



Natchez Trace Parkway

Raised Profile Striping Modeling Report 2025



Photograph of roadway center line raised profile striping.
NPS / KELSEY WHITE

Natchez Trace Parkway: Raised profile striping modeling report 2025

Science Report NPS/SR—2025/289

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Abstract

Raised profile striping (RPS) was installed on the roadway center and edge lines along a 40-mile corridor of Natchez Trace Parkway (NATR) as a safety measure to reduce traffic accidents. To measure potential effects on the acoustic environment, controlled noise measurements were conducted within NATR in May 2023. Uncontrolled measurements were taken in 2024 once the roads reopened to provide background acoustic data for the analysis. These data were used to conduct noise modeling scenarios analyzing the effect of RPS on the acoustic environment. Modeled results indicate that vehicles running over the RPS meaningfully alter the acoustic environment on a single-event overall and spectral level, but not when examining the cumulative effects over longer timeframes, such as hours. In other words, the RPS may not make the overall long-term noise environment louder, but distinct events and tones from drivers hitting the RPS might be heard hundreds of feet from the roadway and may cause short-term effects, such as wildlife fleeing or increased vigilance or disruption of the visitor experience. Heavier vehicles hitting the RPS will produce lower frequency noise that is less likely to attenuate (decrease) over long distances. Areas of NATR with significant medium and heavy truck traffic will likely experience more noise from individual RPS hits at farther distances from the roadway. Audibility and perception for any receiver at a given time will depend on the existing non-road ambient noise amplitude and spectrum, which can fluctuate greatly by time of day, season, year, and land use. The amplitude of the cumulative noise level difference may increase if more vehicles hit the RPS, depending on the vehicle speed. Vehicle fleet mix, roadway alignment, traffic volume, posted speed limit, and driver behavior should be considered when determining RPS installation locations.

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.

Frequency: Related to the pitch of a sound, and 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 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.

Energy Equivalent Sound Level (LA_{eqT}): The sound energy level averaged over the measurement period, T. Generally, it refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz–20 kHz. This is a standard measurement collected using 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. The single-event LA_{eq} described in this report are averaged over T equal to the six-second passby duration. The cumulative LA_{eq1hr} described in this report are averaged over a duration of one hour and represent peak traffic conditions. This descriptor is typically used for highway noise analyses conducted for Federal Highway Administration (FHWA) under 23 CFR 772.

Existing non-road ambient LA_{eq} : Used specifically in this report to describe the ambient conditions absent roadway noise. It is the equivalent sound level average over the duration of 10 randomly selected time periods during which no vehicle passbys were measured. This descriptor is typically used in highway noise analyses to characterize baseline conditions and evaluate changes from the baseline.

Percentile sound levels (LA₁₀, LA₅₀, LA₉₀): Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the LA₅₀ value, while 90 percent of the time the measured levels are higher than the LA₉₀ value, and 10 percent of the time measured levels are higher than the LA₁₀ value.

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

Raised profile striping (RPS) was installed on the roadway center and edge lines along a 40-mile corridor of Natchez Trace Parkway (NATR). This construction project was piloted to evaluate RPS as an alternative roadway departure crash countermeasure with the potential to install more RPS throughout NATR. RPS may have unintended consequences on the surrounding acoustic environment, including park visitors and wildlife who may be disrupted by the exterior noise required to alert the driver drifting out of their lane position.

Noise measurements of a controlled passby experiment in NATR were conducted by the NPS Natural Sounds and Night Skies Division (NSNSD) on May 3rd, 2023, while the section of road was closed. Passbys were conducted with both a compact car and a pickup truck hitched to an empty trailer to represent a range of vehicle weights. A microphone stationed 56-feet from the nearest lane center line, standing 4 feet above ground captured overall and spectral sound pressure levels, which were correlated with the field observer log to discern the passby time and noise treatment condition (i.e., on or off the center line RPS). These data were used as the emissions source data for the modeling in this report.

Once the roads reopened, NSNSD returned to conduct long-term passive noise monitoring from May 2nd, 2024, to June 4th, 2024, along the NATR corridor. The measurement location and duration were selected to capture the acoustic environment in an area with newly installed RPS on both center and edge lines. This time the microphone was placed 100 ft from the roadside to better capture the overall acoustic environment in a well-hidden and flat area, not just roadside noise.

RPS effects were assessed through acoustic modeling using the Federal Highway Administration (FHWA)'s Traffic Noise Model version 3.2 (TNM 3.2)¹. Free-field adaptations of the measured data for each test vehicle and RPS condition were used as the source energy for propagation over a simple model representation of NATR. LA_{eq} calculations were conducted for the following six modeling scenarios:

1. Single-event compact car passby on RPS
2. Single-event compact car passby off RPS
3. Single-event truck + trailer passby on RPS
4. Single-event truck + trailer passby off RPS
5. One hour of peak traffic car passbys in which 20% hit the RPS
6. One hour of peak traffic car passbys in which none hit the RPS

¹ https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_v32/

Noise level computations at four receiver distances were evaluated for all scenarios. The distances relative to the near lane center line and what each receiver is intended to represent are detailed in Table 1.

Table 1. Receiver distances.

Location	Represents	Distance from Near Lane Center Line (ft)
Road edge	Recreation adjacent to the road (e.g., hiking trails, scenic pull-offs), wildlife experience	25
Narrow Park boundary	Interpretive parking pull-offs, hiking trails, wildlife experience	200
Park interior	Hiking trails, wildlife experience	660 (1/8 mile)
Wide Park boundary	Wildlife experience	1320 (1/4 mile)

Noise level results were reported at all receiver locations for the modeled roadway sources in isolation, (i.e., no other noise source is present), as well as a more realistic representation of the existing acoustic environment, which encompasses the modeled roadway sources amongst other existing non-road sources. Modeled results were compared against the 40 dBA threshold for wildlife sensitivity and the 60 dBA threshold for speech interference of normal voice communications at one meter to represent interruptions to visitor experience near the parkway (EPA, 1974). These were used to evaluate the modeled results against potential functional effects.

For transportation noise assessments, such as those conducted for FHWA and other DOT agencies, the baseline condition is defined by the existing noise level determined through modeling and/or noise measurements. For this study, the existing noise level was determined by combining the existing non-road noise level (LA_{eq}) with modeled NATR roadway traffic. The existing non-road noise level (LA_{eq}) was determined to be 49.4 dBA based on noise measurements from the 2024 sampling period. It should be noted that 2024 was abnormal due to a rare emergence of cicada broods that have the potential to raise the baseline ambient to levels higher than other summers. However, it is not expected that this would change the long-term baseline data to an extent that would affect these modeling efforts.

Modeling results found the following:

- Single-event modeling results showed that single passbys on the RPS did not exceed the 60 dBA threshold and would not impact speech intelligibility at any distance from the roadway.
- A single passby of the truck + trailer test vehicle hitting the RPS produced the loudest sound level of all the modeled noise sources.
- The truck + trailer passbys also resulted in a greater noise level difference predicted between RPS hits and misses than the compact car passbys.

- The overall noise level difference was especially significant for single-event predictions with either vehicle type at distances beyond the road edge.
- The modeled noise level differences for both test vehicle types increase with distance from the roadway because the low frequency sound energy generated from RPS hits will travel longer distances without being absorbed.
- The spectral noise level difference between RPS hits and misses was more pronounced and at a lower frequency band for the truck + trailer test vehicle than the compact car.
- The modeled single-event truck + trailer spectral difference peaked at 12.2 Δ dB for 315 Hz at a quarter mile from the roadway, whereas the modeled single-event compact car spectral difference peaked at 7.3 Δ dB for 1,000 Hz at a quarter mile from the roadway.

For context, a 3 dB difference would be perceptible to the human ear, whereas a 6 dB difference is readily perceptible, and 10 dB difference would be perceived as a doubling of loudness. As such, both single-event peak spectral differences could be evident as discrete tones at 1,320 feet from the roadway. The cumulative effect on the 1-hour LA_{eq} between scenarios with either 20% or 0% of the peak hour compact car traffic hitting the RPS is imperceptibly small at all distances from the roadway due to the low traffic volume modeled (152 vehicles/hour) compared to the base capacity of 1850 passenger cars per lane per hour, according to the governing equations in the Highway Capacity Manual. Note that more urban areas of NATR observe peak hour traffic counts of 1,000–1,800, although the lower volume rural scenario modeled in this report is representative of a majority of the Parkway. The spectral $LA_{eq}1hr$ differences are modest and much more concentrated towards the roadway compared to the single-event spectral differences because the $LA_{eq}1hr$ computation is dominated by the existing non-road ambient during the majority of the hour in which no compact car passbys occur. The true cumulative effect of typical RPS usage, including the low frequency difference is likely greater than predicted here due to the spectral contribution from vehicles heavier than the compact car that were not modeled. Modeled $LA_{eq}1hr$ for the peak hour compact car traffic both with and without RPS hits are predicted to be above the 40 dBA wildlife sensitivity threshold and below the 60 dBA speech interference threshold at all receiver locations. Note that the $LA_{eq}1hr$ computation includes the existing non-road noise. This indicates that typical RPS usage does not cause an increase in cumulative impacts to the acoustic environment.

Modeled results indicate that hitting the RPS meaningfully alters the acoustic environment on a single-event overall and spectral level, but not when examining the cumulative effects over longer timeframes, such as hours. In other words, the RPS is not making the overall long-term noise environment louder, but distinct events and tones from drivers hitting the RPS might be heard hundreds of feet from the roadway and may cause short-term disruptions such as wildlife fleeing or increased vigilance. Audibility and perception for any receiver at a given time will depend on the existing non-road ambient noise amplitude and spectrum, which can fluctuate greatly by time of day, season, year, and land use. Because the existing non-road LA_{eq} is influenced by time day/season and location, any suggestions of audibility based on overall levels presented in this report are not conclusive nor applicable to the whole of NATR.

Vehicle weight will change the source characteristics such that heavier vehicles hitting the RPS will produce lower frequency noise that attenuates (decreases) less over long distances, even over a more acoustically absorptive ground cover like grass. Areas of NATR with significant medium and heavy truck traffic will likely experience more noise from individual RPS hits at farther distances from the roadway.

Modeled results indicate that RPS hits have little effect on the long-term noise level within the existing acoustic environment at distances beyond the road edge. However, the amplitude of the noise level difference averaged over an hour of traffic ($LA_{eq}1hr$) would likely increase if more vehicles hit the RPS, such as on a curvier road where a larger proportion of vehicles are more likely to drift their lane position, or on busier sections of NATR with more passbys. Note that more passbys on the RPS do not guarantee a greater impact on the overall acoustic environment. The speed at which vehicles hit the RPS would dictate the amplitude of the noise level difference. Vehicle fleet mix, roadway alignment, traffic volume, posted speed limit, and driver behavior (e.g., excessive speeding, distraction, etc.) should be considered when determining RPS installation locations. Roadways with higher traffic volumes and travel speeds than that which was modeled in this study will likely result in greater noise level differences from drivers hitting the RPS.

This study is based on measurements from passbys on a specific RPS installation along NATR. The modeled results may not be indicative of future RPS installations due to inconsistent RPS construction, especially for the center line RPS.

