



Cedar Creek and Belle Grove National Historical Park

Noise Monitoring Report 2024



Acoustic monitoring at Morning Attack Trail, Cedar Creek and Belle Grove National Historical Park.
VOLPE / JO FLETCHER

Cedar Creek and Belle Grove National Historical Park: Noise Monitoring Report 2024

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Abstract

Cedar Creek and Belle Grove National Historical Park (CEBE) prioritizes maintaining a solemn acoustic environment for park visitors. A Conditional Use Permit (CUP) was issued to a commercial outdoor shooting range operator across Interstate 81 from CEBE in 2022. This document allows outdoor discharge of firearms, assuming “activities associated with the commercial operation shall not produce sound levels which exceed 60 decibels during hours of operation at the nearest property line.” Continuous acoustic and meteorological data were recorded at CEBE during a 25-day period in August 2024 to better understand the acoustic environment in the park. A sampling of hours with potential gunfire activity was evaluated for compliance with permitted noise levels and excluded any contaminating noise events. This analysis demonstrated that the noise level limit established by the CUP is often surpassed, resulting in non-compliance with the CUP. Potential mitigation measures for consideration are offered in the Appendix.

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List of Terms

A-weighting: A-weighting is applied to sound levels to account for the sensitivity of the human ear (Harris 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

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.

Audibility: The ability of animals, including humans, with normal hearing to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by hearing ability of individual animals.

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported as decibels (dB). Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Energy Equivalent Sound Level (L_{AeqT}): The sound energy level averaged over the measurement period, T. Generally, it refers to A-weighted 1-second time averaged sound levels measured between 6.3 Hz and 20 kHz. This is a standard measurement collected using the NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded. This descriptor is typically used for highway noise analyses conducted for Federal Highway Administration (FHWA) under 23 CFR 772 (FHWA 2010).

Frequency: Related to the pitch of a sound, defined as the number of times per second that the wave of sound repeats itself, and 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 of 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.

Sound Pressure: Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.

Sound vs. Noise: Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide

vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

Executive Summary

The Foundation Document for Cedar Creek and Belle Grove National Historical Park (CEBE) states that the “natural landscapes and resources of the park...offer outstanding opportunities for quiet and solitude in an ever-expanding suburban area” (NPS 2018). As such, CEBE prioritizes maintaining the solemn acoustic environment for park visitors. A Conditional Use Permit (CUP) was issued to a commercial outdoor shooting range operator across Interstate 81 from CEBE in 2022. This permit allows outdoor discharge of firearms, assuming “activities associated with the commercial operation shall not produce sound levels which exceed 60 decibels during hours of operation at the nearest property line” (County of Warren Board of Supervisors 2022). CEBE has since received complaints from visitors that the audible noise from the shooting range during hours of live fire operations are intrusive and disturbing to their park experience.

Continuous audio, sound pressure level data and meteorological data were recorded at CEBE during a 25-day period in August 2024 to better understand the acoustic environment in the park. In this document, “sound pressure level” refers to broadband (12.5 Hz–20,000 Hz), A-weighted, 1-second time averaged sound level ($L_{Aeq, 1s [12.5-20,000 \text{ Hz}]}$). 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 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.

The measurement site was selected to capture the acoustic environment where CEBE visitors would be farthest from the highway, construction, and shooting range noise sources. To estimate gunshot sound levels at the shooting range property line, the inverse-square law (Cowan 1993) was applied to the measured data. Per the inverse-square law, gunfire noise would attenuate by about 9 dB from the shooting range property line nearest to CEBE before reaching the microphone. Thus, a 51 dBA¹ threshold was used to evaluate the sound levels of gunshots captured at CEBE for compliance.

A randomized sampling of hours with potential gunfire activity was analyzed by listeners to identify hours with perceivable gunshots. Of this sampling, ten hours were selected for further analysis. These data were evaluated for compliance with permitted noise levels and excluded any contaminating noise events. This analysis demonstrated that the noise level limit established by the CUP is often surpassed, as shown in Table 1, resulting in non-compliance with the CUP. Potential mitigation measures for consideration are offered in the Appendix.

