National Park Service
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Natural Resource Stewardship and Science

Washita Battlefield National Historic Site

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2020/2106

ON THE COVER
Tipi on the Prairie at Washita Battlefield National Historic Site
Photograph by: NPS

Washita Battlefield National Historic Site

Acoustic Monitoring Report

Natural Resource Report NPS/NRSS/NSNS/NRR—2020/2106

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Executive Summary

In 2017, the Natural Sounds and Night Skies Division (NSNSD) received a request to collect baseline acoustical data at Washita Battlefield National Historic Site (WABA). Between October and December 2017, a single acoustical monitoring station was deployed within the park. The goal of the study was to establish a baseline soundscape inventory of the park, especially with regards to noise emanating from a nearby highway, airport, and local industry. This inventory will be used to establish indicators and thresholds of soundscape quality. This will support the park and NSNSD in developing a comprehensive approach to protecting the acoustic environment through soundscape management planning. Additionally, results of this study will help the park identify major sources of noise within the park, as well as provide a baseline understanding of the acoustical environment as a whole for use in potential future comparative studies.

In this deployment, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, "sound pressure level" refers to broadband (12.5 Hz–20 kHz), A-weighted, 1-second time averaged sound level ($L_{Aeq,\ 1s}$), and hereafter referred to as "sound level." Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μPa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels in order to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

Trained technicians calculated time audible metrics after monitoring was complete. See Methods section for protocol details, equipment specifications, and metric calculations. Median existing (L_{A50}) and natural ambient (L_{Anat}) metrics are also reported for daytime (7:00–19:00) and nighttime (19:00–7:00). Prominent noise sources included aircraft, vehicles, and a lift station. Table 1 displays time audible values for each of these noise sources during the monitoring period, as well as ambient sound levels.

Table 1. Mean time audible for human-caused noise, aircraft, vehicle, and lift station noise sources, existing and natural ambient sound levels at WABA001.

			Mean time audible noise (in 24 hour time period, %)[a]				Median Existing Ambient (L_{A50}, dB)[b]		Median Natural Ambient (L_{Anat}, dB)	
Site ID	Site Description	Season	All Noise	Aircraft	Vehicle	Lift Station	Day[c]	Night[c]	Day	Night
WABA001	Field Loop	Fall	99.1	7.7	6.2	98.8	35.6	34.5	29.2	30.0

[a] Over a 24-hour period, based on eight days of analysis.

[b] For comparison, nighttime sound level in a typical residential area ($L_{Aeq,\ 8hr}$) is about 40 dB.

[c] Day hours are 0700–1900; night hours are 1900–0700.

In determining the current conditions of an acoustical environment, it is informative to examine how often sound levels exceed certain values. Table 2 reports the percent of time that measured levels at the monitoring locations were above four key values.

Table 2. Time above metrics for WABA001.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 07:00 to 19:00)				Time above sound level (% of nighttime hours, 19:00 to 07:00)			
		35 dB*	45 dB*	52 dB*	60 dB*	35 dB*	45 dB*	52 dB*	60 dB*
WABA001	12.5–20,000	45.5	2.6	0.0	0.0	41.3	0.8	0.0	0.0
	20–1,250	27.6	0.5	0.0	0.0	26.8	0.2	0.0	0.0

* dB re 20 μPa

The first value, 35 dB ($L_{Aeq, 1s}$), is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This level, 35 dB, is also the desired background sound level in classrooms (ANSI S12.60–2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq, 1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq, 1s}$), is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq, 1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz–20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency ranges. The top value in each split-cell of Table 2 uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range (20–1,250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014). For instance, in the full frequency range, during the day, the 45 dB level was exceeded at WABA001 in the fall approximately 2.6 % of the time. Speech interruption occurs (between two people 1 meter apart) at 60 dB and this level was never exceeded.

The results from this analysis suggest that a nearby lift station is the most prominent noise source in the park; however aircraft, vehicles, and domestic animals such as cows and dogs also contribute to the acoustical environment. The audibility of noise at the monitoring site over the 24-hour day was 99.1%, providing limited opportunity for noise-free solitude, however the overall energy contribution of noise was somewhat limited, minimizing the impact of audible noise on visitor experience.

Additionally, sound levels from noise sources during nighttime hours exceeded levels during daytime hours.

The acoustical environment at this site consists of natural sounds not found in most urban or suburban environments. These unique sounds add a unique dimension to the park experience, and the combination of limited noise-free intervals and relatively quiet overall sound pressure levels afford visitors an opportunity to hear faint or very distant natural sounds.

Acknowledgments

The author of this report wishes to express his gratitude to Damon Joyce and Kevin Mohr for their work in deploying the acoustical monitoring station. Emma Brown and Damon Joyce also provided valuable feedback on early drafts of this report. The author would also like to thank Matt Edrich for his work in the off-site analysis of the acoustical data.