This study leaves several variables unexplored that are worth investigating in future research. The passby data measured at 100 feet were not examined to validate the model noise predictions and propagation conditions for this study, which may affect the results. Subsequent studies should consider measuring different vehicle types, particularly heavier vehicles such as SUVs, vans, buses, and semi-trucks that are more likely to have a meaningful effect on the noise environment. All test vehicle types should be measured at multiple travel speeds, both above and below the 50 mph focus of this study. Future modeling should examine the effect of higher traffic volumes, higher RPS hit rates, and/or higher existing non-road ambient LA_{eq} to simulate the conditions in more populated urban areas. Lower existing non-road ambient LA_{eq} could also be modeled to represent a similar rural area to this study, during a year with a less active cicada population. Models could also investigate propagation of RPS noise through different paths, including over harder ground types than the grass in this study and through forested areas. Further research could also explore the effect of single-event noise level differences caused by the RPS on wildlife experience.

Introduction

Natchez Trace Parkway (NATR) is an NPS unit consisting of 444 miles of roadway spanning from Mississippi to Tennessee. Figure 1 illustrates that the park boundary remains close to the road, while encompassing a wide variety of adjacent land uses. NATR encounters environments ranging from urban Jackson, Mississippi, to rural scenic hiking trails.

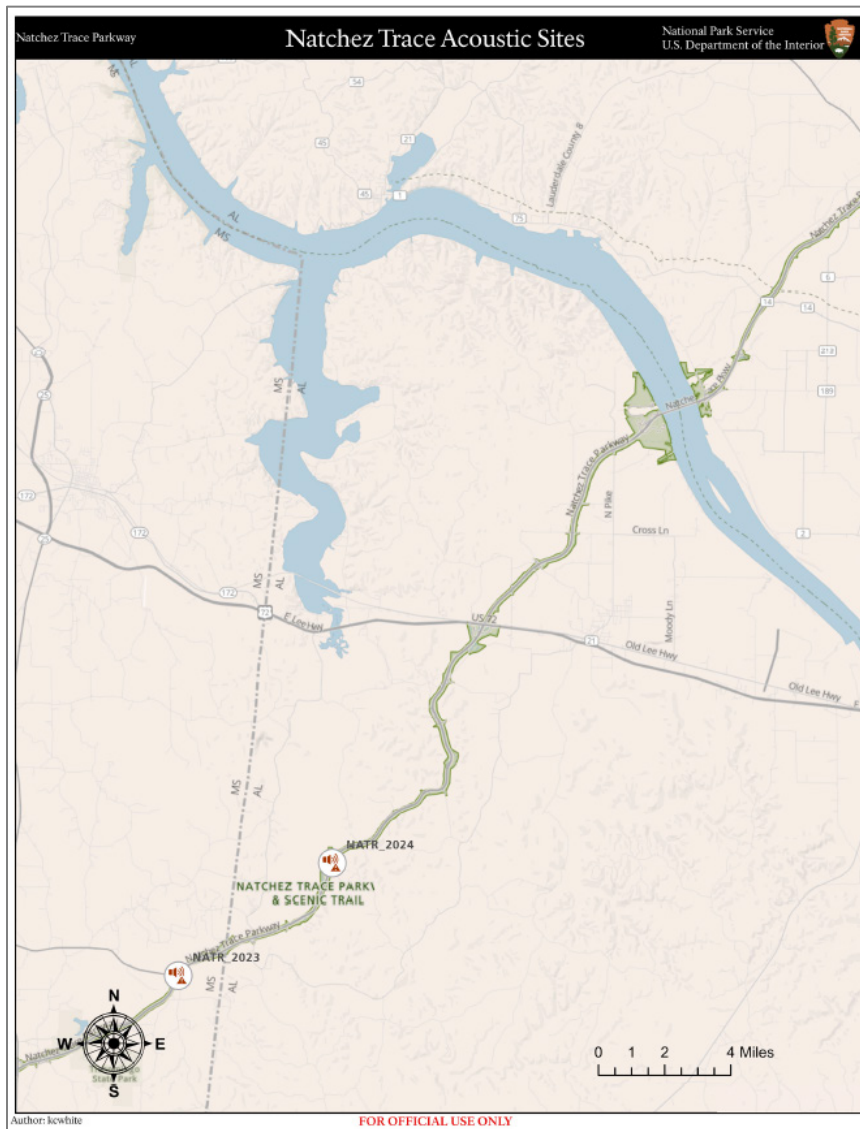


Figure 1. Natchez Trace Parkway Map.

NPS / KELSEY WHITE

Raised profile striping (RPS) was installed on the roadway center and edge lines along a 40-mile corridor of NATR, shown in Figure 2 and Figure 3, respectively. This construction project was piloted to evaluate RPS as an alternative roadway departure crash countermeasure with the potential to install more RPS throughout NATR. RPS was installed in lieu of traditional rumble strips due to

lack of viable pavement width on the narrow parkway. RPS and rumble strips serve the same purpose of alerting the driver to correct their lane position if they have drifted by generating audible sound and tactile vibration when driven over. Both driver alert systems also have unintended consequences on the surrounding acoustic environment, including park visitors and wildlife who may be disrupted by the exterior noise. This report uses noise measurements from a controlled passby experiment to better understand the effect of RPS on the acoustic environment and inform NATR decision making regarding further RPS installation.



Figure 2. Center line RPS at NATR.
NPS / KELSEY WHITE



Figure 3. Edge line RPS at NATR.
NPS / KELSEY WHITE

Measurement Campaign

Controlled Passby Experiment

Noise measurements of a controlled passby experiment in NATR were conducted by the NPS Natural Sounds and Night Skies Division (NSNSD) on May 3rd, 2023. Clean controlled passby measurements containing no extraneous vehicle noise were obtained on a test section of NATR in Mingo, Mississippi, that was closed to the public. No other nearby noise sources were significant. The test site contained only center line RPS but was selected with care to avoid elevation changes on or beside the roadway, roadway alignment curves, and nearby surfaces that would cause acoustic reflections. The measurement location is shown from various geographic extents in Figure 4 and Figure 5.

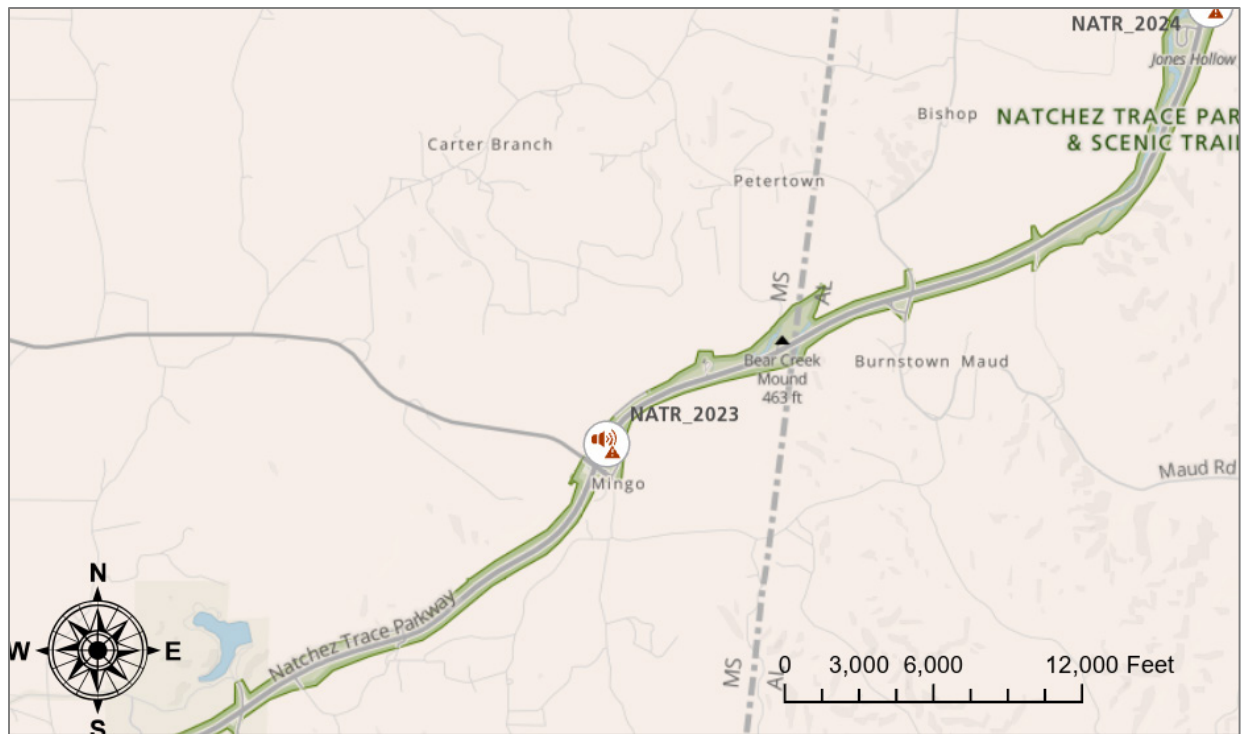


Figure 4. NATR RPS passby experiment measurement location (NATR_2023), wide view.
NPS / KELSEY WHITE



Figure 5. NATR RPS passby experiment measurement location.
NPS / KELSEY WHITE

All test vehicles maintained a constant speed of 50 miles per hour during acceptable passbys. Acceptable passbys were limited to the northeast direction of travel in which the test vehicle was driving in the lane nearest the microphone for source to receiver distance consistency. Passbys in which the test vehicle did not remain on or off the RPS as intended for the six-second duration were removed from the dataset. Passbys were conducted with both a compact car and a pickup truck hitched to an empty trailer (hereafter truck + trailer) to represent a range of vehicle weights. Test vehicles are shown in Figure 6 and Figure 7.



Figure 6. Compact test vehicle used in passby experiment in NATR on 5/3/23.
NPS / KELSEY WHITE



Figure 7. Truck and trailer test vehicle used in passby experiment in NATR on 5/3/23.
NPS / KELSEY WHITE

The main microphone that acquired the noise data used as emissions source data for the modeling in this report is shown in Figure 8. This microphone was located 56 feet from the nearest lane center line at four feet above the ground. The microphone captured overall and spectral sound pressure levels, which were correlated with the field observer log to discern the passby time and treatment condition (i.e., on or off the RPS).



Figure 8. Passby noise measurement setup in NATR on 5/3/23.
NPS / KELSEY WHITE

Acoustic Environment Monitoring

NSNSD also conducted long-term passive acoustic monitoring from May 2nd, 2024, to June 4th, 2024. This measurement location and duration were selected to capture the acoustic environment in an area with newly installed RPS on both the center and edge lines. The site was approximately 100 ft from the roadway edge along a slight curve with both center and edge striping (Figure 9). Measured data consists of natural and anthropogenic noise sources, which during this timeframe included varied uncontrolled passes over the RPS as well as an abnormal amount of sound coming from cicada broods. Both were noted during field visits.