¹ The permit does not specify a particular frequency weighting, therefore A-weighting was assumed due to its approximation of human hearing (Harris 1998).

Table 1. Analysis results for a sampling of hours measured at Cedar Creek and Belle Grove National Historical Park (CEBE) in August 2024. A 51 dBA threshold was used to evaluate uncontaminated gun fire activity for compliance.

Day of Week	Date	Time	Clean Gunshot Events L_{Aeq, 1-s} > 51 dBA at CEBE
Wednesday	August 7, 2024	10:00 AM–11:00 AM	8
Sunday	August 11, 2024	1:00 PM–2:00 PM	23
Friday	August 16, 2024	1:00 PM–2:00 PM	11
Saturday	August 17, 2024	1:00 PM–2:00 PM	22
Sunday	August 18, 2024	12:00 PM–1:00 PM	83
Monday	August 19, 2024	10:00 AM–11:00 AM	32
Monday	August 19, 2024	3:00 PM–4:00 PM	12
Friday	August 23, 2024	11:00 AM–12:00 PM	2
Saturday	August 24, 2024	11:00 AM–12:00 PM	8
Wednesday	August 28, 2024	1:40 PM–2:40 PM	32

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 and 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). Acoustic 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 acoustic issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustic 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 acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments.

“Soundscape Preservation and Noise Management” was issued in 2000 and builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. 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.

Cedar Creek and Belle Grove National Historical Park

Cedar Creek and Belle Grove National Historical Park (CEBE) is an NPS unit consisting of approximately 3,713 acres that preserves, protects, and interprets a nationally significant Civil War landscape and antebellum agricultural community; tells the rich story of Shenandoah Valley history from early American Indian occupation onward; and preserves and interprets the significant historic, natural, cultural, military, and scenic resources of the park. Figure 1 illustrates the significance of CEBE's land during the Civil War.