Glossary of Acoustical Terms

Table 3. Acoustic terms and definitions.

Term	Definition
Acoustic Environment	A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.
Acoustic Resources	Include both natural sounds like wind, water, & wildlife and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.
Amplitude	The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.
Audibility	The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by an individual animal's hearing ability.
Decibel (dB)	A unit of sound energy. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy. When sound levels are adjusted for human hearing they are expressed as dB(A).
Frequency	Related to the pitch of a sound, it is defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted ("weighted") to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable or hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.
Intrinsic Sound	Belongs to a park by the park's very nature, based on its purposes, values, and establishing legislation. Intrinsic sounds can include natural, cultural, and historic sounds that contribute to the acoustical environment of the park.
L_{A50}, L_{A90}	Metrics used to describe sound pressure levels (L), in decibels, exceeded 50 and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value.
L_{dn}	Day-Night Average Sound Level. Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.
L_{Aeq}	Energy Equivalent Sound Level. The sound energy level averaged over the measurement period.
LAnat (Natural Ambient Sound Level)	The natural sound conditions in parks, which exist in the absence of any human-produced noise.
Noise Free Interval (NFI)	The length of the continuous period of time during which no human-caused sounds are audible.

Table 3 (continued). Acoustic terms and definitions.

Term	Definition
Time Above Natural Ambient	The amount of time that various sound sources are above the natural ambient sound pressure levels in a given area. It is most commonly used to measure the amount of time that human-caused sounds are above natural ambient levels. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long human-caused sounds exceed natural ambient levels.
Time Audible	The amount of time that various sound sources are audible to humans with normal hearing. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, percent time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).
Sound Exposure Level (SEL)	The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.
Sound Pressure	Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.
Sound vs. Noise	The NSNSD differentiates between the use of *sound* and *noise*, since these definitions have been used inconsistently in the literature. Although *noise* is sometimes incorrectly used as a synonym for sound, it is in fact sound that is undesired or extraneous to an environment. Humans perceive *sound* as an auditory sensation created by pressure variations that move through a medium such as water or air and are measured in terms of amplitude and frequency (Harris 1998; Templeton 1997).
Soundscape	The human perception of physical sound resources.

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). Acoustical monitoring provides a scientific basis for assessing the status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

National Park Service Natural Sounds and Night Skies Division

The Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that protects park resources and the visitor experience. The NSNSD addresses acoustical issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustical environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to soundscape protection with respect to park resources and visitor use. The program also provides technical assistance to parks in the form of acoustical monitoring, data processing, park planning support, and comparative analyses of acoustical environments.

Soundscape Planning Authorities

The National Park Service Organic Act of 1916 states that the purpose of national parks is "… to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress."

Direction for management of natural soundscapes[1] is represented in 2006 Management Policy 4.9:

> The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise), and will protect natural soundscapes from unacceptable impacts. Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The frequencies, magnitudes, and durations of acceptable levels of

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[1] The 2006 Management Policy 4.9 and related documents refer to "soundscapes" instead of "acoustic resources." When quoting from this authority, it is advisable to note that the term often refers to resources rather than visitor perceptions.

> unnatural sound will vary throughout a park, being generally greater in developed areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes [acoustic resources], including noise caused by mechanical or electronic devices. The Service will take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape [acoustic resource] or other park resources or values, or that exceeds levels that have been identified through monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored (NPS 2006a).

It should be noted that "the natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated" (NPS 2006b). However, the desired acoustical condition may also depend upon the resources and the values of the park. For instance, "culturally appropriate sounds are important elements of the national park experience in many parks" (NPS 2006b). In this case, "the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established" (NPS 2006b).

Further guidance is provided in 2006 Management Policies 4.1.4 Partnerships, 4.1.5 Restoration of Natural Systems, 8.2 Visitor Use, 8.2.2 Recreational Activities, 8.2.3 Use of Motorized Equipment, and 8.4 Overflights and Aviation Uses (NPS 2006).

Directors Order 47, Preservation of the Acoustic Environment and Noise Management (2015) builds on the principles set out in Management Policies, but goes on to direct how and when to consider acoustic resources in park management. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

National Parks Air Tour Management Act (NPATMA) was passed on April 5, 2000 to regulate commercial air tour operations for each unit of the National Park System, or abutting tribal land, where such operations occur or are proposed. The Act required the Federal Aviation Administration (FAA), in cooperation with the NPS, to develop an Air Tour Management Plan (ATMP) for each unit of the National Park System to provide acceptable and effective measures to mitigate or prevent the significant adverse impacts, if any, of commercial air tour operations upon natural and cultural resources and visitor experiences. In 2012, NPATMA was amended to allow the FAA and NPS to enter into voluntary agreements with a commercial air tour operator as an alternative to an ATMP.