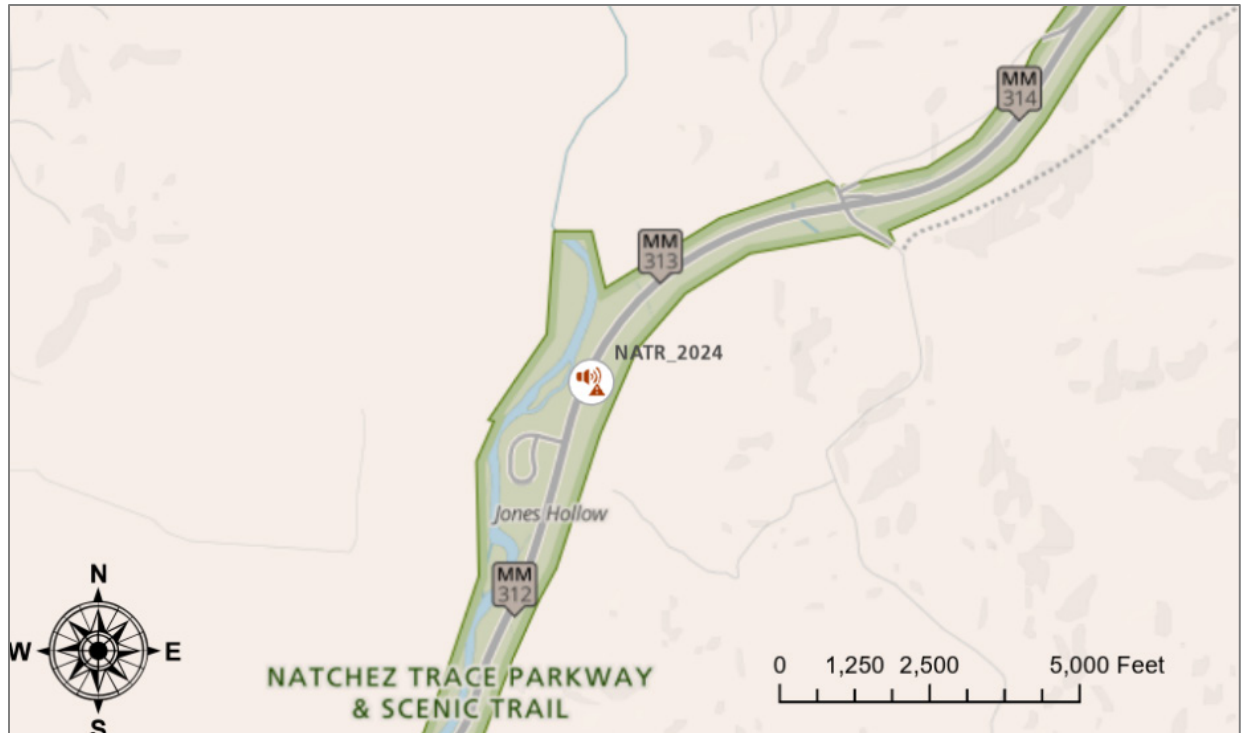


Figure 9. NATR passive noise monitoring location (NATR_2024), wide view.

NPS / KELSEY WHITE

The microphone that acquired the existing ambient data used to determine the non-road LA_{eq} for the analysis in this report is shown in the foreground of Figure 10. This microphone was located approximately 100 feet from the road edge at five feet above the ground to represent standard human ear height. The microphone captured overall and spectral acoustic data, which were used to generate LA_{eq} at times with no traffic.

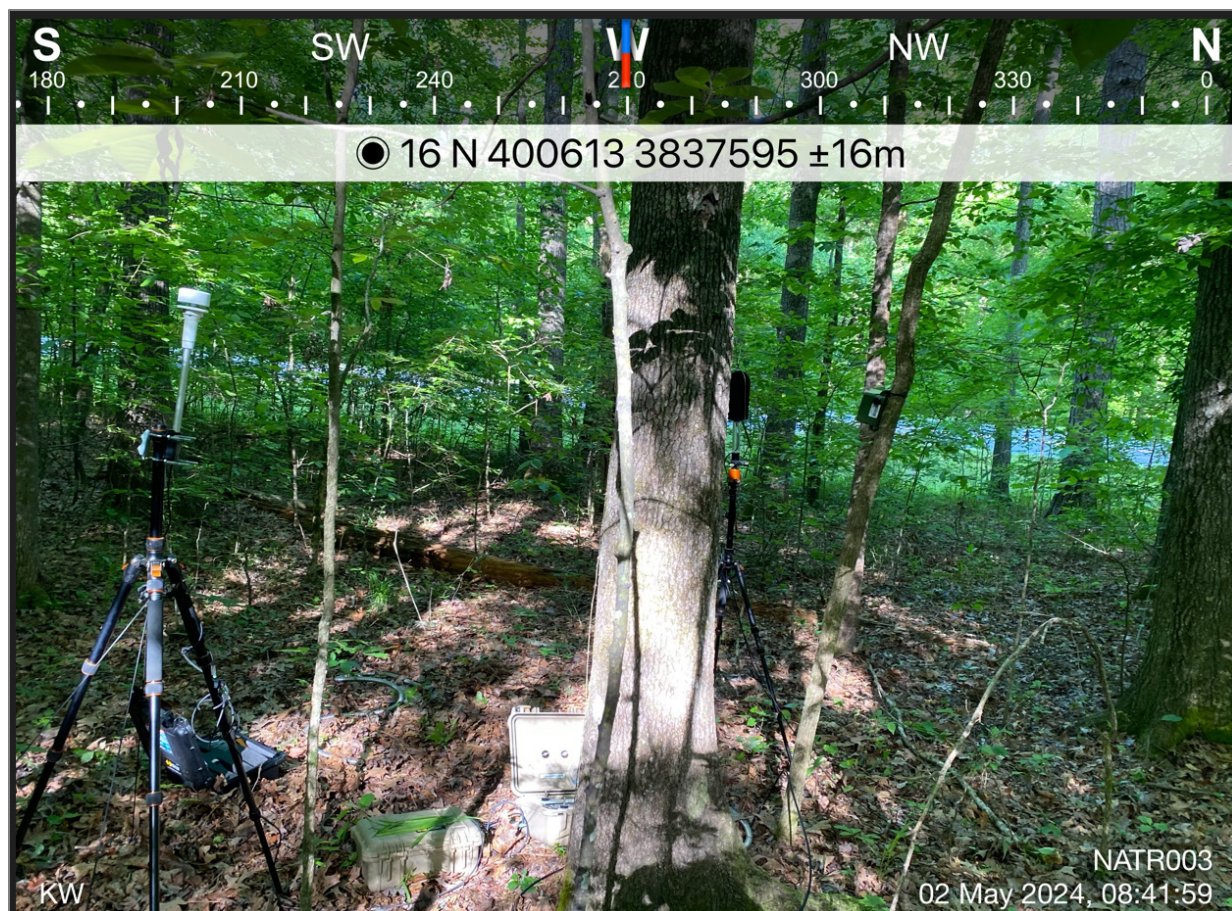


Figure 10. Passive noise monitoring setup in NATR on 5/2/24.

NPS / KELSEY WHITE

Modeling Methods

Acoustic modeling was conducted using the Federal Highway Administration (FHWA)'s Traffic Noise Model version 3.2 (TNM 3.2).² TNM 3.2 can propagate user-defined source spectra of measured sound energy. The propagation algorithms used in TNM's noise level computations with user-defined source spectra are nearly identical to that of TNM's traditional roadway noise computations using pre-defined source data. The only difference is the accommodation of an expanded spectral range in 1/3 octave bands from 12.5 Hz to 20,000 Hz in TNM 3.2.

Source Spectra Derivation

Four source spectra for modeling were derived from NSNSD's data measured during the 2023 controlled passby experiment (microphone at 56ft distance from center line). Measurements were comparable to standard FHWA procedures and thus can be used to derive user-defined source spectra for TNM. Source spectra for both the compact car and truck + trailer hitting the center line RPS were obtained by linearly averaging spectra from ten clean controlled passbys of the respective vehicle type according to the field observer logs. Source spectra for both the compact car and truck + trailer driving in the near lane without hitting the RPS was obtained by averaging spectra from two to three clean passbys of the respective vehicle type according to the field observer logs.

In-situ measurements inherently include attenuation from the ground along the propagation path from the source to the microphone. These ground effects must first be removed from the source data to avoid excess attenuation when the ground effects are applied during the modeling. The spectral measurement averages from the controlled passby experiment were corrected to the free-field condition for model propagation using the following equations. First, the measured sound pressure levels were converted to sound energy as the base unit for modeling in TNM.

$$E(f) = 10^{\left(\frac{SPL(f)}{10}\right)}$$

where

$E(f)$ = sound energy as a function of one-third octave band center frequency

$SPL(f)$ = sound pressure level as a function of one-third octave band center frequency

Four simple scenarios in TNM 3.2 using each spectral measurement average energy spectrum as the source data were then modeled to replicate the measurement conditions. These scenarios are illustrated in Figure 11 and Figure 12 where the receiver location is unchanged such that the distance between the truck + trailer and the four feet tall microphone in each image is indicative of the adjusted lane position between passbys hitting the center line RPS (56 ft) and passbys driving in the near lane without hitting the RPS (50 ft). The shaded dark grey region behind the truck + trailer

² https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_v32/

represents the roadway width, which accounts for the acoustic reflectivity of the pavement surface in the model compared to the acoustically soft grass that will attenuate (reduce) more noise between the roadway and the microphone modeled in the light grey region.

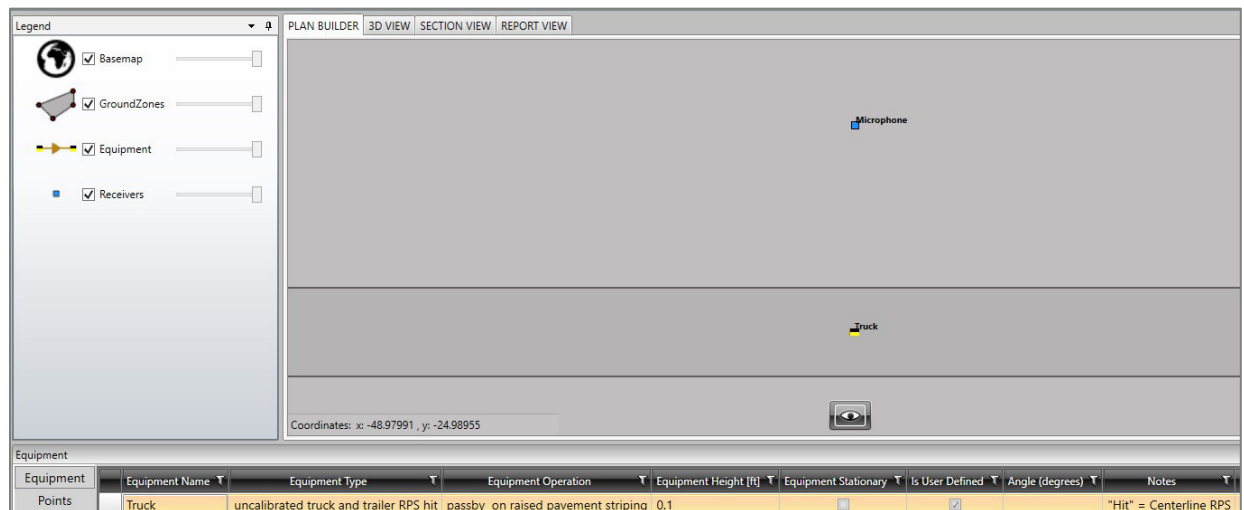


Figure 11. TNM 3.2 example calibration scenario plan view, truck + trailer hitting RPS.