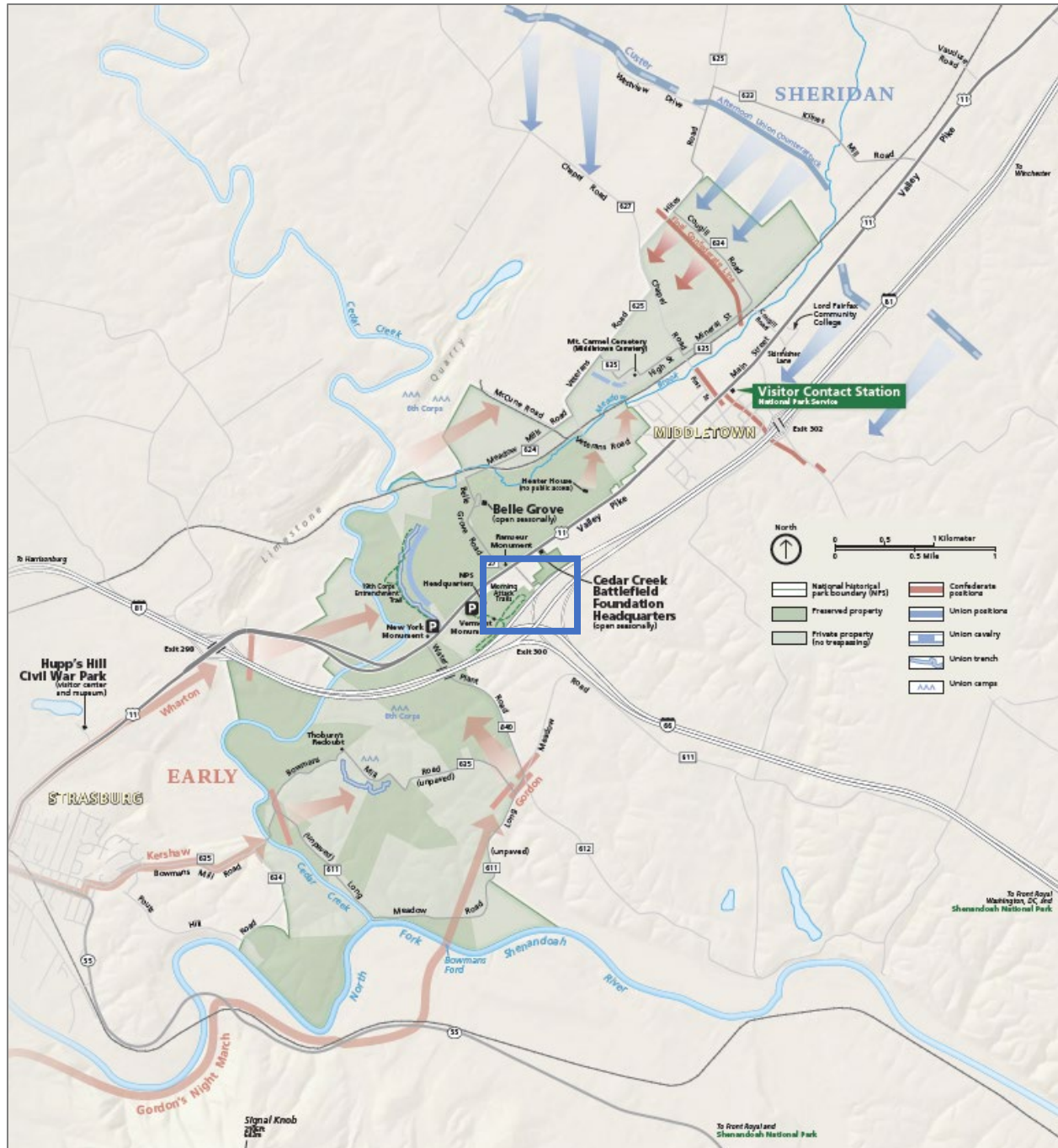


Figure 1. Cedar Creek and Belle Grove National Historical Park map with a blue box showing general project area.

NPS / CEBE

The Foundation Document for CEBE states that the “natural landscapes and resources of the park...offer outstanding opportunities for quiet and solitude in an ever-expanding suburban area” (NPS 2018). As such, CEBE prioritizes maintaining the solemn acoustic environment for park visitors. Noise sources that are potentially detrimental to preservation of the quiet reverence of the

Civil War battlefield at CEBE include gunfire from a commercial outdoor shooting range recently established across Interstate 81, vehicle pass by noise from travelers on nearby roads, and construction noise from improvements to the local I-81/I-66 interchange (Figure 1).

A Conditional Use Permit (CUP) was issued to the shooting range operator by the County of Warren Virginia Planning and Zoning Department on February 22nd, 2022. This document allows outdoor discharge of firearms, assuming “activities associated with the commercial operation shall not produce sound levels which exceed 60 decibels during hours of operation at the nearest property line” (County of Warren Board of Supervisors 2022). This shooting range has both indoor and outdoor live fire activity for instructional demonstrations and exercises or recreational purposes. Both single shot and automatic weapons have been used on site. CEBE has since received complaints from visitors that audible noise from the shooting range during live fire operations is intrusive and disturbing to their park experience.

To follow up on these complaints, the park requested assistance from NSNSD to determine if the shooting range was operating within permitted guidelines and how such noise could be mitigated. Through collaboration with Volpe Center, continuous acoustical data were collected at CEBE during a 25-day period in August 2024 to better understand the acoustic environment in the park.

Acoustic Environment Monitoring

Long-term passive acoustic monitoring was conducted from August 6th to August 31st, 2024, at a site in CEBE represented by the microphone in Figure 2. This site was located less than 100 ft from CEBE's Morning Attack Trail behind a wire fence to avoid equipment disturbance from visitors without obstructing the propagation path. The microphone location represents an area within the park where visitors may go to experience nature, including natural quiet along the Morning Attack Trail. This location is also away from areas within the park with higher visitation and an increased chance for ancillary sounds from park visitation and traffic.

