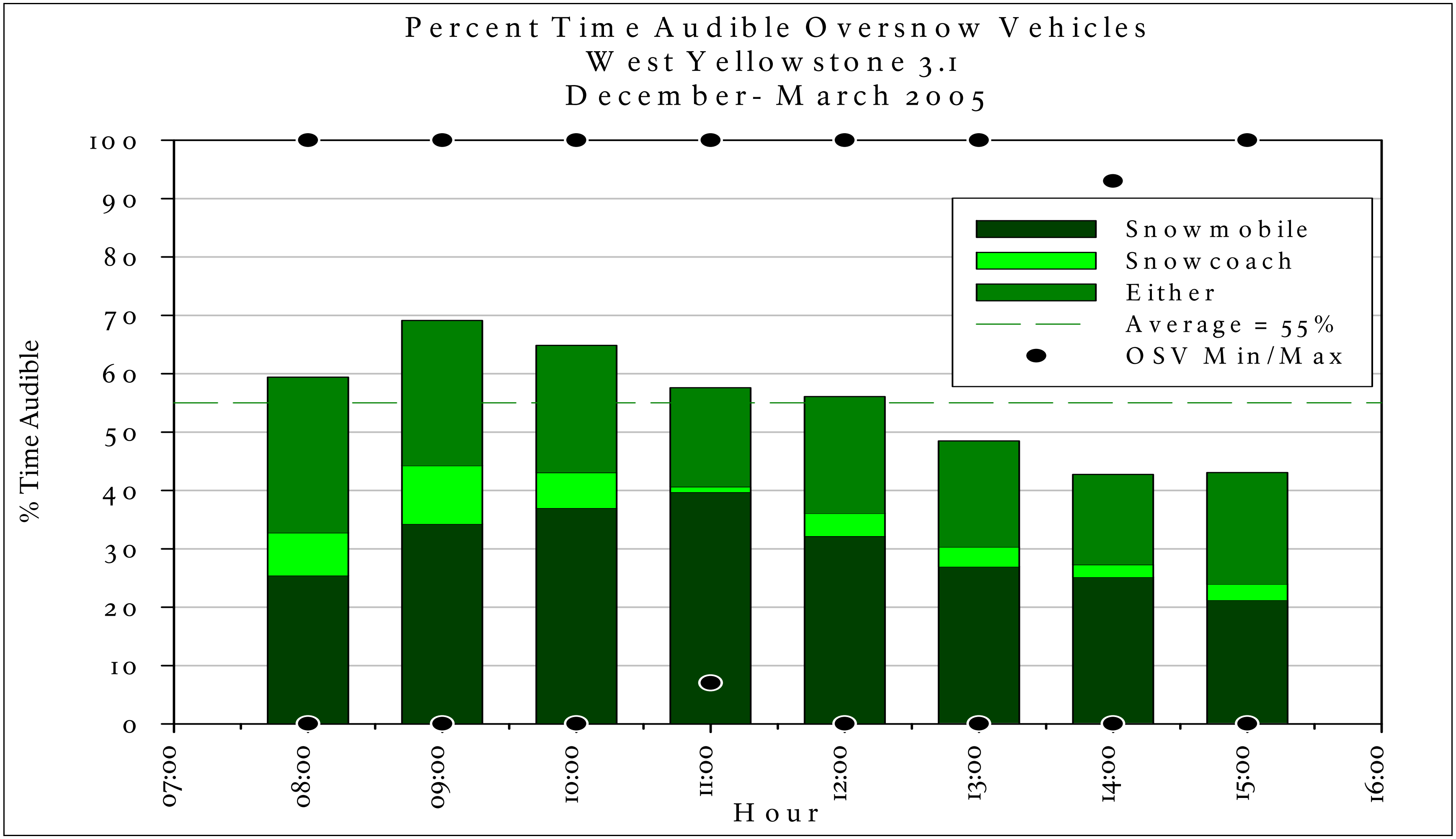

Figure 18. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at West Yellowstone 3.1, Yellowstone National Park, December 2004- March 2005.

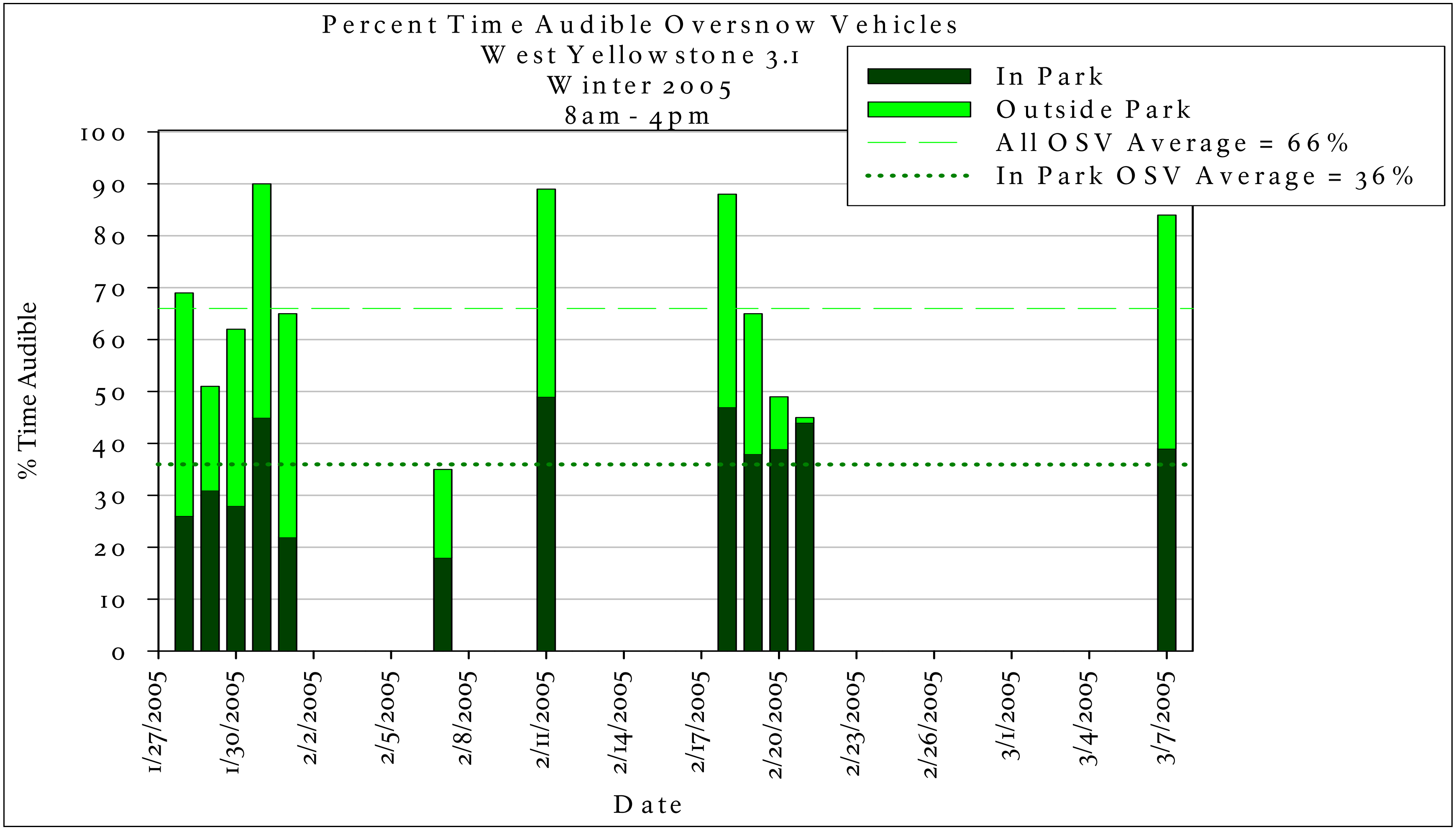

Figure 19. The percent time audible by date (8 am- 4 pm) of snowmobiles and snowcoaches inside and outside the park (Gallatin National Forest) at West Yellowstone 3.1 during a subset of sampled days, Yellowstone National Park, 28 January- 7 March 2005.

West Thumb

Acoustic data were collected for one week in early February 2005 to estimate the percent time oversnow vehicles were audible within the developed area within the geyser basin at West Thumb (Figs. 20 and 21). The monitor was located about 425 feet from the warming hut, 650 feet from Yellowstone Lake, 850 from the West Thumb to Canyon groomed road and 1800 feet from the South Entrance to West Thumb groomed road. Oversnow vehicles were audible at this site 47% of the time between 8 am and 4 pm (Fig. 20). The six days were surprisingly consistent regardless of wind conditions.

The percent time audible by hour had a bimodal distribution with oversnow vehicles audible more during peaks in the 10 am and 2 pm hours (Fig. 21). This pattern was present at all monitoring sites along travel corridors.

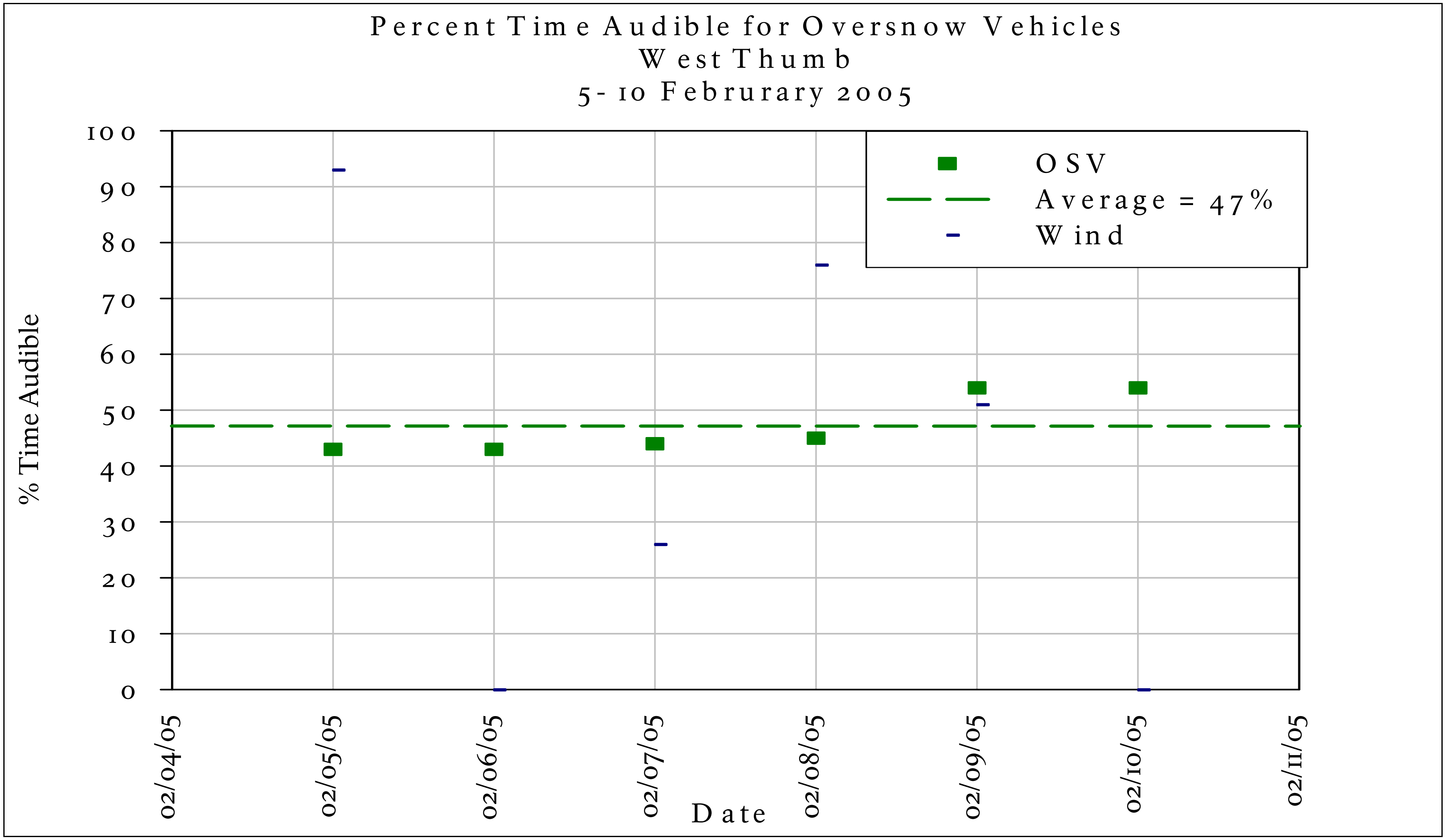

Figure 20. The percent time audible of snowmobiles and snowcoaches and wind by date at West Thumb Yellowstone National Park, (8 am- 4 pm), 5- 10 February 2005.

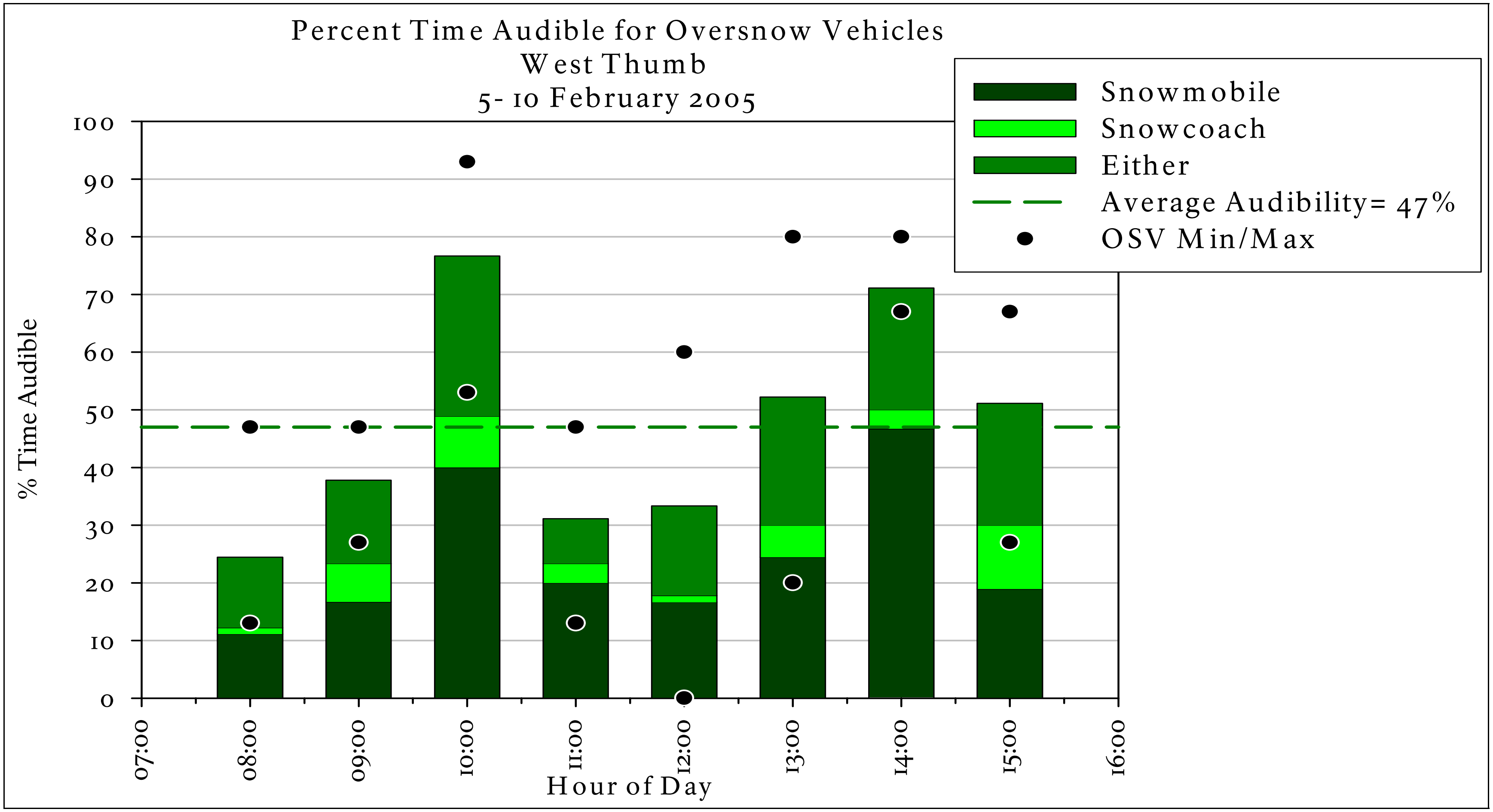

Figure 21. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at West Thumb, Yellowstone National Park, 5- 10 February 2005.

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 acoustical management zone. Acoustic data were collected over Presidents Day Weekend in 2005, 2004 and 2003 (Fig. 22). Snowmobiles and snowcoaches were audible for 61% of the time during Saturday and Sunday of Presidents Day Weekend 2005.