Study Area

Washita Battlefield National Historic Park (WABA) was formally established in 1996 by President Bill Clinton as a way to document the history of the Washita Battle on November 27, 1868 and to honor those who died during the event. From October–December 2017, an acoustical monitoring station was deployed in the park. Table 4 shows site information regarding the monitoring station. Figure 1 shows the location of the acoustic monitoring station within the park.

Table 4. WABA acoustical monitoring site.

Site ID	Site Name	Dates Deployed	Vegetation	Elevation (m)	Latitude	Longitude
WABA001	Trail Loop	10/15/2017–12/4/2017	Flooded Grasslands	577	35.620917	−99.700722

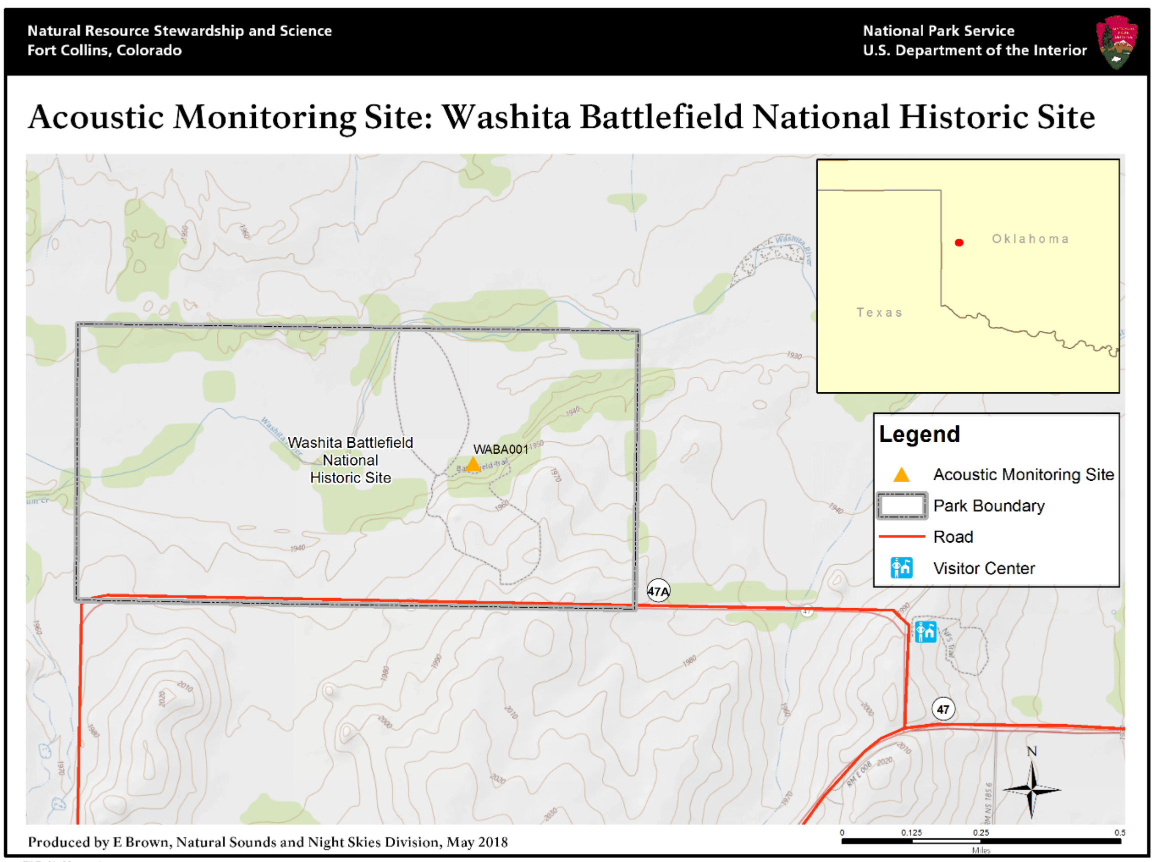

Figure 1. Location of acoustic monitoring site at Washita Battlefield National Historic Site.

Methods

Automatic Monitoring

A Larson Davis 831 sound level meter (SLM) was deployed during the fall season at the monitoring site. The Larson Davis SLM is a hardware-based, real-time analyzer which constantly records one second sound pressure level (SPL) and 1/3 octave band data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards. The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustical monitoring equipment is used by many industries to determine noise levels in different environments, both indoors and outdoors. NPS uses equipment that is similar to the equipment used by other industries but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks. The microphone with environmental shroud was set up on a tripod at 1.5 m, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio throughout the entire monitoring period. An anemometer was attached to a tripod and placed near the microphone, to capture local wind conditions without recording possible sound from anemometer wind cup rotation.