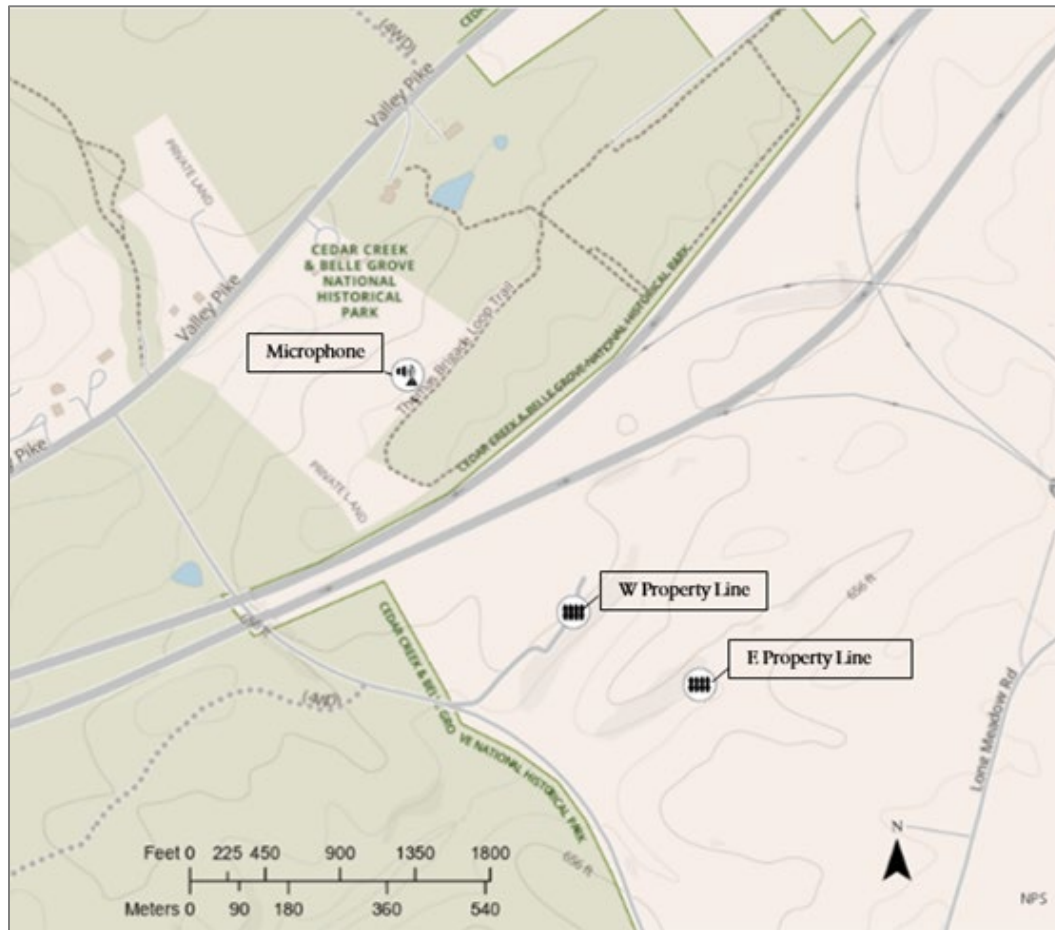


Figure 2. CEBE noise monitoring points of interest.

NPS / KELSEY WHITE

The western property line callout in Figure 2 indicates the point along Water Plant Road nearest to the microphone. The CUP states that Water Plant Road separates the property area under lease for agriculture from the property area in which the shooting range operates (County of Warren Board of Supervisors 2022). Thus, this point was assumed to represent the closest shooting range property line to CEBE, at which noise levels were evaluated against the 60 dBA permitted level (see Analysis Methods). The eastern property line callout in Figure 2 is along the axis of the other two points,

located on the shooting range property line as far as possible from the microphone. This point was assumed to represent the gun fire origination point used to estimate noise propagation from the source to the property line nearest to CEBE (see Analysis Methods).

