Cross-Spectrum Acoustics

Cross-Spectrum Acoustics Inc.

Massachusetts

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California

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Mike Renshaw, ICMA-CM, MPA
Town Manager
Town of Falmouth
59 Town Hall Square
Falmouth, MA 02540

Project Reference: J2024-1770 – Falmouth Pickleball Noise Assessment

Dear Mr. Renshaw:

At the request of the Town of Falmouth, MA, Cross-Spectrum Acoustics Inc. (CSA) conducted a noise assessment of the planned new pickleball facility at three potential locations. The purpose of the study was to assess noise from the use of the planned future pickleball courts relative to current ambient background noise conditions for comparison with applicable criteria.

Introduction

We understand that the Town of Falmouth, MA is planning to construct a new pickleball facility with 16 courts at one of three possible locations: Trotting Park, the town-owned parcel on Thomas B. Landers Road, or the town-owned parcel on Nathan Ellis Highway (Rt-151). Earlier preliminary work by Stantec was conducted at the Trotting Park location and a potential layout of 16 pickleball courts was identified at that time. Additionally, ambient noise measurements were previously conducted by Acentech at the Trotting Park location.

The following report summarizes the applicable noise basics, noise criteria, ambient noise measurements, reference pickleball noise measurements, other recreation activity noise measurements, pickleball noise assessment, and mitigation options. A section on acoustical descriptors used in this report is included in Appendix A. Measurement site photographs are included in Appendix B.

Noise Basics

Sound is defined as small changes in air pressure above and below the standard atmospheric pressure and noise is usually considered to be unwanted sound. The three parameters that define noise include:

- **Level**: The level of sound is the magnitude of air pressure change above and below atmospheric pressure and is expressed in decibels (dB). Typical sounds fall within a range between 0 dB (the approximate lower limit of human hearing) and 120 dB (the highest sound level generally experienced in the environment). A 3 dB change in sound level is perceived as a barely noticeable change outdoors and a 10 dB change in sound level is typically perceived as a doubling (or halving) of loudness.

- **Frequency**: The frequency (pitch or tone) of sound is the rate of air pressure changes and is expressed in cycles per second, or Hertz (Hz). Human ears can detect a wide range of frequencies from about 20 Hz to 20,000 Hz; however, human hearing is less sensitive at high and low frequencies, and the A weighting system (dBA) is used to obtain a single-number descriptor that correlates with human response to noise. The A-weighted sound level has been widely adopted by acousticians as the most appropriate descriptor for environmental noise.

- **Time Pattern**: Because environmental noise changes continuously, it is sometimes convenient to describe a particular noise event or source in terms of its maximum sound level (L_{max} or L_{Amax}). While the maximum sound level is useful in describing one aspect of an event or noise source, it provides no information on the duration of the event or the cumulative exposure to a noise source. A common way to account for the cumulative exposure is to express the energy-average of the actual time-varying sound level over a period of time as a single number, called the "equivalent" sound level (L_{eq} or L_{Aeq}). The L_{eq} is the constant or "equivalent" sound level that would contain the same amount of sound energy as the time-varying sound level over the same period. Due to the logarithmic addition of noise sources described above, L_{eq} is influenced strongly by the loudest events that occur during a particular period. Because the L_{eq} represents the changing sound level over a specific interval, such as one hour, it is important that the time period be expressed or understood when using the metric.
  For assessing the noise impact of some projects at residential land use, the Day-Night Sound Level (L_{dn}) is the noise descriptor commonly used as the best way to describe how people respond to noise in their environment. L_{dn} is a 24-hour cumulative A-weighted noise level that includes all noise that occurs during the day, with a 10-dB penalty for nighttime noise (10:00 PM to 7:00 AM). This nighttime penalty means that any noise event at night is equivalent to ten similar events during the daytime.

In addition to the L_{eq} and L_{dn}, there are other metrics used to describe environmental noise:

- **L_{max}**: The loudest one second of noise over a measurement period, or maximum A-weighted sound level (L_{max}), is used in many local and state ordinances for noise emitted from private land uses and for construction noise impact evaluations. L_{max} sound levels can be quantified using a meter set for a 1-second exponential delay period (L_{max} "slow" or L_{ASmax}) or a 0.125-second exponential delay period (L_{max} "fast" or L_{AFmax}). L_{AFmax} is often used to characterize impulsive sound events such as pickleball paddle strikes.

- **L_n**: Environmental noise can also be viewed on a statistical basis using percentile sound levels (L_n) which refer to the sound level exceeded "n" percent of the time. For example, the sound level exceeded 33 percent of the time, denoted as L_{33}, is often found to approximate the L_{eq} in the absence of loud intermittent noises (e.g., from trains or aircraft) and the sound level exceeded 90 percent of the time, denoted as L_{90}, is often used to represent the "background" noise in a community.

- **L_{eq}**: The "equivalent" sound level over a time period, typically 1 hour or 24-hours. It is the level of steady sound that has the same energy as a fluctuating sound measured over the same time period. L_{eq} is indicative of the average sound level during the measurement period.

Noise Criteria

Town of Falmouth Regulation:

The Town of Falmouth does not have a detailed noise ordinance that includes noise limits. Chapter 150, Article 1: Excessive, Loud and Unusual Noises states:

It shall be unlawful for any person or persons occupying or having charge of any building or premises or any part thereof in the Town, other than that section of any establishment licensed under MGL C. 138, to cause or suffer or allow any unnecessary, loud, excessive or unusual noises in the operation of any radio, phonograph or other mechanical soundmaking device or instrument, or reproducing device or instrument, or in the playing of any band, orchestra, musician or group of musicians, or in the use of any device to amplify the aforesaid, or the making of loud outcries, exclamations or other loud or boisterous noise or loud and boisterous singing by any person or group of persons or in the use of any device to amplify the aforesaid noise, where the noise is plainly audible at a distance of one hundred and fifty (150) feet from the building, structure, vehicle or premises in which or from which it is produced. The fact that the noise is plainly audible at a distance of one hundred and fifty (150) feet from the vehicle or premises from which it originates shall constitute prima facie evidence of a violation of this chapter.

Chapter 150, Article 2: Responsibilities of Persons on Premises states:

It shall be unlawful for any person or persons being present in or about any building, dwelling, premises, shelter, boat or conveyance or any part thereof, other than that section of any establishment licensed under MGL C. 138, who shall cause or suffer or countenance any loud, unnecessary excessive or unusual noises in the operation of any radio, phonograph or other mechanical soundmaking device, or instrument, or reproducing device or instrument, or in the playing of any band, orchestra, musician or group of musicians, or the making of loud outcries, exclamations or other loud or boisterous noise or loud and boisterous singing by any person or group of persons, or in the use of any device to amplify the aforesaid noise, where the aforesaid noise is plainly audible at a distance of one hundred fifty (150) feet from the building, dwelling, premises, shelter, boat or conveyance in which or from which it is produced. The fact that the noise is plainly audible at a distance of one hundred fifty (150) feet from the premises from which it originates shall constitute prima facie evidence of a violation of this Article. Any person shall be deemed in violation of this Article who shall make, or aid, or cause, or suffer, or countenance, or assist in the making of the aforesaid and described improper noises, distance, breach of peace and the presence of any person or persons in or about the building, dwelling, premises, shelter, boat or conveyance or any part thereof during a violation of the Article shall constitute prima facie evidence that they are a countenancer to such violation.

Massachusetts Department of Environmental Protection Noise Policy:

The Massachusetts Department of Environmental Protection (Mass DEP) has implemented a noise control policy based on 310 Code of Massachusetts Regulations 7.10. The Mass DEP noise policy criteria are typically used to assess impact from noise sources on projects requiring DEP permitting of industrial facilities. However, in lieu of other applicable noise limits and only to provide a frame of reference, the DEP noise criteria have been used in this assessment.

A noise source will be considered to be violating the Department's noise regulation (310 CMR 7.10) if the source:

1. *Increases the broadband sound level by more than 10 dB(A) above ambient, or*
2. *Produce a "pure tone" condition – when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 decibels or more.*

The Mass DEP noise policy specifies that a broadband noise source must not increase the background noise levels (where the background noise level is characterized by the 90th percentile sound level[1] , L_{90}) by 10 dB or more as measured at the property line.

The Mass DEP also has a frequency-based noise impact criterion that limits "pure tone" conditions, where a pure tone is defined as an octave[2] band sound level that is 3 dB higher than adjacent frequency bands.

Ambient noise typically fluctuates with the time of day and with the day of the week. Lower noise levels are typically, though not always, observed at night-time and on weekends. Therefore, Mass DEP guidelines require that ambient measurements capture existing noise levels during the quietest periods that encompass potential future pickleball operating hours. Nighttime is typically defined as between the hours of 10 PM and 7 AM for the purposes of noise assessments. The operating hours of the future pickleball courts are not currently known.

Ambient Noise Measurements

An ambient background noise measurement survey was conducted at all three potential pickleball facility study areas. Noise monitoring equipment was deployed on Sunday, June 1 and retrieved on Friday, June 6. Figures 1, 2, and 3 show the noise measurement sites at the three study areas. The figures include parcel lines and building outlines from available Falmouth and Massachusetts GIS databases.

Figure 1 shows the ambient noise measurement locations at Trotting Park. The original layout drawing[3] of the 16 pickleball courts has been georeferenced and placed over the aerial imagery in the figure. The figure shows the three ambient noise measurement sites labeled N1, N2, and N3. N1 is located near the residential property line of residences at 18-20 Woodview Drive to the south. Site N2 is located near the property line of residences to the east near 108 Trotting Park Road. Site N3 is located near the property line of the multi-family development to the west at 30 Pine Valley Drive.

Figure 2 shows the ambient noise measurement locations at the Thomas B Landers Road location. The original Trotting Park pickleball courts layout drawing has been overlaid onto this location map for the purpose of this noise study. CSA assumed that the same layout and configuration of 16 pickleball courts would be used and that the courts would be approximately centered within this town-owned parcel. The figure shows noise measurement sites N4 to the west and N5 to the east. Site N4 was chosen to represent the ambient noise conditions at the residence to the west at 225

[1] L_{90} is the sound level that is exceeded 90% of the time during the measurement period. L_{90} is the metric commonly associated with the background noise and is used by Mass DEP to assess background noise.
[2] An octave band is a range of frequencies where the upper frequency limit is twice the lower frequency limit. For example, the frequency range of 25 Hz to 50 Hz is one octave. Octave bands are identified by their "center" frequencies.
[3] "Trotting Park Pickleball Courts", Stantec, August 2023

Thomas B Landers Road. Site N5 was chosen to represent the ambient noise conditions at the residence to the east at 254 Turner Road.

Figure 3 shows the ambient noise measurement locations at the Nathan Ellis Highway location. The town-owned parcel at this location was sufficiently large so it was not clear where the pickleball courts would potentially be located, and the location of the courts within the parcel would greatly affect the results of the noise assessment due to varying distances to nearby residential land use. For the purpose of the noise study, CSA assumed that the same layout and configuration of 16 pickleball courts would be used, and two potential placements of those courts were assumed. One option assumed the pickleball courts would be located in the northwest corner of the parcel and is referred to as the "Ellis Highway-A" location in the noise assessment section below. The second option assumed the pickleball courts would be located in the southwest area of the parcel and is referred to as the "Ellis Highway-B" location in the noise assessment section below.

Noise measurement site N6 was located near the Ellis Highway-A courts location and was chosen to represent the nearby residence on the opposite side of the road at 340 Nathan Ellis Highway to the north. N6 was positioned to be a similar setback distance from Nathan Ellis Highway as these residences so that the traffic noise would be comparable. Measurement site N7 was located near the Ellis Highway-B courts location and was chosen to represent the nearby residences to the southeast at a similar setback distance from Nathan Ellis Highway as the residence at 17 Esker Place.

The acoustical measurements were conducted with NTi Audio model XL2 noise monitors that conform to American National Standard Institute (ANSI) Standard S1.4 for Class 1 sound level meters. Field calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were conducted in the field before and after each set of measurements using an acoustical calibrator. In all cases, the measurement microphone was protected by a windscreen and supported on a tripod at a height of four to six feet above the ground and was positioned to characterize the exposure of the site to the dominant noise sources in the area.

A portable weather monitoring station was also deployed at site N1. The weather monitoring station recorded temperature, humidity, wind speed, and wind direction.