There was a striking difference in oversnow vehicle percent time audible among the three years (Fig. 22). Oversnow vehicles were audible for 93% of the two day weekend in 2003, 24% in 2004 and 61% in 2005. Nearly three times the number of snowmobiles entered the West Entrance during Saturday and Sunday of Presidents Day Weekend in 2003 (1679 snowmobiles) compared to 2004 (589 snowmobiles) and 2005 (506). If the percent time oversnow vehicles were audible was strictly determined by the number of snowmobiles entering the park then the 2005 percent time audible should be similar to 2004. The percent time audible in 2005 was twice the 2004 percentage (Fig. 22). To help determine what proportion of oversnow vehicles traveling in the park could be attributed to the numbers of snowmobiles entering the park (guided groups) we logged over 48 hours of observations of snowmobile usage in several areas along motorized routes. See Appendix D for details. From these observations we determined that guided groups comprised 62% of all groups along travel corridors. Snowmobile percent time audible at any location can be better predicted by number of groups rather than number of snowmobiles because groups can be thought of a one extended sound event separated in time and space from the next group. Individual snowmobiles travel together in an average group size of about seven snowmobiles. To return to the disparity among years, there may have been more guided or administrative (38% of all snowmobile groups in our observational study) groups traveling past the Madison Junction 2.3 monitor in 2005 than in 2004. The road surface condition may have propagated sounds farther in 2005 than 2004. Oversnow vehicles near the monitor may have traveled slower and idled more for wildlife observations in 2005 than 2004. These possibilities may explain the difference between 2004 and 2005 though other unidentified factors may be responsible. It should be noted, though, that this comparison among years is with a very small sample size of two days each year.

The difference in audibility between 2003 and the subsequent years can likely be explained by fewer overall numbers and the required grouping of snowmobiles in 2005 and 2004 unlike in 2003, and the overall lower sound level due to the predominate use of four- stroke snowmobiles rather than two- stroke snowmobiles of 2003.

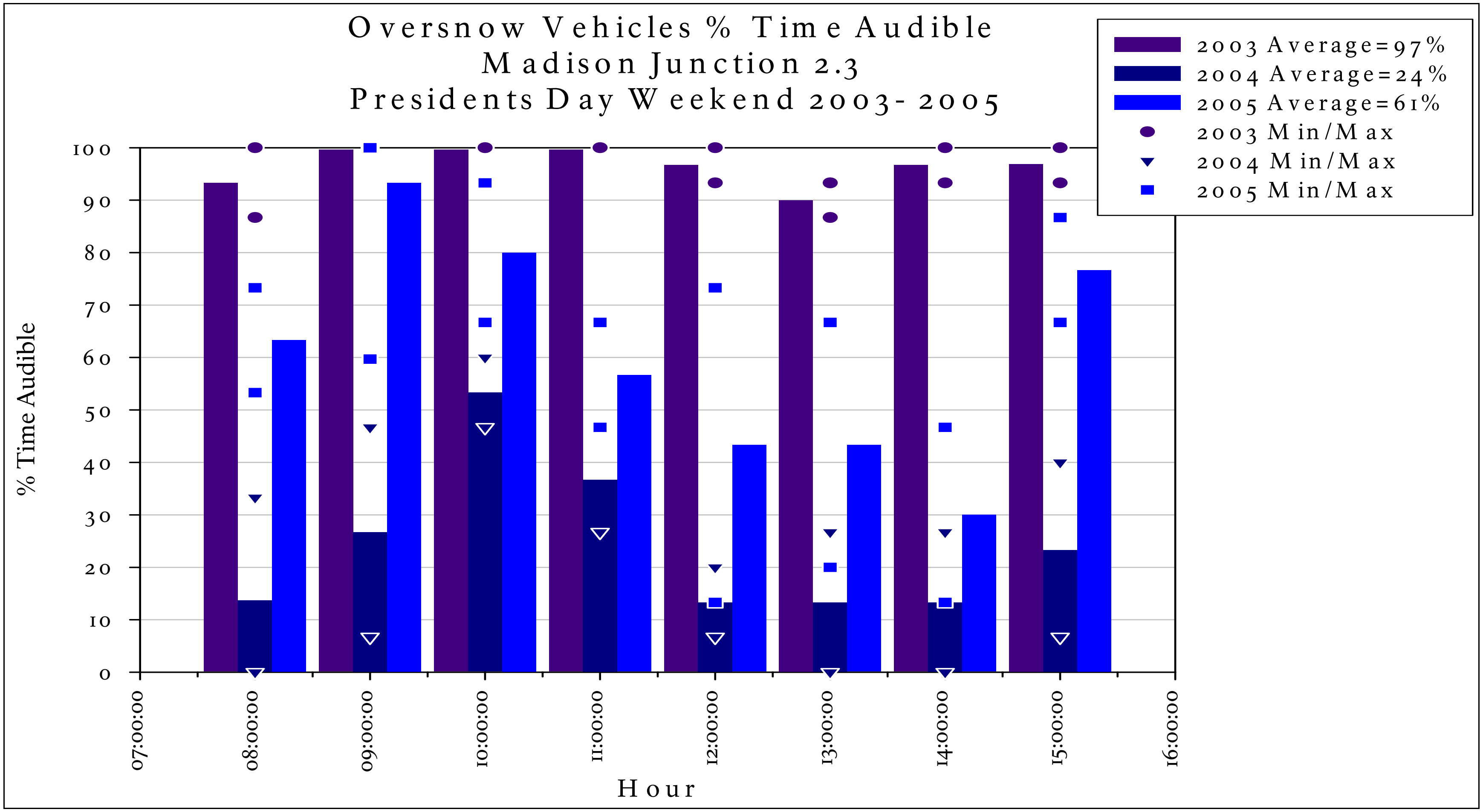

Figure 22. The average percent time audible by hour (8 am- 4 pm) of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park during Saturday and Sunday of Presidents Day Weekend 2003- 2005.

Event Analysis:

The loudest sound events at each site were recorded and later identified. Thresholds 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 percent of all loud sources. These sites differed in wind susceptibility and therefore had different thresholds. Both West Yellowstone 3.1 and Madison Junction 2.3 were 100 feet from a 35 mph travel corridor, Old Faithful Weather Station was 230 feet from a 15 mph motorized travel corridor, but only 40 feet from a well- traveled foot path. Therefore, the greater distance from the monitor to the motorized travel route at Old Faithful reduced the number of oversnow vehicles exceeding the threshold at this location. Few to no loud motorized events occurred at the four sites away from the developed area or travel corridors and are not included here. Wheeled vehicles were allowed to travel from West Yellowstone to Old Faithful until 1 January 2005. No wheeled vehicle exceeded these thresholds.

Table 4. The number and percentage of sound events exceeding user- defined thresholds of sound level and duration at three locations in Yellowstone National Park, winter use season 2004/2005. These represent the loudest sounds recorded at these locations. Wind- caused events were excluded from analysis.

	Old Faithful Weather Station[1]		**West Yellowstone 3.1**[2]		**Madison Junction 2.3**[3]	
	15 Dec- 23 Feb		**15 Dec- 3 Mar**		**17- 22 Feb**	
Sound Source	**Number**	**%**	**Number**	**%**	**Number**	**%**
Snowmobile	6	8%	911	76%	266	75%
Snowcoach	1	1%	163	14%	61	17%
Oversnow Vehicle	2	3%	20	2%	3	1%
Snow Groomer	34	44%	71	6%	16	5%
Wheeled Vehicle	0	0%	0	0%	0	0%
Jet	1	1%	16	1%	2	1%
Prop	0	0%	1	0%	0	0%
Helicopter	10	13%	0	0%	2	1%
People	22	29%	0	0%	2	1%
Natural	0	0%	2	0%	3	1%
Unknown	1	1%	10	1%	0	0%
Total	77		1194		355	

[1] Thresholds were over 75 dBA/1 second or 55 dBA/10 seconds
[2] Thresholds were over 70 dBA/1 second or 55 dBA/10 seconds
[3] Thresholds were over 70 dBA/1 second or 50 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 25 million seconds of data collected in this study 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. Table 5 has typical sound levels of some common sound sources to introduce decibel levels.

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 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," 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 its value, even though the sound levels are typically lower.

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

Table 5. 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 defined as 0 – 130 dBA.

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	Snake River at 300 ft	Quiet bedroom
20		Winter wilderness	Recording studio
10	Barely audible	Below noise floor	

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 in locations other than those most heavily impacted from non- natural sounds. However, using this or any L_x metric can give misleading results in areas where natural sounds such as thermal activity (Lone Star Geyser), wind (Mary Mountain 8K), or other natural sounds are common and louder than the quietest x% of the sounds. Also using L_{90} or other L_x metrics as the natural ambient is inappropriate in locations with constant non- natural sounds (Old Faithful).

While there is no easy solution to these problems, using several sound level metrics diminish the disadvantages of any one metric. The noise floor, the lowest level the acoustic equipment could measure, was approximately 19- 20 dBA (see Table 5). The quietest sound levels in YNP were sometimes below this noise floor so the lowest documented measurements may be higher than the actual sound levels.

Two differences between the analyses of the winters 2003/2004 and 2004/2005 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. 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. During 2003/2004 some data was 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. This likely largely explains the difference between years at Lone Star Geyser in January (Fig. 38 and 39). 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.

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 demonstrated.

Old Faithful Weather Station

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 23- 30. Sound levels collected from the same site during the winter of 2003/2004 are included for comparative purposes. 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, adding an additional 6 dBA to the maximum sound levels in the following figures would approximate the levels at 100 feet (using the reasonable assumption that the maximum sound levels originate from oversnow vehicles traveling 230 feet from the sound monitor). 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 instrumentation near the sound monitor, etc. and therefore the distance is unknown and thus the correction factor is also unknown.

Oversnow vehicles were often used outside the period covered by the WUP measurement periods, even in the middle of the night, and the nighttime snow groomer sometimes had the loudest sound levels during the 24 hour day (e.g., Fig. 29; 8 p.m.).

Because the loudest sounds have the most influence on L_{eq} values, oversnow vehicle sound largely determined the L_{eq} value at Old Faithful on all but the windiest days.

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 (Figs. 23, 25 and 27).

To demonstrate some of the sound level variability, Figure 31 shows each of the hourly sound metrics for the month of January 2004.

Figures 32, 33 and 34 show the sound levels over Presidents Day Weekend during 2005, 2004 and 2003. The L_x values for this comparison are calculated the same way for all three years so can be compared directly. Recalling that a 10 dBA difference is perceived as a doubling of loudness there were large differences among years. The change from two- stroke snowmobiles to four- stroke likely explains much of the difference between 2003 and 2004- 2005.

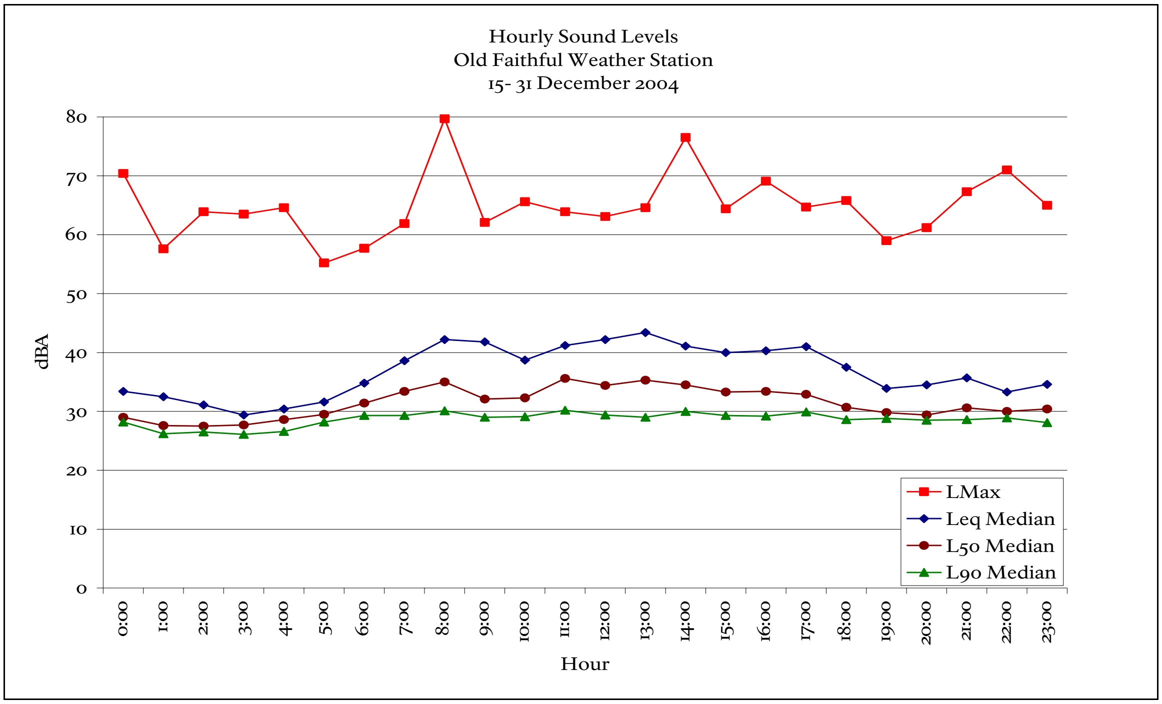

Figure 23. Median hourly sound levels for 15- 31 December 2004, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non- natural sounds. L_{max} is the highest sound level measured during the measurement period. (n=370 hours).

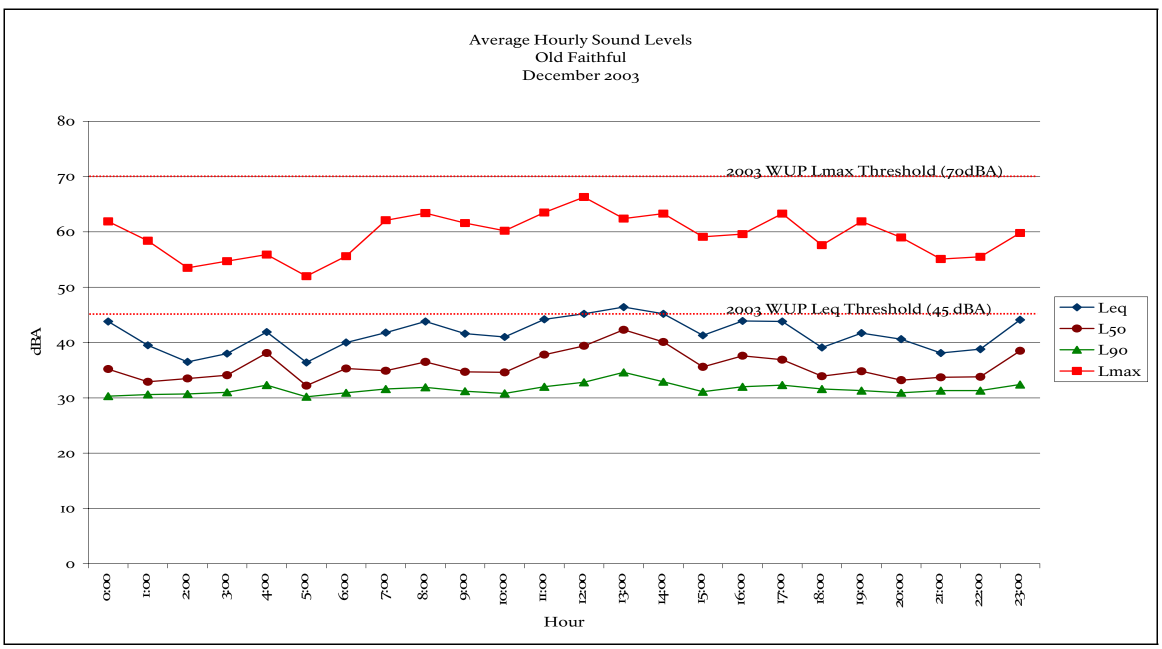

Figure 24. Average hourly sound levels for 17- 31 December 2003, Old Faithful Weather Station, Yellowstone National Park. **These sound levels include all** natural and non- natural sounds. See Fig. 23 caption for additional details. Dotted red lines indicate acoustic thresholds of 2003 WUP. (n=358 hours).