The geometry shown in Figure 2 and detailed in Table 2 presumes that the shooting range operator intends to respect the CUP's intent of protecting the surrounding community by locating and orienting the shooting line towards the tree line farthest from neighboring occupied properties. The assumed shooting line location is relevant due to the distance over which sound will attenuate from the source before reaching the microphone, while the assumed orientation of the shooting line is relevant because gun fire noise emanates directionally. This means that much of the noise energy from a gunshot initially travels towards the target, while the remaining noise energy spreads in all directions, including towards CEBE.

Table 2. Points of interest.

Point of Interest	Description	Latitude (°)	Longitude (°)
Microphone	Microphone location at CEBE	39.00869	-78.30540
W. Property Line	Assumed property line for evaluation	39.00567	-78.30268
E. Property Line	Assumed gun fire location	39.00474	-78.30062

A Larson Davis model 831 sound level meter (SLM) and Roland model R-05 digital audio recorder (DAR) were deployed for the measurement campaign. The signal from a single microphone (Figure 3, foreground) was captured by the two devices to collect continuous $L_{Aeq, 1-s}$ measurements and 96 kilobits per second audio with a 44.1 kHz sampling rate, respectively. The microphone was positioned five feet above the ground to represent standard human ear height. The Vaisala model WXT-520 weather sensor (Figure 3, background) was connected to the SLM to capture continuous wind speed and direction data, with a time history synced to the $L_{Aeq, 1-s}$ measurements.



Figure 3. Passive acoustic monitoring setup in CEBE on 8/6/24.
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The data acquired by the microphone shown in Figure 3 consist of natural and anthropogenic noise sources, which include gunfire activity from the shooting range, vehicle noise from the highway, construction noise, aircraft flyovers, and activity from woodland wildlife such as insects, birds, and squirrels. Audible live fire activity from the shooting range was observed by the field crew when retrieving the measurement equipment at the end of the 25-day deployment.

Analysis Methods

The measured data were analyzed to determine whether the shooting range operations comply with the CUP, or whether the noise level limit established by the permit is being exceeded. The permit only applies during shooting range operational hours, therefore any exceedance outside of these hours is out of compliance, yet not studied here. The 25-day continuously recorded dataset was trimmed to just measurements captured on Mondays through Saturdays from 10:00 AM to 6:00 PM, and on Sundays from 12:00 PM to 4:00 PM. All measured $L_{Aeq, 1-s}$ sound level data coinciding with instantaneous wind speeds measuring greater than five meters per second were removed from the analysis due to wind noise contamination. The period during which CEBE staff visited the monitoring equipment for a routine check, including approach and departure time, was also removed from the analysis.

Since the permit governs noise levels at the shooting range property lines, and the noise measurements were captured on CEBE property (Figure 2), noise level estimates at the shooting range property line nearest to CEBE were derived from the measured values using the inverse-square law. The inverse-square law dictates that noise attenuates at 6 dB per distance doubling from the source along the propagation path, a reasonable assumption given the relatively flat terrain of the area. Also assuming the live fire activity occurs near the shooting range property line farthest from the noise-sensitive environment at CEBE in order to respect the permit's intent, there is approximately 750 feet between the shooting line (i.e., the source) and the shooting range property line closest to CEBE, while the microphone (i.e., the receiver) was located roughly 2080 feet from the source (Figure 4). For the shooting range activity to exceed 60 dB at the property line nearest to CEBE, the noise level measured at CEBE must be at least 51 dB, by the following equation (Cowan 1993, Equation 3-5):

$$L_2 = L_1 - 20 * \log_{10} \left(\frac{D_2}{D_1} \right)$$
$$51.1 \text{ dB} = 60 \text{ dB} - 20 * \log_{10} \left(\frac{2080 \text{ ft}}{750 \text{ ft}} \right)$$

Where:

L_1 = Sound pressure level at the property line

L_2 = Sound pressure level measured at the microphone

D_1 = Distance from presumed shooting line and shooting range property line

D_2 = Distance from presumed shooting line to microphone

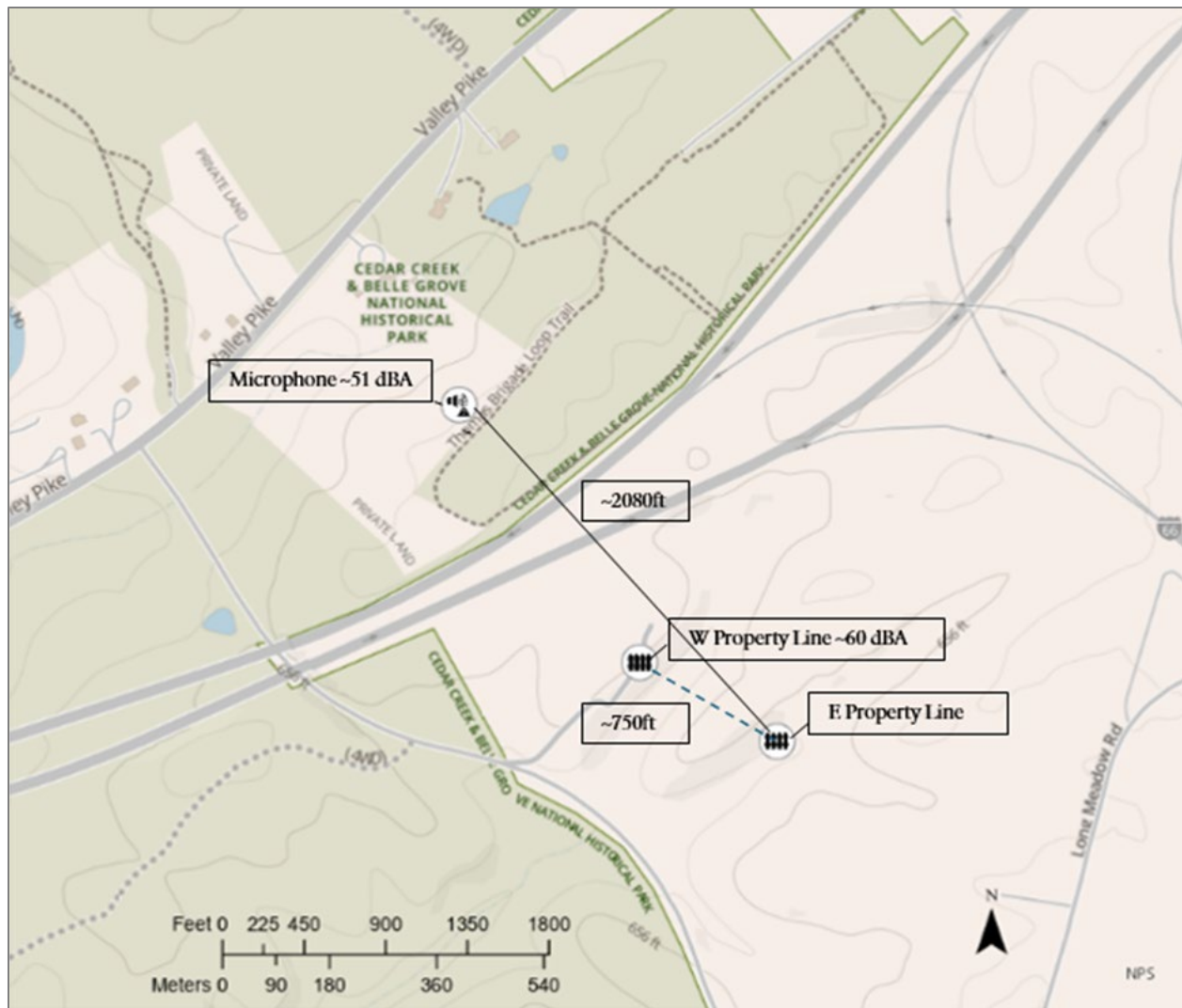


Figure 4. CEBE noise monitoring points of interest with distance annotations.
NPS / K. WHITE