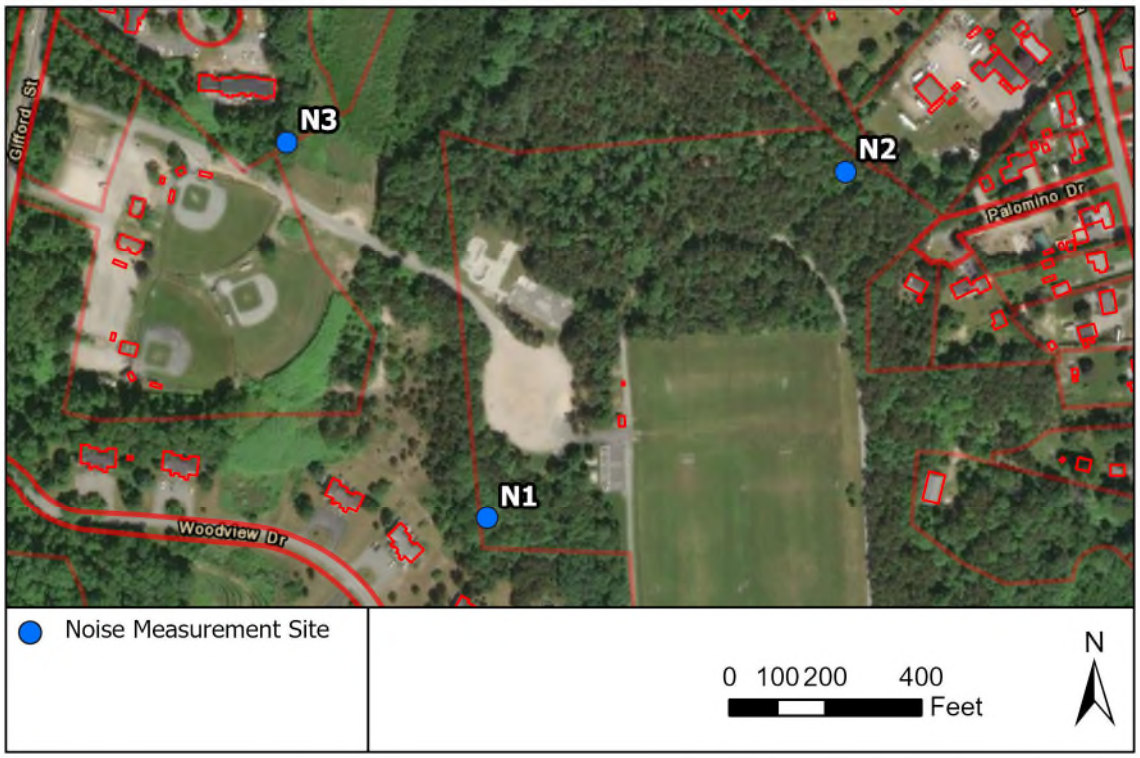


Figure 1. Trotting Park Noise Measurement Locations

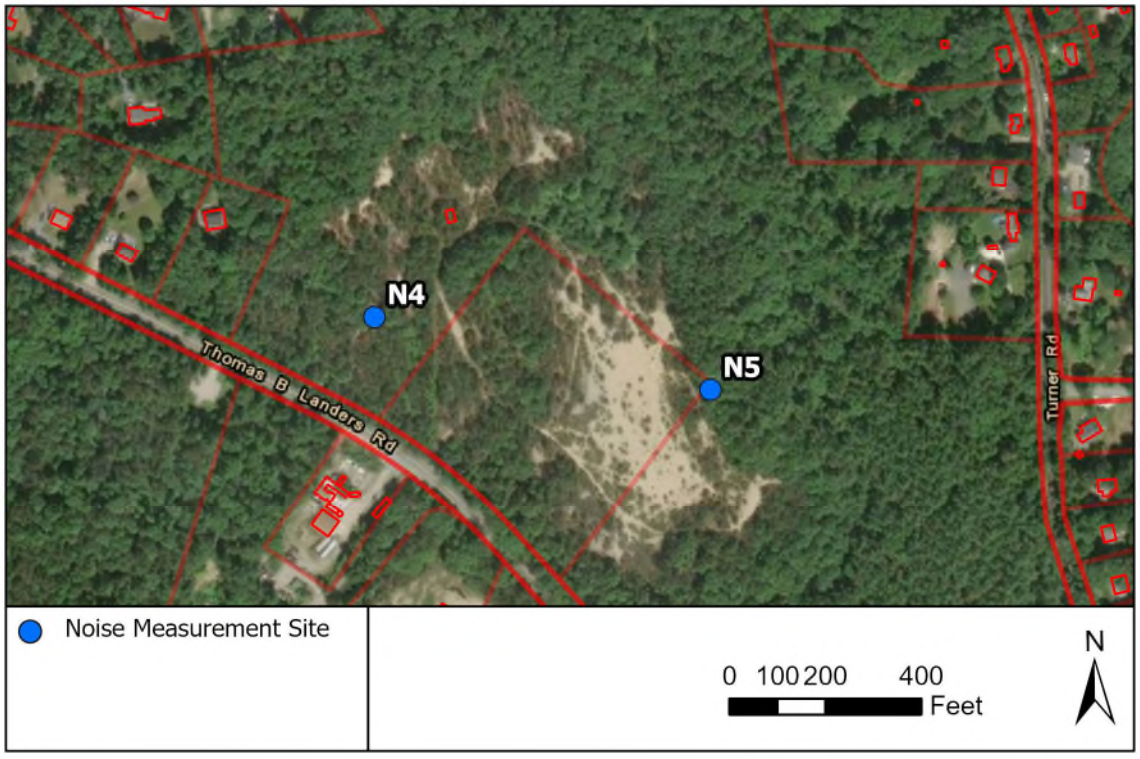


Figure 2. Thomas B. Landers Road Noise Measurement Locations

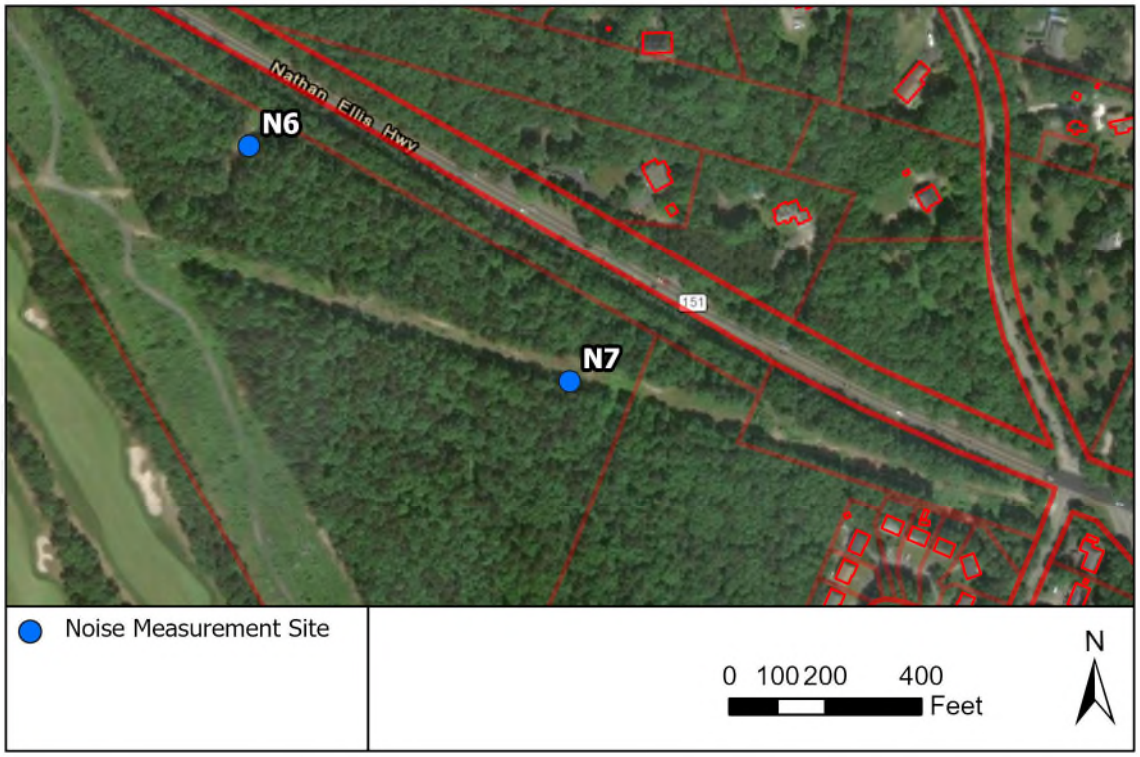


Figure 3. Nathan Ellis Highway Noise Measurement Locations

Ambient Noise Measurement Results

Figures 4 through 10 show the hourly ambient noise measurement results at site N1 through N7 respectively. The plots summarize the measured ambient hourly L_{eq}, L_{max}, L_1, L_{10}, L_{33}, and L_{90}. The percentile metrics represent the noise level exceeded 1 percent, 10 percent, 33 percent, and 90 percent of the time respectively. These low percentile metrics (L_1, L_{10}) are typically used to assess the noise levels of loud, repetitive events (such as pickleball strikes). The medium percentile metrics (L_{33}) represent the average noise level of more regular, continuous events, such as traffic or engine noise. The high percentile metrics such as L_{90} are representative of the lowest noise levels during a measurement period.

Photographs of the noise monitoring sites are included in Appendix B.