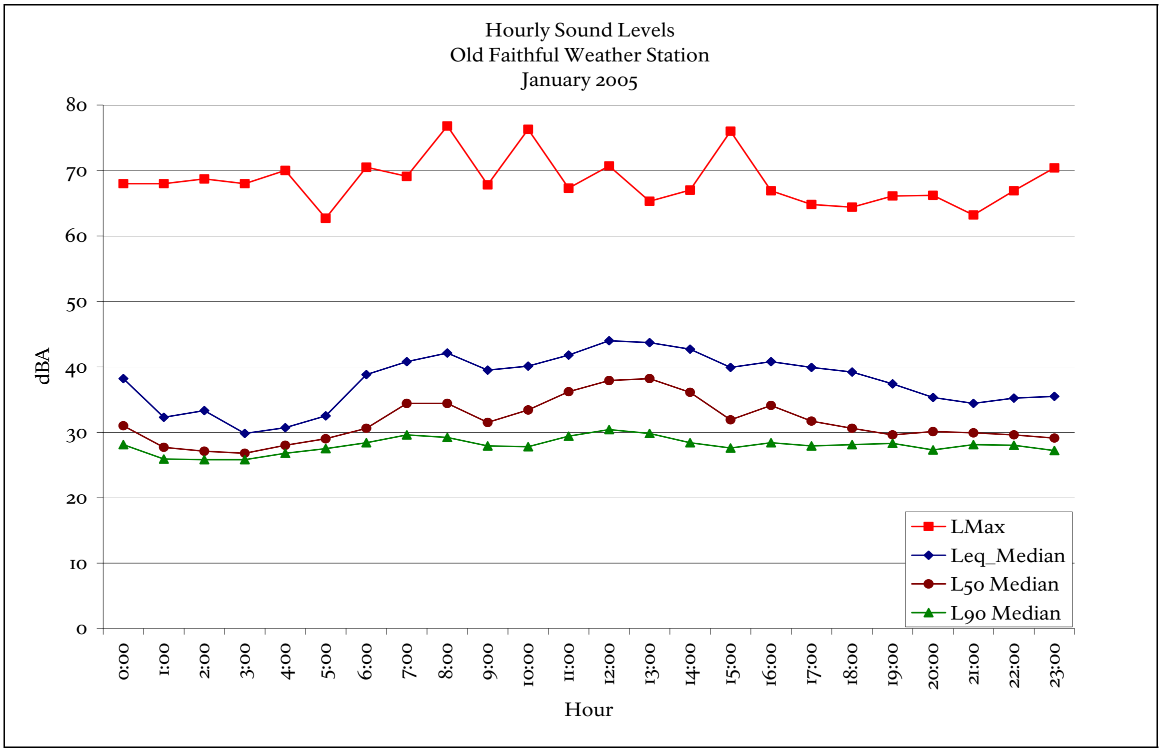

Figure 25. Median hourly sound levels for January 2005, Old Faithful Weather Station, Yellowstone National Park. **See Fig. 23 for additional details. (n=736).**

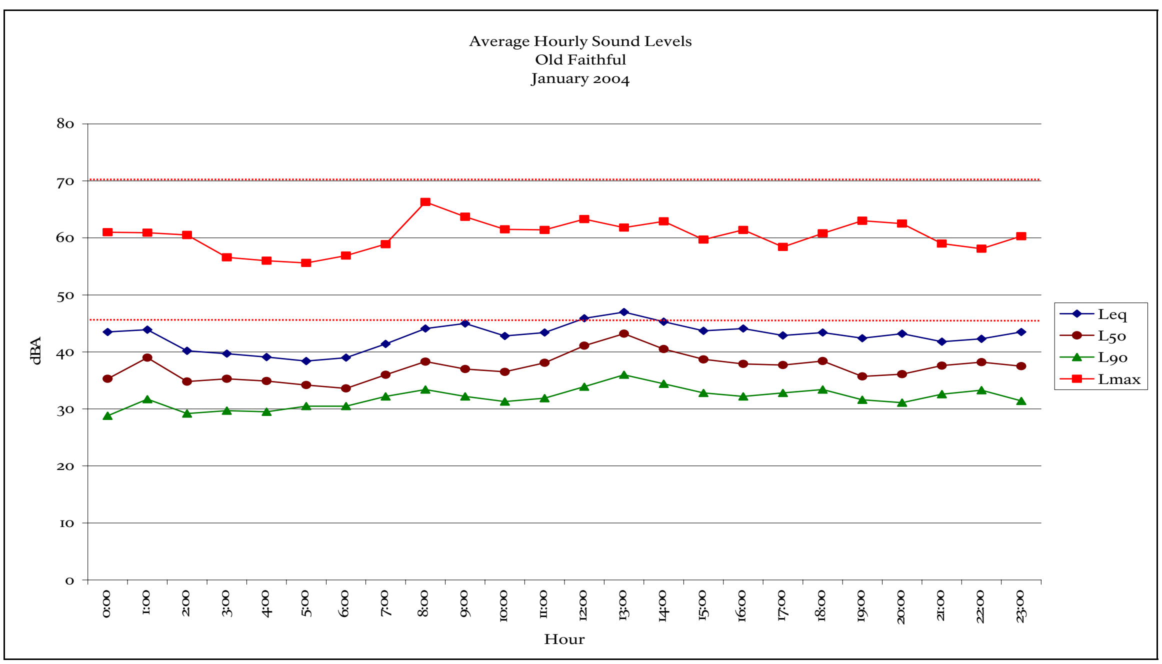

Figure 26. Average hourly sound levels for January 2004, Old Faithful Weather Station, Yellowstone National Park. **See Fig. 24 for additional details. (n=735).**

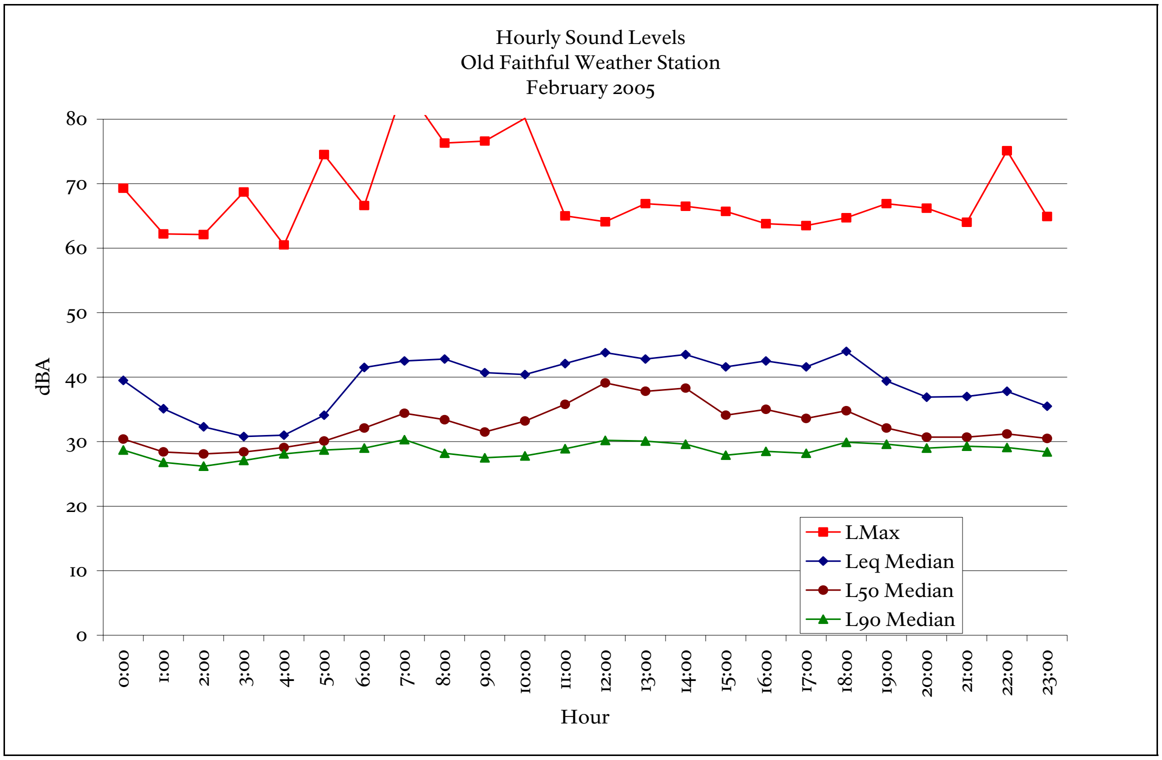

Figure 27. Median hourly sound levels for February 2005, Old Faithful Weather Station, Yellowstone National Park. **See Fig. 23 for additional details. (n=609).**

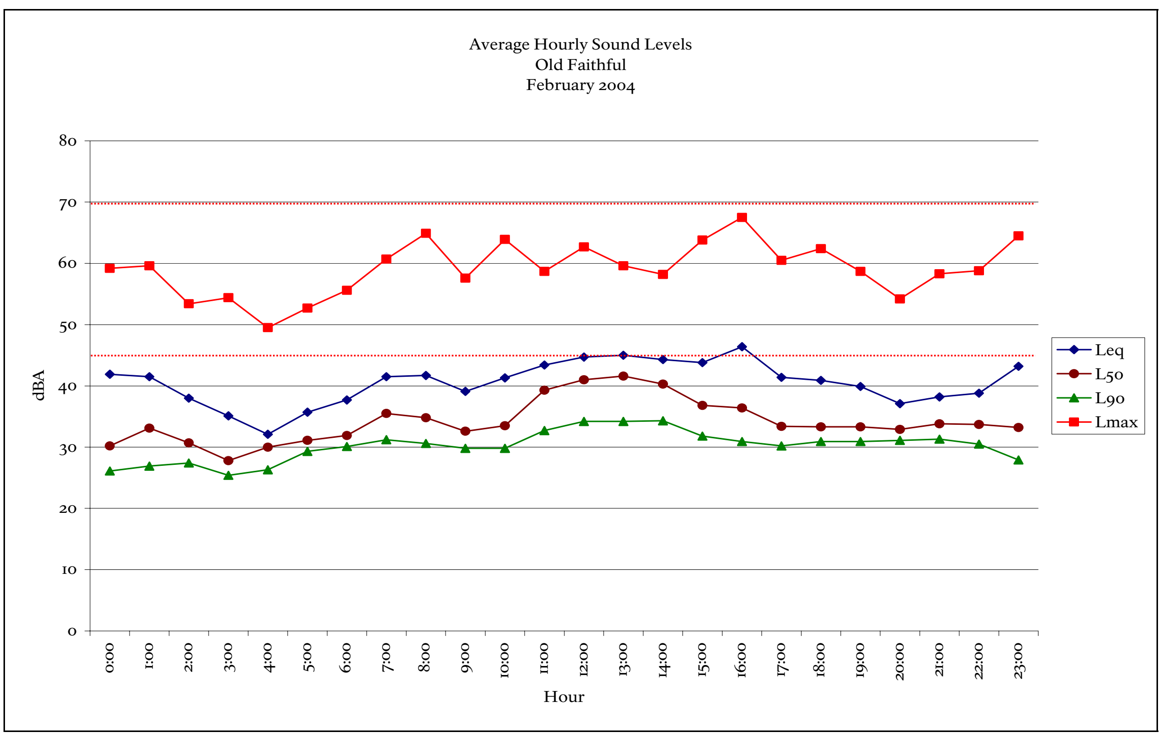

Figure 28. Average hourly sound levels for February 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 24 for additional details. (n=435).

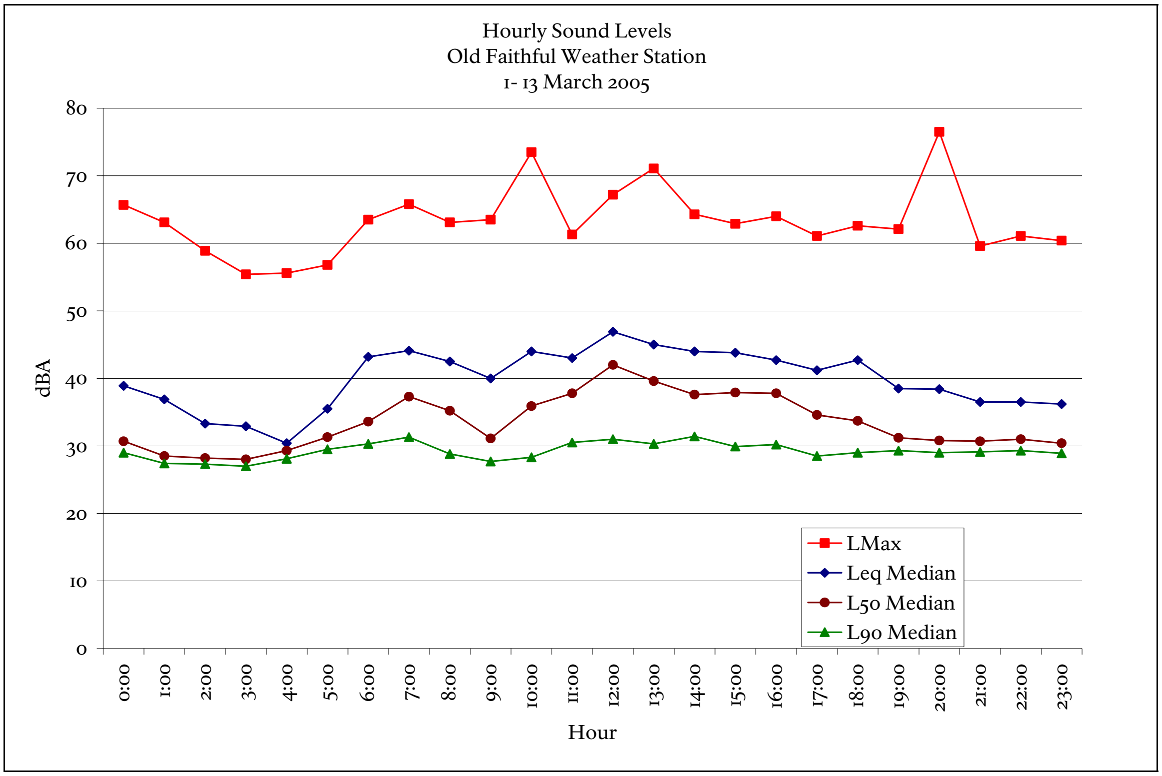

Figure 29. Median hourly sound levels for 1- 13 March 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 23 for additional details. (n=281).

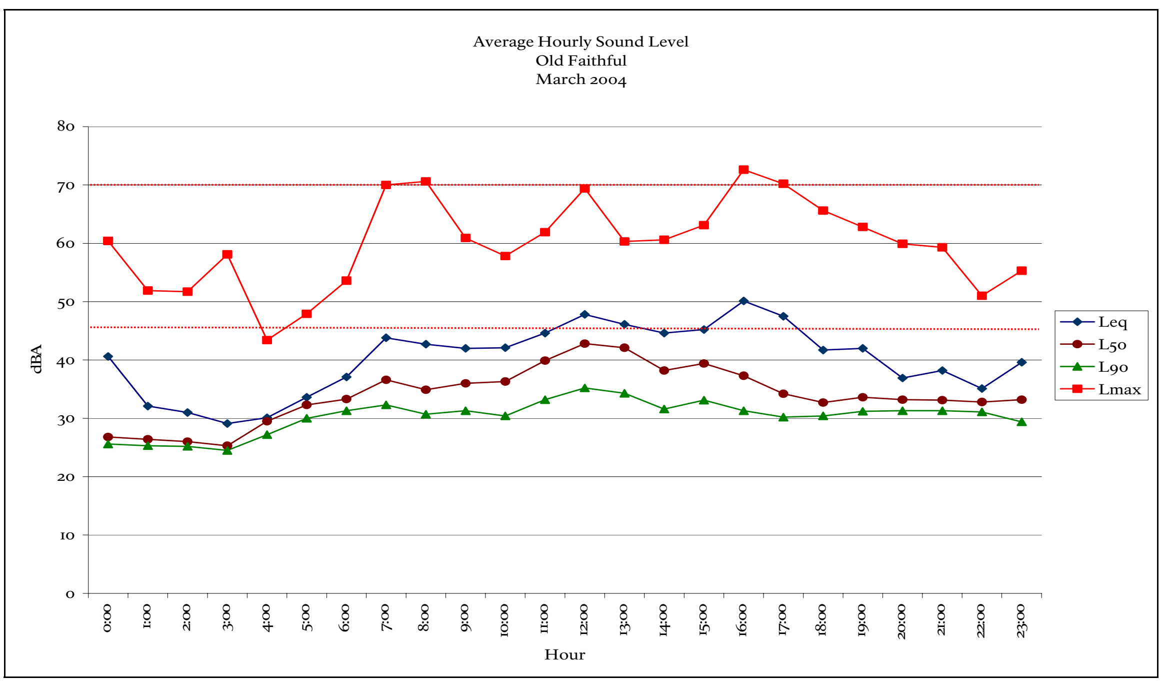

Figure 30. Average hourly sound levels for 1- 4 March 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 24 for additional details. (n=82).