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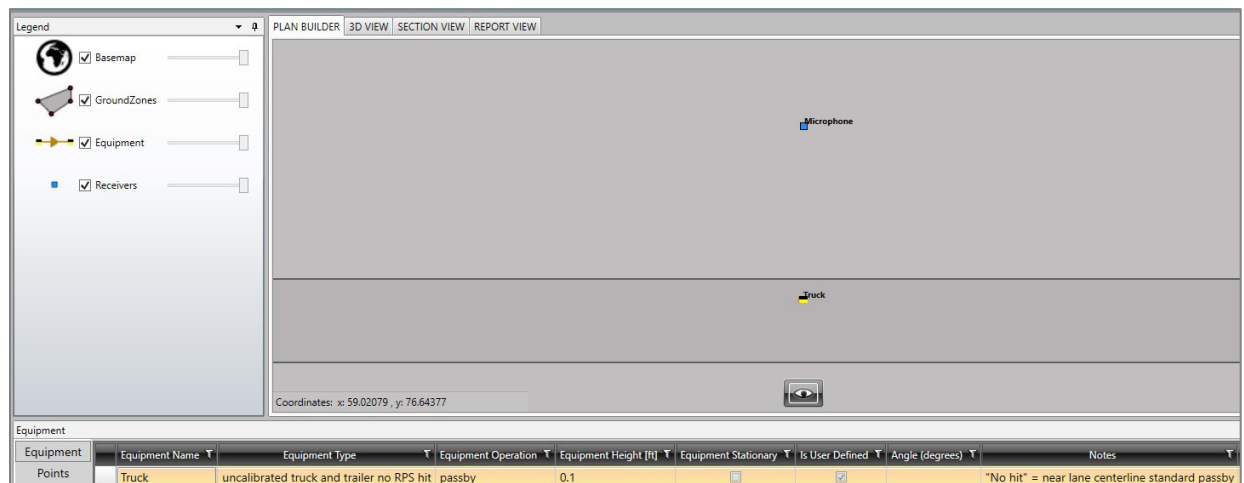


Figure 12. TNM 3.2 example calibration scenario plan view, truck + trailer driving in the near lane without hitting the RPS.

VOLPE / SOPHIE SON

In all source calibration scenarios as well as the subsequent modeling effort using the calibrated data, the respective source energy was modeled to emit from a height of 0.1 feet, which is consistent with the height of the tire/pavement interface default noise source in TNM's roadway noise calculations. No changes in elevation on or near the roadway were modeled to simulate the flat terrain of the measurement area.

The correction factor spectrum needed to remove the excess attenuation from the measured data was determined using the ratio of the measured energy to the energy predicted using TNM 3.2 with the spectral measurement average energy as the source.

$$m(f) = \frac{E_{meas}(f, d)}{E_{TNM}(f)}$$

where

$m(f)$ = sound energy multiplier as a function of one-third octave band center frequency

$E_{meas}(f, d)$ = measured sound energy as a function of one-third octave band center frequency and emission direction

$E_{mod}(f)$ = modeled sound energy as a function of one-third octave band center frequency

The correction factor spectrum was applied to each average measured energy spectrum, the results of which were then used for the remainder of the modeling.

$$E_{cal}(f, d) = m(f) \times E_{meas}(f, d)$$

where

$E_{cal}(f, d)$ = calibrated sound energy as a function of emission direction and one-third octave band center frequency.

The calibrated A-weighted sound pressure level spectra for each source can be found in the [Supplemental Information \(Son 2025b\)](#) for this report.

Modeling Scenarios

LA_{eq} calculations were conducted in TNM 3.2 for the following six modeling scenarios using the free-field average measured energy spectra³:

1. Single-event compact car passby on RPS
2. Single-event compact car passby off RPS
3. Single-event truck + trailer passby on RPS
4. Single-event truck + trailer passby off RPS
5. One hour of peak traffic car passbys in which 20% hit the RPS
6. One hour of peak traffic car passbys in which none hit the RPS

³ TNM input reports can be found in the [Supplemental Information \(Son 2025a\)](#) for this report.

The various noise source configurations for each scenario were applied to a consistent modeling environment. All models used grass as the default ground cover to simulate the attenuating surface⁴ between the roadway and receivers, as well as a 24-ft wide pavement ground zone used to simulate the reflective surface⁵ of a two-lane road. No changes in elevation on or near the roadway were modeled to simulate the flat terrain of the measurement area.

No intervening objects along the propagation path between the roadway and receivers were modeled in any scenario. Although trees are evident in the measurement areas of Figure 8 and Figure 10, they were not included in the modeling. In areas of wider NATR boundaries wherein the trees adjacent to the roadway are owned by NPS, the foliage is not dense enough to block line of sight, leaving a direct propagation path from source to receiver. This is especially true in the winter when there are no deciduous leaves to attenuate (reduce) noise. Excluding trees from the model is also the most conservative (i.e., worst case) approach when evaluating propagation far from the roadway. Furthermore, the forests adjacent to the narrow NPS boundary are subject to private land development including clearcutting for pine plantations or housing developments. The southeastern US forests are also subject to frequent natural disturbances including hurricanes, tornados, severe drought, and beetle outbreaks, which also cause high mortality rates for trees in the surrounding forests.

Noise level computations at four receiver distances were evaluated for all scenarios. The distances relative to the near lane center line and what each receiver is intended to represent are detailed in Table 2. All receivers were located five feet above the ground to simulate the average human ear height when standing on the near side of the roadway relative to the modeled passbys.

Table 2. Receiver distances.

Location	Represents	Distance from Near Lane Center Line (ft)
Road edge	Recreation adjacent to the road (e.g., hiking trails, scenic pull-offs), wildlife experience	25
Narrow Park boundary	Interpretive parking pull-offs, hiking trails, wildlife experience	200
Park interior	Hiking trails, wildlife experience	660 (1/8 mile)
Wide Park boundary	Wildlife experience	1320 (1/4 mile)

All sources were modeled as 16,000-ft long roadways with receivers centered along the roadway length such that propagation to all receiver distances in the noise level computations starts with the same amount of source energy. The result is a simulated infinitely long, straight roadway that is widely applicable to any location. Sources modeling passbys on the RPS were located in the center of

⁴ effective flow resistivity of 300 cgs Rayls

⁵ effective flow resistivity of 20,000 cgs Rayls

the two-lane roadway ground zone width, per the measurement conditions. Sources modeling passbys off the RPS was located six feet closer to the receivers, representing the center of a 12-ft near lane. As such, receiver distances from the RPS sources are six feet greater than the values in Table 2. The model geometry including receiver distances, source locations, and roadway pavement ground zone width are shown in Figure 13 and Figure 14.

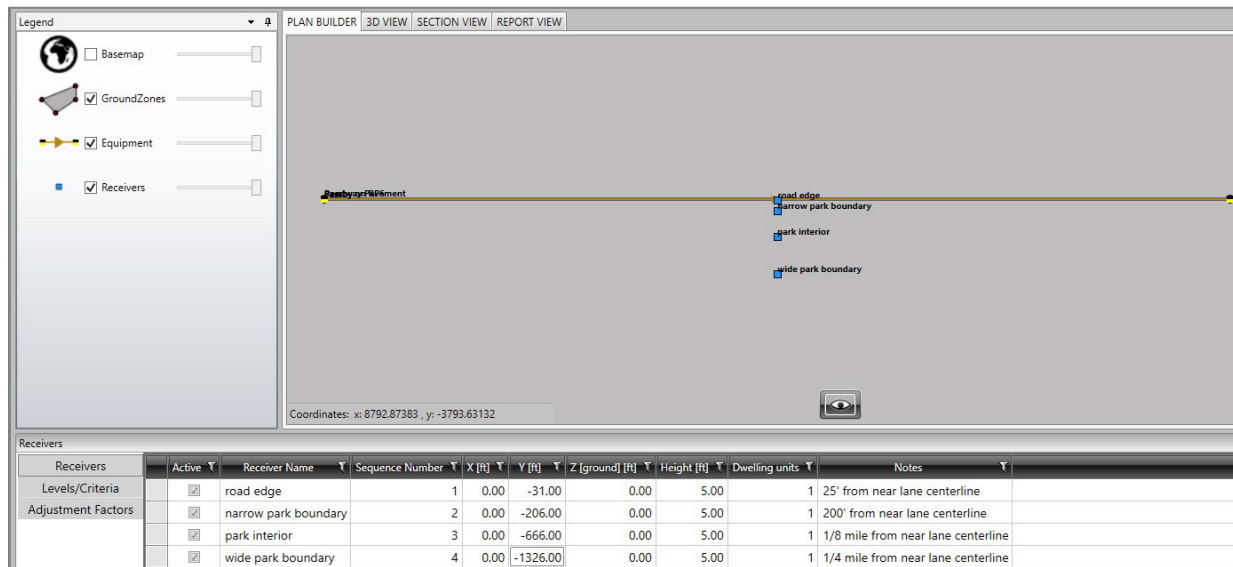


Figure 13. TNM 3.2 example analysis scenario plan view, receiver details.
VOLPE / SOPHIE SON