The sampling station consisted of:

- Type 1 sound level meter
- Microphone with environmental shroud
- Preamplifier
- 12 V battery pack
- Anemometer (wind speed and direction)
- Digital audio recorder

The sampling station collected:

- A-weighted 1 second time averaged sound level (LAeq, 1s) in dB re 20 μPa
- Continuous digital audio recordings
- One-third octave band data every second ranging from 12.5 Hz–20,000 Hz
- Continuous meteorological data for wind speed

Monitoring Period

NSNSD has determined that 25 day monitoring periods during opposing seasons allow the data to capture seasonal difference that occur at each site within a reasonable margin of error (NPS 2005). The monitoring station was outfitted with a newer solar panel, and NSNSD decided to leave the system out longer than usual to test the new power supply. The deployment period ultimately lasted 50 days at WABA001, with the system successfully logging data the entire time.

Calculation of Metrics

The status of the acoustical environment can be characterized by spectral measurements, durations, and overall sound levels. The NSNSD uses descriptive figures and metrics to interpret these characteristics. Two fundamental descriptors are existing ambient (L_{A50}) and natural ambient (L_{Anat}) sound levels. These are both examples of percentile levels, where each Lx value refers to the sound level that is exceeded x% of the time. The L_{A50} represents the median sound level, and is drawn from a full dataset (removing data with wind speed > 5m/s to eliminate error from microphone distortion). The L_{A50} is the preferred metric to represent prevailing acoustic conditions. The natural ambient (L_{Anat}) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. L_{Anat} is the preferred metric to represent baseline or reference conditions.

For a given hour (or other specified time period), L_{Anat} is calculated to be the decibel level exceeded x percent of the time, where x is defined by equation (1):

$$x = \frac{100 - P_H}{2} + P_H, \tag{1}$$

P_H is the percentage of samples containing noise for the hour. For example, if human caused sounds are present 30% of the hour, x = 65, and the L_{Anat} is equal to the L_{65}, or the level exceeded 65% of the time. To summarize and display these data, the median of the hourly L_{Anat} values for the daytime hours (0700–1900) and the median of the hourly L_{Anat} values for the nighttime (1900–0700) are displayed in Figure 2 in the results section. Additionally, this figure separates the data into 33 one-third octave bands.

Off-Site Listening

Off-site listening is normally done by listening to an audio recording and simultaneously visually analyzing a spectrogram. Auditory analysis was used to calculate the audibility of sound sources at the monitoring location. A trained technician at Colorado State University analyzed a subset of .mp3 samples (10 seconds every two minutes for eight days of audio) in order to identify durations of audible sound sources. Staff used the total percent time noise was audible to calculate the natural ambient sound level for each hour (see Equation 1 above for more information). Bose Quiet Comfort Noise Canceling headphones were used for off-site audio playback to minimize limitations imposed by the office acoustical environment. For the complete results of this thorough audibility analysis, see Table 7 in the Off-Site Data Analysis section below.

Results

Off-Site Data Analysis

Metrics

In order to determine the effect that noise has on the acoustical environment, it is useful to examine the median hourly exceedance metrics. The sound pressure levels for 33 one-third octave band frequencies over the day and night periods are shown in Figure 2. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 smaller ranges, each encompassing one-third of an octave. For each one-third octave band, the sound level ($L_{eq,\ 1s}$) was recorded once per second for the duration of the monitoring period.