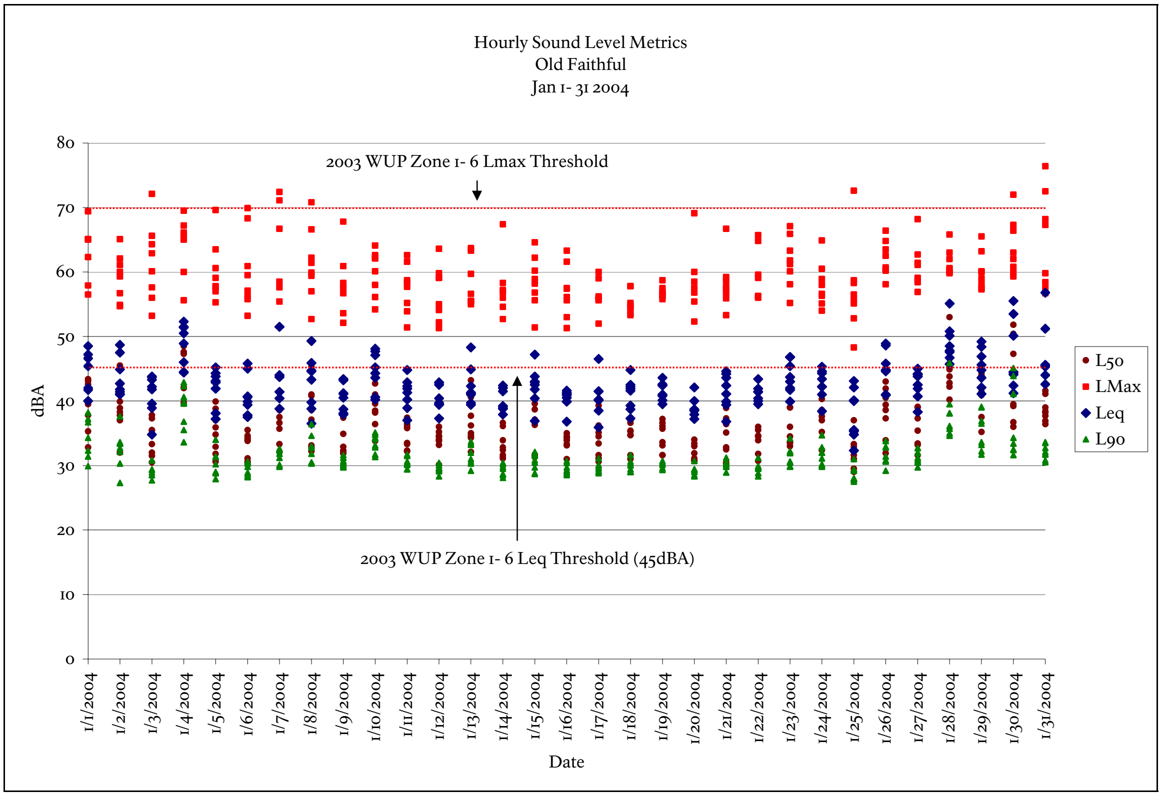

Figure 31. The hourly sound level metrics (8 am- 4 pm) of natural and non-natural sounds at Old Faithful Weather Station, Yellowstone National Park, January 2004. See Fig. 24 for additional details. (n=243).

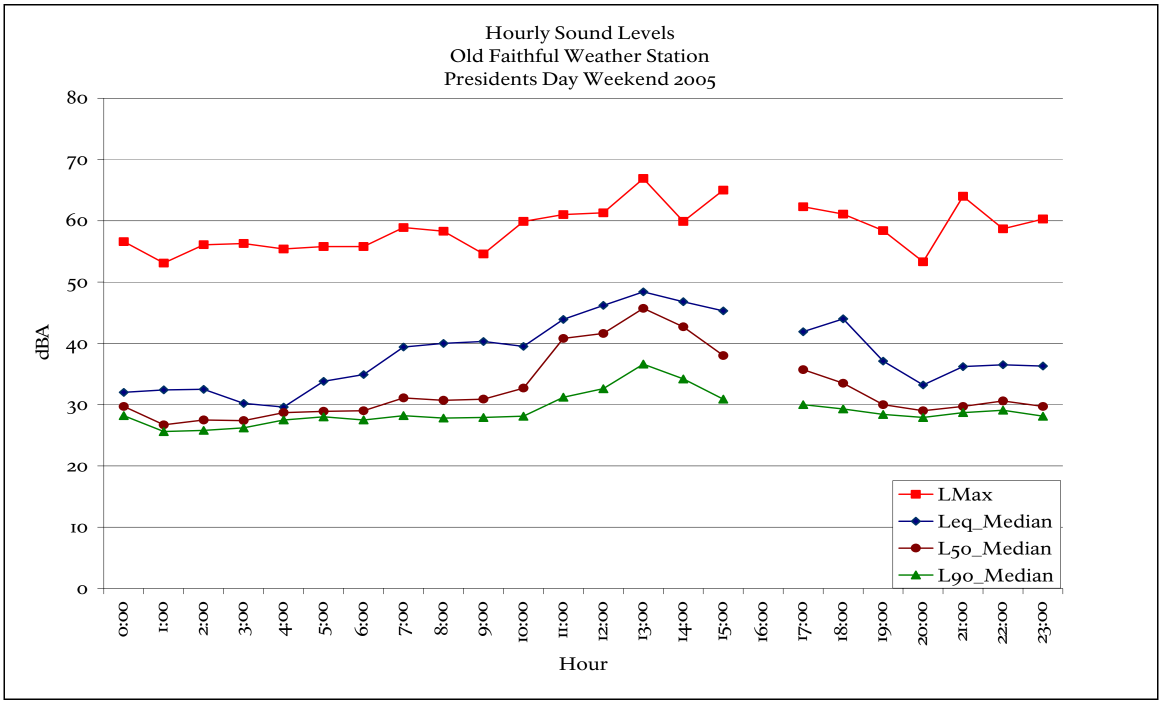

Figure 32. Median hourly sound levels for Presidents Day Weekend 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 23 for additional details. Missing hours due to excessive wind speeds. (n=61).

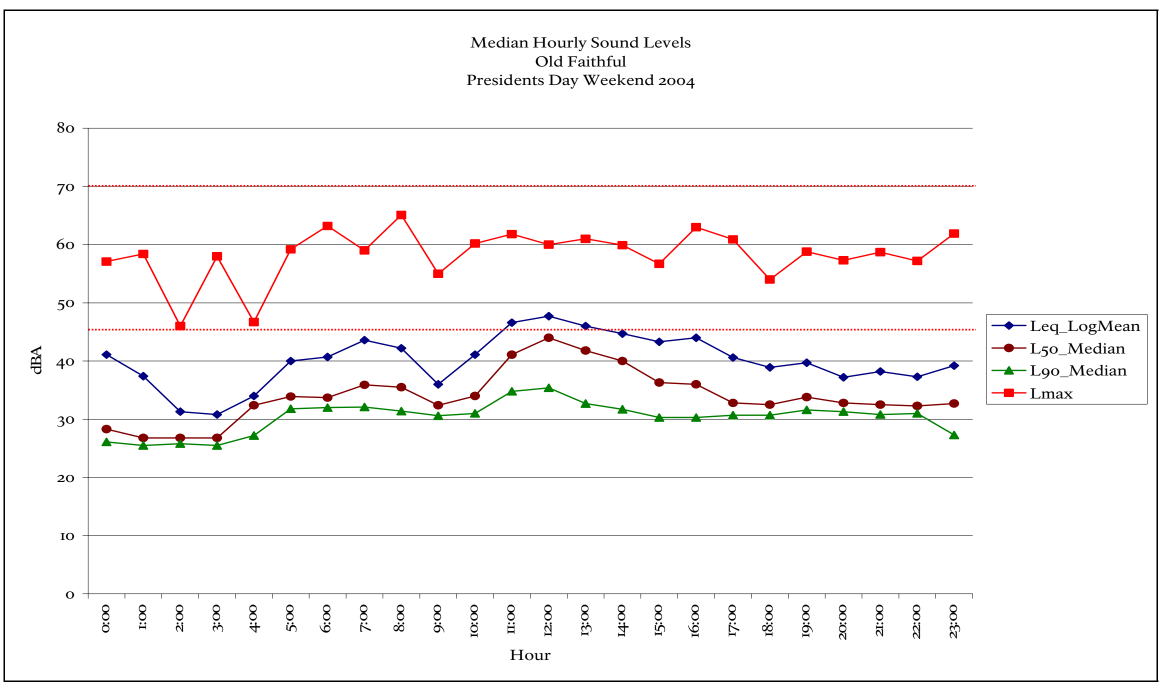

Figure 33. Median hourly sound levels for Presidents Day Weekend 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 24 for additional details. (n=55).

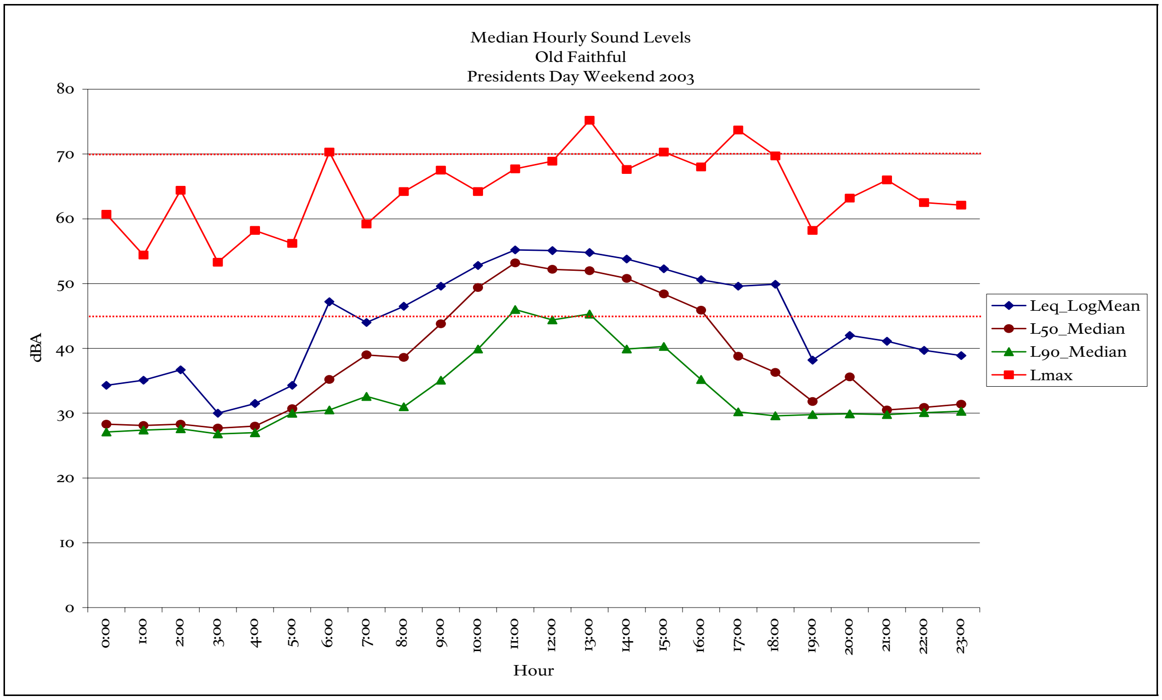

Figure 34. Median hourly sound levels for Presidents Day Weekend 2003, Old Faithful Weather Station, Yellowstone National Park. See Fig. 2 for additional details. (n=71).

Old Faithful Upper Basin

The relatively tight clustering of the hourly L_{eq}, L_{50} and L_{90} sound levels at the Old Faithful Basin (Fig. 35) compared to those at the nearby Old Faithful Weather Station (Fig. 25) indicate that the Upper Basin had consistent sound levels with very few loud events (Fig. 35). Both the minimum and maximum sound levels were largely determined by natural thermal activity, gurgling and sputtering at low levels and erupting geysers at the higher levels. Footsteps on the nearby boardwalk and people's voices also contributed to the sound levels documented. Oversnow vehicles were often audible (Figs. 9 and 10) and contributed to the soundscape, but only at intermediate and lower sound levels.

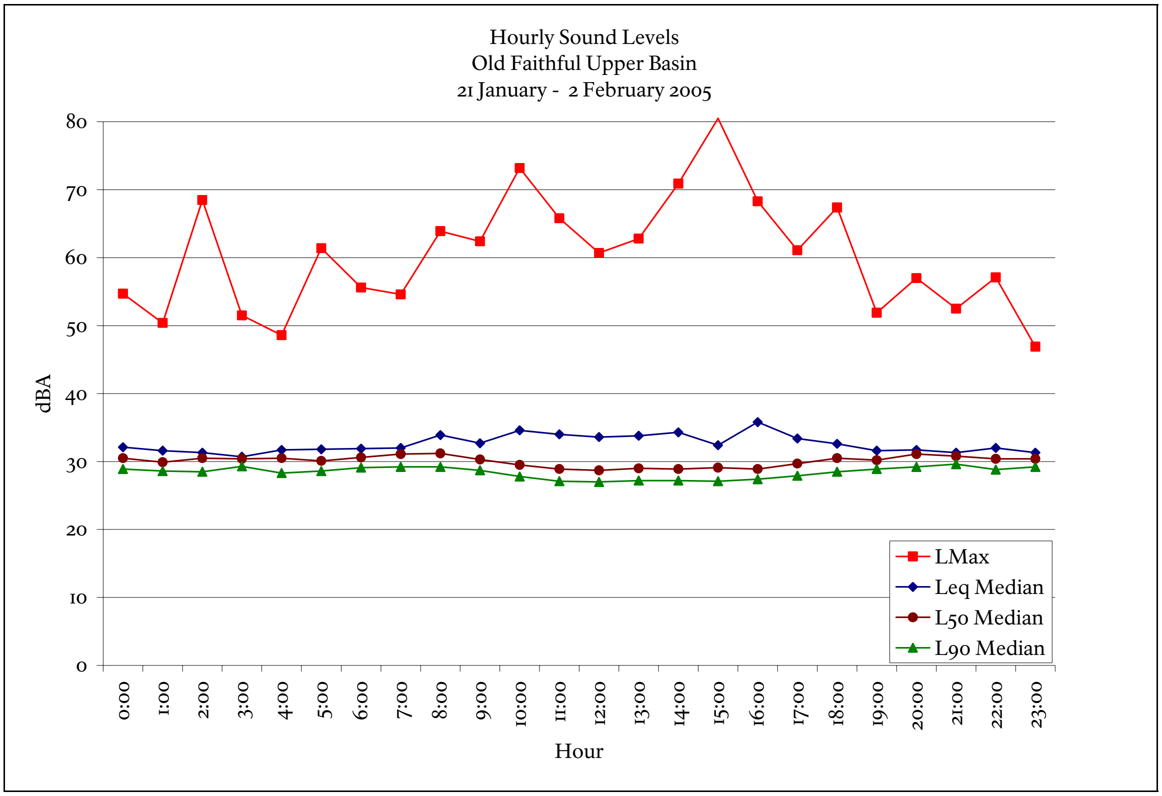

Figure 35. Median hourly sound levels 21 January- 2 February 2005, Old Faithful Upper Basin, Yellowstone National Park. See Fig. 23 for additional details. (n=280).

Lone Star

Oversnow vehicles traveling along the main road approximately one mile away from the Lone Star Geyser sound monitor were audible at this site but their sound levels were generally near the natural ambient sound levels. The maximum sound levels were influenced from oversnow vehicles only during the periodic track grooming on the nearby trail. The 2004/2005 hourly sound levels by month for the Lone Star Geyser site are shown in Figures 36, 38, 40 and 42. For comparison, 2003/2004 hourly sound levels are shown in Figs. 37, 39, 41 and 43.

Natural sounds largely determined the sound levels at this site. The predominate sounds were wind blowing through the trees, geyser activity every three hours, Raven and other bird and mammal vocalizations, and human voices during the midday, especially as the season progressed. Aircraft, distant oversnow vehicles and the periodic snowmobile track groomer also influenced the sound levels at this site.

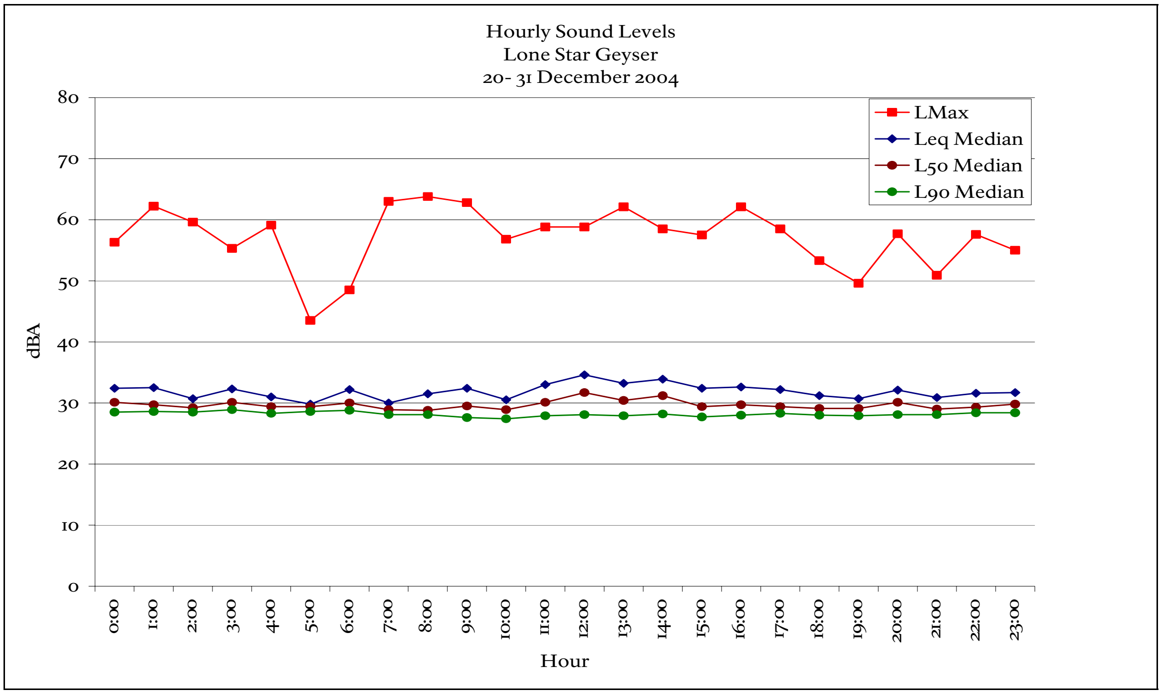

Figure 36. Median hourly sound levels for December 2004, Lone Star Geyser, Yellowstone National Park. See Fig. 23 for additional details. (n=263).