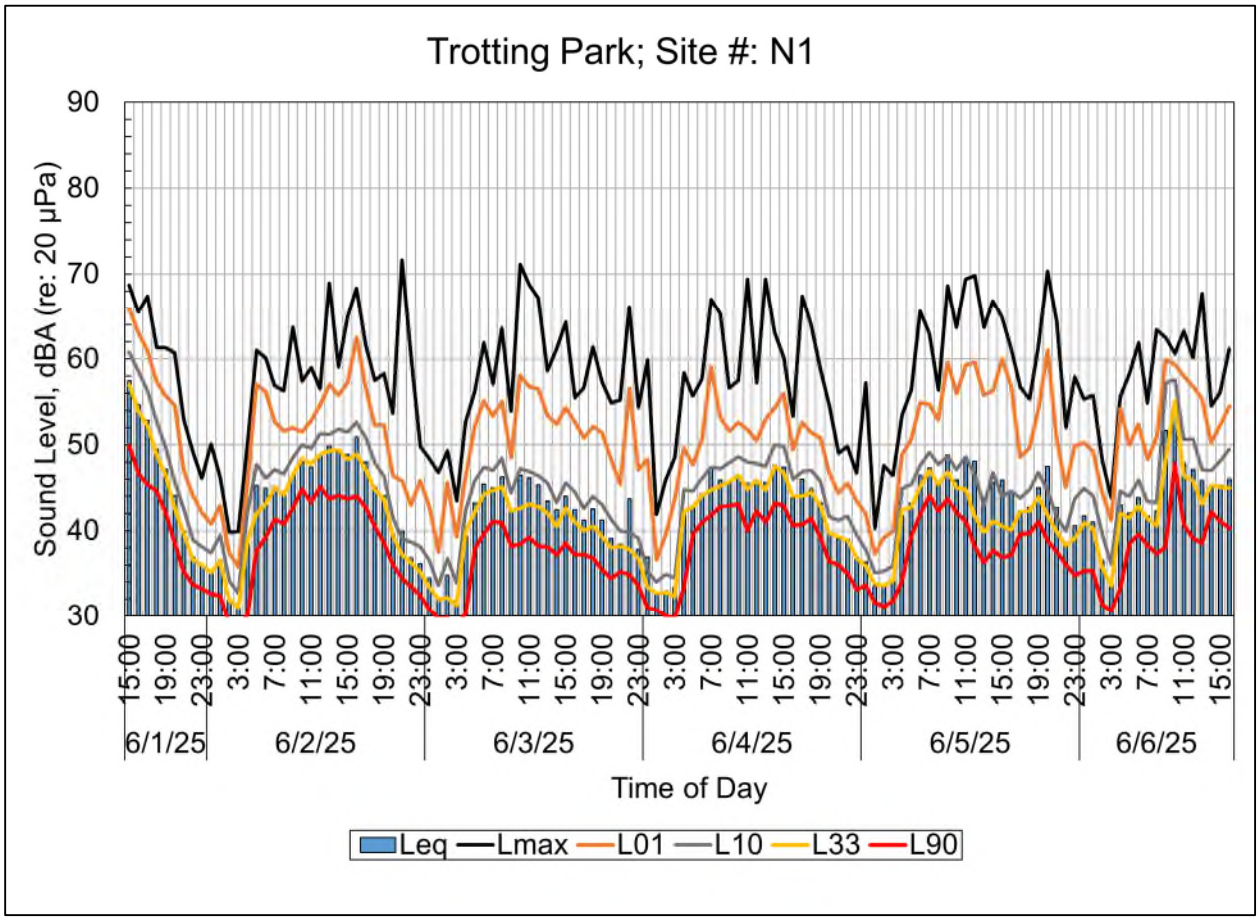


Figure 4. Trotting Park Site N1 Ambient Noise Measurement Results

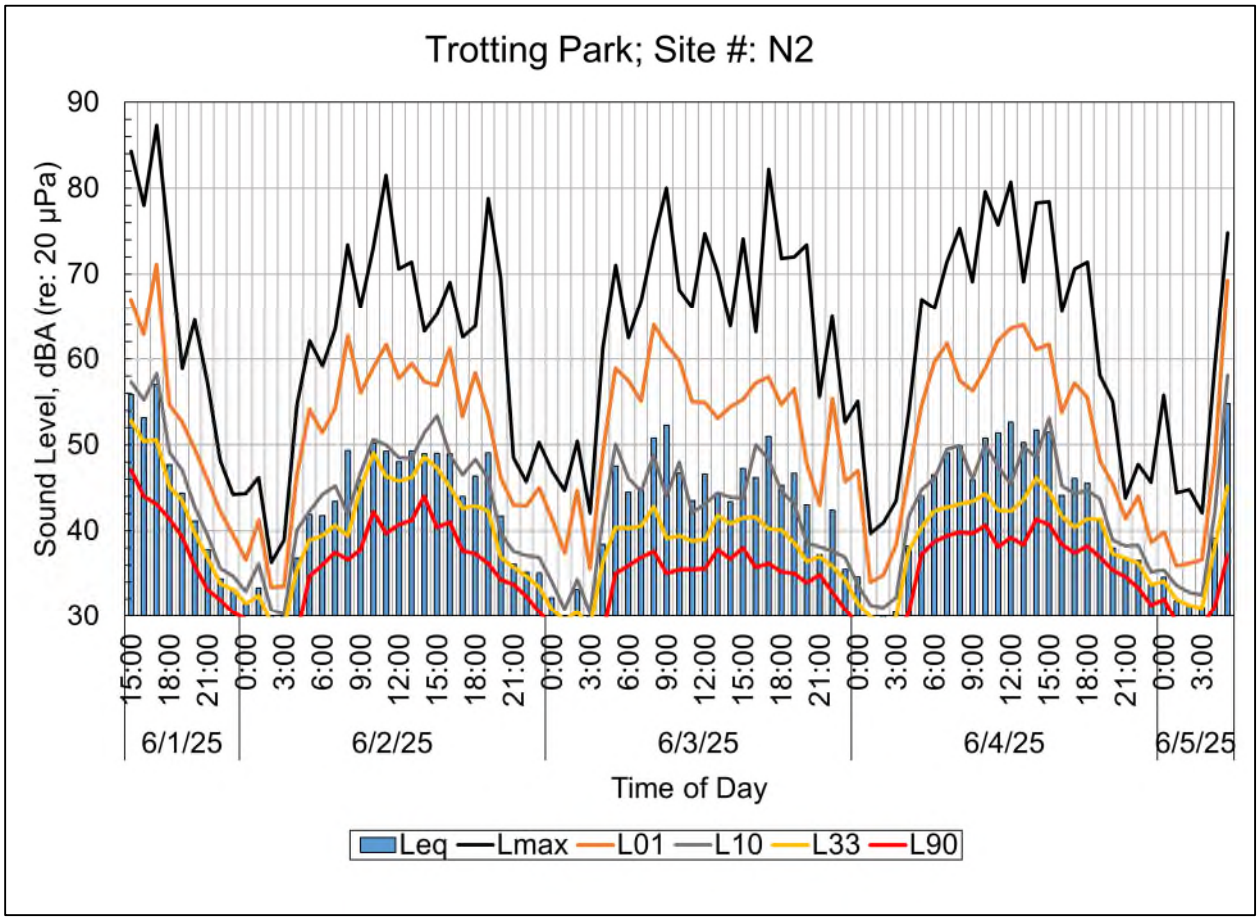


Figure 5. Trotting Park Site N2 Ambient Noise Measurement Results

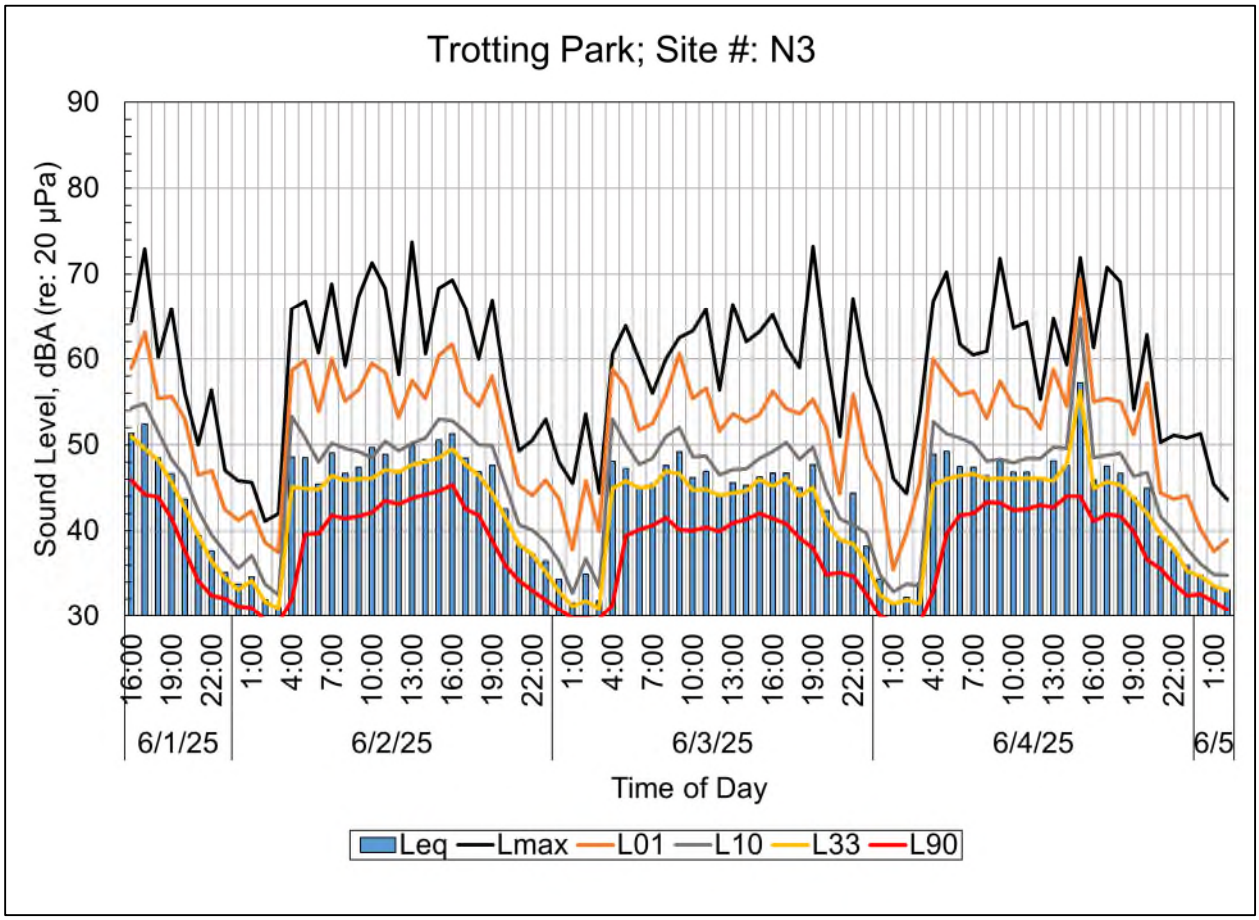


Figure 6. Trotting Park Site N3 Ambient Noise Measurement Results

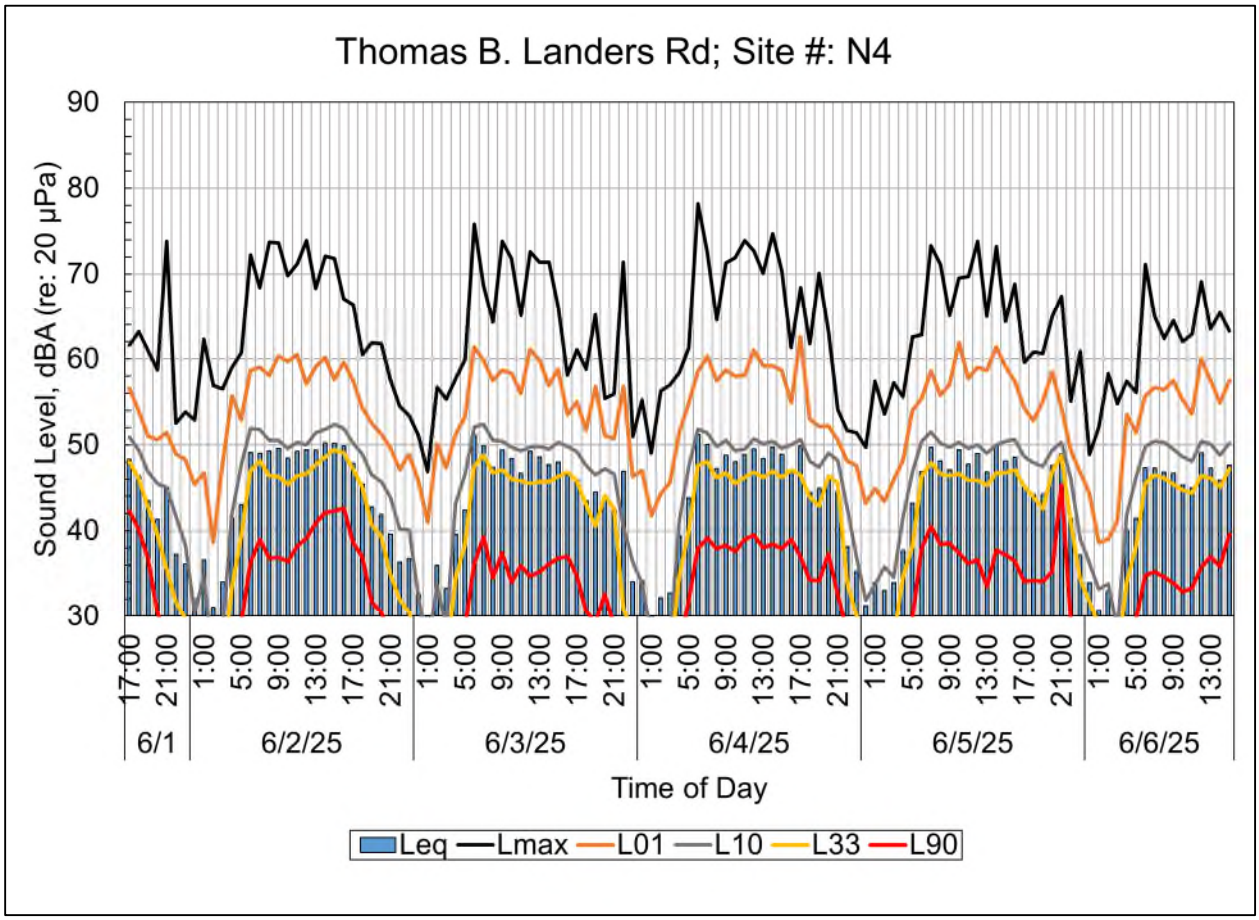


Figure 7. Landers Road Site N4 Ambient Noise Measurement Results

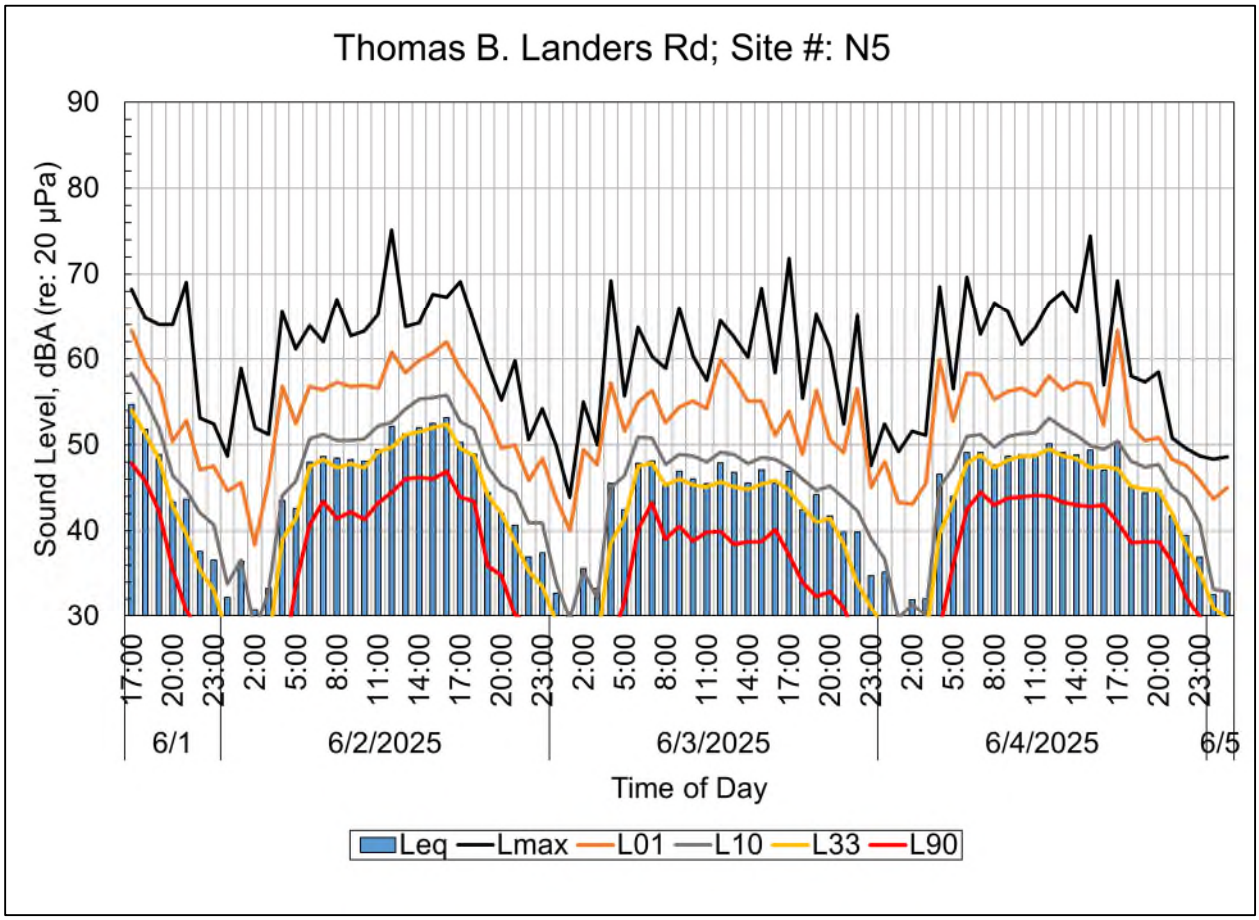


Figure 8. Landers Road Site N5 Ambient Noise Measurement Results

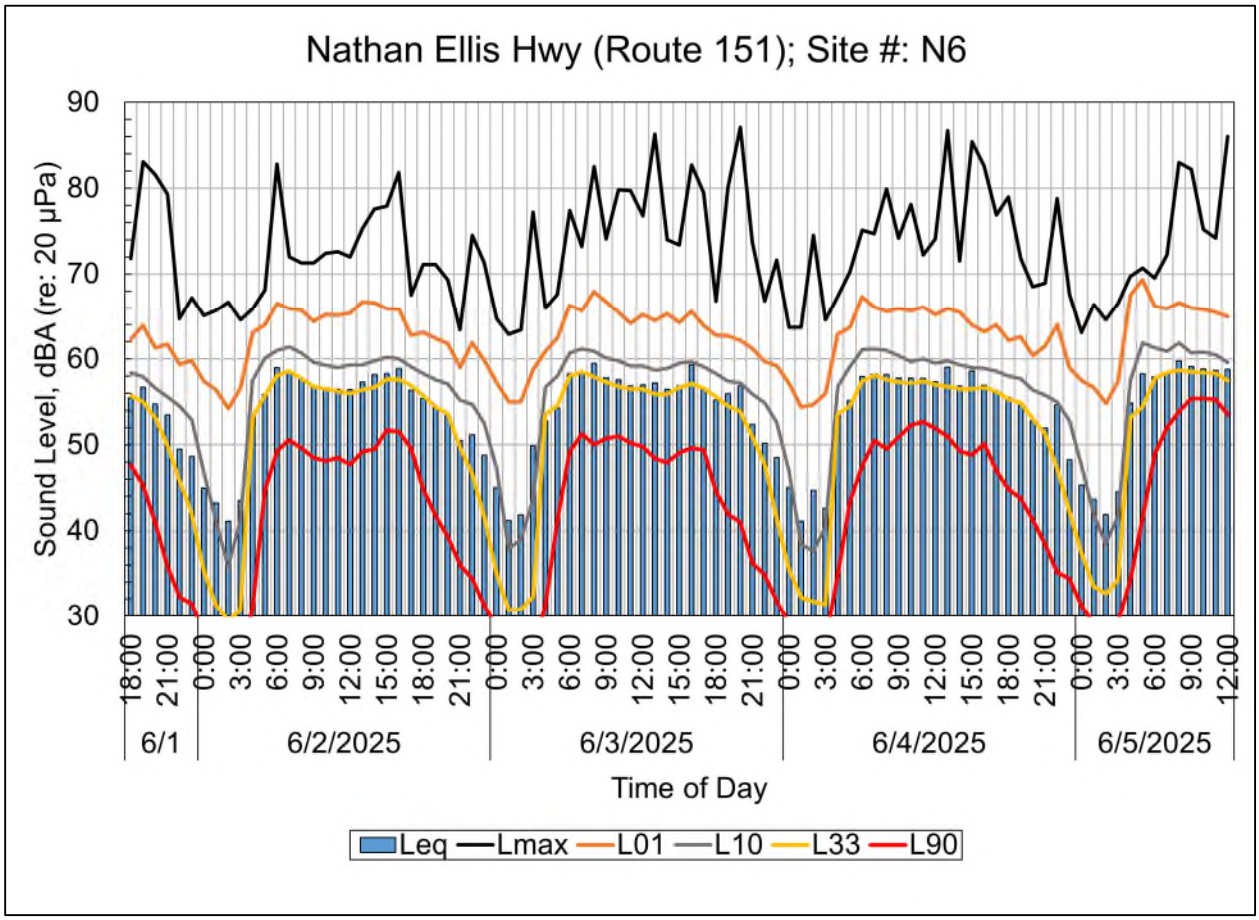


Figure 9. Ellis Highway Site N6 Ambient Noise Measurement Results

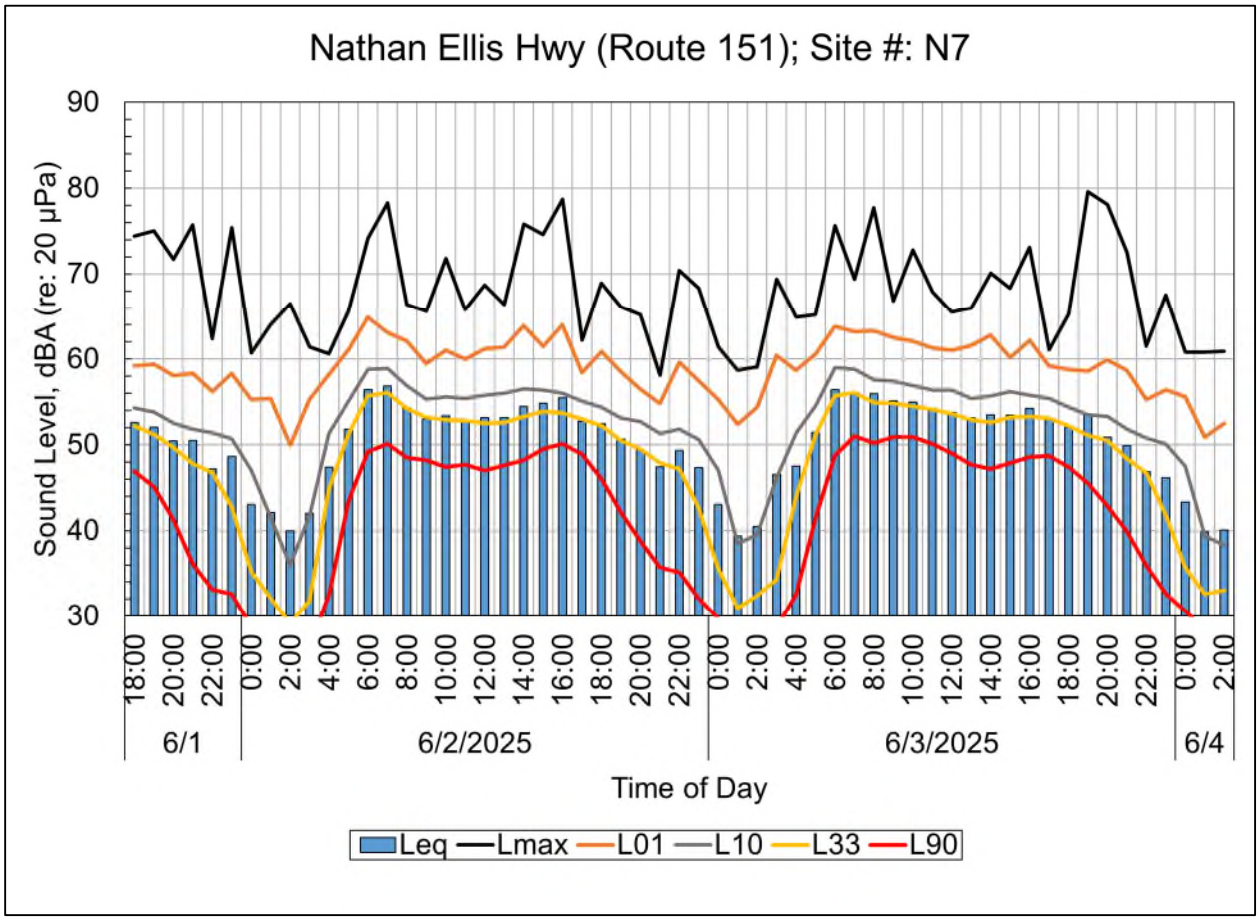


Figure 10. Ellis Highway Site N7 Ambient Noise Measurement Results

The ambient noise monitoring duration at each site varied from approximately 2.5 days up to over 5 days depending on battery capacity. The hourly L_{eq}'s and L_{90}'s at sites N1 to N3 at Trotting Park were similar, however, the ambient L_{max} results at site N2 were typically more than 10 dB greater than at sites N1 and N3. Review of the measured ambient noise recordings indicated there were periods of dirt bikes operating near N2 and N3 and some periods of bird noise near the microphone at N2 that were removed from the data. Note that there is currently no activity at the existing baseball/softball fields near N3 as the fields appeared to be unused. Activity was observed at the soccer fields and at the skate park.

The ambient noise measurement results at the Landers Road location at sites N4 and N5 were consistent. There were periods of time with frog noise that were removed from the data at N4. The dominant noise source based on CSA staff field observations was traffic noise on Landers Road.

The ambient noise results at the Ellis Highway location were significantly higher than at Trotting Park or Landers Road locations due to the traffic noise from Ellis Highway. Some periods of time with bird noise near the microphone were removed from the data at N7. The dominant noise sources based on CSA staff field observations were traffic noise on Ellis Highway.

Table 1 summarizes the ambient noise monitoring results at all sites. The table summarizes the measurement duration, average hourly L_{eq}, and hourly L_{90} results at each site. The results are broken down by the following time periods: Weekday-Daytime periods, Weekday-Nighttime

periods, Weekend-Daytime periods, and Weekend-Nighttime periods. All measured sound levels are rounded to the nearest whole decibel.

Table 1. Ambient Noise Monitoring Results

Pickleball Facility Location	Noise Measurement Site #	Time Period [a]	Ambient Noise Measurement Duration (# hours)	L_{eq} (dBA)[b]	L_{90} (dBA)[b]
Trotting Park	N1	*Total*	*122*	*43*	*31*
		Weekday-Daytime	70	45	36
		Weekday-Nighttime	43	38	30
		Weekend-Daytime	7	49	37
		Weekend-Nighttime	2	36	33
	N2	*Total*	*87*	*42*	*28*
		Weekday-Daytime	45	47	35
		Weekday-Nighttime	33	36	27
		Weekend-Daytime	7	48	35
		Weekend-Nighttime	2	34	31
	N3	*Total*	*83*	*44*	*30*
		Weekday-Daytime	45	47	36
		Weekday-Nighttime	30	39	29
		Weekend-Daytime	6	47	36
		Weekend-Nighttime	2	36	32
Thomas B. Landers Road	N4	*Total*	*118*	*43*	*23*
		Weekday-Daytime	68	47	33
		Weekday-Nighttime	43	38	23
		Weekend-Daytime	5	45	28
		Weekend-Nighttime	2	37	24
	N5	*Total*	*81*	*44*	*25*
		Weekday-Daytime	45	47	34
		Weekday-Nighttime	29	38	24
		Weekend-Daytime	5	48	33
		Weekend-Nighttime	2	37	27
Nathan Ellis Highway (Rt-151)	N6	*Total*	*91*	*54*	*28*
		Weekday-Daytime	51	57	41
		Weekday-Nighttime	34	49	26
		Weekend-Daytime	4	55	37
		Weekend-Nighttime	2	49	32
	N7	*Total*	*57*	*50*	*29*
		Weekday-Daytime	30	53	42
		Weekday-Nighttime	21	46	28
		Weekend-Daytime	4	51	38
		Weekend-Nighttime	2	48	33

[a] Daytime is defined as 7:00 AM to 10:00 PM and nighttime is defined as 10:00 PM to 7:00 AM.
[b] All sound levels have been rounded to the nearest whole decibel.

The local weather monitoring station results at Trotting Park noise measurement site N1 are summarized in Table 2. Weather data were collected for the first two days of the noise monitoring period. The temperature and humidity did not vary much during the monitoring period. The wind

speed and direction were fairly steady on Sunday and Monday with wind speeds generally less than 10 mph from the southeast.

Additional weather data was collected from www.wunderground.com at three weather stations located near the three study areas. These data are also included in Table 2.

Table 2. Weather Monitoring Results

Day	Location	Temperature (deg F)	Humidity (%)	Wind Speed (mph)	Wind Gust (mph)	Wind Direction (Avg.)
Source: Weather Monitoring Station Results at Trotting Park Noise Measurement Site N1						
Sunday, June 1, 2025	Trotting Park Site N1	55-62	59-84	0-8	0-14	230
Monday, June 2, 2025	Trotting Park Site N1	52-65	48-96	0-6	0-8	211
Source: Weather Station near Trotting Park [a]						
Sunday, June 1, 2025	Near Trotting Park	51-66	56-92	1-9	1-15	214
Monday, June 2, 2025		53-70	49-99	0-8	0-14	214
Tuesday, June 3, 2025		51-81	33-98	0-5	0-9	193
Wednesday, June 4, 2025		54-79	50-95	0-6	0-13	215
Thursday, June 5, 2025		58-86	56-100	0-5	0-9	215
Friday, June 6, 2025		61-87	58-100	0-6	0-10	200
Source: Weather Station near Landers Road [b]						