This computation yields that the gunfire noise would attenuate by about 9 dB from the shooting range property line nearest to CEBE before reaching the microphone. Thus, 51 dBA² measured at the microphone was the threshold used to evaluate compliance with the permitted limit. Note that 51 dBA is an upper-bound estimate because the inverse-square law governs free-field propagation. This means it does not account for the additional attenuation from the expansive grassy fields between the shooting range property line and the microphone. Field grass is relatively absorptive of environmental noise (Hastings and Son 2024), such that the actual attenuation from source-to-receiver is likely higher than 9 dB, which would result in a more stringent threshold for compliance

² The permit does not specify a particular frequency weighting, therefore A-weighting was assumed due to its approximation of human hearing (Harris, 1998).

evaluation. In other words, 51 dBA measured at the microphone likely corresponds to a noise level even greater than the 60 dBA permitted limit at the assumed shooting range property line (Table 2).

Because of the contributions from other noise sources, especially highway traffic, it was not feasible to use the 51 dBA threshold as the sole means of pinpointing potential non-compliant activity from the shooting range. Instead, listeners evaluated randomly selected hours of continuous digital audio during the range's hours of operation to identify timestamps of potential gunfire events. Then, $L_{Aeq, 1-s}$ data for the corresponding timestamps were reviewed in a spreadsheet to confirm whether the identified events exceeded 51 dB at the microphone. Identified exceedances were deemed noncompliant if the shooting range activity was the dominant noise source and did not include contaminating noise events (i.e., distinct highway vehicle pass bys, wildlife activity near the microphone, aircraft flyovers, etc.). Without a record of when the nearby construction site was active, any events that were suspected to be construction noise rather than gunfire were also excluded.

Analysis Results and Conclusions

Table 3 demonstrates that the permitted noise level is often exceeded due to live fire activity at the shooting range. The specific shooting range activity that took place during the examined hours was unobserved. The non-compliant events in Table 3 may represent noise from instructional demonstrations and exercises or recreational activity.

Table 3. Analysis results for a sampling of hours measured at CEBE during live fire activity on the nearby shooting range.

Day of Week	Date	Time	Clean Gunshot Events L _{Aeq, 1-s} > 51 dBA at CEBE
Wednesday	August 7, 2024	10:00 AM–11:00 AM	8
Sunday	August 11, 2024	1:00 PM–2:00 PM	23
Friday	August 16, 2024	1:00 PM–2:00 PM	11
Saturday	August 17, 2024	1:00 PM–2:00 PM	22
Sunday	August 18, 2024	12:00 PM–1:00 PM	83
Monday	August 19, 2024	10:00 AM–11:00 AM	32
Monday	August 19, 2024	3:00 PM–4:00 PM	12
Friday	August 23, 2024	11:00 AM–12:00 PM	2
Saturday	August 24, 2024	11:00 AM–12:00 PM	8
Wednesday	August 28, 2024	1:40 PM–2:40 PM	32

Evaluation of noise measured at CEBE in August 2024 demonstrates that the 60 dB noise level limit established by the CUP issued to the shooting range operator is often exceeded, resulting in non-compliance with the CUP.

Discussion

CEBE prides itself on an acoustic environment of “quiet and solitude” (NPS 2018). This solemn backdrop is especially important for park visitors at the reverent monuments and cemetery (Figure 1). Efforts to maintain such a deferential acoustic environment are made more difficult by the audible gunfire noise from the nearby commercial outdoor shooting range. The CUP established a noise level limit for the shooting range property lines to help protect CEBE and the surrounding community. This study found that shooting range operations were not in compliance with the CUP 233 times in ten hours (Table 3). Shooting range operations that adhere to the CUP would likely improve visitor experience and time spent at CEBE, which would in turn help pass on the rich history of the nationally significant natural, cultural, military, and scenic resources of the park. The Appendix contains potential mitigation measures to consider in order for the shooting range to achieve compliance with permitted noise levels. If mitigation measures were implemented such that the shooting range never exceeds the CUP’s 60 dBA limit at the property line nearest to CEBE, it is still possible that live fire activity could be heard by CEBE visitors. However, any noise reduction would help decrease the frequency and severity of disturbances for park visitors.