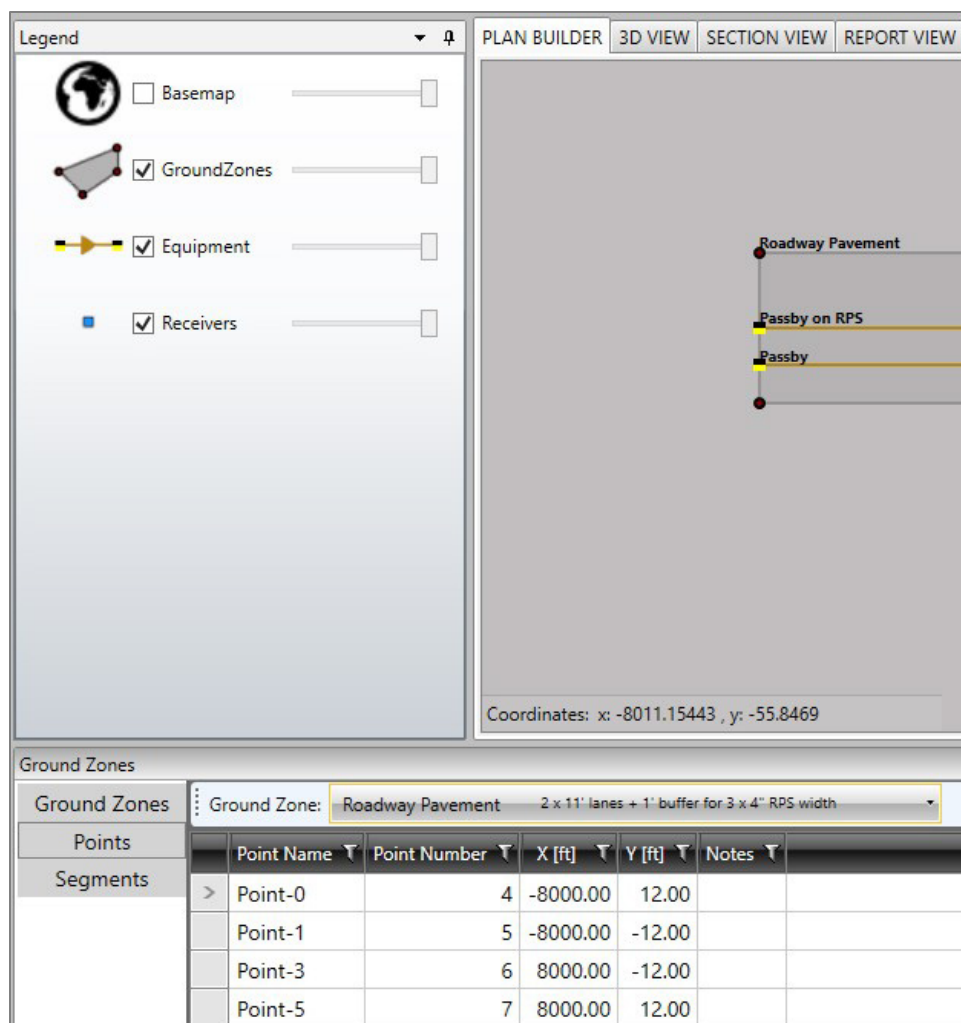


Figure 14. TNM 3.2 example analysis scenario plan view, ground zone and source details.
VOLPE / SOPHIE SON

In the four single-event modeling scenarios, the LA_{eq} time averaging duration was equivalent to the six-second passby duration to represent the impact of the source energy on a near-impulsive basis. The two peak-hour modeling scenarios used an LA_{eq} time averaging duration of one hour ($LA_{eq}1hr$) and represent the cumulative effect of exposure to non-continuous flow traffic indicative of peak hour (or worst-case) traffic conditions in NATR.

The scenarios were constructed using measured traffic counts within NATR based on publicly available data within the Alabama Department of Transportation website. A random day was selected within 2021, which indicated a traffic mix containing five trucks and two motorcycles out of 97 vehicles during a peak hour (92.78% cars). 2021 data was selected to match available data within NSNSD where 152 passbys were measured during the peak hour.⁶ The 92.78% car proportion of the

⁶ Note that more urban areas of NATR observe peak hour traffic counts of 1,000-1,800, although the lower volume rural scenario modeled in this report is representative of a majority of the Parkway.

vehicle fleet was applied to the traffic count total of 152, resulting in 141.03 car passbys per hour. An RPS hit rate of 20% was employed for the $LA_{eq}1hr$ model scenario with RPS hits (scenario 5), resulting in 28.21 cars hitting the RPS and 112.82 missing the RPS during the peak hour.⁷

The measured data from the controlled passby experiment showed that a single passby at 50 mph takes six seconds, as indicated by the duration required for a 10 dB rise and fall as the test vehicle approaches and subsequently drives away from the microphone. Applying the six-second passby duration to 28.21 passbys on RPS and 112.82 passbys off RPS resulted in 4.7% of the hour-long LA_{eq} averaging duration modeled with the compact car RPS hit source energy and 18.8% of the hour modeled with the source energy for the standard compact car passby without hitting the RPS. The latter source was used for all 141.03 passbys in the $LA_{eq}1hr$ model scenario without RPS hits (scenario 6), resulting in 23.5% of the hour containing vehicle source energy. The breakdown of source energy for both scenarios is shown in Figure 15.

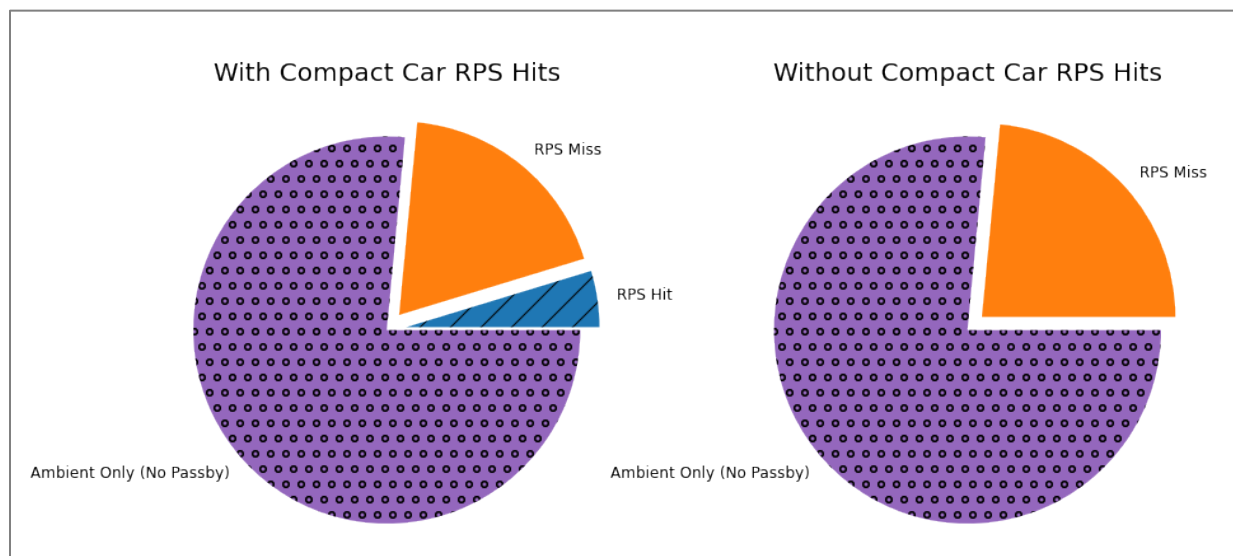


Figure 15. $LA_{eq}1hr$ source energy breakdown, scenarios 5 and 6.
VOLPE / SOPHIE SON

$LA_{eq}1hr$ results presented in this study include the existing non-road ambient LA_{eq} to simulate a real-world roadside acoustic environment. Note that the existing non-road ambient LA_{eq} includes other anthropogenic noise sources present in the environment but not clearly discernible, such as distant aircraft overflights. The overall and spectral LA_{eq} of the existing non-road ambient were established by averaging data from the NATR acoustic environment monitor for times when no passbys were measured. These time periods were determined via visual examination of the measured spectrograms.

⁷ Note that trucks were not included in this model because no measured data were collected to represent anything larger than a pickup truck hauling a trailer in the model's source data. Pickup trucks were not distinguished from cars in the vehicle type traffic study so their representative portion in the vehicle fleet is unknown with no basis for an estimate to use in this modeling effort.

The annotations in Figure 16 illustrate several example time periods throughout the day on May 8th, 2024, during which it is evident that no passby occurred due to the lack of transient spectral data. Ten time periods like these throughout the acoustic environment monitoring duration were selected for averaging to ascertain the existing non-road ambient noise LA_{eq} . A range of relatively loud and quiet time periods were intentionally selected to encompass varied levels of other anthropogenic and wildlife activity, such as cicadas. Care was also taken to represent a breadth of days of the week and times of day. Data measured during Memorial Day weekend was avoided due to possible anomalous anthropogenic activities during this time. The resultant existing non-road ambient equivalent noise level (LA_{eq}) was 49.4 dBA. The resultant existing non-road ambient LA_{eq} spectrum can be found in the [Supplemental Information \(Son 2025b\)](#). The existing ambient sound level (LA_{eq}), including *all* natural and anthropogenic noise sources, during that same time period and prior to RPS installation was 49.6 dBA.

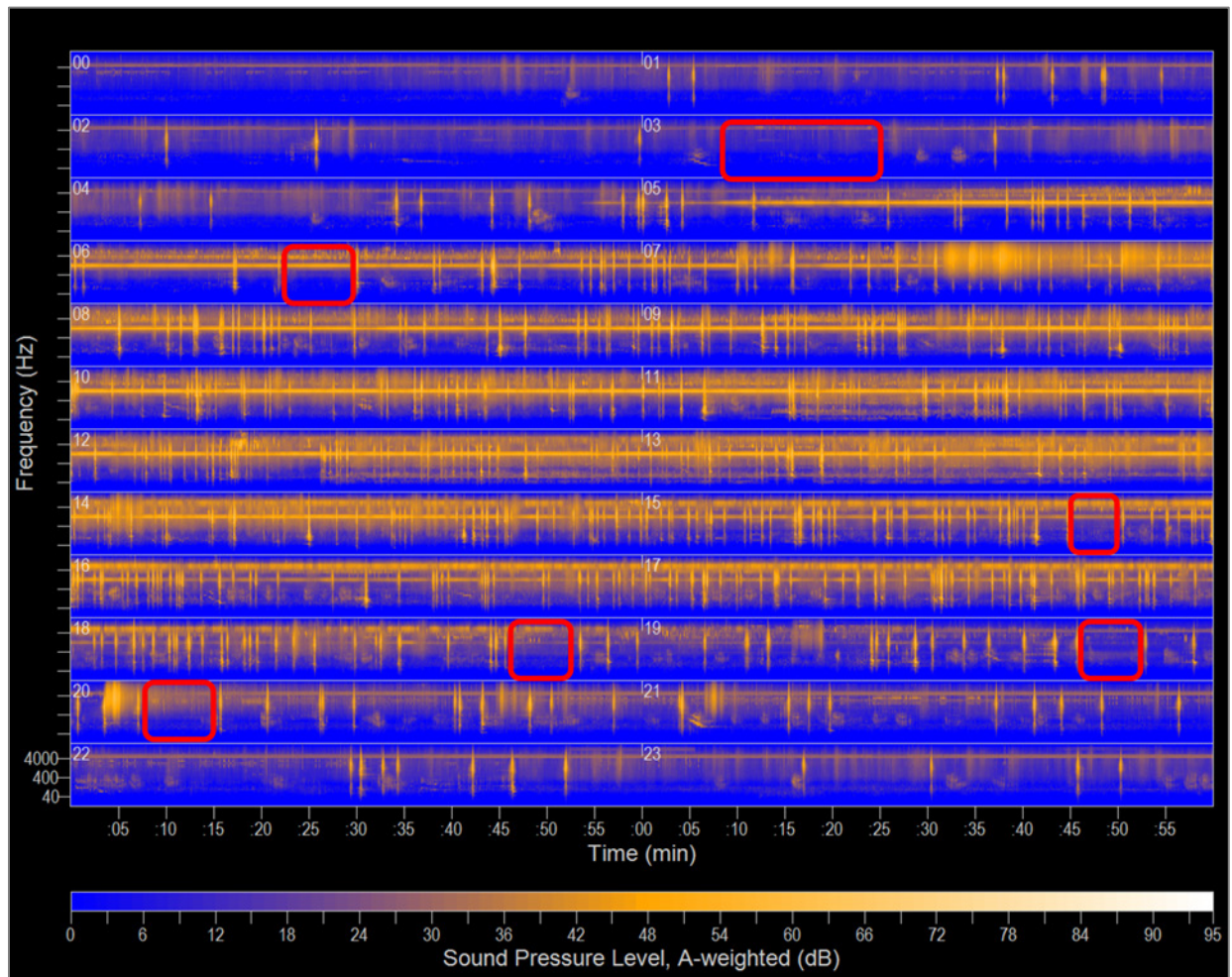


Figure 16. Spectrogram of acoustic environment measurement in NATR on 5/8/24, annotated to highlight time periods without passbys.