Sunday, June 1, 2025	Near Landers Road Location	51-61	64-89	0-9	0-14	58
Monday, June 2, 2025		50-66	52-97	0-7	0-11	53
Tuesday, June 3, 2025		51-76	30-94	0-6	0-7	84
Wednesday, June 4, 2025		54-75	48-87	0-6	0-9	56
Thursday, June 5, 2025		58-82	63-92	0-3	0-5	55
Friday, June 6, 2025		64-82	65-98	0-6	0-8	81
Source: Weather Station near Ellis Highway [c]						
Sunday, June 1, 2025	Near Ellis Highway Location	51-61	63-93	0-5	0-11	193
Monday, June 2, 2025		51-67	53-99	0-4	0-8	221
Tuesday, June 3, 2025		52-78	32-97	0-2	0-7	236
Wednesday, June 4, 2025		54-74	54-96	0-3	0-7	173
Thursday, June 5, 2025		59-79	67-96	0-3	1-6	224
Friday, June 6, 2025		63-85	63-99	0-3	0-6	224

[a] https://www.wunderground.com/dashboard/pws/KMAFALMO22
[b] https://www.wunderground.com/dashboard/pws/KMAEASTF151
[c] https://www.wunderground.com/dashboard/pws/KMAEASTF149

Reference Pickleball Noise Measurements

Additional noise measurements of pickleball activity were conducted at Nye Park at 6 Chester St, North Falmouth on June 6, 2025. The purpose of these measurements was to obtain reference noise levels that could be used to predict future pickleball noise levels at the proposed future locations. The Nye Park pickleball facility includes four pickleball courts arranged in quadrants (not a linear side-by-side layout). Noise measurements were conducted at various positions around the four courts including near the back corner of one of the courts at a distance of 15 feet back from the

fence, behind and near the center 10 feet back from the fence, and to the side of the courts near the center at distances of 10 feet, 25 feet, and 50 feet back from the fence. All four pickleball courts were in active use during the noise measurements, and the games were typically doubles with two players on each side (16 total players on the four courts). Our understanding from interaction with numerous participants is that all or most of players were using standard pickleball paddles and balls.

Table 3 summarizes the reference pickleball activity noise measurement results at Nye Park in Falmouth. The microphone distance from the fence around the courts is listed, along with the estimated distance to the nearest pickleball player, and the estimated distance to the center of all four courts. The table includes the measurement duration at each position, the total L_{eq} for that time period, the maximum 1-second L_{eq} during the time period, and the highest L_{AFmax} during the time period.

Table 3. Nye Park Pickleball Reference Noise Measurement Results

Measurement Location Description	Distance to Fence (ft)	Est. Dist. To Nearest Player (ft)	Est. Dist. To Center of All Courts	Measurement Duration (mins)	Total L_{eq} (dBA)	Maximum 1-second L_{eq} (dBA)	L_{AFmax} (dBA)
Back Corner	15	25	75	6 mins	63	76	84
Back Center	10	25	65	10 mins	65	80	88
Side Center	10	25	40	10 mins	64	76	83
Side Center	25	37	54	10 mins	61	73	81
Side Center	50	62	80	18 mins	54	65	74

The pickleball reference noise measurement results above were also compared to the measured percentiles. The results indicate that the L_1 percentile is typically similar to the 1-second L_{eq} of pickleball activity. The total, or 5-to-10-minute L_{eq} results of pickleball activity, were similar to the percentiles between the L_{10} and the L_{33}.

The measurement data were reviewed and analyzed for use in the future noise predictions at the proposed pickleball facility locations. The noise data from the two closest measurement positions were identified as the “cleanest”, meaning they had the highest signal to noise ratio relative to other environmental noise sources in the area. The noise data at these two microphone positions were averaged and normalized to a reference distance of 50 feet for use in the noise prediction models.

The reference pickleball noise data used in the predictions is summarized in Table 4. As discussed in the Noise Assessment section below, the pickleball noise predictions at the three locations were conducted using three separate reference noise levels: the Total L_{eq}, the 1-second L_{eq}, and the L_{AFmax}. The Total L_{eq} corresponds to the total L_{eq} calculated over the duration of the measurement at each position, in this case 10 minutes. The difference between the Total L_{eq} and the 1-second L_{eq} and the difference between the Total L_{eq} and the L_{AFmax} are included in the table. The noise modeling effort utilized the difference between these reference values to reduce complexity.

Table 4. Pickleball Reference Noise Measurement Results (Normalized to 50 feet)

Reference Distance (ft)	Total L_{eq} (dBA)	1-sec L_{eq} (dBA)	L_{AFmax} (dBA)	*1-sec* L_{eq} *vs. Total* L_{eq} *Difference (dB)*	L_{AFmax} *vs. Total* L_{eq} *Difference (dB)*
25	65	72	80	*7*	*15*

The Nye Park pickleball noise measurement results were compared to other pickleball noise measurement data collected by CSA at another pickleball facility in Mashpee. This analysis showed very consistent results. The Nye Park reference pickleball 1-second L_{eq} and L_{AFmax} levels were within 2 dB of the pickleball data collected elsewhere, and the total 10-minute L_{eq} level was within 4 dB. This comparison shows that the reference pickleball noise measurement results at Nye Park were typical.