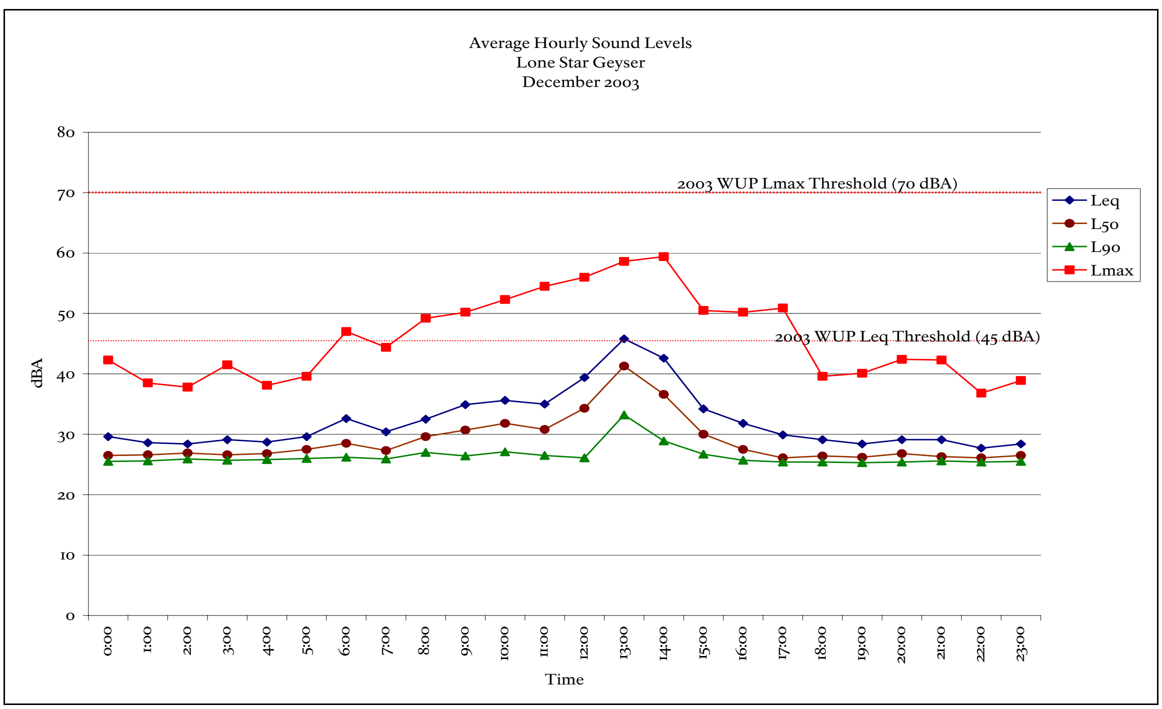

Figure 37. Average hourly sound levels for December 2003, Lone Star Geyser, Yellowstone National Park. See Fig. 24 for additional details. (n=232).

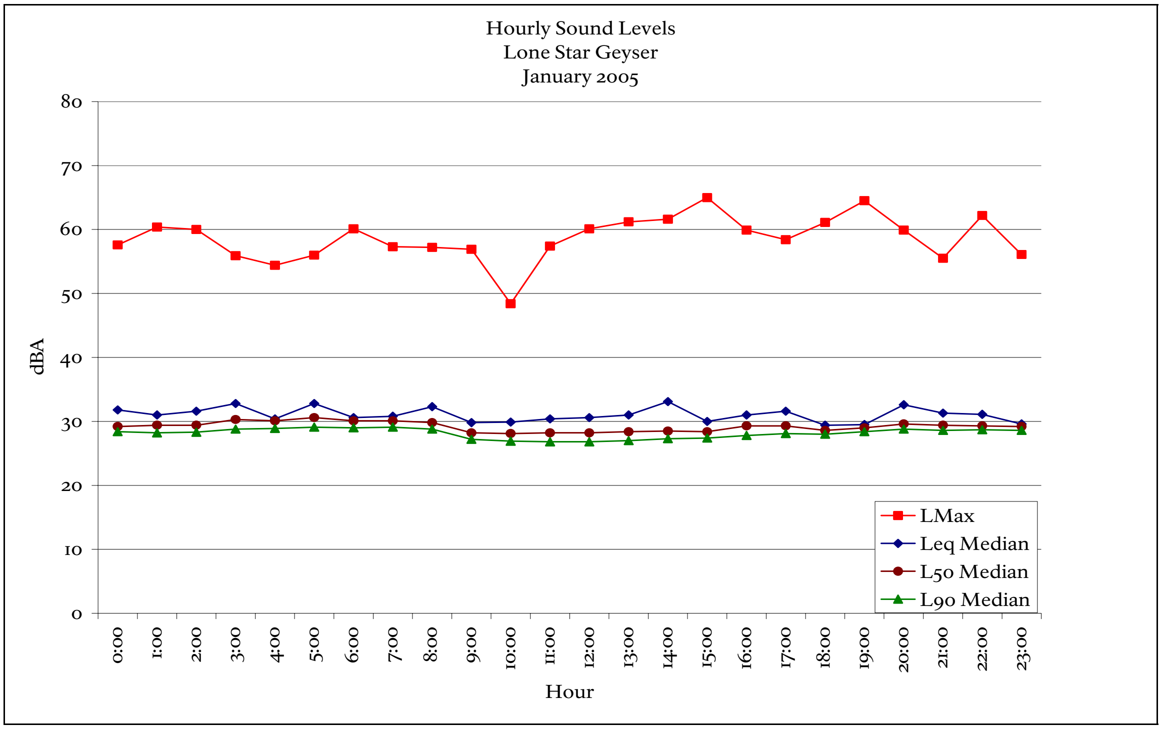

Figure 38. Median hourly sound levels for January 2005, Lone Star Geyser, Yellowstone National Park. See Fig. 23 for additional details. (n=365).

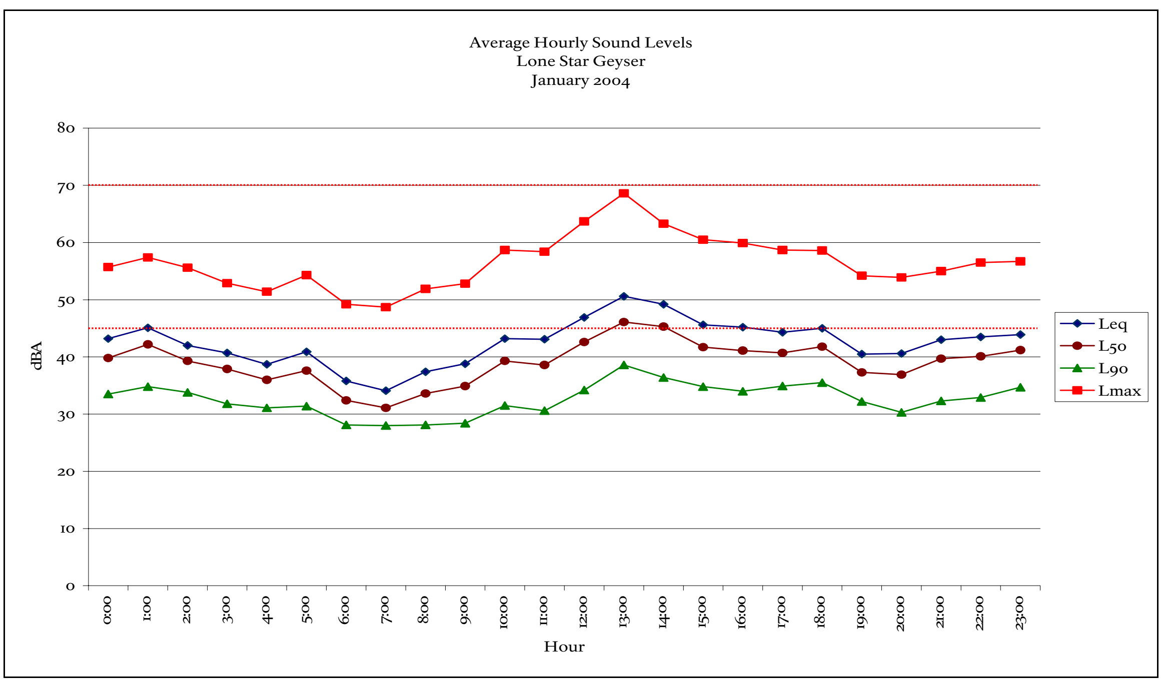

Figure 39. Average hourly sound levels for January 2004, Lone Star Geyser, Yellowstone National Park. See Fig. 24 for additional details. (n=537).

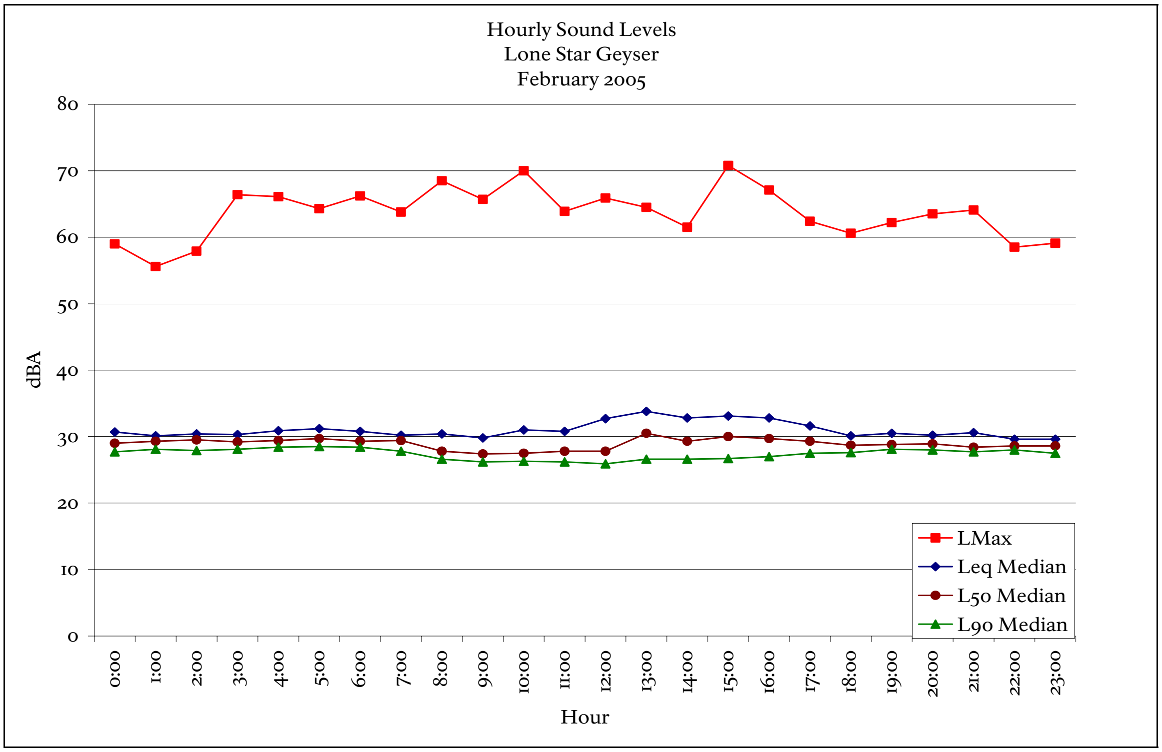

Figure 40. Median hourly sound levels for February 2005, Lone Star Geyser, Yellowstone National Park. See Fig. 23 for additional details. (n=654).

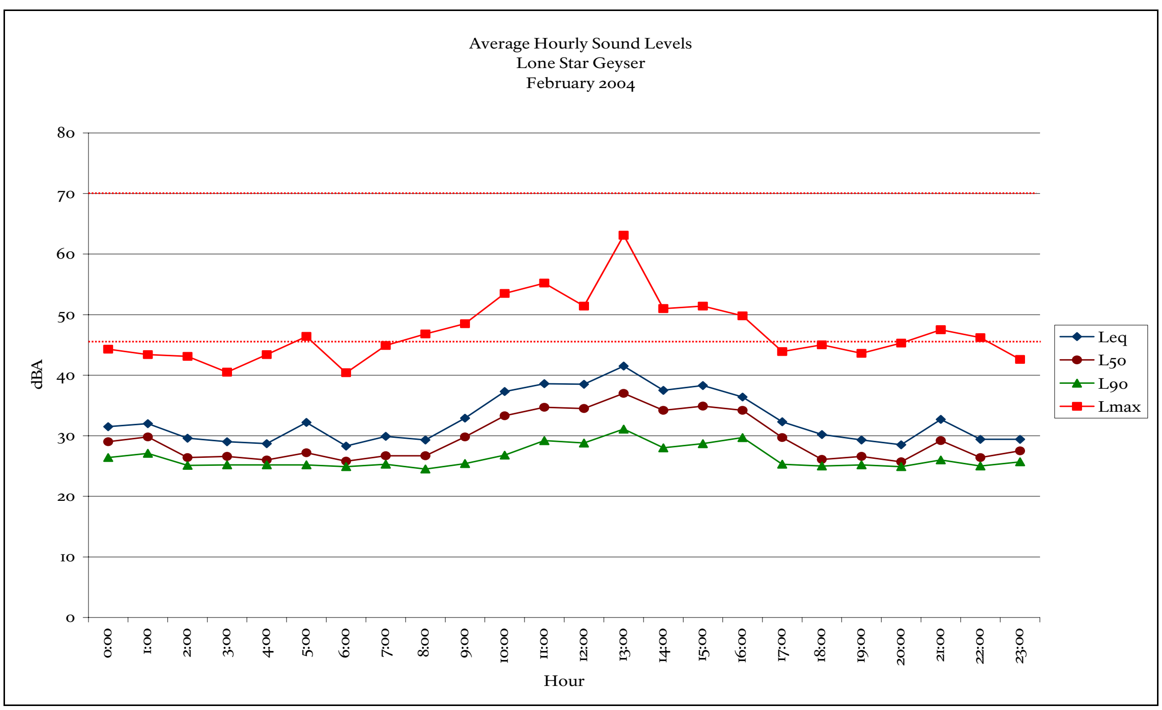

Figure 41. Average hourly sound levels for February 2004, Lone Star Geyser, Yellowstone National Park. See Fig. 24 for additional details. (n=382).

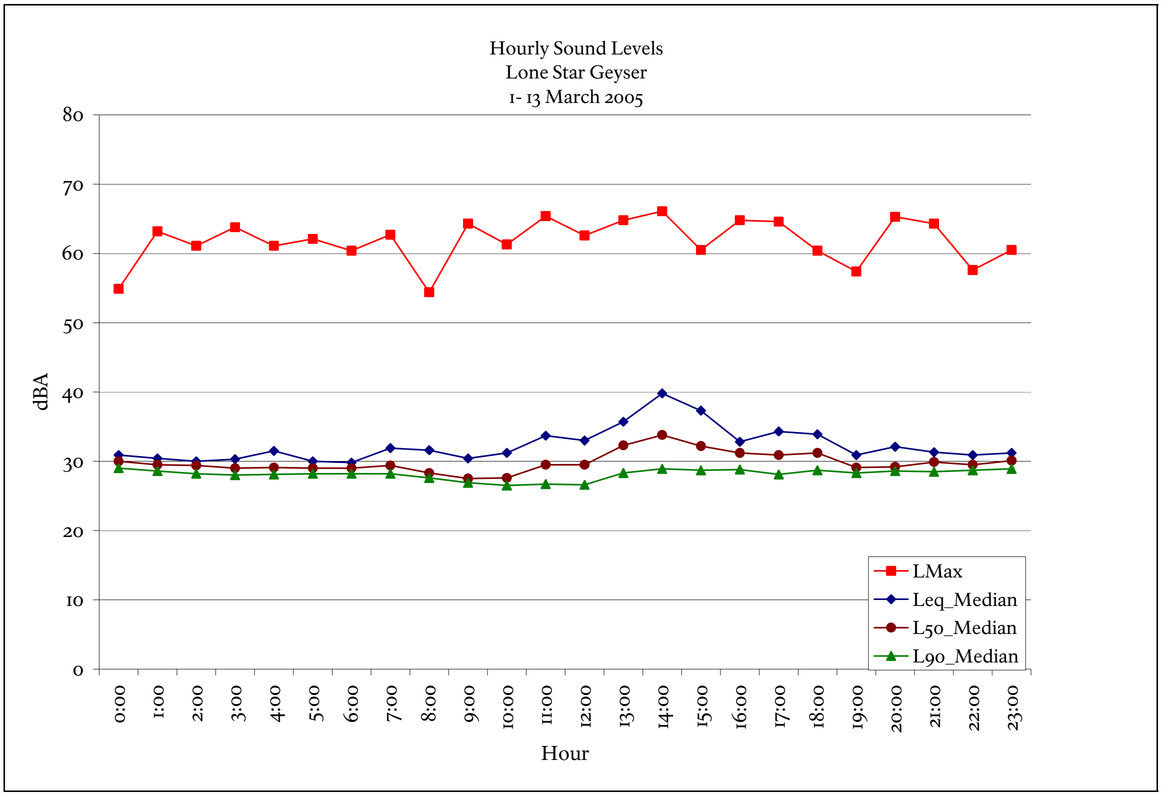

Figure 42. Median hourly sound levels for 1- 13 March 2005, Lone Star Geyser, Yellowstone National Park. See Fig. 23 for additional details. (n=310).