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The modeled vehicle source noise and the existing non-road ambient noise level are summed according to the following equation:

$$SPL(f) = 10 \log \left[10^{\frac{E(f)_{mod}}{10}} + 10^{\frac{E(f)_{amb}}{10}} \right]$$

where

$E(f)_{mod}$ = modeled vehicle source sound energy as a function of one-third octave band center frequency

$E(f)_{amb}$ = existing non-road ambient sound energy as a function of one-third octave band center frequency

Modeling Results

The results presented in this section are modeled results from all four receiver locations. The analyses presented in the “Single-Event LAeq” section show noise level results for the modeled roadway sources in isolation (i.e., no other noise source is present). The analyses presented in the “Peak Hour Cumulative LAeq” section demonstrate a more realistic representation of the acoustic environment, which encompasses the modeled roadway sources amongst the existing non-road ambient LAeq. Note that the ambient noise level consists of noise from any natural or anthropogenic source other than the roadway. NSNSD’s thresholds for wildlife sensitivity⁸ and speech interference⁹ are overlaid on the overall noise levels presented in two sets of results as a means to evaluate the modeled results against potential detrimental effects.

Single-Event LAeq

The single-event LAeq predictions shown in Figure 17 show a decrease with distance from the roadway, as expected. The single-event LAeq predicted at the road edge is at least 5 dB greater than the 40 dBA wildlife sensitivity threshold for all vehicle types on and off the RPS. None of the single-event LAeqs for any test vehicle type either on or off the RPS are predicted to be greater than the 60 dBA speech interference threshold, indicating that RPS is likely not impacting speech intelligibility. It is evident that the truck + trailer test vehicle off the RPS is louder than the compact car, even when the compact car hits the RPS at closer distances to the roadway. The truck + trailer test vehicle hitting the RPS is the loudest modeled source at all receiver distances.

⁸ 40 dBA

⁹ 60 dBA

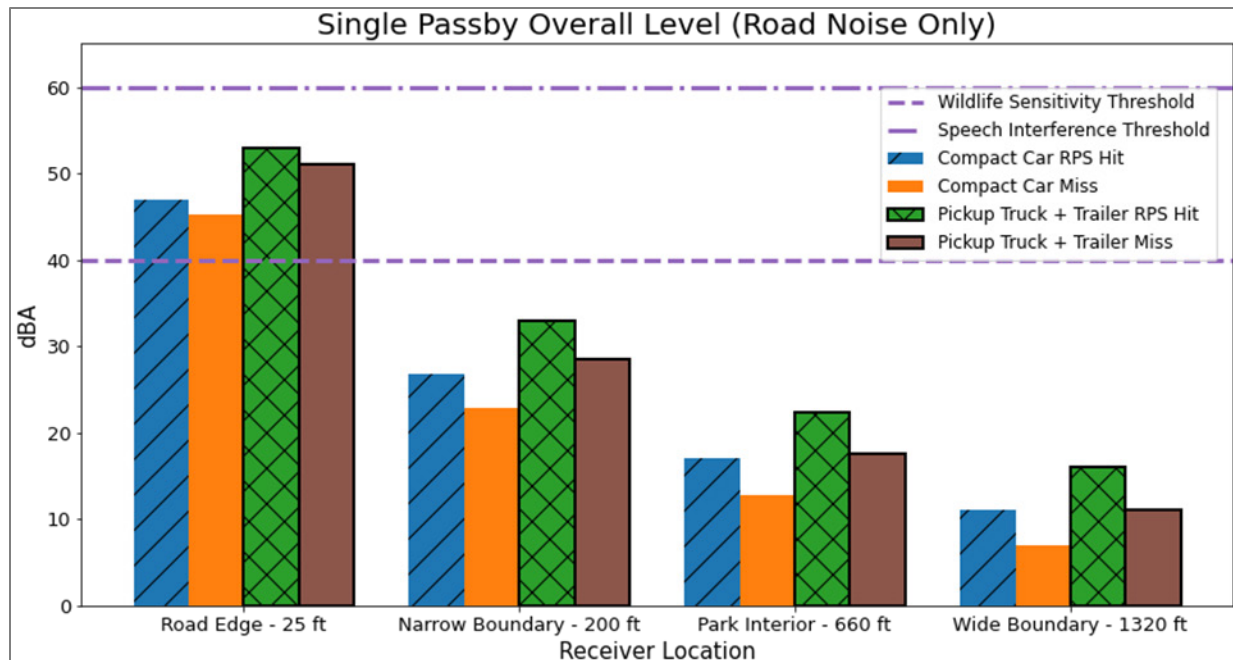


Figure 17. Modeled single-event LA_{eq} by receiver location.

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Figure 18 displays the predicted overall noise level differences between otherwise identical scenarios in which a single vehicle either hits or misses the RPS. The noise level differences are about 2 dB at the road edge and 4–5 dB at farther distances, depending on the vehicle type. Note that a 3 dB difference would be perceptible to the human ear, whereas a 6 dB difference is readily perceptible, and 10 dB difference would be perceived as a doubling of loudness. The truck + trailer test vehicle hitting the RPS produces a greater noise level difference than the compact car. The noise level differences for both test vehicle types increase with distance from the roadway. The noise level difference is especially significant for predictions at distances beyond the road edge. This non-intuitive phenomenon warrants investigation of the spectral differences.

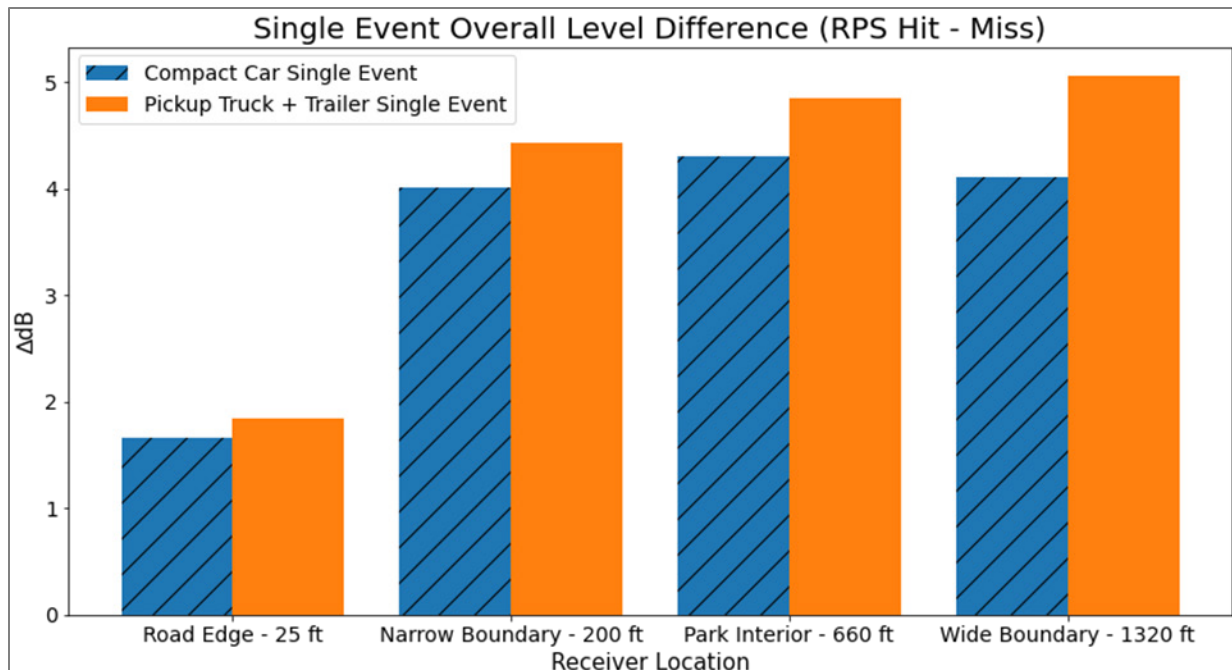


Figure 18. Modeled single-event overall level difference by receiver location.
VOLPE / SOPHIE SON

Figure 19 illustrates the predicted spectral noise levels differences between otherwise identical scenarios in which a single vehicle either hits or misses the RPS. Values above the 0 line indicate when a hit event is louder than a miss event and vice versa for values below 0. Values nearer to 0 indicate smaller differences between hits and misses. At certain 1/3 octave bands, misses can be louder than hits; however, overall, hits are louder than misses (see Figure 17).

There is a clear low frequency (63–315 Hz) difference at all receiver distances with both test vehicle types. Above 1,000 Hz the differences are closer to 0. The difference is more pronounced at lower frequency bands for the truck + trailer test vehicle. The truck + trailer spectral difference peaks at 12.2 ΔdB for 315 Hz at a quarter mile from the roadway, whereas the compact car spectral difference peaks at 7.3 ΔdB for 1,000 Hz at a quarter mile from the roadway. Note that a 3 dB difference would be perceptible to the human ear, whereas a 6 dB difference is readily perceptible, and 10 dB difference would be perceived as a doubling of loudness. As such, both single-event peak spectral differences could be evident as discrete tones at 1,320 feet from the roadway. The low frequency differences increase at greater distances from the roadway because the sound energy generated from RPS hits will travel longer distances without being attenuated.