Other Recreational Activities Reference Noise Measurements

CSA also conducted reference noise measurements of other recreational activities for comparison with the pickleball noise measurement results. Specific sports were identified that were presumed to have similar characteristics to the nature of pickleball activity noise, such as repetitive, transient noise events. Three other sporting activities were chosen for comparison purposes: golf ball hits, basketball bounces, and baseball bat hits.

Noise measurements were conducted by CSA staff at a golf driving range where there were many golfers striking balls repetitively. While there were other people at the driving range, the microphone was placed close to one person hitting balls at the range. Specific noise events were analyzed, and golf club driver and irons hits were summarized. Reference noise measurements were conducted at an outdoor basketball court, and numerous individual basketball bounces were analyzed and summarized. There were three people playing basketball on the court during these noise measurements. Lastly, noise measurements were conducted at an outdoor batting cage facility and numerous baseball bat hits and softball bat hits were analyzed and summarized. There was other activity at the batting cages, but the microphone was placed close to one person hitting balls at the batting cage. The noise measurement data were then normalized to a distance of 50 feet for comparison with other types of activities.

Table 5 summarizes the results of the reference noise measurements of other recreational activities. The table also includes the Nye Park pickleball noise measurement results for comparison. All noise data has been normalized to the same reference distance of 50 feet. The table includes the total measurement L_{eq}, the 1-second L_{eq}, and the L_{AFmax} for each activity as well as the difference between the total L_{eq} and 1-second L_{eq} and the difference between the total L_{eq} and the L_{AFmax}.

The total L_{eq} of pickleball activity is louder than the other sports, which is at least in part due to there being four courts and pickleball games occurring simultaneously, whereas the other sports noise measurement results are limited to fewer simultaneous noise events. The pickleball noise results were the highest of the other sports, with golf driver hits being the second highest. The basketball bounces were the lowest of all activities. The baseball bat hits were slightly higher than the softball bat hits. The golf driver hits produced higher noise levels than the irons hits.

The two right-hand columns in the table show the differences between the 1-second L_{eq} and L_{AFmax} versus the overall measurement time period (typically about 10 minutes) L_{eq} for each sporting activity. The greater differences indicate that the sound levels from those sports increase very rapidly with time. The basketball data show very little difference compared to the overall L_{eq}. The baseball and softball differences are very similar to the pickleball results, with the typical 1-second L_{eq} being approximately 4-7 dB greater than the overall L_{eq} and the typical L_{AFmax} being approximately 11-15 dB greater than the overall L_{eq}. The golf club hits show the largest differences, with the typical 1-second L_{eq} being approximately 12-14 dB greater than the overall L_{eq} and the typical L_{AFmax} being approximately 20-22 dB greater than the overall L_{eq}

Table 5. Recreation Activities Reference Noise Measurement Results (Normalized to 50 feet)

Recreation Activity	**Reference Distance (ft)**	**Total L_{eq} (dBA)**	**1-sec L_{eq} (dBA)**	**L_{AFmax} (dBA)**	***1-sec* L_{eq} *vs. Total* L_{eq} *Difference (dB)***	***L_{AFmax} vs. Total* L_{eq} *Difference (dB)***
Pickleball (4 Courts)	50	65	72	80	*7*	*15*
Golf Driver (driving range)	50	55	69	77	*14*	*22*
Golf Irons (driving range)	50	48	60	68	*12*	*20*
Basketball (outdoor)	50	56	55	59	*-1*	*3*
Baseball (batting cage)	50	57	62	69	*5*	*12*
Softball (batting cage)	50	56	60	67	*4*	*11*

Figures 11 through 14 show sample time history plots with results of the pickleball and other sports noise measurements. The data in these set of figures are the varying 1-second L_{eq} with time for a sample of 5 minutes of activity. All noise levels have been normalized to a distance of 25 feet for comparison to one another. Figure 11 shows the pickleball activity at Nye Park with 4 games being played on the 4 courts. Figure 12 shows the results of golf driver hits at a driving range. Figure 13 shows the results of basketball at an outdoor court. Figure 14 shows the results of baseball hits and then softball hits at an outdoor batting cage. Note that the lowest levels in each of these sample time histories represent the ambient noise levels at each individual location at the time the data were collected.

This comparison of results shows the impulsive nature of golf and baseball hits. The sound levels increase very rapidly from the background ambient levels and then decrease very rapidly. The greatest A-weighted 1-second L_{eq} noise levels from golf driver hits, baseball bat hits, and pickleball paddle hits are all very similar, typically within about 5 dB of one another. The pickleball data shows numerous peaks of varying sound levels, which is likely due to many players hitting the ball often, at varying distances at the 4 courts from the microphone, whereas the golf driving range and baseball batting cage data were all at the same distance from the microphone. The pickleball data also includes significantly more noise from the players themselves talking and shouting during game play.

The basketball sound levels were steadier with time compared to the other sports, with individual basketball bounces not rising much above the overall noise. However, the time-varying noise levels from basketball play were similar to the pickleball results, only about 5 dB lower maximum 1-second L_{eq} noise levels.

These results indicate the usefulness of different noise metrics to describe various types of noise events. While all of the measured recreational activities can be described only using the L_{max}, that may not fully describe the nature of the noise source. Some activities such as golf driver hits at a driving range may be best described using the L_{max}. Other activities such as pickleball game play may be better described by the overall L_{eq} than the L_{max} of one individual paddle hit, or perhaps a combination of multiple metrics since individual L_{max} values are not consistent from hit-to-hit.