Literature Cited

- County of Warren Board of Supervisors. 2022. Board of Supervisors Special Meeting, 22 February 2022. Virginia, United States of America.
- Cowan, J.P. 1993. Handbook of environmental acoustics. John Wiley & Sons.
- Federal Highway Administration (FHWA). 2010. "Procedures for Abatement of Highway Traffic Noise and Construction Noise," United States Code of Federal Regulations Part 772 (23 CFR 772).
- Haas, G.E., and T.J. Wakefield. 1998. National parks and the American public: A national public opinion survey on the national park system. Washington D.C. and Fort Collins, CO: National Parks and Conservation Association and Colorado State University.
- Harris, C.M., editor. 1998. Handbook of Acoustical Measurements & Noise Control. 3rd ed., American Institute of Physics, Woodbury.
- Hastings, A., and S. Son. 2024. Technical Manual Traffic Noise Model 3.2. Federal Highway Administration, Washington, District of Columbia.
- McDonald, C.D., R.M. Baumgarten, and R. Iachan. 1995. Aircraft management studies: National Park Service Visitors Survey. HMMH Report No. 290940.12; NPOA Report No. 94-2, National Park Service, U.S. Department of the Interior.
- National Park Service (NPS). 2018. Foundation Document: Cedar Creek and Belle Grove National Historical Park, November 2018. National Park Service
<https://irma.nps.gov/DataStore/Reference/Profile/2287354>
- Smillie, M. 2016. BC Wildlife Federation: Noise Management for Outdoor Shooting Ranges. Gustavson School of Business, Victoria.
- Solman, G., W. Chupp, A. Plovnick, and A.L. Hastings. 2019. Noise Levels Research Synthesis: Review and Updates to Findings in Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, DOT-VNTSC-HUD-19-01.
- Templeton, D., editor. 1997. Acoustics in the built environment: advice for the design team. Architectural Press, Oxford.

Appendix: Potential Mitigation Measures

Sound is often analyzed using the “source, path, receiver” framework. Efforts to attenuate noise are most effective where the sound originates (i.e., the source), and to a lesser extent, along the route of travel (i.e., the path) towards the area of interest (i.e., the receiver). Altering the operating conditions of the noise source to produce less sound energy is the ideal mitigation measure. If doing so is unfeasible, blocking the direct line-of-sight between the source and the receiver using a solid object near the noise source is the next best option. Sound’s ability to travel through or around the obstacle depends on properties such as distance from the noise source, as well as size, weight, and reflective/absorptive material characteristic of the obstruction (Solman et al. 2019).

Potential mitigation measures to aid in the reduction of non-compliant shooting range noise levels include, in no particular order (Smillie 2016):

- Installing a firing line cover
- Surrounding the shooting range with earthen or straw berms
- Creating natural berms by lowering the shooting range via excavation
- Surrounding the shooting range with wall barriers
- Increasing the height of existing berms or barriers to block line-of-sight from the shooting range to the surrounding community
- Moving existing berms or barriers closer to the firing line to increase efficacy
- Coupling wall barriers to the firing line cover to prevent noise leakage
- Installing tube ranges to encase discharge activity
- Retrofitting existing infrastructure (e.g., firing line cover, barriers, overhead baffles, tubes) with acoustically absorptive materials, such as spray-on foam, insulative batting, or sound blankets
- Limiting the use of traditionally loud firearms
- Limiting the use of firearm components such as muzzle brakes or compensators that alter the noise emission direction, thus increasing up-range discharge noise

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