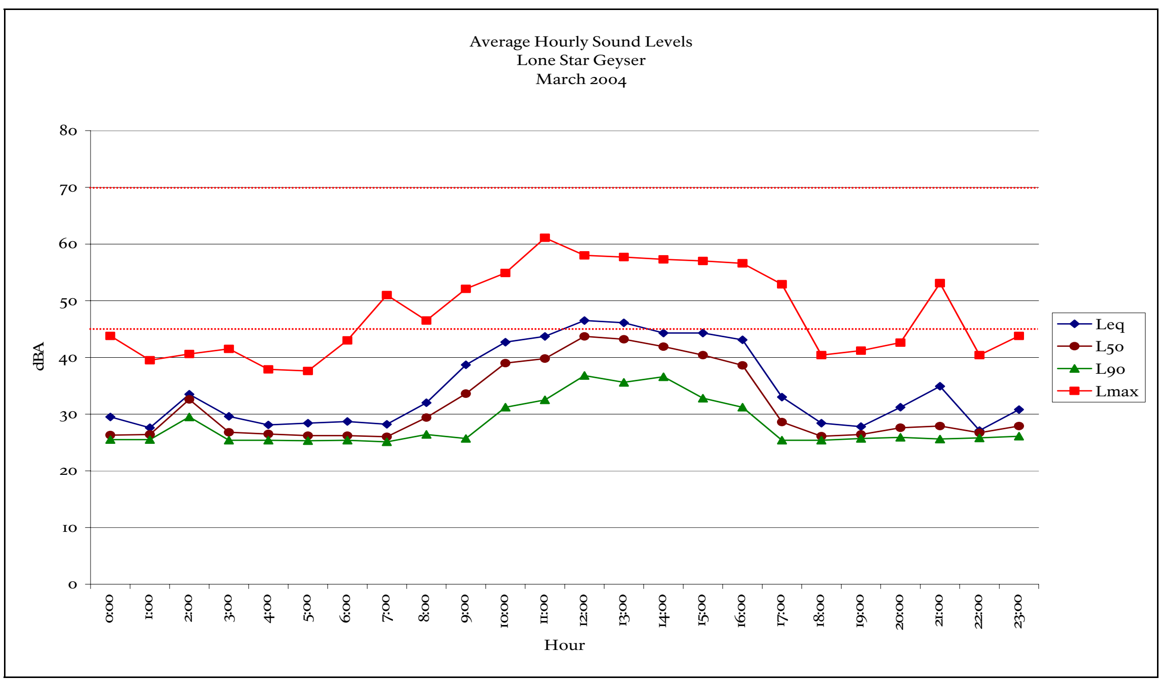

Figure 43. Average hourly sound levels for 1- 5 March 2004, Lone Star Geyser, Yellowstone National Park. See Fig. 24 for additional details. (n=107).

Mary Mountain 8K

Figures 44- 46 show the hourly sound levels for Mary Mountain 8K during January- March 2005. The snowmobiles and snowcoaches traveling along the corridor between Old Faithful and Madison Junction at least 8000 feet from the measurement location were audible at this site but were near natural ambient sound levels. Similar to the Lone Star and Old Faithful Upper Basin sites, Mary Mountain 8K had a consistently low sound level with occasional louder sounds. The sounds generated by the frequent afternoon winds in March are shown by the higher L_{eq} and L_{50} values (Fig. 46). The loudest sounds at Mary Mountain 8K were aircraft and wind in the trees. The nearby Nez Perce Creek determined the lowest sound levels measured.

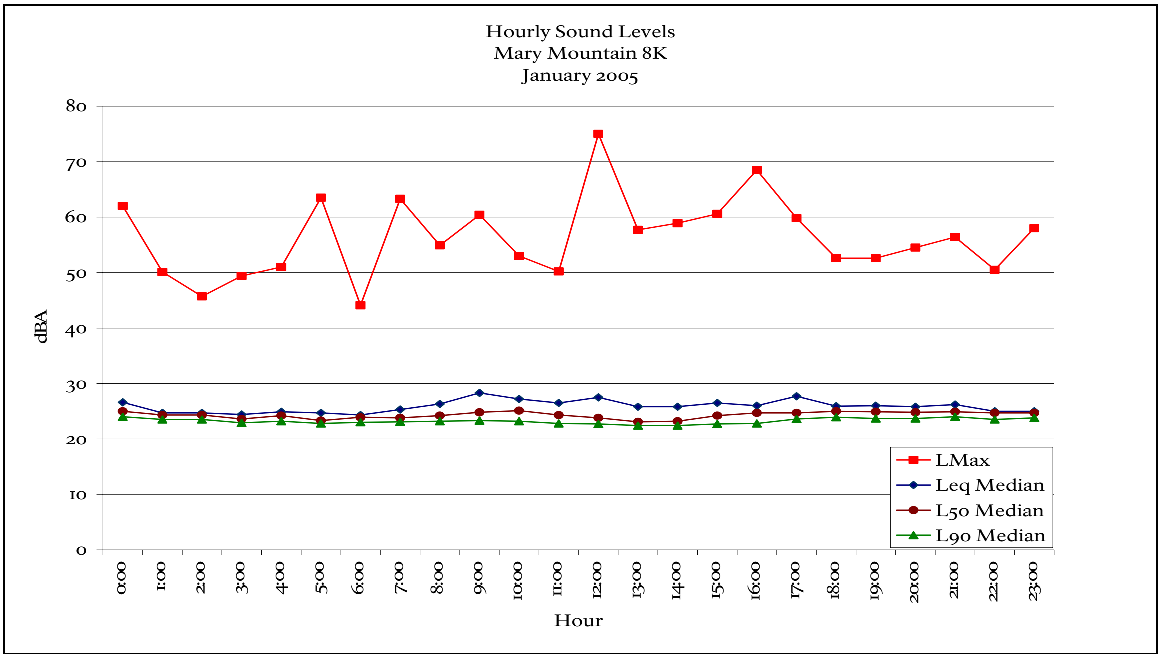

Figure 44. Median hourly sound levels for 7- 31 January 2005, Mary Mountain 8K, Yellowstone National Park. See Fig. 23 for additional details. (n=476)

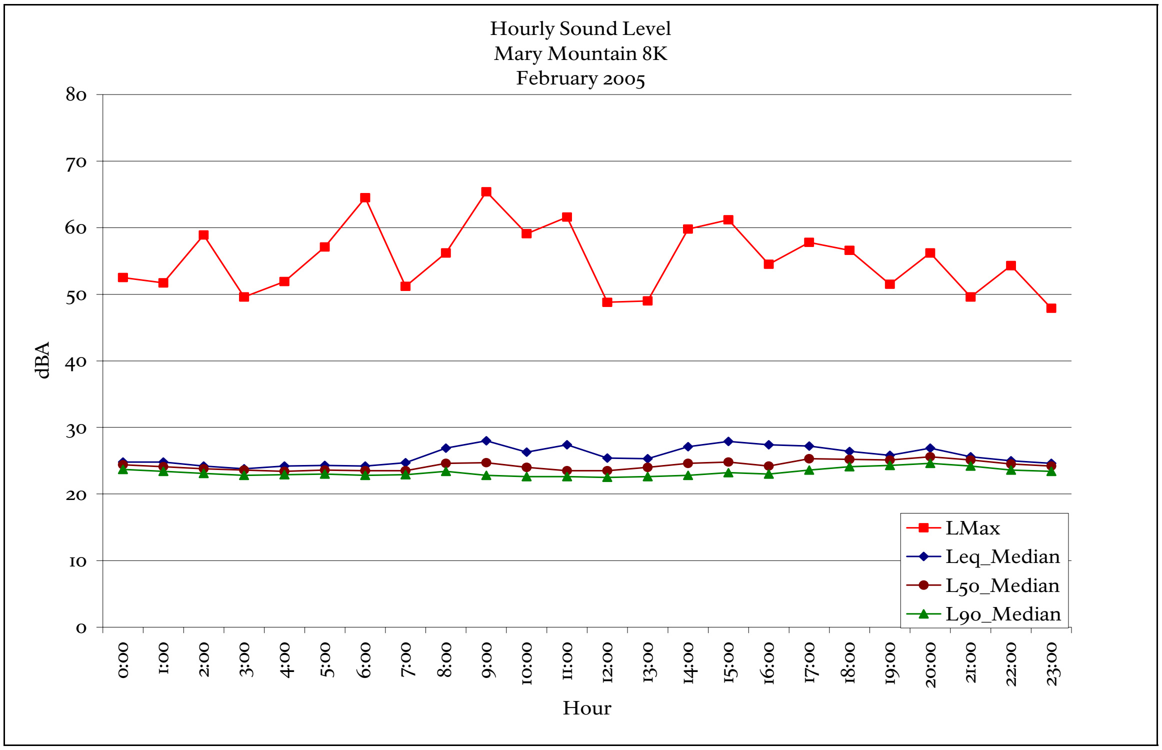

Figure 45. Median hourly sound levels for February 2005, Mary Mountain 8K, Yellowstone National Park. See Fig. 23 for additional details. (n=591)

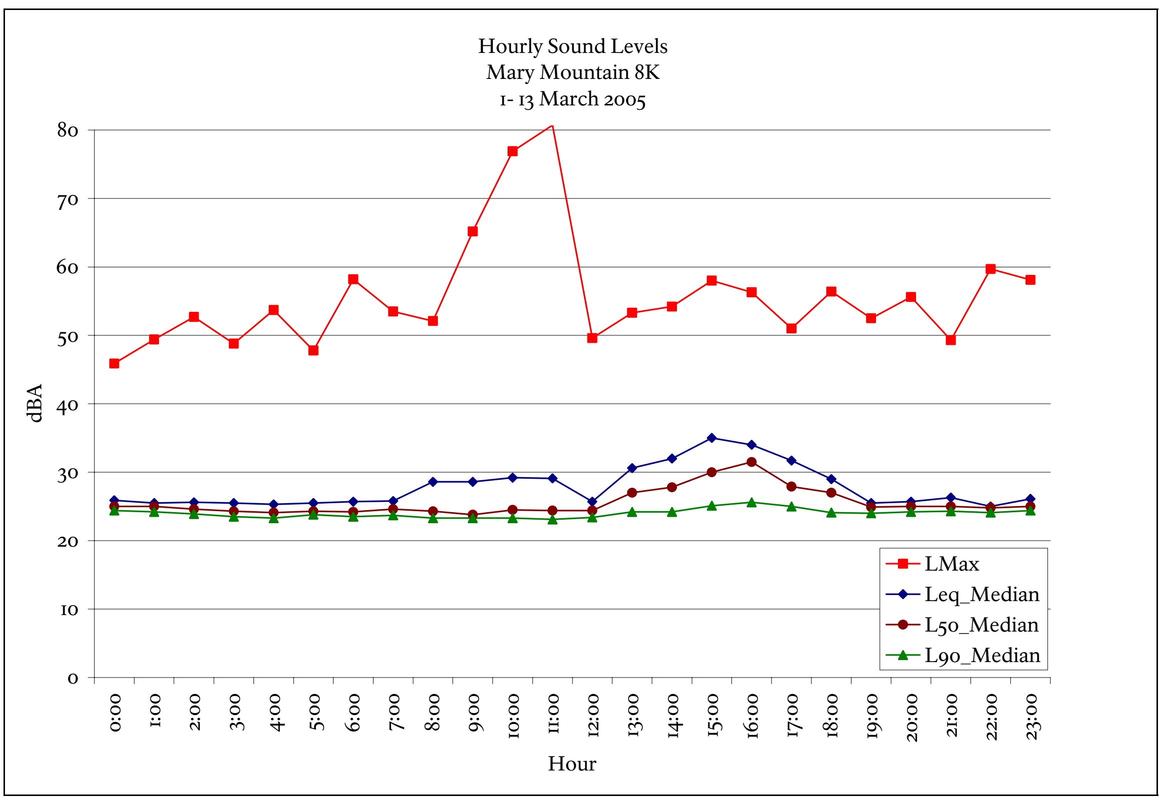

Figure 46. Median hourly sound levels for March 2005, Mary Mountain 8K, Yellowstone National Park. See Fig. 23 for additional details. (n=591)

West Yellowstone 3.1

The measurement site at West Yellowstone 3.1 was located 100 feet from the travel corridor between West Yellowstone and Madison Junction. Oversnow vehicles and snow groomers exceeded the impact definition threshold of 70 dBA for maximum sound level for most of the hours of the measurement period (8 am- 4 pm) (Figs. 47- 49). The lowest sound levels were likely determined by the Madison River and approached the noise floor of the instrumentation. The patterns of the hourly L_{eq}, L_{50} and L_{90} levels show the time during the morning and afternoon that the majority of guided snowmobile groups passed by the measurement site (Figs 47- 49). The sound levels from the frequently audible distant 2- stroke snowmobiles were generally close to the natural ambient sound level.

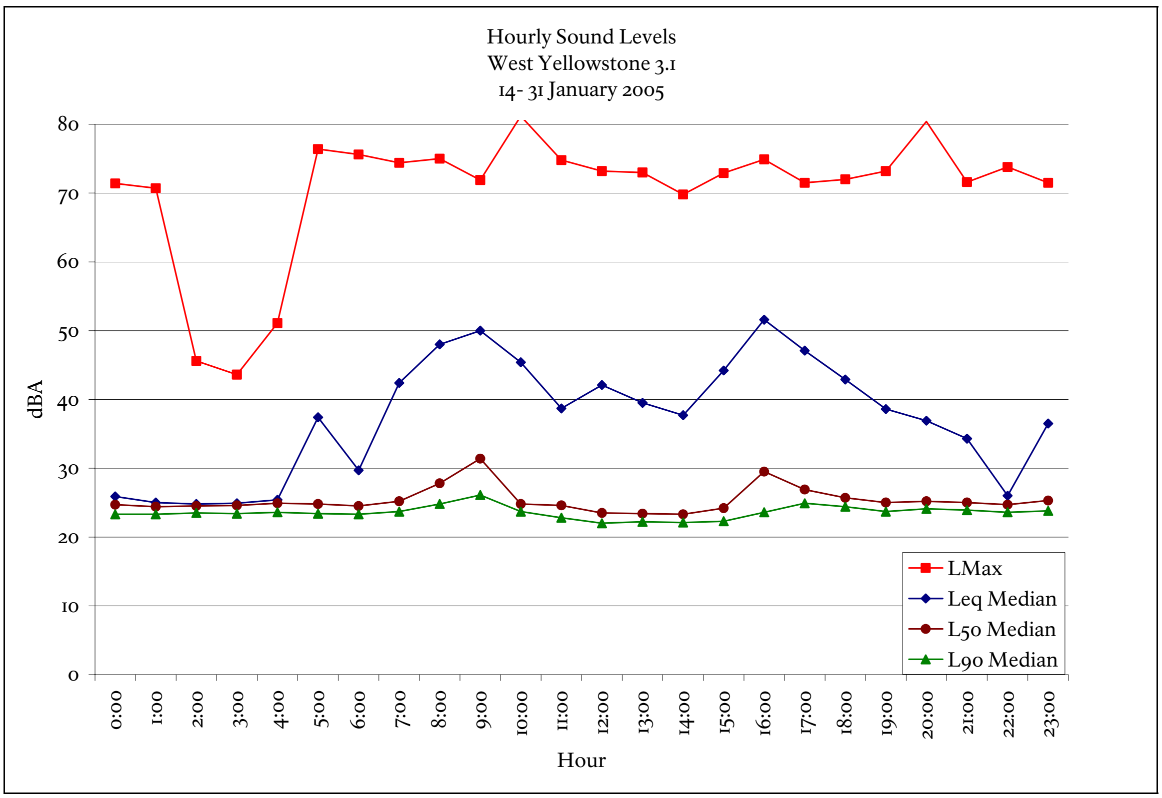

Figure 47. Median hourly sound levels for 14- 31 January 2005, West Yellowstone 3.1, Yellowstone National Park. See Fig. 23 for additional details. (n=411)