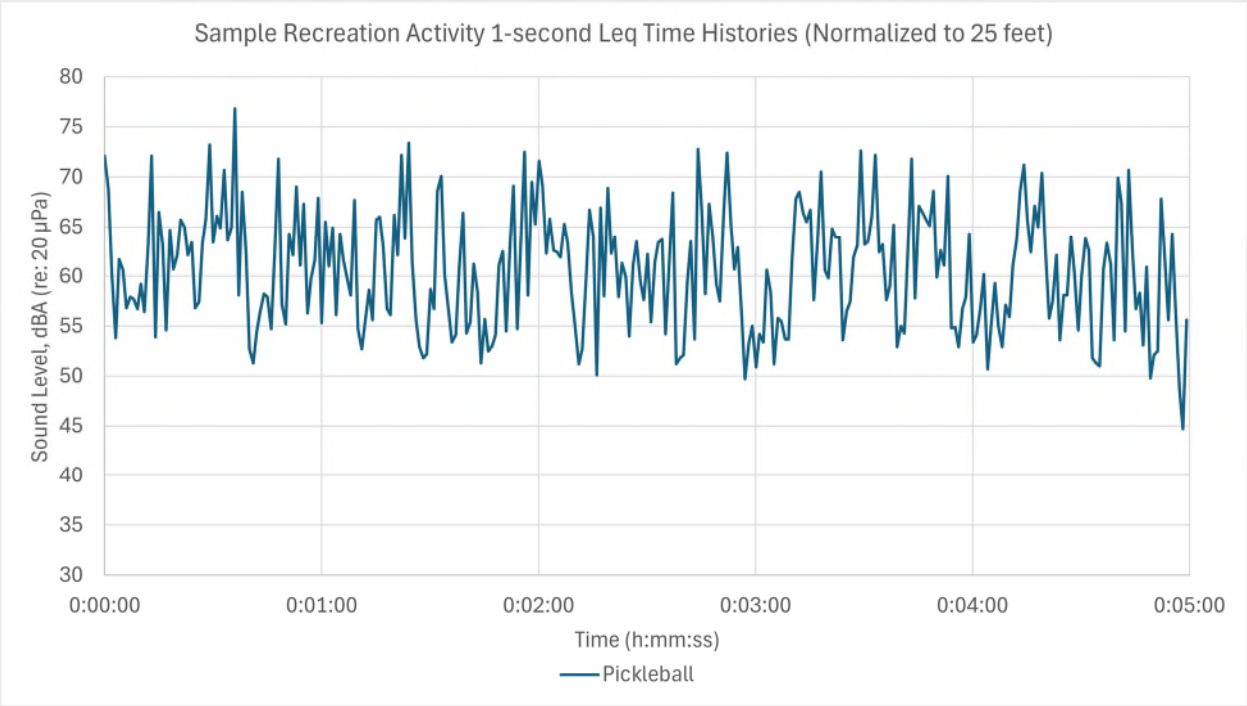


Figure 11. Pickleball Sound Level Time History

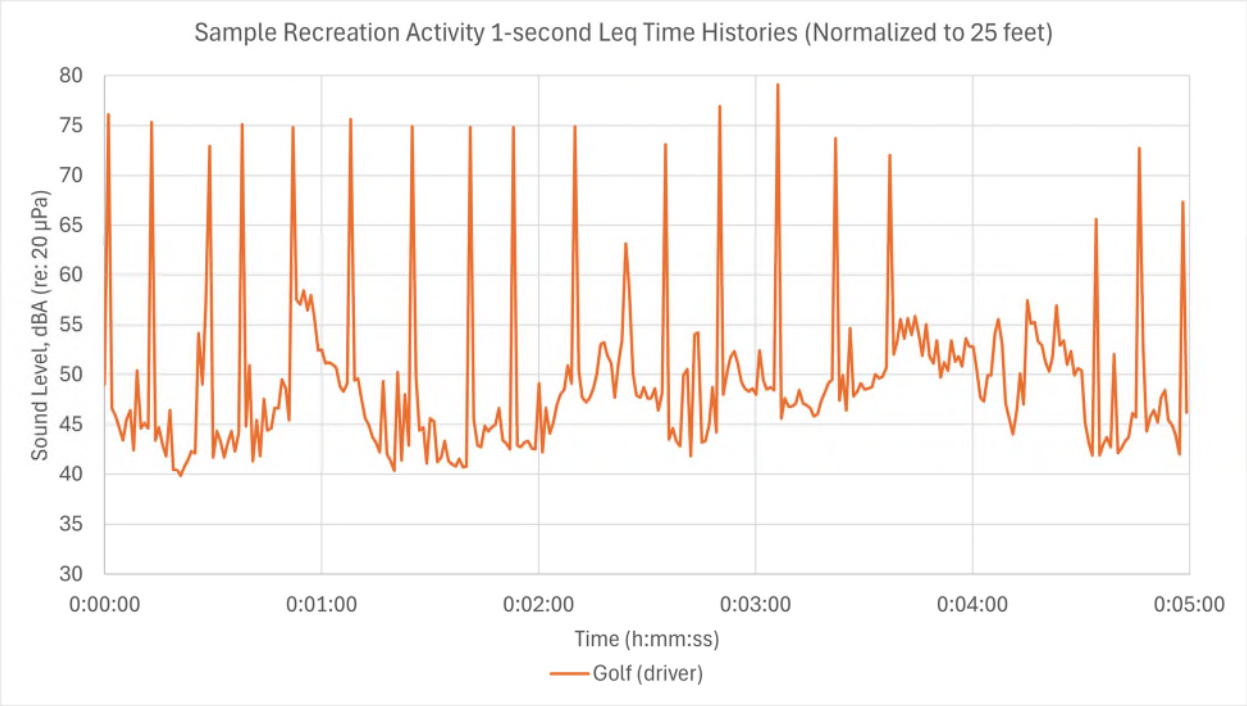


Figure 12. Golf Driver (driving range) Sound Level Time History

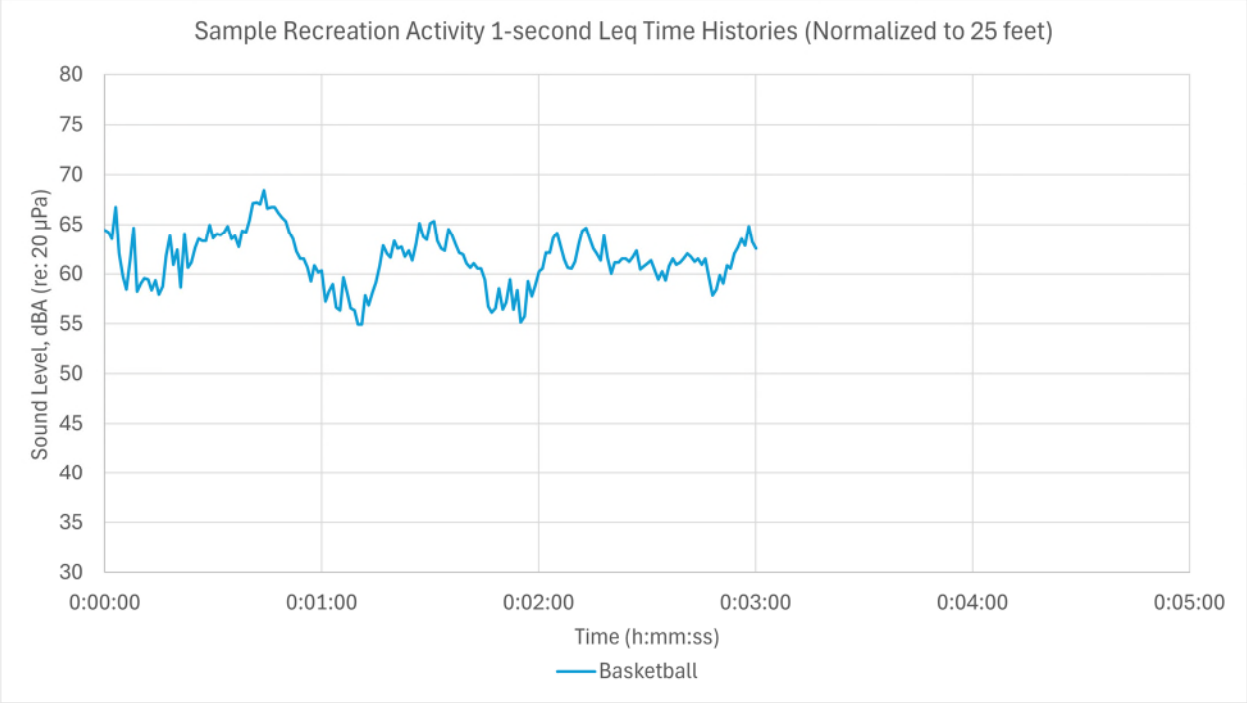


Figure 13. Basketball Sound Level Time History

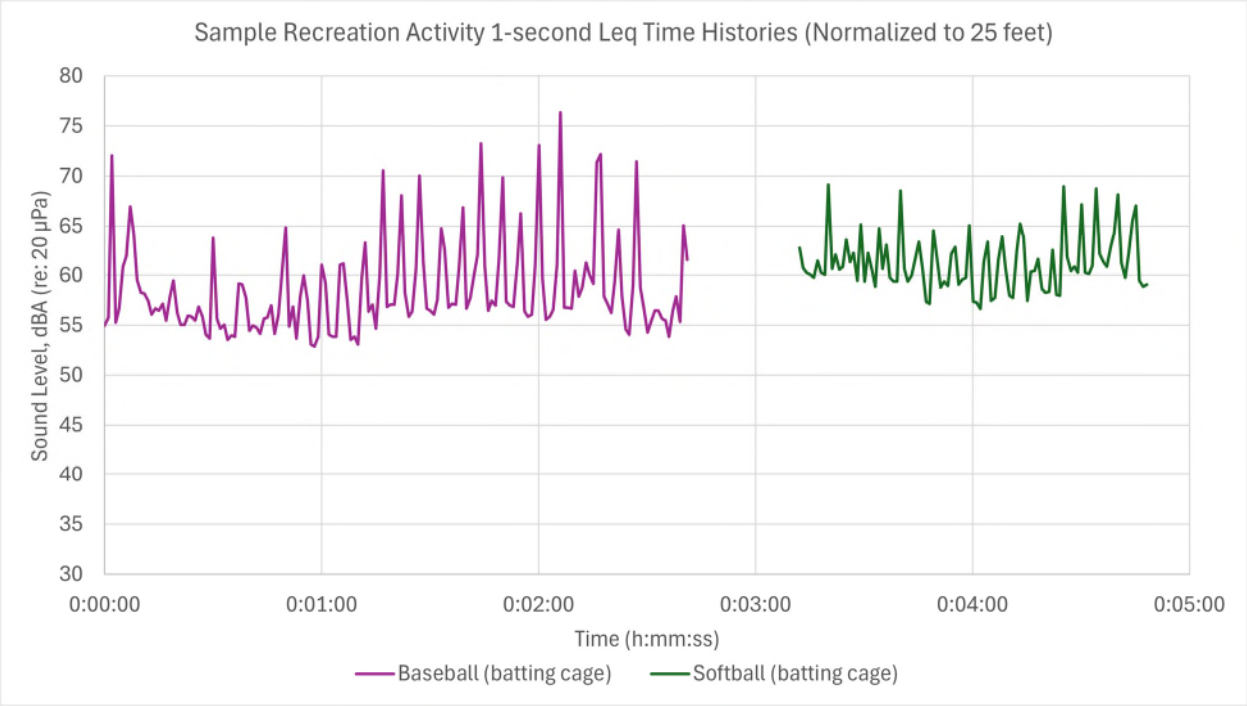


Figure 14. Baseball and Softball (batting cage) Sound Level Time History

The noise measurements of pickleball at Nye Park and the other sports activities included the collection of frequency data. Figure 15 shows the average 1/3 octave-band sound level spectra for each sport. The sound levels have been normalized to a distance of 25 feet for comparison. Each of these spectra represent an individual impact or noise event including: a pickleball paddle hit, a golf driver hit, a basketball bounce, and a baseball hit.

The frequency data for each of these four activities is unique. The pickleball paddle hit spectrum shows a significant peak centered at the1250 Hz 1/3 octave-band with most of the sound energy between 800 Hz and 2000 Hz. This frequency range coincides with the range where human hearing is most sensitive and may contribute to the annoyance generated by pickleball activities. The golf driver hit spectrum shows high levels between 500 Hz and 2000 Hz and significant high frequency peaks centered at 4000 Hz and 8000 Hz. The basketball bounce spectrum shows significant sound energy below 250 Hz and dropping off significantly above that, which explains the lower measured A-weighted noise levels compared to other sports. The baseball hit spectrum shows relatively flat sound levels at lower and mid-frequencies with the highest levels at 100 Hz and 2000 Hz.

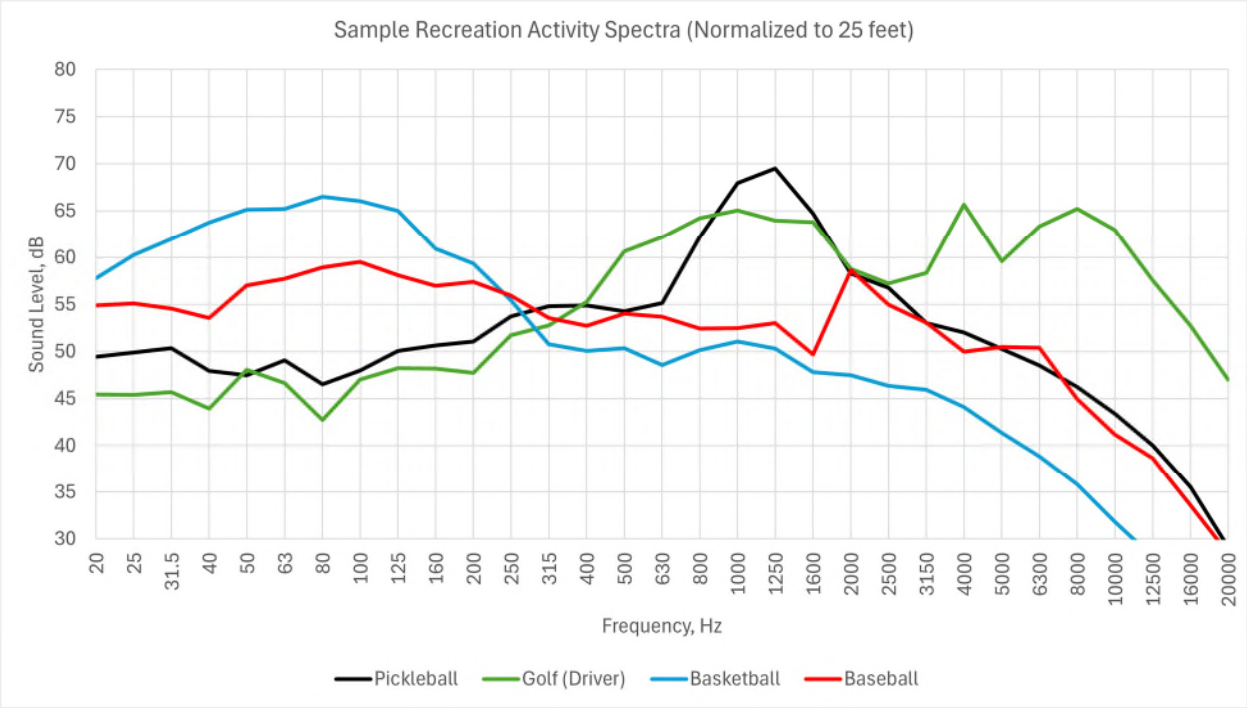


Figure 15. Pickleball and Other Sports Activity Sound Level Frequency Spectra

Noise Assessment

Three-dimensional acoustical models of each potential pickleball facility location were created using the industry standard SoundPLAN Essential[4] acoustical modeling software package. The models incorporated ground elevations, ground surfaces, and sections of trees and dense foliage. The model's implementation of ISO Standard 9613-2[5] was used. The models were used to calculate the future noise levels from pickleball facility activity at adjacent noise-sensitive locations.

The software produced digital ground models that closely matched the real-world locations based on imported terrain elevation information. Undulations in the ground can cause relatively significant changes in noise propagation when the sounds paths between noise sources and receiver locations are impeded by small amounts. Sound diffracts over the top of terrain features. Sections of trees and dense foliage were included in some locations in the acoustical models where appropriate. Trees often do not provide much attenuation of overall A-weighted sound levels, however, they can reduce sound levels somewhat when the path between the source and receiver travels through significant lengths of foliage.

The original layout drawing of the 16 pickleball courts at the Trotting Park location was georeferenced and placed over aerial imagery at each potential future pickleball location. Layout drawings showing the exact location and configuration of future pickleball courts were not available at the Landers Road or Ellis Highway locations, therefore, CSA made assumptions about the layouts and placement of the courts at these locations. At the Landers Road location, CSA assumed that the same layout and configuration of 16 pickleball courts as the original Trotting Park

[4] https://www.soundplan.eu/en/
[5] ISO Standard 9613-2, "Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation," International Organization for Standardization, Geneva, 1996

court configuration would be used and that the courts would be approximately centered within this town-owned parcel.

At the Ellis Highway location the town-owned parcel was large enough that it was not clear where the pickleball courts would be located, and the location of the courts within the parcel could affect the results of the noise assessment due to varying distances to nearby residential land use. Therefore, CSA assumed that the same layout and configuration of 16 pickleball courts as the original Trotting Park plan would be used, and two potential placements of those courts were assumed for this noise study. One option assumed the pickleball courts would be located in the northwest corner of the parcel and is referred to as the "Ellis Highway-A" location. The second option assumed the pickleball courts would be located in the southwest area of the parcel and is referred to as the "Ellis Highway-B" location.

Figures 16, 17, and 18 show the location and layout of the potential pickleball facilities at the three locations that were analyzed. The ground elevation at the future courts was assumed to be flat relative to the existing terrain for the placement of the noise source points in the acoustical models. However, no additional terrain features or changes to the existing terrain were included in the models. Any future changes to the design of the courts that could affect sound propagation should be considered and potentially reanalyzed, such as any walls, stands, or steps. Any changes to the elevation of the courts could significantly affect the noise prediction results. Raising the elevation of the future courts above the existing terrain could increase predicted noise levels and lowering the elevation of the courts, for example into a "bowl-shaped" area, could potentially reduce noise predicted levels.

The figures show the location of the ambient noise measurement sites as well as additional noise prediction points used in the noise assessment at Landers Road and Ellis Highway. At the Trotting Park location shown in Figure 16, the three ambient noise measurement sites are labeled N1, N3, and N3. N1 is located near the residential property line of the residences at 18-20 Woodview Drive to the south. Site N2 is located near the property line of the residence to the east at 108 Trotting Park Road and Site N3 is located near the property line of the multi-family development to the west at 30 Pine Valley Drive.

Figure 17 shows the Landers Road location. The figure shows noise measurement sites N4 to the west and N5 to the east of the parcel. Site N4 was chosen to represent the ambient noise conditions at the residence to the west at 225 Thomas B Landers Road, so an additional noise prediction site was included at the actual residential parcel line farther to the west labeled Rec-Lan-1. Noise measurement site N5 was chosen to represent the ambient noise conditions at the residence to the east at 254 Turner Road, so an additional noise prediction site was included at the actual residential parcel line farther to the northeast labeled Rec-Lan-2. While the placement of N4 and N5 is useful for characterizing the existing ambient noise conditions, their placement relative to the potential future pickleball courts would provide unrepresentatively high noise predicted noise levels that would not be useful for the assessment, therefore noise prediction results are only included for Rec-Lan-1 and Rec-Lan-2 sites.

Figure 18 shows the Ellis Road location. The figure shows noise measurement sites N6 near the Ellis Highway-A pickleball courts location and N7 near the Ellis Highway-B location. Noise measurement sites N6 and N7 were chosen to represent the ambient noise conditions at the nearby residential land uses at the residential parcel at 340 Nathan Ellis Highway and 17 Esker Place respectively, as discussed in the noise measurement section of this report. While the placement of N6 and N7 is useful for characterizing the existing ambient noise conditions, their placement relative to the potential future pickleball courts would provide unrepresentatively high predicted

noise levels that would not be useful for the assessment. Therefore, additional noise prediction sites were included at the actual nearest residential parcel lines and are labeled Rec-Ell-1, Rec-Ell-2, and Rec-Ell-3.

The figures show the pickleball noise source point locations used in the acoustical models. The source reference levels are based on the pickleball noise measurements at Nye Park in Falmouth and discussed in the Reference Pickleball Noise Measurements section of this report. The Nye Park pickleball court layout includes four courts positioned in quadrants relative to one another. The reference pickleball noise measurements were conducted while simultaneously pickleball games were being played on all four courts, therefore, the reference noise pickleball noise levels correspond to approximately that same layout and number of courts. The Nye Park pickleball noise measurements were used to calibrate the acoustical model.

The layout of 16 courts used in this assessment includes two rows of six courts, where the spacing is similar to the courts at Nye Park, and one row of four courts where the courts are spaced slightly farther apart. The acoustical models include five source points at each location representing the 16 total pickleball courts. Three of the source points represent 12 courts, and two points represent the four additional courts spaced farther apart from one another. This combination of five total source points is somewhat conservative (meaning potentially higher sound levels) based on the number of courts at Nye Park relative to the number of source points in the acoustical models.