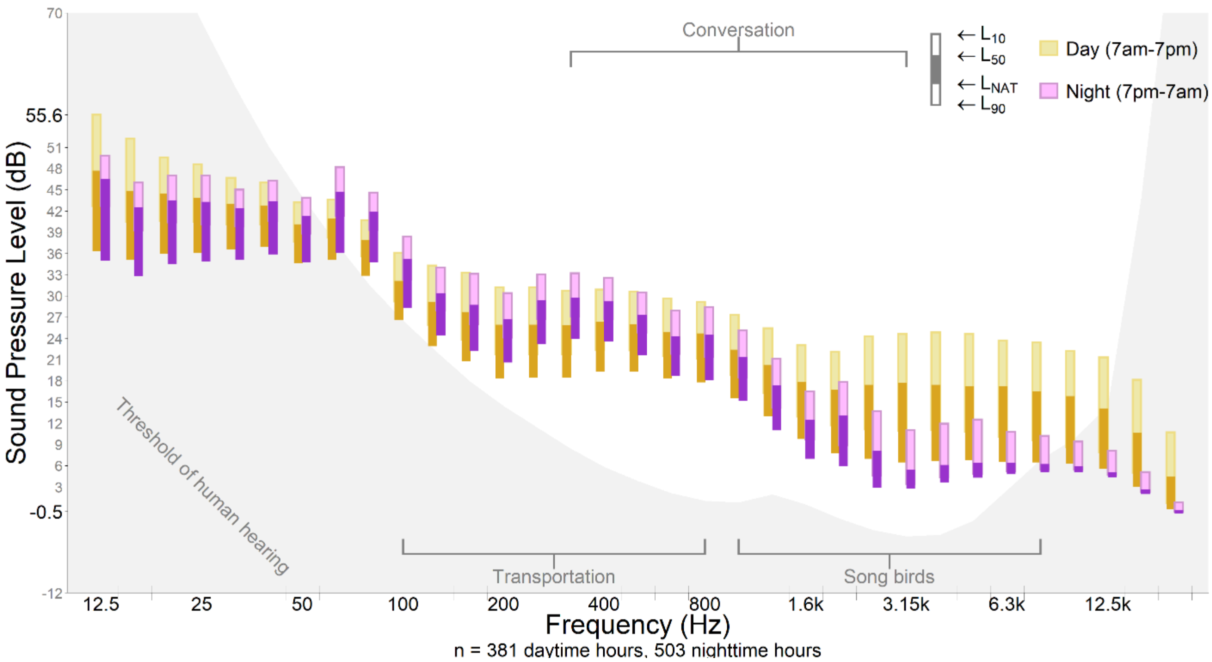

Figure 2. Day and night percentile sound pressure levels for 33 one-third octave bands at WABA001 during the fall.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound level of a site. The grayed area of the graph represents sound levels outside of the typical range of human hearing. The exceedance levels (L_x) are also shown for each one-third octave band. They represent the sound level exceeded x percent of the time. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10}. The bold portion of the column represents the difference between existing ambient and natural ambient. The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing ambient sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing ambient levels were either very close to each other, or were equal.

L_{nat} and L_{50} are bordered above by L_{10} and below by L_{90}, which essentially marks the median (L_{50}), near minimum (L_{90}), and near maximum (L_{10}) sound pressure levels over the monitoring period at the monitoring site. This bar shows 80% of the sound levels recorded excluding extremes. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

Table 5 reports the L_{A90}, L_{Anat}, L_{A50}, and L_{A10} values for the monitoring site in WABA. The top value in each cell focuses on the conventional full frequency range, whereas the lower value uses frequencies affected by transportation noise. Most human-caused noise is confined to the truncated, lower-frequency range, while many loud natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range is more appropriate for identifying noise levels in parks (Acoustical Society of America 2014). As described above, exceedance levels (L_x) represent the sound level exceeded **x** percent of time during the given measurement period. For instance, in Table 5, the L_{A90} for WABA001 during the daytime in the summer is 32.1 dB, a level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{A10} for the same time period at this site is 40.3 dB, a level that has been exceeded only 10% of the time, and 90% of the measurements are quieter than the L_{A10}.

Table 5. Exceedance levels for existing conditions in WABA.

Site	Frequency (Hz)	Exceedance levels (dB) 0700 to 1900 hours (Day)				Exceedance levels (dB) 1900 to 0700 hours (Night)			
		L_{A90}	L_{Anat}	L_{A50}	L_{A10}	L_{A90}	L_{Anat}	L_{A50}	L_{A10}
WABA001	12.5–20,000	32.1	29.2	35.6	40.3	32.3	30.0	34.5	37.5
	20–1,250	29.0	26.5	32.3	36.6	31.3	29.1	33.4	36.3

In determining the current conditions of an acoustical environment, it is important to examine how often sound levels exceed certain values. reports the percent of time that measured levels were above four key values during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the lower value focuses on frequencies affected by transportation noise sources. The first, 35 dB ($L_{Aeq,1s}$), is designed to address the health effects of sleep interruption. Recent studies suggest that sound events as low as 35 dB can have adverse effects on blood pressure in sleeping humans (Haralabidis et al. 2008). This is also the desired background sound level in classrooms (ANSI S12.60–2002). The second value addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), provides a basis for estimating impacts on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations. The top value in each split-cell uses the full frequency range (12.5–20,000 Hz), whereas the bottom value focuses on frequencies affected by lower-frequency noise (20–1250 Hz). Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. Therefore, the truncated range (20–1250 Hz) is more appropriate for identifying impacts from anthropogenic noise in parks (Acoustical Society of America 2014).

Table 6. Time above metrics for existing conditions in WABA.

Site ID	Frequency (Hz)	Time above sound level (% of daytime hours, 0700 to 1900)				Time above sound level (% of nighttime hours, 1900 to 0700)			
		35 dB	**45 dB**	**52 dB**	**60 dB**	**35 dB**	**45 dB**	**52 dB**	**60 dB**
WABA001	12.5–20,000	45.5	2.6	0.0	0.0	41.3	0.8	0.0	0.0
	20–1,250	27.6	0.5	0.0	0.0	26.8	0.2	0.0	0.0

Audibility of noise sources

Identifying the percent of time a noise source is audible is an important step in understanding the acoustic environment. Table 7 shows the mean percentage of time that aircraft and vehicles, as well other all other sources of anthropogenic noise, were audible by hour.

Figure 3 shows hourly audibility results and compares overall noise audibility to that of individual noise sources such as vehicles and the lift station.

Table 7. Mean hourly time audible (%) for each noise source at WABA001, n=8.