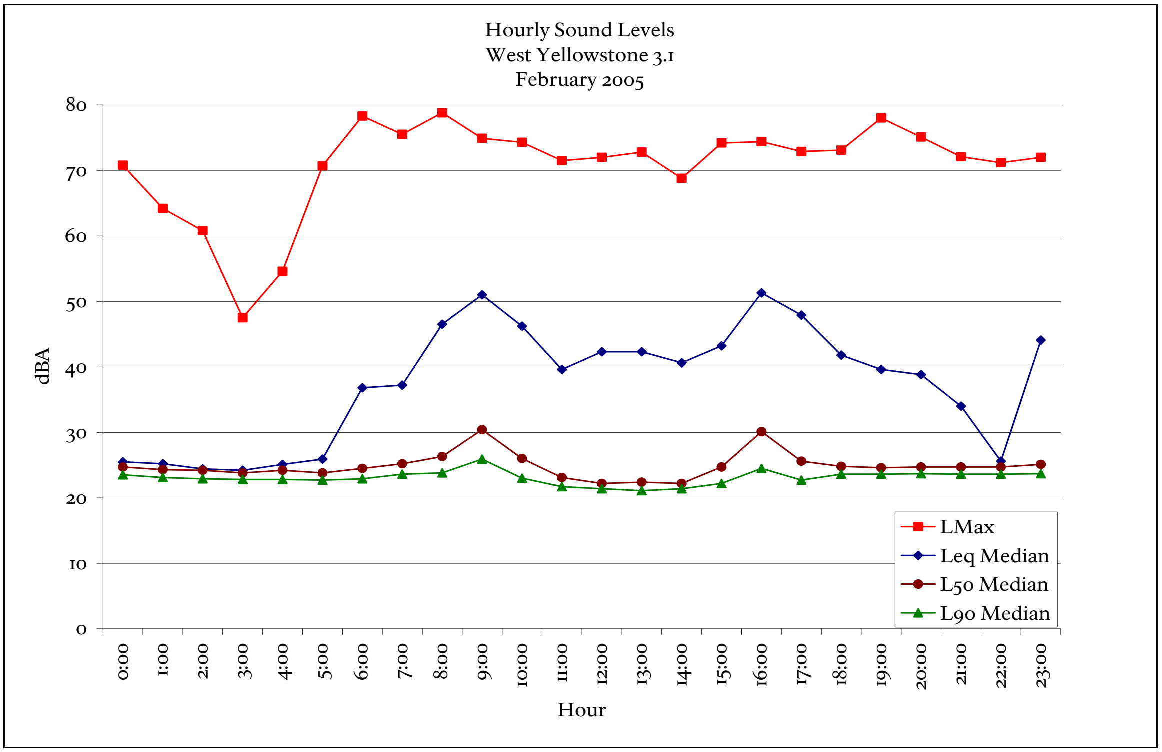

Figure 48. Median hourly sound levels for February 2005, West Yellowstone 3.1, Yellowstone National Park. See Fig. 23 for additional details. (n=646)

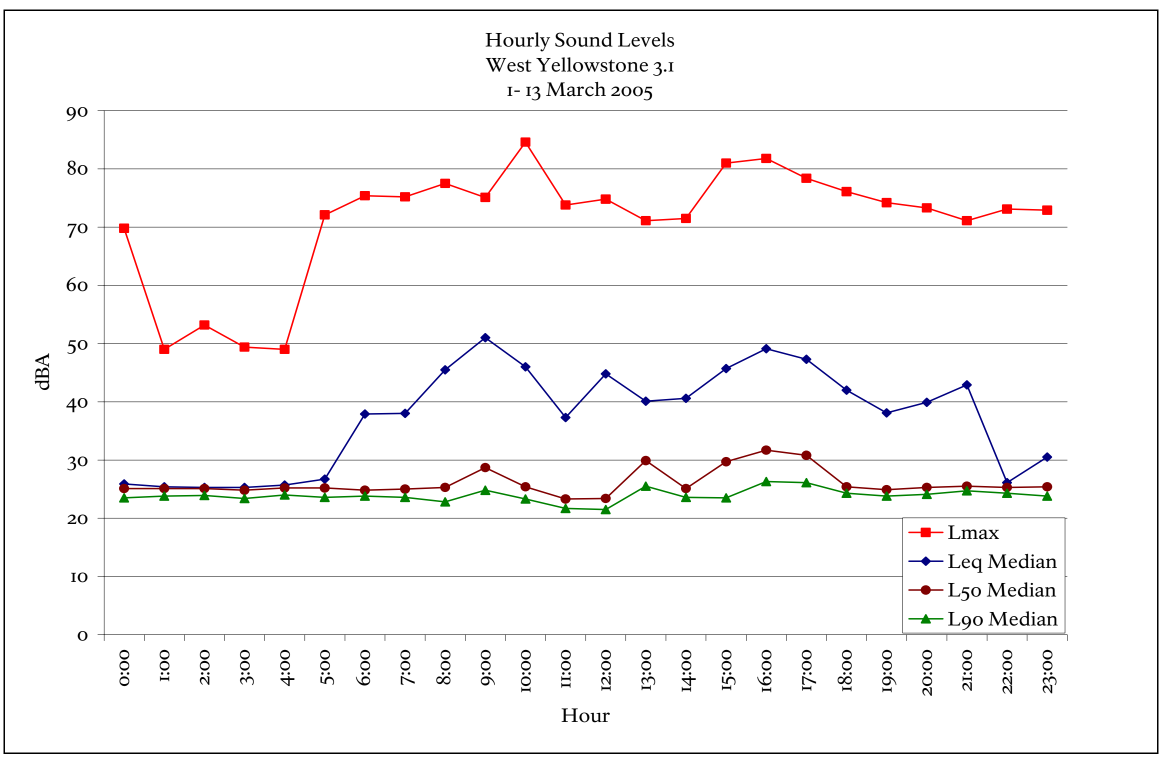

Figure 49. Median hourly sound levels for 1- 13 March 2005, West Yellowstone 3.1, Yellowstone National Park. See Fig. 23 for additional details. (n=306)

West Thumb

The measurement site at West Thumb was adjacent to a boardwalk within the geyser basin 450 feet from the nearest motorized area (parking lot) and 850 feet from the nearest groomed main road (West Thumb to Canyon Road). The sound level data, especially the L_{50} and L_{eq}, (Fig. 50) indicate the morning and afternoon periods when the majority of oversnow vehicles were near this site. The period (9 am- 5pm) when visitors were visiting is also shown by the increased L_{90}, L_{50} and L_{eq} (Fig. 50). Human voices were generally the maximum sound levels during the day and natural sounds (wind and splashes) during the night. The minimum sound levels were determined by the noise floor of the instrumentation and the nearly constant low level thermal activity.

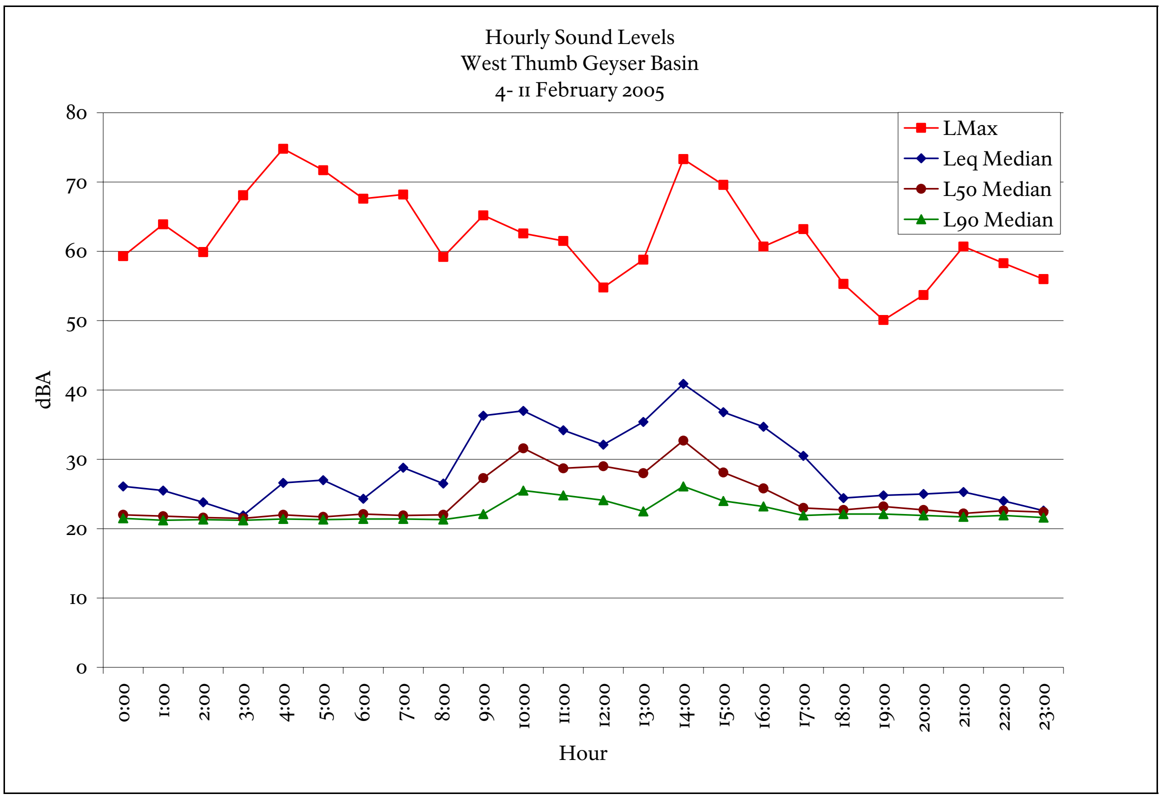

Figure 50. Median hourly sound levels for 4- 11 February 2005, West Thumb Geyser Basin, Yellowstone National Park. See Fig. 23 for additional details. (n=172)

Madison Junction 2.3

Consistent with the results from West Yellowstone 3.1 and Old Faithful Weather Station, the sound levels from oversnow vehicles at Madison Junction 2.3 exceeded the 2004 WUP maximum sound level impact definition threshold during half the hours of the measurement day (8 am- 4 pm) in 2004 (Fig. 51).

For comparison, Figures 52 and 53 presents sound level data collected at the same location during the two day Presidents Day Weekend in 2004 and 2003. The hourly pattern between 2005 and 2004 is remarkably similar. These both differ from 2003 when there were both greater numbers and louder two stroke snowmobiles.

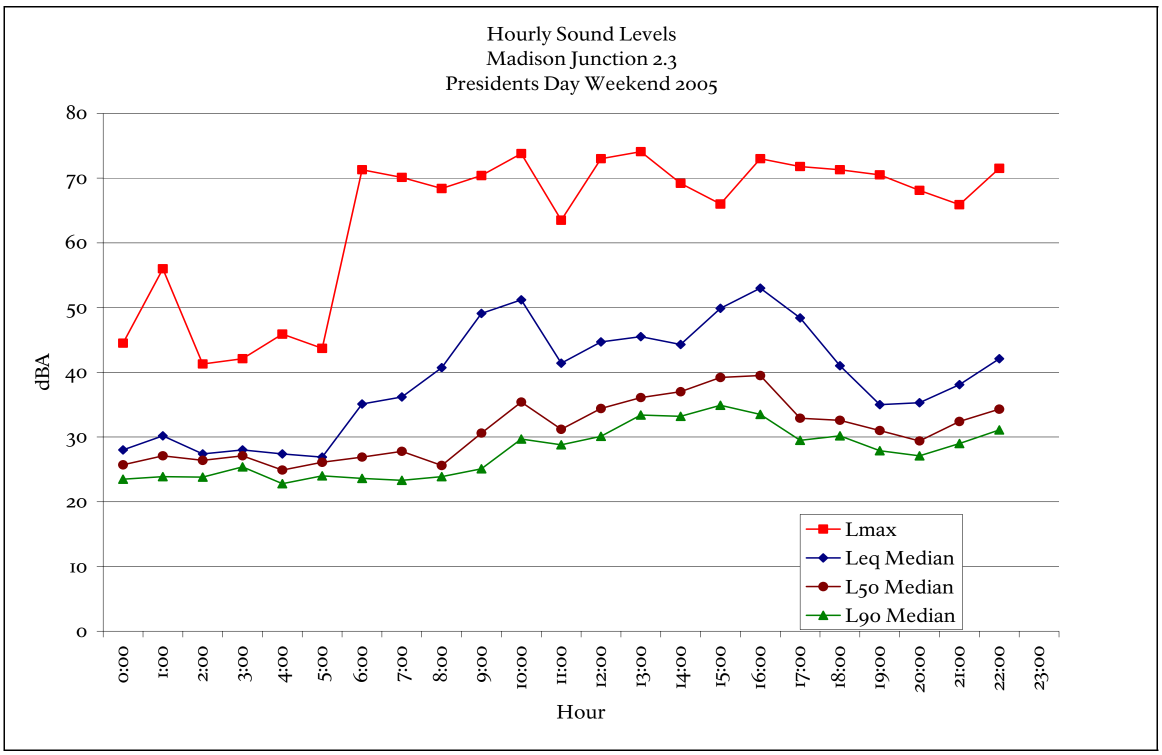

Figure 51. Median hourly sound levels for 19- 20 February 2005, Madison Junction 2.3, Yellowstone National Park. See Fig. 23 for additional details. (n=46)

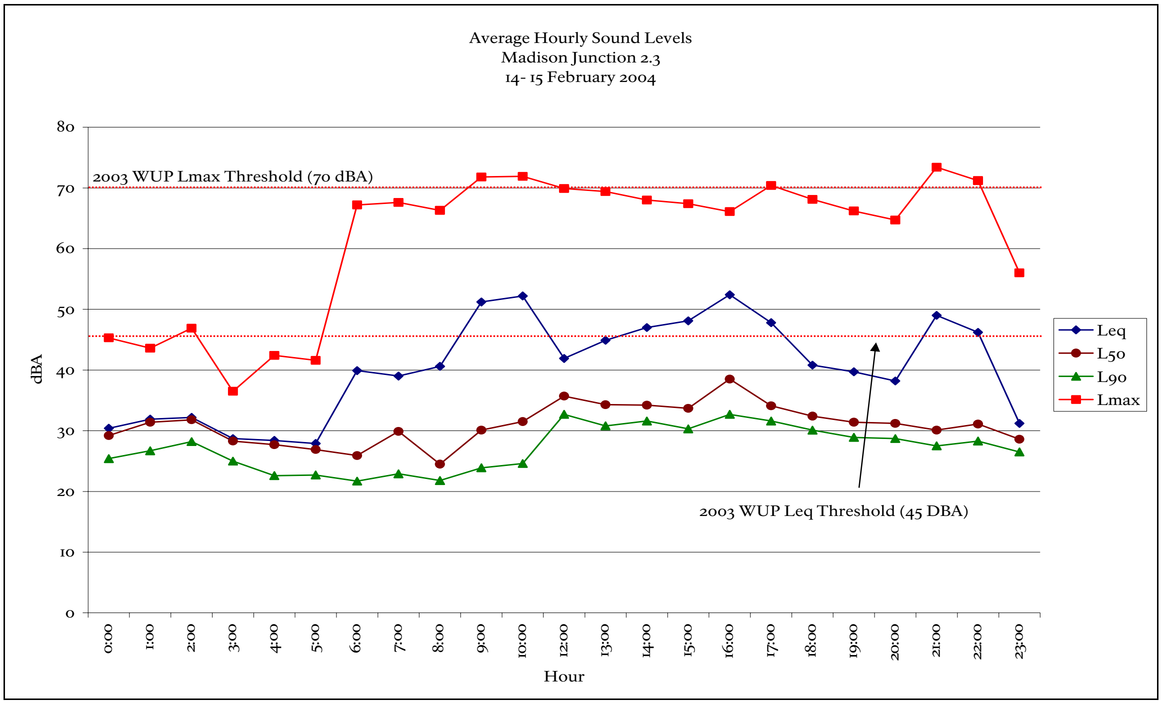

Figure 52. Average hourly sound levels for 14- 15 February 2004, Madison Junction 2.3, Yellowstone National Park. See Fig. 23 for additional details. (n=47)

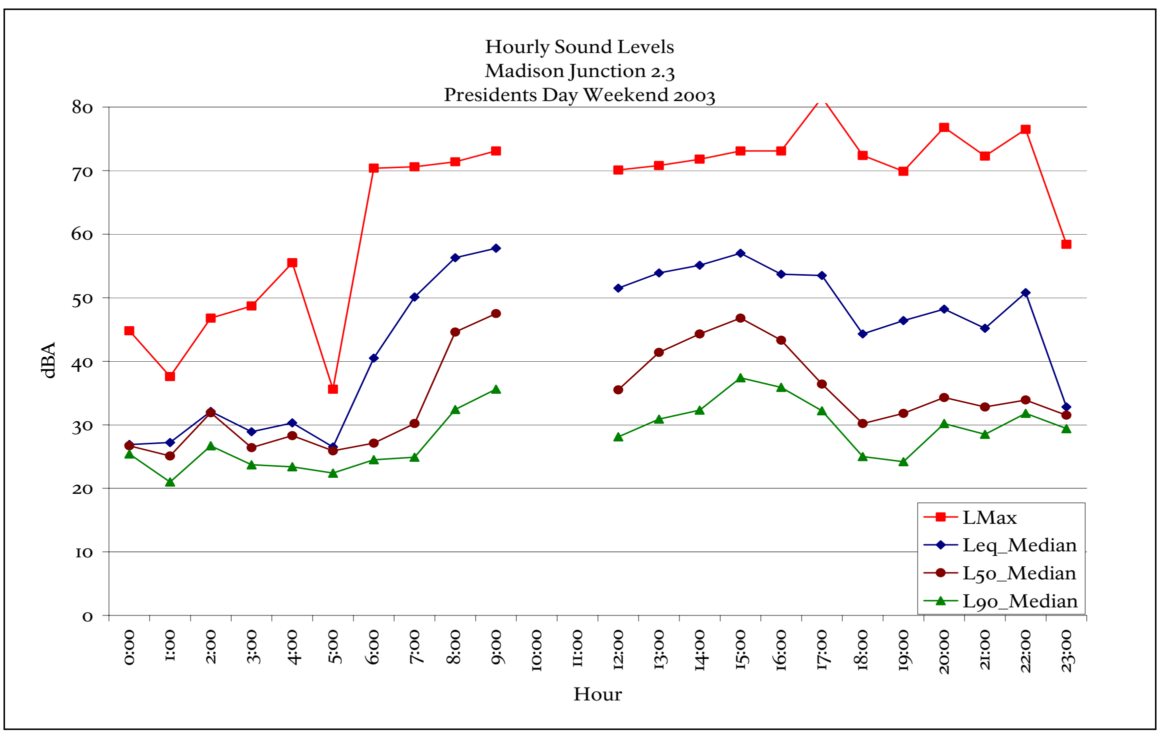

Figure 53. Median hourly sound levels for 15- 16 February 2003, Madison Junction 2.3, Yellowstone National Park. See Fig. 23 for additional details. Missing hours are due to site visits. (n=44)

Recommendations:

1- 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 critically 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.