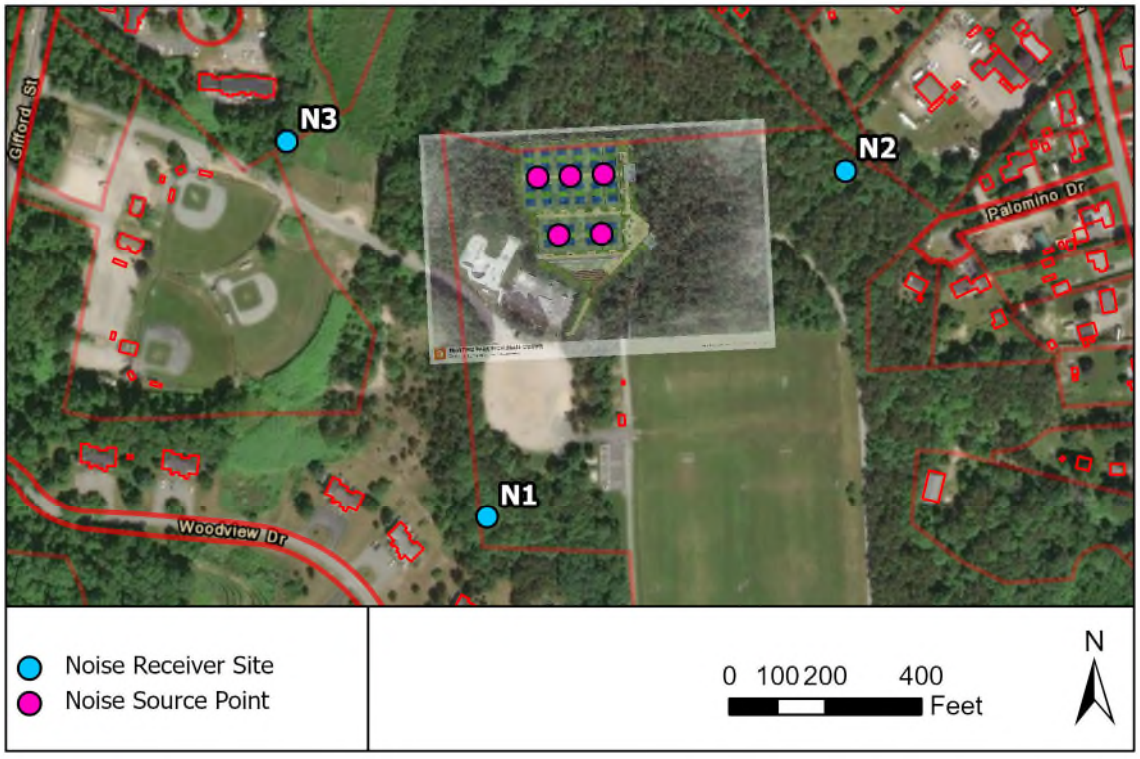


Figure 16. Trotting Park Noise Assessment Locations

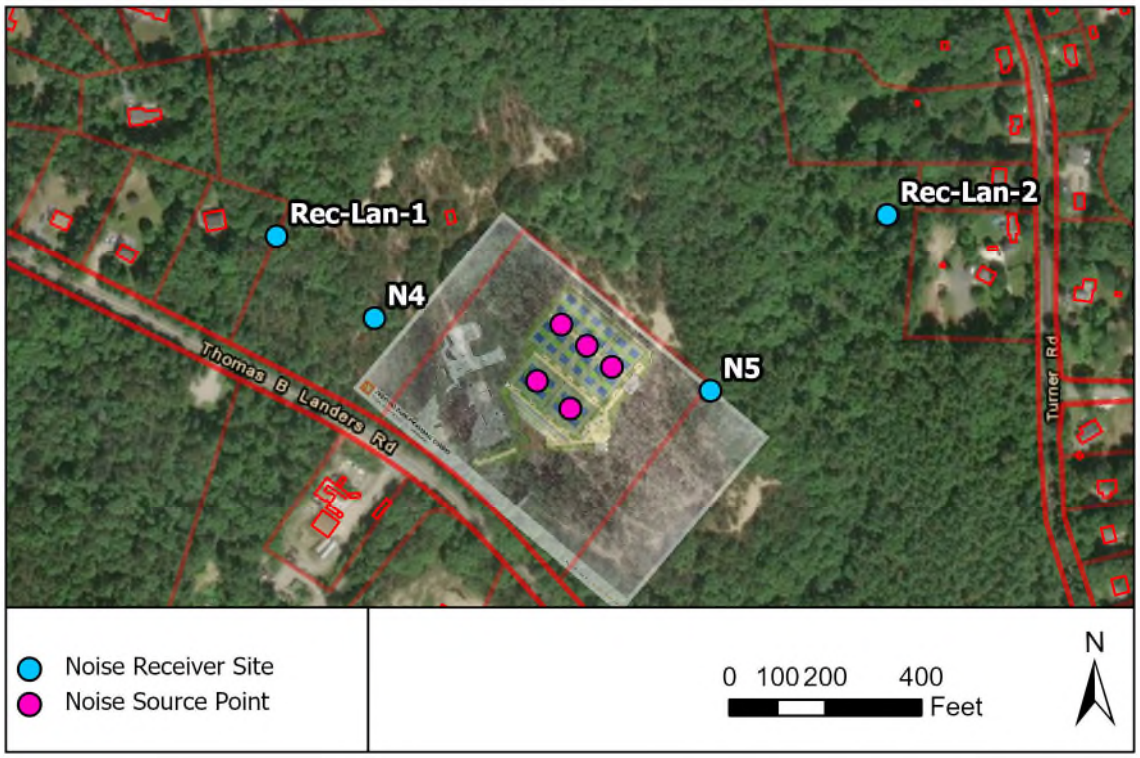


Figure 17. Thomas B. Landers Road Noise Assessment Locations

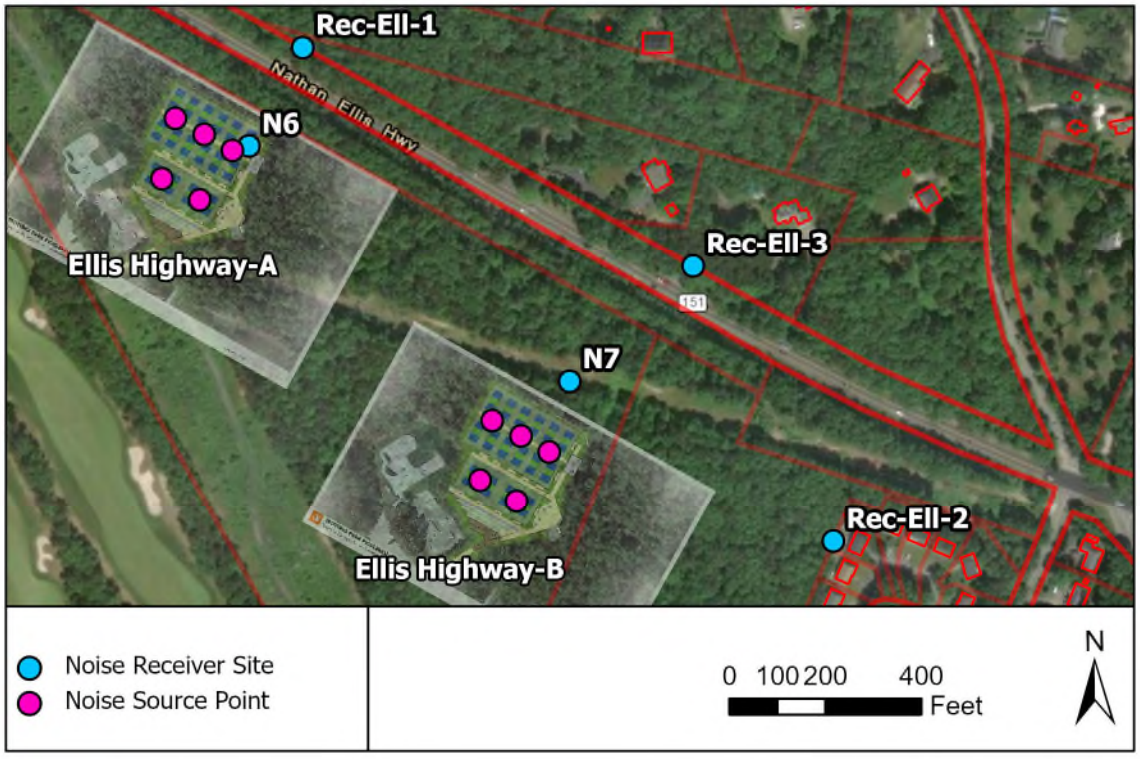


Figure 18. Nathan Ellis Highway Noise Assessment Locations

Table 6 summarizes the pickleball noise assessment results at the three study areas and four potential court locations (including two potential locations at the Ellis Highway parcel.) Future noise level predictions are included at the noise measurement sites (where applicable) and the additional receiver sites. The noise assessment was conducted for four separate time periods: weekday-daytime, weekday-nighttime, weekend-daytime, and weekend-nighttime.

It is not known if the future courts would operate between the hours of 10 PM and 7 AM, so separate noise predictions were made for both daytime and nighttime periods. The pickleball noise predictions show potential exceedances of the Mass DEP criteria at most sites during nighttime periods. Therefore, the noise assessment results summarized in Table 6 include only the daytime noise predictions for simplicity.

The table includes the ambient L_{eq} and L_{90} at each prediction site for each analyzed time period. The table includes predictions for three separate noise metrics as discussed in the Reference Pickleball Noise Measurements section of this report: the Total L_{eq}, the 1-second L_{eq}, and the L_{AFmax}. The Total L_{eq} corresponds to the overall L_{eq} during active pickleball activity at all courts simultaneously, and the L_{eq} timeframe is approximately 10 minutes. The 1-second L_{eq} and L_{AFmax} predictions also correspond to periods where there would be active pickleball activity at all 16 courts simultaneously.

For the purpose of summarizing the results in this report, the pickleball noise predictions were compared to the measured ambient L_{90} at each site for each assessed time period and then compared to the Mass DEP noise criteria. The Mass DEP policy does not specify the noise level metric (L_{eq}, L_{AFmax}, etc) that should be used to represent project noise, so the assessment compares all of the potential applicable metrics to the existing L_{90} plus 10 decibels. The numbers in bold/shaded text in the table are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

Table 6. Pickleball Noise Assessment Results (with No Mitigation)

Pickleball Facility Location	Site #	Time Period [a]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
Trotting Park	N1	MF-Day	45	36	41	46	**54**
		SS-Day	49	37	41	46	**54**
	N2	MF-Day	47	35	38	43	**51**
		SS-Day	48	35	38	43	**51**
	N3	MF-Day	47	36	41	**47**	**55**
		SS-Day	47	36	41	**47**	**55**
Thomas B. Landers Road	N4 [d]	MF-Day	47	33	-	-	-
		SS-Day	45	28	-	-	-
	N5 [d]	MF-Day	47	34	-	-	-
		SS-Day	48	33	-	-	-
	Rec-Lan-1	MF-Day	47	33	36	40	**48**
		SS-Day	45	28	34	**40**	**48**
	Rec-Lan-2	MF-Day	47	34	35	36	39
		SS-Day	48	33	33	35	39
Nathan Ellis Highway-A [c]	N6 [d]	MF-Day	57	41	-	-	-
		SS-Day	55	37	-	-	-
	N7 [d]	MF-Day	53	42	-	-	-
		SS-Day	51	38	-	-	-

Pickleball Facility Location	Site #	Time Period [a]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
	Rec-Ell-1	MF-Day	57	41	51	**58**	**66**
		SS-Day	55	37	**51**	**58**	**66**
	Rec-Ell-2	MF-Day	53	42	42	42	40
		SS-Day	51	38	38	39	40
	Rec-Ell-3	MF-Day	57	41	42	43	46
		SS-Day	55	37	38	41	46
Nathan Ellis Highway-B [c]	N6 [d]	MF-Day	57	41	-	-	-
		SS-Day	55	37	-	-	-
	N7 [d]	MF-Day	53	42	-	-	-
		SS-Day	51	38	-	-	-
	Rec-Ell-1	MF-Day	57	41	42	44	49
		SS-Day	55	37	39	43	**49**
	Rec-Ell-2	MF-Day	53	42	42	42	40
		SS-Day	51	38	38	39	40
	Rec-Ell-3	MF-Day	57	41	47	**52**	**60**
		SS-Day	55	37	46	**52**	**60**

[a] "MF-Day" = weekday-daytime and "SS-Day" = weekend-daytime time periods.
[b] All sound levels have been rounded to the nearest whole decibel.
[c] Two potential locations for the pickleball courts at the Nathan Ellis Highway location were evaluated separately. See Figure 15 for details on the assumed locations.
[d] Future noise predictions were not made at measurement sites N4, N5, N6, and N7 because they are within or near areas where potential pickleball facilities would be located. The ambient noise measurement results at these sites were assumed to apply to the other nearby noise receptors where future pickleball noise predictions were considered.
[e] The numbers in bold/shaded text are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

At the Trotting Park location during daytime periods, there would be no exceedances from the Total L_{eq} at the three receiver sites, exceedances from the 1-second L_{eq} at only N3, and exceedances from the L_{AFmax} at all three receivers. Based on these results, the design of the potential pickleball courts at Trotting Park should consider mitigation measures for all receiver sites, but especially N3.

At the Landers Road location during daytime periods, there would be no exceedances from the Total L_{eq} at the two receivers, exceedances only during the weekend days at Rec-Lan-1 from the 1-second L_{eq}, and exceedances from the L_{AFmax} only at Rec-Lan-1. Based on these results, mitigation measures should be considered for receiver Rec-Lan-1 at the potential Landers Road location.

At the Ellis Highway-A location during daytime periods, there would be exceedances from the Total L_{eq}, the 1-second L_{eq}, and the L_{AFmax} at Rec-Ell-1, and no exceedances at receivers Rec-Ell-2 or Rec-Ell-3. These results are due to the relatively short sound propagation distance from the potential courts location to the receiver point (compared to other receivers). However, the Rec-Ell-1 receiver point is located at the closest point of the nearby residential property on the opposite side of Ellis Highway even though the residence itself is approximately 700 feet away. The next closest residential parcels near this receiver site are residences on Cloverfield Way. So even though the noise predictions show exceedances of the Mass DEP criteria at Rec-Ell-1, it is likely that potential future pickleball noise levels would be lower at the farther away residences on Cloverfield Way and closer to the residences on Ellis Highway located farther to the southeast. Regardless, additional

consideration, analysis, or mitigation measures should be considered for receiver Rec-Ell-1 if the Ellis Highway-A pickleball location is selected.

At the Ellis Highway-B location during daytime periods, there would be no exceedances of the Total L_{eq}, exceedances of the 1-second L_{eq} only at receiver Rec-Ell-3, and exceedances of the L_{AFmax} at receivers Rec-Ell-1 and Rec-Ell-3. Based on these results, additional consideration and mitigation measures should be considered for receiver Rec-Ell-3 if the Ellis Highway-B location is selected.

The assessment results are not compared to the measured ambient L_1 or L_{max} levels, however, some limited comparisons may provide useful context to the potential future noise conditions. The Nye Park noise measurements showed that the 1-second L_{eq} is similar to the L_1 percentile sound levels. At the Trotting Park sites, the measured ambient L_1 during the daytime typically ranged between 50-60 dBA and the L_{max} typically ranged from 60-80 dBA. The predicted 1-second L_{eq} results from pickleball activity ranges from 43-47 dBA and the L_{AFmax} ranges from 51-55 dBA. At the Landers Road sites, the ambient L_1 typically ranged between 50-60 dBA and the L_{max} ranged from 60-75 dBA. The predicted 1-second L_{eq} results from pickleball activity ranges from 32-40 dBA and the L_{AFmax} ranges from 39-48 dBA. At the Ellis Highway sites, the ambient L_1 typically ranged between 60-70 dBA and the L_{max} ranged from 65-85 dBA. The predicted 1-second L_{eq} results from pickleball activity ranges from 33-58 dBA and the L_{AFmax} ranges from 40-66 dBA.