Sound Source	00h	01h	02h	03h	04h	05h	06h	07h	08h	09h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h
Aircraft	3.8	0.8	0.8	1.2	3.3	2.5	2.5	2.9	2.1	6.7	12.1	17.1	17.1	13.8	17.9	15.0	15.0	12.1	9.2	9.6	3.3	6.2	6.2	4.2
Vehicle	2.5	0.8	2.9	0.4	2.5	2.9	10.0	16.7	14.6	11.3	9.2	6.7	2.5	4.6	2.5	3.3	5.4	12.5	13.8	10.0	3.8	2.5	5.0	1.7
People	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.4	0.0	0.0	0.4	0.0	0.8	3.3	2.1	0.0	0.0	0.4	0.0	0.0
Cows	37.1	32.1	30.8	21.7	15.0	4.2	16.3	41.7	50.8	35.8	18.8	13.3	5.0	5.8	1.2	0.8	2.5	4.6	12.1	5.0	2.9	0.8	1.7	2.5
Dogs	10.4	2.5	3.3	3.8	2.9	1.7	1.7	7.1	3.3	2.1	0.8	0.4	0.4	0.0	0.4	0.0	0.8	3.3	6.7	13.3	15.0	21.2	16.7	15.4
Building Sounds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Lift Station	98.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.2	100.0	98.3	97.1	96.7	97.1	92.9	96.2	98.3	100.0	100.0	100.0	99.6	100.0	98.7	99.2
Non-Natural Unknown[a]	1.2	0.8	1.7	2.5	1.2	1.7	4.6	0.8	2.1	1.7	4.2	7.1	1.7	4.2	1.7	3.3	1.7	2.9	5.0	2.9	1.7	0.4	2.1	0.4
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.7	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mammal	1.7	1.7	2.9	2.1	0.4	4.2	0.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	3.8	1.7	0.8	1.2	2.9
Bird	3.8	3.8	0.8	3.8	2.1	2.9	2.9	59.2	91.7	79.2	73.8	70.8	46.3	38.8	33.7	34.6	24.2	29.6	45.8	10.0	0.4	2.1	0.4	1.7
Insect	56.3	62.9	45.4	43.8	47.9	36.2	32.9	7.9	1.7	20.4	32.5	40.8	50.0	57.5	59.2	59.6	73.3	90.4	97.1	87.5	72.5	66.7	63.8	61.7
Animal	0.8	0.8	1.2	1.2	0.0	1.7	0.8	0.8	1.2	0.0	2.5	2.1	0.0	0.0	0.4	0.0	0.8	0.8	0.0	2.5	1.7	0.4	0.0	0.4
Wind-Induced Natural	44.6	55.8	51.3	32.5	26.7	11.7	19.2	13.8	23.7	49.6	57.5	75.8	83.3	86.7	78.3	82.5	88.3	70.4	35.0	33.7	19.6	12.9	22.1	35.8
Natural Unknown[b]	0.4	0.0	3.3	5.8	2.5	1.2	0.4	0.0	7.5	1.2	0.0	0.0	0.0	0.0	0.0	0.8	0.0	2.1	1.2	1.2	0.8	0.8	0.0	0.8

[a] Non-natural unknown noise sources are associated with human activity, but their exact identity is unclear.

[b] Natural unknown sound sources are not associated with human activity, but their exact identity is unclear.

[c] Shaded rows represent natural sound sources.