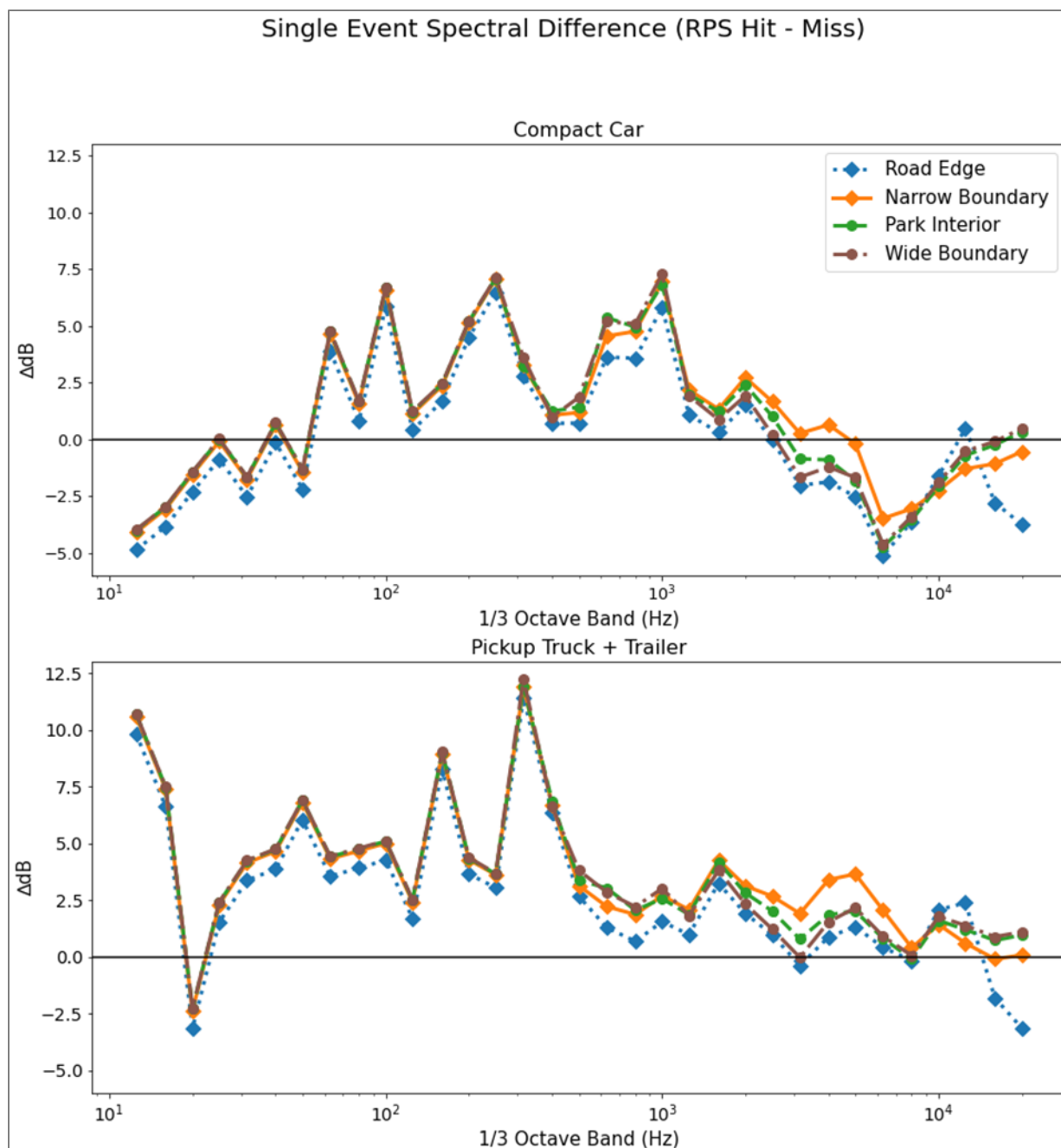


Figure 19. Modeled single-event spectral difference by receiver location.
VOLPE / SOPHIE SON

Peak Hour Cumulative LA_{eq}

As stated above in Figure 15, we consider two modeling scenarios under peak hour traffic. The first is a roadway free of RPS. The second is a roadway with RPS, where RPS noise is present for 4.7% of a typical hour (3 minutes). In both scenarios the overall amount of compact car noise is the same, 23.5% of the typical hour (14 minutes). Figure 20 shows the predicted $LA_{eq,1hr}$ for both scenarios. Because RPS noise is only present for a small amount of a typical hour, it does not influence the

hourly averages. In fact, for both modeling scenarios $LA_{eq,1hr}$ differs by less than 1 dBA at all receiver locations. Truck + trailer passby source energy is not modeled in these scenarios because there are no measured traffic data with which to estimate the unique vehicle's representative proportion of peak hour traffic. $LA_{eq,1hr}$ both with and without RPS hits at all receiver locations are predicted to be between 49 and 50 dBA, which is far greater than the wildlife sensitivity threshold of 40 dBA. Note that the peak hour $LA_{eq,1hr}$ descriptor includes the existing non-road ambient LA_{eq} . This indicates that typical RPS usage does not cause an increase in cumulative impacts to the wildlife's acoustic environment. Note however, the $LA_{eq,1hr}$ predictions likely underestimate the true cumulative impact of typical RPS usage as no vehicles heavier than the compact car test vehicle were included in these models.

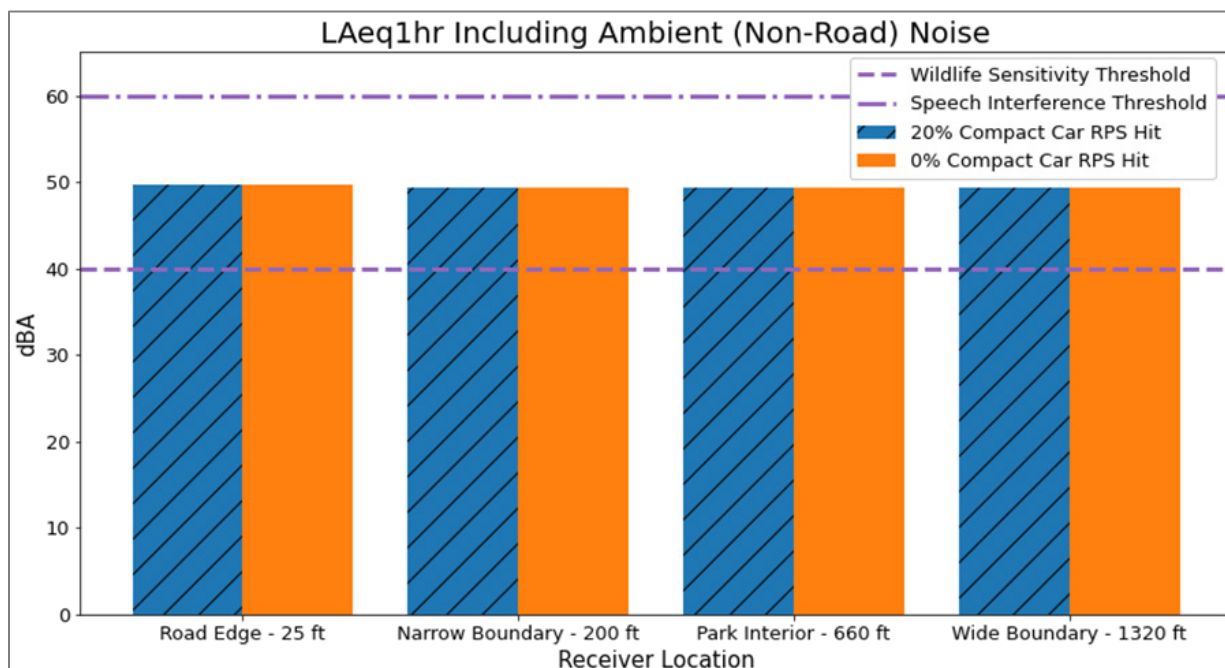


Figure 20. Modeled $LA_{eq,1hr}$ by receiver location.

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Figure 21 displays the predicted $LA_{eq,1hr}$ differences between otherwise identical scenarios in which RPS noise is either present for 0% or 4.7% of a typical hour (3 minutes). In both scenarios, the overall amount of compact car noise is the same, 23.5% of the typical hour (14 minutes). The predicted differences are less than 0.1 dB at all distances from the roadway. This imperceptibly small noise level difference compared to the significant noise level difference shown in Figure 18 for the single events is due to the low peak hour traffic in the measurement corridor of NATR (152 cars per hour compared to the base capacity of 1850 passenger cars per lane per hour, according to the governing equations in the Highway Capacity Manual. Note that more urban areas of NATR observe peak hour traffic counts of 1,000–1,800, although the lower volume rural scenario modeled in this report is representative of a majority of the Parkway. Figure 15 shows that the majority of the modeled peak hour consists only of the existing non-road ambient LA_{eq} , during which no passbys

occur. The negligible difference in the overall predicted noise levels when considering the entire noise environment warrants investigation of the spectral differences.

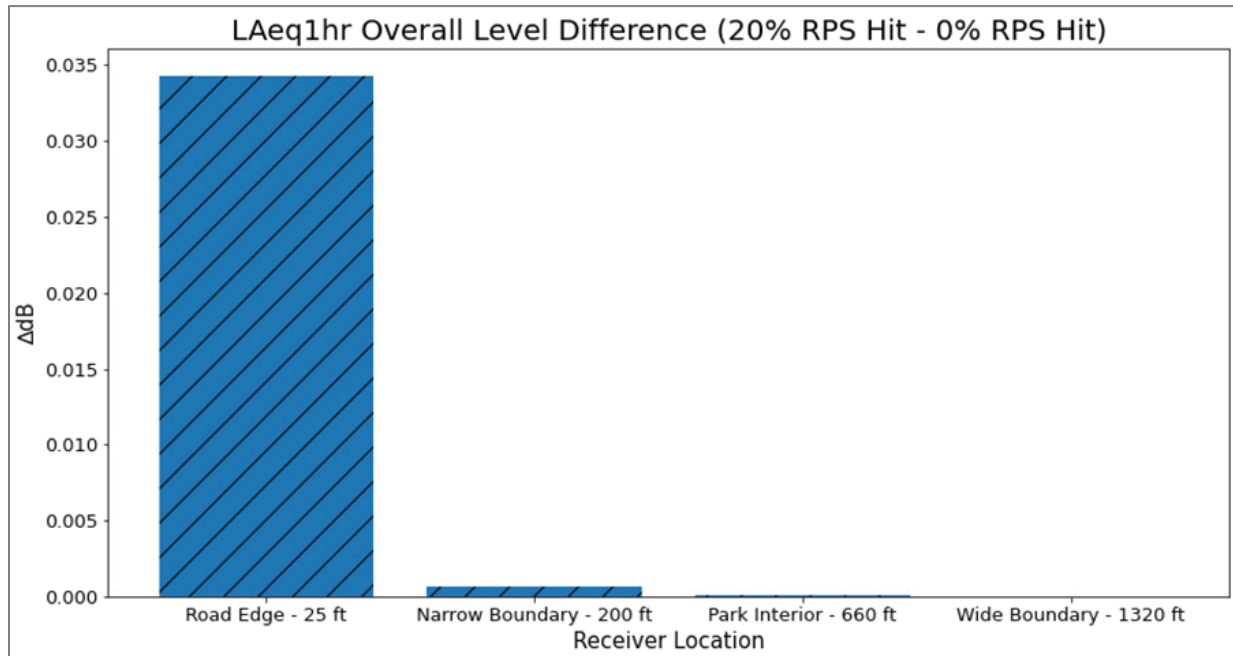


Figure 21. Modeled overall LA_{eq}1hr difference by receiver location.

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Figure 22 illustrates the predicted spectral noise levels differences between otherwise identical scenarios in which RPS noise is either present for 0% or 4.7% of a typical hour (3 minutes). In both scenarios, the overall amount of compact car noise is the same, 23.5% of the typical hour (14 minutes). There are small low frequency differences closer to the roadway, with a peak of 1.2 ΔdB at the road edge at 315 Hz. The significant spectral differences observed between the compact car single-event scenarios shown in the top panel of Figure 19 are greatly diminished in Figure 22 because the LA_{eq}1hr computation is dominated by the existing non-road ambient LA_{eq} spectra during the majority of the hour in which no compact car passbys occur. The true low frequency difference is likely greater than predicted here due to the spectral contribution from vehicles heavier than the compact car that were not modeled.