2- Conduct acoustical experiments to fill in gaps in our understanding of 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.

3- Audibility and sound level metrics standards and thresholds should continue to be used for impact definitions. These standards should include percent time audible and maximum sound level.

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).

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

Sound levels and audibility from motorized oversnow vehicles can be reduced by lowering speed limits, especially in popular areas for visitors such as around Old

Faithful, reducing unnecessary idling and rapid acceleration, and other driver behavior modifications. Comprehensive soundscape awareness training should be presented to operators of motorized oversnow vehicles. The NPS should work with manufacturers to further reduce sound levels of oversnow vehicles.

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

The representativeness of the 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. Data collected during non-winter seasons allows 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.

Acknowledgements:

Skip Ambrose (NPS Natural Sound Program) developed an initial study plan that led to this project. Brent Hetzler (on detail from Zion National Park) provided Herculean efforts keeping the systems running during the depth of winter. The Old Faithful Ranger staff, especially Bonnie Schwartz, and the Old Faithful Maintenance staff, especially Roy Jenkins and Grant Gifford, provided logistical and much appreciated help on this project. Robin Long and Margaret Wilson expertly analyzed much of the audibility data. Kevin Schneider, Jon Christensen and Sean Miculka skillfully conducted the majority of the observational logging of oversnow usage. Debbie VanDePolder remained cheerful during the unenviable task of digitizing the observational logging data. Skip Ambrose provided ongoing assistance on many aspects of this project. John Sacklin, Kevin Schneider, Denise Swanke, Robin Long and Margaret Wilson provided valuable editorial comments on an earlier version of this report. The report also was improved from a technical review by Temple Stevenson of the Office of the Governor, State of Wyoming, by Patrick Flowers of the Montana Fish, Wildlife and Parks, and Gregg Fleming of the U.S. DOT Volpe Center, Cambridge, Massachusetts.

Literature Cited:

Ambrose, S. and S. Burson. 2004. Soundscape studies in national parks. George Wright Forum 21(1): 29- 38

American National Standards Institute (ANSI). 1992. Quantities and procedures for description and measurement of environmental sound. Part 2: Measurement of long- term, wide- area sound. Accredited Standards Committee S12, Noise. Acoustical Society of America, New York, NY. 12 pp.

Dunholter, P. H., V. E. Mestre, R. A. Harris, and L. F. Cohn. 1989. Methodology for the measurement of and analysis of aircraft sound levels within national parks. Unpublished report to National Park Service, Contract No. CX 8000- 7- 0028. Mestre Greve Associates, Newport Beach, CA.

Fleming, G., C. J. Roof, and D. R. Read. 1998. Draft guidelines for the measurement and assessment of low- level ambient noise (DTS- 34- FA865- LR1). U. S. Department of Transportation, Federal Aviation Administration, John A. Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA. 83 pp.

Harris Miller Miller and Hanson, Inc. 2001. Technical report on noise: winter use plan final environmental impact statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr. Memorial Parkway. Report No. 295860.18. June 2001.

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, Less Source of Interest
All sounds in a given area excluding a specific sound of interest. For example, when assessing the potential impacts of air tour aircraft, the "ambient sound level less source of interest" would be all sources of sound except air tour aircraft.

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.

Amplitude
The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

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.

Audiogram
A graph showing hearing acuity as a function of frequency and amplitude.

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.

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.

Events per Hour
The number of times a non- natural sound source is heard, on average, in one hour (this may be specific to a particular non- natural sound or to all non- natural sounds). If this information is known, presentation and documentation provides another easily comprehended measure of how often the particular intruding sounds are heard. It provides an additional means for communicating the sense of the soundscape.

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 Parts 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).

Infrasound
Frequencies below 20 Hz. Humans perceive frequencies below about 20 Hz as pressure rather than sound.

Intensity
The sound energy flow through a unit area in a unit time.

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 Exceedence (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 (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 Exposure Level (SEL)
The total sound energy of an actual sound calculated for a specific time period. SEL is usually expressed using a time period of one second.

Sound Level
The *weighted* sound pressure level obtained by frequency weighting, generally A- or C- weighted.

Sound Level 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 Power (W)
The total sound energy radiated by a source per unit time. The unit of measurement is the Watt.

Sound Power Level (L_W)
The acoustic power radiated from a given sound source as related to a reference power level (typically 10^{-12} watts) and expressed as decibels. A sound power level of 1 watt = 120 dB (reference level = 10^{-12} watts).

Sound Pressure
Fluctuations in air pressure caused by the presence of sound waves. Sound pressure is the instantaneous difference between the actual pressure produced by a sound wave and the average barometric pressure at a given point in space. Not all pressure fluctuations detected by a microphone are sound (e.g., wind over the microphone). Sound pressure is measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

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.

Sound Speed
The speed of sound in air is about 344 m/sec (1,130 ft/sec or 770 mph) at 70° F at sea level. It substantially varies depending on temperature and type of medium.

Time Weighting
The response speed of the detector in a sound level meter. For Slow response, the response speed is 1 second. Slow time weighting is frequently used in environmental sound measurements. Fast response time is 1/8 second (0.125). This is less frequently used, but will detect changes in sound levels more rapidly. Both Fast and Slow time weightings have been used in previous NPS acoustic studies, and, when compared over long measurement periods (over several days), there is very little difference in results (differences are often less than the accuracy of the meter). Fast and slow time weightings were developed, in part, to slow needle movement (called a "decay" factor) in analog meters so investigators could read and record sound levels. New digital sound level meters, while changing numbers rapidly on the screen, store sound level data in memory for later analysis, thus, the ability to read numbers on the screen is less important. Hence, the most accurate "weighting" is none.

Ultrasound
Sounds of a frequency higher than 20,000 Hz.

Wave
A particular type of disturbance that travels through a medium by virtue of the elastic properties of that medium.

Wavelength
Wavelength is the distance a wave travels in the time it takes to complete one cycle. A wavelength can be measured between successive peaks or between any two corresponding points on the cycle. Wavelength (ft) = Speed of Sound (ft) / Frequency (Hz).

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:

Acoustic Alliance. 2001. Glossary of Terms, Acoustic Alliance Products and Services Catalog. Provo, UT.

American National Standards Institute. 1976. Standard Acoustical Terminology, S1.1. American National Standards Institute, New York, NY. 1976.

Bruel & Kjaer. 2002. Environmental Noise. Bruel & Kjaer Sound and Vibration Measurement. Naerum, Denmark.

Everest, F. A. 2001. Master Handbook of Acoustics. McGraw- Hill, New York, NY.

Hirschorn, M. 2002. Noise Control Reference Handbook. Sound & Vibration, Bay Village, OH.

Kelso, D. and A. Perez. 1983. Noise Control Terms Made Somewhat Easier. Minnesota Pollution Control Agency, St. Paul, MN.

U. S. Environmental Protection Agency. 1976. About Sound. Environmental Protection Agency, Washington, D. C.

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% (anywhere within area boundary)
2	Plowed Road (within 100 feet either side of road)	Audibility: NTE 50% at 100 feet
3	Groomed Motorized Route Clean and Quiet (within 100 feet either side route)	Audibility: NTE 50% at 100 feet
4	Groomed Motorized Route (within 100 feet either side route)	Audibility: NTE 50% at 100 feet
5	Groomed Motorized Trail Clean and Quiet (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
6	Groomed Motorized Trail (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
7	Ungroomed Motorized Trail (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
8	Groomed Non- motorized Trail	Audibility: NTE 10% at 500 feet
9	Ungroomed Non- motorized Trail or Area	Audibility: NTE 10% at 500 feet
10	Backcountry non- motor trail or area	Audibility: NTE 10% at 500 feet 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% dBA: NTE 70 dBA L_{eq}: NTE 45dBA
2	Plowed Road (within 100 feet either side of road)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
3	Groomed Motorized Route (within 100 feet either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
4	Groomed Motorized Trail (within 100 feet either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
5	Ungroomed Motorized Trail or Area (within 100 feet either side of trail)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
6	Groomed Non- motorized Trail (within 100 feet either side of trail)	Audibility: NTE 25% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
7	Ungroomed Nonmotorized Trail or Area (within 100 feet either side of trail)	Audibility: NTE 20% dBA: NTE Lnat[5] - 6 dBA L_{eq}: NTE to Lnat
8	Backcountry Nonmotorized Area (anywhere within area >1,000 feet from motorized area)	Audibility: NTE 20% dBA: NTE Lnat - 6 dBA 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. Observational study of oversnow vehicle usage.

The audibility analysis using remote unattended sound monitoring equipment estimated the percent time all sounds are audible at those locations. It did not, though, 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 late winter 2005. Four 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 27 logging periods at five locations (combining four locations within the Old Faithful developed area), 17 February- 5 March 2005. The total observer logging period was 48 hr 38 min 30 sec, 7am to 5pm, evenly split between morning and afternoon.

Oversnow usage types included guided visitors, NPS administrative use, contractors, and Xanterra administrative use. (See sample data sheet Table D- 1). These data were then transferred to an MS Access™ database for summary and analysis. Tables D- 2 to D- 4 present these summary analyses.

The number and proportion of snowmobiles was analyzed by group (Table D- 2) and by individual machine (Table D- 3). The Old Faithful, non- Old Faithful 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. Eight hundred and thirty- five groups of oversnow vehicles were documented, including 562 snowmobile groups (D- 2). Group size ranged from 1- 19. Average size for all snowmobile groups was four snowmobiles per group; seven snowmobiles per guided group and just over one snowmobile per administrative group. Two thousand five hundred and thirty- three individual oversnow vehicles were 2533 tallied, including 2219 snowmobiles (D- 3).

Of all individual snowmobiles observed, guided visitors (recreational use) accounted for 90% along travel corridors and 76% at Old Faithful (Table D- 3). Guided visitors comprised 62% of all groups documented along travel corridors (Table D- 2). As would be expected, more local administrative travel occurred in the Old Faithful developed area than along travel corridors between developed areas (Tables D- 2 and D- 3). Contractors working on the Old Faithful Inn comprised 11% of all groups of snowmobiles documented traveling in the Old Faithful area (Table D- 2). This may help partially explain the increased oversnow percent time audible at Old Faithful in 2004/2005 compared to 2003/2004 (Figs. 2 and 3). Other administrative travel totaled 47% of the total number of groups observed at Old Faithful (Table D- 2).

Guided snowmobiles comprised 52% of all snowmobiles audible. All oversnow vehicles were audible for 55% of the study period and comprised 89% of the motorized sounds audible (Table D- 4; compare to Figs. 2 and 17). Snowmobiles were audible for 16 hours 27 minutes and 47 seconds (34%) of the 48 hours 38 minutes and 30 second study period (Table D- 4). No motorized sounds (natural sounds only) were audible for 38% of the study period (Table D- 4).

Table D- 1. Field data sheet for logging oversnow usage type in Yellowstone National Park, 17 February- 5 March 2005.

Date:			Time:		Page of
Name, Address, Telephone:					
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:
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:				Instructions
0	None audible	8	People	
1.1	Aircraft, jet	19	Motorized, unknown	
1.2	Aircraft, propeller	20	Non-natural other	Record when non-natural sounds are audible. Give priority to oversnow.
1.3	Aircraft, helicopter			Record other non-natural sounds as possible. Note when ignoring them.
2	Vehicle (type)			Record time in hours, minutes and seconds. Try to use GPS time (that is.
3	Watercraft (type)			accurate time). Record stop time as well as start time.
4	Oversnow Vehicle			Record oversnow type (4.1, 4.2, 4.3, 4.4) and number making up group.
4.1	Snowmobile			Record type of user (contractor, Xanterra, NPS researcher, Ranger, admin,
4.2	Snowcoach			snowcoach or guided snowmobile group) in Remarks column.
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	Building sounds			Record direction of travel in Location column

Table D- 2. Number and proportion of snowmobile groups by usage type traveling within Yellowstone National Park, 17 February- 5 March 2005.

Location	Guided Snowmobiles	Contractor	NPS- Maintenance	Ranger	Research	NPS- Other/Unknown	Conces- Admin	Unk. Admin	Xanterra_Admin	*Unknown*
Old Faithful										
OF Main Road	3			2					7	*1*
OF Entrance Road	79	6	6	14	5	14			42	*16*
OF Ranger Station	4		2			1			8	*5*
OF Inn Parking Lot	6	23	1	10		6		4	7	*0*
OF Total	92	29	9	26	5	21	0	4	64	*22*
	34%	11%	3%	10%	2%	8%	0%	1%	24%	*8%*
				NPS- All[a]	61					
					22%					
				Admin- All[b]	124					
					47%					
Mary Mnt Trailhead	69		2	15	11	14	3		6	*3*
Madison Jnct- West	2	2								*5*
West Entrance- East	79		1	1		16	9		3	*6*
TuffCliff	31			4	2	4	2			
Non- OF areas	181	2	3	20	13	34	14	0	9	*14*
	62%	1%	1%	7%	4%	12%	5%	0%	3%	*5%*
				NPS- All	70					
					24%					
				Admin- All	93					
					32%					
All areas	273	31	12	46	18	55	14	4	73	*36*
	49%	6%	2%	8%	3%	10%	2%	1%	13%	*6%*
				NPS- All	131					
					23%					
				Admin- All	222					
					40%					

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

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

Table D- 3. Number and proportion of individual snowmobiles by usage type traveling within Yellowstone National Park, 17 February- 5 March 2005.

Location	Guided Snowmobiles	Contractor	NPS- Maintenance	Ranger	Research	NPS- Other/Unk	Concess- Admin	Unk. Admin	Xanterra_Admin	*Unknown*	Total
Old Faithful											
OF Main Road	14			2					8	*1*	25
OF Entrance Road	576	19	7	14	5	15			45	*16*	697
OF Ranger Station	39		4			1			8	*6*	58
OF Inn Parking Lot	29	26	1	10		6		5	8		85
OF Total	658	45	12	26	5	22	0	5	69	*23*	865
	76%	5%	1%	3%	1%	3%	0%	1%	8%	*3%*	100%
				NPS- All[a]	65						
					8%						
				Admin- All[b]	139						
					16%						
Mary Mnt Trailhead	459		4	16	12	16	4		6	*4*	521
Madison Jnct- West	17	10								*7*	34
West Entrance- East	530		2	1		17	15		4	*10*	579
TuffCliff	206			4	2	4	4				220
Non- OF Total	1212	10	6	21	14	37	23	0	10	*21*	1354
	90%	1%	0%	2%	1%	3%	2%	0%	1%	*2%*	100%
				NPS- All	78						
					6%						
				Admin- All	111						
					8%						
All areas	1870	55	18	47	19	59	23	5	79	*44*	2219
	84%	2%	1%	2%	1%	3%	1%	0%	4%	*2%*	100%
				NPS- All	143						
					6%						
				Admin- All	250						
					11%						

[a]NPS- All — Includes maintenance, rangers, research and NPS others/unknown
[b]Admin- All — Includes all but guided snowmobiles, contractors and unknowns

Table D- 4. Elapsed time and percentages for motorized vehicles during observational study, February and March 2005, Yellowstone National Park.

Snowmobiles Only			
User Group	**Elapsed Time**	**Percentage**	**Combined Total**
Guided Snowmobile	8:32:05	52%	52%
Contractor	0:33:58	3%	3%
NPS- Maintenance	0:16:25	2%	
NPS- Ranger	0:53:46	5%	
NPS_Research	0:17:09	2%	
NPS Other/Unknown	1:02:36	6%	15%
Admin- Concession	0:17:42	2%	
Administrative- Xanterra	1:33:05	9%	11%
Administrative- Unknown	0:02:20	0%	0%
Unknown User	2:58:41	18%	18%
	16:27:47		

All Motorized Sounds			
Jets	0:56:24	3%	
Props	0:44:02	2%	6%
Snowmobile	16:27:47	55%	
Snowcoach	6:21:55	21%	
Snowmobile or Snowcoach	0:07:32	0%	
Unknown Oversnow Vehicle	3:36:08	12%	89%
Groomer	0:33:21	2%	2%
Unknown/Other Motorized	1:07:51	4%	4%
	29:55:00		

Total Observation Time	48:38:30	
Motorized Sounds	29:55:00	62%
Oversnow Vehicles	26:33:22	55%
Snowmobiles	16:27:47	34%
No Motorized Sounds	18:43:30	38%