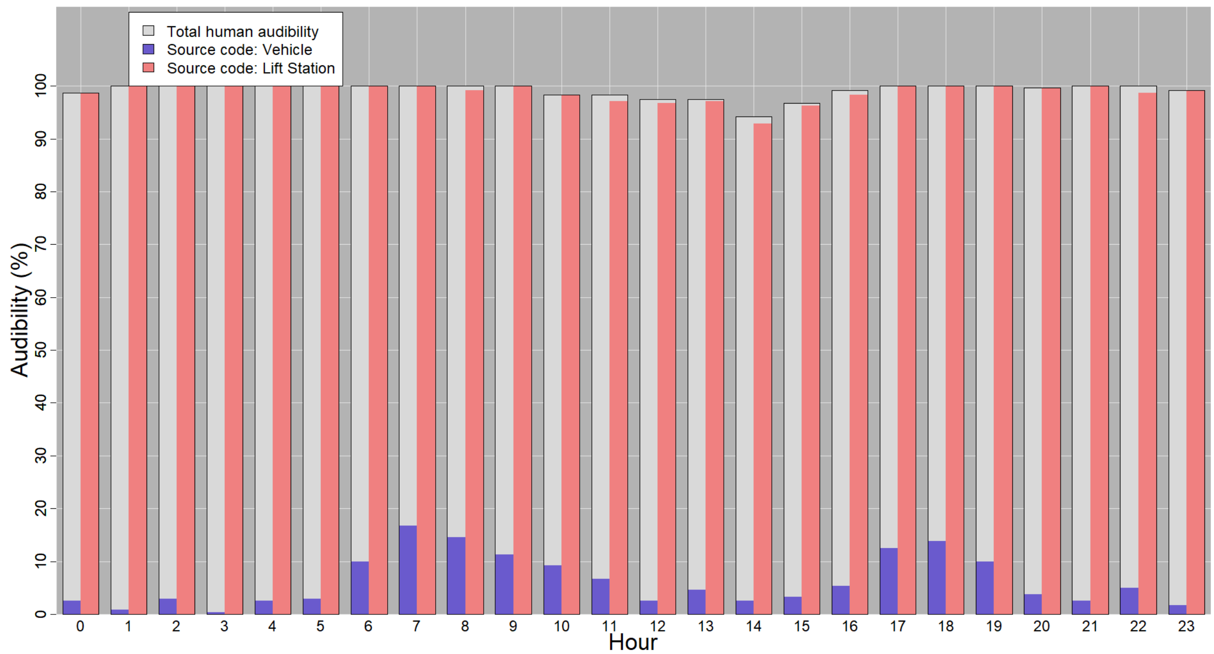

Figure 3. Comparison of hourly vehicle, lift station, and overall noise audibility at WABA001 during the fall.

Discussion

The purpose of this study was to assess current conditions of the acoustical environment at WABA. Monitoring results characterize existing sound levels and estimate natural ambient sound levels within the park, which are intended to provide the park with baseline information and to inform management decisions. Continuous audio, sound pressure level data, and meteorological data were collected at a single acoustical monitoring site within the park. The monitoring station was chosen to assess the effects of noise on the acoustical environment from a single front country site.

Results indicate that the natural ambient sound level (L_{Anat}) at WABA001 ranged from 29.2 dB during the daytime to 30.0 dB at night. Existing ambient sound levels (L_{A50}) were higher, ranging from 35.6 dB during the day to 34.5 dB at night. For comparison, a comprehensive 1982 study of noise levels in residential areas found that nearly 87% of US residents were exposed to day-night sound levels (L_{dn}) over 55 dB, and an additional 53% were exposed to L_{dn} over 60 dB (EPA 1982). Noise levels have increased nationally with population growth since the EPA study (Suter 1991; Barber et al. 2010). Additionally, a nationwide study modeling daytime summer sound levels indicated that only 23 % of the continental United States was predicted to have an existing ambient sound level above 40 dB ($L_{A50,\ 12\ hr}$), and only 1% of the continental U.S. was predicted to have an existing ambient sound level above 50 dB ($L_{A50,\ 12\ hr}$) (Mennitt 2013). Therefore, the results imply that the natural ambient sound level during the monitoring period was considerably quieter than most residential areas.

Despite the low overall sound levels, noise still exists at WABA, and visitors to WABA are likely to experience noise throughout both the day and night within the park. The mean 24 hour audibility of noise was 99.1%, preventing visitors from experiencing prolonged moments of noise-free solitude. Noise at WABA001 largely originated from sources outside park boundaries. For instance, noise from a nearby lift station, the most common noise source, was present 98.8% of the time. Other prominent sources of noise included vehicles, aircraft, and domestic animals such as cows and dogs.

Human-generated noise originating from outside the park, but also within, contributes energy to the acoustic environment of the park. This is further supported by comparing sound levels found in the frequencies typically attributed to human-generated noise (20–1,250 Hz) to those found in the overall sampled frequency range (12.5–20,000 Hz) (Table 5). These two metrics rarely differ by more than 3 dB, suggesting that human-generated noise is influencing the acoustical environment.

Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014), or simply by limiting opportunities for solitude. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, or increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB ($L_{Aeq,\ x}$).[2] Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq,\ 1s}$) (Shannon et al. 2015).

Natural sound sources were quite prevalent and varied. The most common source was the sound of grasses blowing in the wind, which is characteristic of the habitat type where the monitoring station was located. Additionally, other sound sources included birds, coyotes, and insects. Insect sounds were most common at night (Table 7) and produced considerable acoustical energy, causing natural sound levels to be higher at night than during the day (Table 5). These natural sounds provide visitors with a unique opportunity to connect with nature within the park.

[2] This metric is a composite of multiple metrics with varying time averaging metrics.

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Appendix A. Modeled Impact Levels

NSNSD developed a model (Mennitt et al. 2014) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports.

The resulting model can predict sound levels anywhere in the contiguous U.S., and it can estimate how much lower these sound levels would be in the absence of human activities. The modeled difference between the existing and predicted natural sound level (L_{A50} impact) at WABA is shown in Figure 4, and provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level, on an average summer day, in the park. At WABA, the mean modeled sound level impact is 2.7 dB, and this value represents a close approximation of expected impact levels at a randomly chosen point within the park.