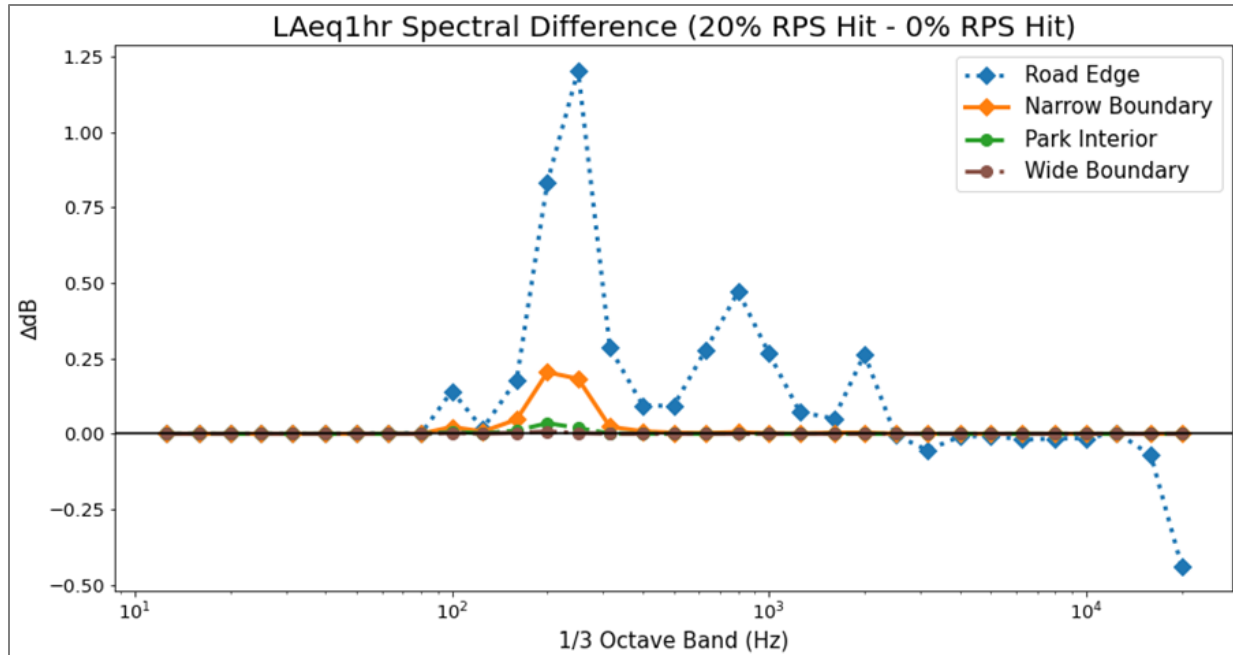


Figure 22. Modeled $LA_{eq}1hr$ spectral difference by receiver location.

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Conclusions

Figure 19 and Figure 21 indicate that hitting the RPS meaningfully alters the acoustic environment on a single-event spectral level, but not when examining the cumulative effects over longer timeframes, such as hours. In other words, the RPS is not making the overall long-term noise environment louder, but distinct events and tones from drivers hitting the RPS might be heard hundreds of feet from the roadway and may cause in short-term effects such as wildlife fleeing or increased vigilance or disruptions to the visitor experience. Note that the conclusion regarding long-term noise levels assumes an RPS hit rate of 20% with an increase of $LA_{eq}1hr$ at less than 1dB along the roadside (and even less the further away from the road). More vehicles hitting the RPS would have a greater impact on the cumulative overall noise level. This also assumes a constant existing non-road ambient noise spectrum, which does not reflect the real-world instantaneous fluctuations of both anthropogenic and natural noise sources.

Discussion

It is possible that tonal components of single passbys on the RPS could be audible amidst the existing non-road ambient noise, even at far distances from the roadway. The modeled single-event truck + trailer spectral difference peaked at 12.2 Δ dB for 315 Hz at a quarter mile from the roadway, whereas the modeled single-event compact car spectral difference peaked at 7.3 Δ dB for 1,000 Hz at a quarter mile from the roadway. Note that a 3 dB difference would be perceptible to the human ear, whereas a 6 dB difference is readily perceptible, and 10 dB difference would be perceived as a doubling of loudness. As such, both single-event peak spectral differences could be evident as discrete tones at 1,320 feet from the roadway. It has long been understood that low-level, infrequent, tonal intrusions which may not exceed the ambient sound level in terms of the overall, A-weighted level, can be audible and disproportionately annoying. Audibility and perception for any receiver at a given time will depend on the existing non-road ambient noise amplitude and spectrum, which can fluctuate greatly. For a given location in NATR, the composition of existing non-road ambient LA_{eq} will vary by time of day as well as by season or year according to anthropogenic and wildlife level of activity. For example, aircraft overflight noise will be concentrated during daytime hours. Cicadas are a significant sound source in the area during the summers, especially in years with large broods. Varied land use adjacent to the 444-mile extent of NATR will also dictate the existing non-road ambient noise LA_{eq} . Rural areas will have lower existing non-road ambient noise due to the smaller contribution from anthropogenic activity, in which the case individual passbys on the RPS will likely be more audible than in urban areas. Because the existing non-road ambient LA_{eq} is driven by time and location, any suggestions of audibility based on overall levels presented in this report are not conclusive nor applicable to the whole of NATR.

Sound levels at far distances from the roadway will also depend on the ground cover, which may differ throughout NATR. Acoustically soft ground cover like grass will attenuate (reduce) more noise per distance, whereas harder surfaces like densely packed soil will allow more source noise to propagate farther from the roadway. Vehicle weight will change the source characteristics such that heavier vehicles hitting the RPS will produce lower frequency noise that is less likely to attenuate (decrease) over long distances. This is evidenced in Figure 19 in which the truck + trailer noise displays louder and lower spectral content than the compact car. Only the low frequency tones from the truck + trailer hitting the RPS can be seen above the existing non-road ambient noise a quarter mile from the roadway. This phenomenon would likely be even greater for larger vehicle types such as medium and heavy trucks that were not modeled in this study due to lack of data. Areas of NATR with significant medium and heavy truck traffic will likely experience more noise from individual RPS hits at farther distances from the roadway.

Figure 20 through Figure 22 show that RPS hits have little effect on the long-term, cumulative acoustic environment including the existing non-road ambient noise at distances beyond the road edge. However, the spectral content of the $LA_{eq}1hr$ noise level difference would certainly change if given the ability to model a more robust estimation of the vehicle fleet. Beyond the handful of heavier trucks that were left out of the peak hour traffic model, most standard automobiles are

heavier than the compact car test vehicle. This is especially true of more modern vehicles due to the recent proliferation of SUVs. The amplitude of the LA_{eq1hr} noise level difference would likely increase if more vehicles hit the RPS. This could happen on a curvier road where a larger proportion of the same number of vehicles are more likely to drift their lane position, as may be the case along certain corridors of NATR. A busier section of NATR with more passbys per hour could result in more vehicles hitting the RPS if the assumed 20% hit rate is maintained. However, more passbys on the RPS doesn't guarantee a greater impact on the overall noise environment. The speed at which vehicles hit the RPS would dictate the amplitude of the noise level difference such that more passbys on the RPS at a slower speed may actually decrease the cumulative noise level, whereas fewer passbys on the RPS at a faster speed could increase the cumulative noise level. As such, vehicle fleet mix, roadway alignment, traffic volume, posted speed limit, and driver behavior (e.g., excessive speeding, distraction, etc.) should be considered when determining RPS installation locations. Roadways with higher traffic volumes and travel speeds than that which was modeled in this study will likely result in greater impacts from drivers hitting the RPS.

This study is based on measurements from passbys on a specific RPS installation along NATR. The modeled results may not be indicative of future RPS installations due to the idiosyncrasies of RPS construction. Figure 23 and Figure 24 show that the dimensions of individual stripes are inconsistent, differing in length by 40%. Inconsistent stripe length varies the spacing between the stripes, which alters the frequency content of a passby on the RPS. This inconsistency applies more to the center line striping than the edge line striping (Figure 3) due to the construction methods. The placement of edge stripe is automated whereas the center line stripe requires a more manual application due to variability in stripe types (i.e., solid vs. dashed).



Figure 23. NATR RPS installation example 1.
NPS / KELSEY WHITE



Figure 24. NATR RPS installation example 2.
NPS / KELSEY WHITE

This study leaves several variables unexplored that are worth investigating in future research. The passby data measured at 100 feet were not examined to validate the model's noise predictions and propagation conditions for this study, which may affect the results. Subsequent studies should consider measuring different vehicle types, particularly heavier vehicles such as SUVs, vans, buses, and semi-trucks that are more likely to have a meaningful effect on the noise environment. All test vehicle types should be measured at multiple travel speeds, both above and below the 50 mph focus of this study. Future modeling should examine the effect of higher traffic volumes, higher RPS hit rates, and/or higher existing non-road ambient LA_{eq} to simulate the conditions in more populated urban areas. Lower existing non-road ambient LA_{eq} could also be modeled to represent a similar rural area to this study, during a year with a less active cicada population. Models could also investigate propagation of RPS noise through different paths, including over harder ground types than the grass in this study and through forested areas. Further research could also explore the effect of single-event noise level differences caused by the RPS on wildlife experience.

Literature Cited

- Environmental Protection Agency. 1974. Information on Levels of Noise Requisite to Protect the Public Health and Welfare with an Adequate Margin of Safety, Washington, District of Columbia.
- Environmental Protection Agency. 2024. Highlights of the Automotive Trends Report. Ann Arbor, Michigan.
- Federal Highway Administration. Procedures for Abatement of Highway Traffic Noise and Construction Noise. United States Code of Federal Regulations, Part 772 (23 CFR 772).
- Fidell, S., S. Teffeteller, R. Horonjeff, and D. M. Green. 1979. Predicting Annoyance from Detectability of Low-Level Sounds. *Acoust. Soc. Am.*, 66:5.
- Hastings, A., and S. Son. 2024. Technical Manual Traffic Noise Model 3.2. Federal Highway Administration. Washington, District of Columbia.
- Lee, C. S. Y., and G. G. Fleming. 1996. Measurement of Highway Related Noise, Report No. FHWA-PD-96-046. U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, Massachusetts.
- Lynch, E., D. Joyce, and K. Fristrup. 2011. An assessment of noise audibility and sound levels in U.S. National Parks. *Landscape Ecol.* 26:1297–1309.
- National Academies of Sciences, Engineering, and Medicine. 2022. Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis. Washington, DC: The National Academies Press. <https://doi.org/10.17226/26432>
- Shannon, G., L. M. Angeloni, G. Wittemyer, K. M. Fristrup, and K. R. Crooks. 2014. Road traffic noise modifies behavior of a keystone species. *Anim Behav.* 94:135–141.
- Son, S. 2025a. Natchez Trace Parkway: TNM Input Reports. Supplemental unpublished report available at: <https://irma.nps.gov/DataStore/Reference/Profile/2310278>
- Son, S. 2025b. Natchez Trace Parkway: Values of Noise & Ambient Conditions. Supplemental tabular dataset available at: <https://irma.nps.gov/DataStore/Reference/Profile/2310528>

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