Each pixel in the graphic shown in Figure 4 represents 270m. For reference in translating sound level impacts into functional effects (for human visitors and resident wildlife), an increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level in WABA by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half. Furthermore, an increase of 7 dB leads to an approximate decrease in listening area of 80%, and an increase of 10 dB decreases listening area by approximately 90%. The modeled results of 2.7 dB over the entire park would decrease listening area by 46.3%. Observed impact at WABA001 was 6.4 dB (which would decrease listening area by 77.1%).

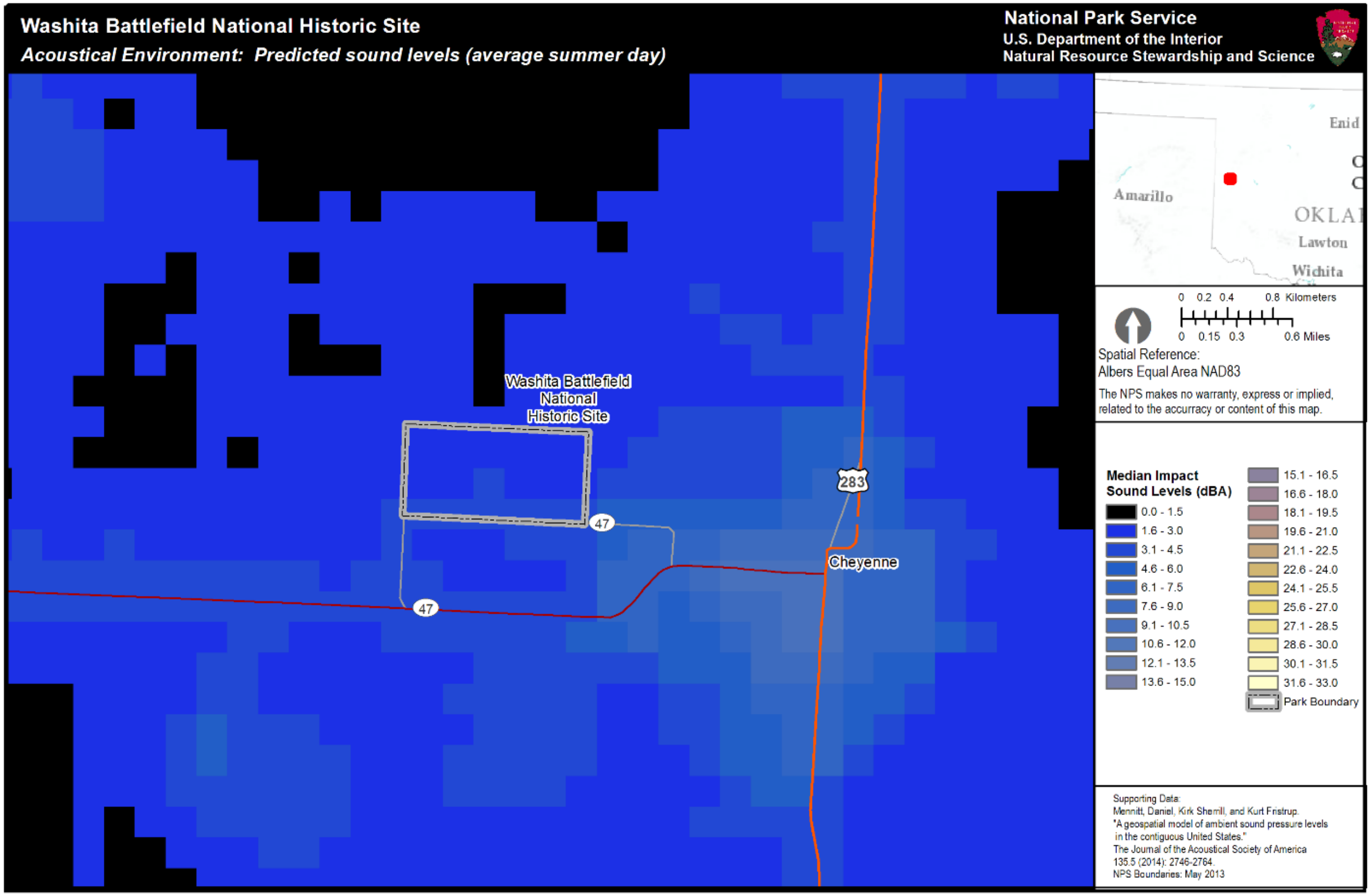

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Figure 4. Modeled median sound level impacts in the area immediately surrounding WABA and the nearby region (inset). Map of predicted acoustic impact levels in the park for an average summer day. The color scale indicates how much man-made noise increases the sound level (Noise impact or noise exceedance [$L_{A50,\ impact}$]), with 270 m resolution. Black or dark blue colors indicate low impacts while yellow or white colors indicate greater impacts. Note that this graphic may not reflect recent localized changes such as new access roads or development. The mean modeled acoustic impact level at the park is 2.7 dB.

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