For informational purposes, additional noise predictions were conducted with the same acoustical models but using different noise sources. The results of the other recreational sports activity noise measurements were used to predict potential future noise levels at each of the three study areas. Table 7 summarizes the results of these noise predictions. Results were predicted at each receiver site for all time periods, though the table summarizes only the daytime results. The table summarizes the results in terms of the difference relative to the measured L_{90} at each receiver, in the same format as the standard pickleball assessment results in Table 6.

Table 7. Pickleball vs. Other Sports Noise Assessment Results (with No Mitigation)

Pickleball Facility Location	Site #	Time Period [a]	Ambient L_{90} [b]	Pickleball			Golf-Driver (Driving Range)			Basketball			Baseball (Batting Cage)		
				Total L_{eq} [b]	1-sec L_{eq} [b]	L_{AFmax} [b]	Total L_{eq} [b]	1-sec L_{eq} [b]	L_{AFmax} [b]	Total L_{eq} [b]	1-sec L_{eq} [b]	L_{AFmax} [b]	Total L_{eq} [b]	1-sec L_{eq} [b]	L_{AFmax} [b]
Trotting Park	N1	MF-Day	36	41	46	54	37	42	49	37	37	34	37	39	41
		SS-Day	37	41	46	54	38	43	49	38	38	34	38	39	41
	N1	MF-Day	35	38	43	51	35	40	46	36	36	33	35	37	38
		SS-Day	35	38	43	51	35	40	46	36	36	33	35	37	38
	N3	MF-Day	36	41	47	55	37	43	50	38	37	35	37	39	42
		SS-Day	36	41	47	55	37	43	50	37	37	35	37	39	42
Landers Road	Rec-Lan-1	MF-Day	33	36	40	48	33	37	43	34	33	31	33	34	35
		SS-Day	28	34	40	48	29	36	43	31	30	31	30	32	35
	Rec-Lan-2	MF-Day	34	35	36	39	34	35	35	35	34	26	34	35	27
		SS-Day	33	33	35	39	33	34	35	33	33	26	33	33	27
Ellis Highway-A [c]	Rec-Ell-1	MF-Day	41	51	58	66	44	55	62	45	44	45	45	49	54
		SS-Day	37	51	58	66	42	54	62	43	42	45	44	49	54
	Rec-Ell-2	MF-Day	42	42	42	40	42	42	35	42	42	23	42	42	27
		SS-Day	38	38	39	40	38	38	35	38	38	23	38	38	27
	Rec-Ell-3	MF-Day	41	42	43	46	41	42	41	41	41	28	41	41	33
		SS-Day	37	38	41	46	37	39	41	38	38	28	37	38	33
Ellis Highway-B [c]	Rec-Ell-1	MF-Day	41	42	44	49	41	42	44	41	41	30	41	42	36
		SS-Day	37	39	43	49	38	40	44	38	38	30	38	38	36
	Rec-Ell-2	MF-Day	42	42	42	40	42	42	35	42	42	27	42	42	29
		SS-Day	38	38	39	40	38	38	35	38	38	27	38	38	29
	Rec-Ell-3	MF-Day	41	47	52	60	42	49	56	43	42	40	42	45	49
		SS-Day	37	46	52	60	39	49	56	40	39	40	40	44	49

[a] "MF-Day" = weekday-daytime and "SS-Day" = weekend-daytime time periods.
[b] All sound levels have been rounded to the nearest whole decibel.
[c] Two potential locations for the pickleball courts at the Nathan Ellis Highway location were evaluated separately. See Figure 15 for details.
[d] The numbers in bold/shaded text are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

The results in Table 6 show the results with pickleball at each site and the results if each of three other sporting activities were taking place in the same location instead of pickleball. The table compares predictions of future pickleball at each receiver site to predictions from golf driver hits (driving range), basketball, and baseball bat hits (outdoor batting cage).

The results indicate that there would theoretically be more exceedances of the Mass DEP criteria with pickleball compared to the other sporting activities. Golf driver hits in place of pickleball activity would cause the second most exceedances analyzed. With baseball hits there would be only a few exceedances of the L_{AFmax} and with basketball there would be no exceedances. These theoretical results are as expected based on the measurement results summarized in the Reference Pickleball Noise Measurements section of this report.

The pickleball noise results were also analyzed in comparison to the Mass DEP tonal criteria. The predicted 1/1 octave-band pickleball noise results at each site were combined with the ambient measured noise levels and compared to the tonal criteria. The analysis showed no exceedances of the tonal criteria caused by pickleball activity.

Mitigation Analysis

Preliminary noise mitigation measures were analyzed at each pickleball location. The mitigation analysis results are intended to provide approximations of the amount of noise reduction that could potentially be provided with different height noise barriers at each pickleball court location. At each pickleball location, a sample noise barrier was added to the acoustical models approximately around the outside of the layout of all 16 courts. Figure 19 shows the Trotting Park model with the sample noise barrier surrounding the courts. The same sample noise barrier was also added to the models at the other locations.

Figure 19. Trotting Park Pickleball Courts with Sample Noise Barrier

The noise results were calculated, assuming the noise barriers surrounded all 16 courts. The models calculated results with 6-foot-tall, 10-foot-tall, and 15-foot-tall noise barriers. Tables 8, 9, and 10 summarize the noise barrier analysis results. The mitigation analysis was calculated for all time periods at all sites, but the tables summarize only the daytime results. The 6-foot-tall noise barriers would eliminate most of the exceedances of the Total L_{eq} and 1-second L_{eq}, but there would still be exceedances of the L_{AFmax} at many sites. The 10-foot-tall noise barriers would further reduce the number of receiver exceedances. The 15-foot-tall noise barriers would mitigate most of the exceedances, however, some would still remain.

Note that this noise mitigation design is preliminary and not intended to represent a final design of a particular noise barrier option. If noise barriers could be placed closer to the pickleball courts, they would provide even greater noise mitigation. The barriers also would not necessarily need to continue all the way around all of the courts. They would only need to be located on portions near or facing noise sensitive or impacted locations.

Additional noise mitigation analysis at some selected sites at Trotting Park showed that pickleball noise levels could potentially be further reduced by approximately 1 decibel by adding sound absorptive treatments to the barriers. The absorption would be placed on the "inside" facing the courts to reduce the sound reflections.

Locating noise barriers even closer to the courts would potentially reduce the future pickleball noise levels by approximately 1 decibel as well. Another consideration that could potentially further reduce noise from the courts would be to place some barriers within the layout of courts, such as adding acoustic mitigation that can attach to fencing between some or all of the courts. Note that this internal fencing with noise reducing capabilities would be considered in addition to standard noise barriers around the perimeter of all the courts.

Table 8. Pickleball Noise Assessment Results with 6 foot High Noise Barrier

Pickleball Facility Location	Site #	Time Period [a]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
Trotting Park	N1	MF-Day	45	36	40	45	52
		SS-Day	49	37	40	45	52
	N1	MF-Day	47	35	37	41	48
		SS-Day	48	35	37	41	48
	N3	MF-Day	47	36	40	46	53
		SS-Day	47	36	40	46	53
Landers Road	Rec-Lan-1	MF-Day	47	33	35	38	45
		SS-Day	45	28	32	38	45
	Rec-Lan-2	MF-Day	47	34	35	35	37
		SS-Day	48	33	33	34	37
Ellis Highway-A [c]	Rec-Ell-1	MF-Day	57	41	48	54	62
		SS-Day	55	37	47	54	62
	Rec-Ell-2	MF-Day	53	42	42	42	41
		SS-Day	51	38	38	39	41
	Rec-Ell-3	MF-Day	57	41	41	42	43
		SS-Day	55	37	38	39	43

Pickleball Facility Location	Site #	Time Period [a]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
Ellis Highway-B [c]	Rec-Ell-1	MF-Day	57	41	42	44	48
		SS-Day	55	37	39	42	48
	Rec-Ell-2	MF-Day	53	42	42	42	40
		SS-Day	51	38	38	39	40
	Rec-Ell-3	MF-Day	57	41	45	50	58
		SS-Day	55	37	44	50	58

[a] "MF-Day" = weekday-daytime and "SS-Day" = weekend-daytime time periods.
[b] All sound levels have been rounded to the nearest whole decibel.
[c] Two potential locations for the pickleball courts at the Nathan Ellis Highway location were evaluated separately. See Figure 15 for details on the assumed locations.
[d] The numbers in bold/shaded text are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

Table 9. Pickleball Noise Assessment Results with 10 foot High Noise Barrier

Pickleball Facility Location	Site #	Time Period [b]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
Trotting Park	N1	MF-Day	45	36	39	44	51
		SS-Day	49	37	40	44	51
	N1	MF-Day	47	35	37	41	48
		SS-Day	48	35	37	41	48
	N3	MF-Day	47	36	39	44	51
		SS-Day	47	36	39	44	51
Landers Road	Rec-Lan-1	MF-Day	47	33	34	37	44
		SS-Day	45	28	32	37	44
	Rec-Lan-2	MF-Day	47	34	34	35	35
		SS-Day	48	33	33	34	35
Ellis Highway-A [c]	Rec-Ell-1	MF-Day	57	41	46	51	59
		SS-Day	55	37	45	51	59
	Rec-Ell-2	MF-Day	53	42	42	42	40
		SS-Day	51	38	38	39	40
	Rec-Ell-3	MF-Day	57	41	41	42	43
		SS-Day	55	37	38	40	43
Ellis Highway-B [c]	Rec-Ell-1	MF-Day	57	41	42	43	46
		SS-Day	55	37	38	41	46
	Rec-Ell-2	MF-Day	53	42	42	42	40
		SS-Day	51	38	38	39	40
	Rec-Ell-3	MF-Day	57	41	44	49	56
		SS-Day	55	37	43	49	56

[a] "MF-Day" = weekday-daytime and "SS-Day" = weekend-daytime time periods.
[b] All sound levels have been rounded to the nearest whole decibel.

[c] Two potential locations for the pickleball courts at the Nathan Ellis Highway location were evaluated separately. See Figure 15 for details on the assumed locations.
[d] The numbers in bold/shaded text are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

Table 10. Pickleball Noise Assessment Results with 15 foot High Noise Barrier

Pickleball Facility Location	Site #	Time Period[a]	Ambient L_{eq}[b]	Ambient L_{90}[b]	Total L_{eq}[b]	1-sec L_{eq}[b]	L_{AFmax}[b]
Trotting Park	N1	MF-Day	45	36	39	44	51
		SS-Day	49	37	39	44	51
	N1	MF-Day	47	35	37	41	47
		SS-Day	48	35	37	40	47
	N3	MF-Day	47	36	39	43	50
		SS-Day	47	36	38	43	50
Landers Road	Rec-Lan-1	MF-Day	47	33	34	37	43
		SS-Day	45	28	31	36	43
	Rec-Lan-2	MF-Day	47	34	34	35	34
		SS-Day	48	33	33	34	34
Ellis Highway-A[c]	Rec-Ell-1	MF-Day	57	41	44	49	56
		SS-Day	55	37	43	48	56
	Rec-Ell-2	MF-Day	53	42	42	42	38
		SS-Day	51	38	38	38	38
	Rec-Ell-3	MF-Day	57	41	41	42	44
		SS-Day	55	37	38	40	44
Ellis Highway-B[c]	Rec-Ell-1	MF-Day	57	41	42	43	47
		SS-Day	55	37	39	41	47
	Rec-Ell-2	MF-Day	53	42	42	42	41
		SS-Day	51	38	38	39	41
	Rec-Ell-3	MF-Day	57	41	44	48	55
		SS-Day	55	37	42	48	55

[a] "MF-Day" = weekday-daytime and "SS-Day" = weekend-daytime time periods.
[b] All sound levels have been rounded to the nearest whole decibel.
[c] Two potential locations for the pickleball courts at the Nathan Ellis Highway location were evaluated separately. See Figure 15 for details on the assumed locations.
[d] The numbers in bold/shaded text are exceedances of the Mass DEP criteria (L_{90} + 10 dB).

Recommendations

- No nighttime use at the pickleball facility between the hours of 10 PM and 7 AM in order to reduce noise during sensitive hours.

- Design and install a noise barrier around all of the courts on the sides of the facility facing adjacent noise sensitive parcels. Install the tallest noise barriers that are feasible based on the mitigation results above. Noise barriers should be made of an impervious material with a minimum surface density of 4 lb./sq. ft. There should not be any gaps or holes. Place barriers as close as possible to the courts.

- Consider adding sound absorption treatments to the noise barriers on the sides facing the pickleball courts to reduce sound reflections that can degrade the acoustical performance of the barriers.

- Consider additional noise-reducing fence products that can be attached to standard fencing within the layout of the courts, between courts if possible.

- When designing the layout of the pickleball court facility, consider the placement relative to the noise prediction results above. At the Landers Road location, the pickleball courts should be located as far to the east within the town-owned parcel as possible in order to reduce future noise levels at the residences to the west. At the Ellis Highway location, the pickleball courts should be located as far to the southwest as possible so that they are as far as possible from the residences to the north across Ellis Highway and to the southwest.

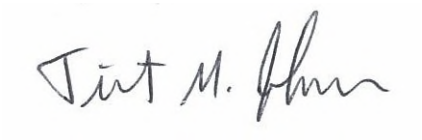
- If possible, when designing the court layout and earth work associated with construction, consider if it is possible to have the courts at a lower elevation where elevated ground around the facility will assist in breaking the line-of-site between the facility and sensitive receivers. If large amounts of earth need to be moved in the normal course of leveling a site, consider utilizing the spoil in the form of a berm to further reduce sound levels.

- Ensure that there are no gaps between the sound barrier material sheets, especially at corners and overlapping sections that sound can easily pass through.

- Recommend the use of quieter pickleball equipment, including balls and paddles that produce lower sound levels.

If you have any questions or concerns regarding this analysis, please feel free to contact me.

Sincerely,



Timothy M. Johnson

CC: Herbert Singleton Jr, P.E., INCE Bd. Cert.

Appendix A: Acoustical Terms

Sound is a vibrational disturbance that propagates through the air in a predictable manner and can be detected by human hearing organs. Sound can be mathematically expressed as rapid changes in air pressure that travel from a vibrating source (speaker diaphragm, mouth, etc) to a receiver.

Vibration is the mechanical oscillation of a solid or fluid object about an equilibrium or rest position. Vibration is typically described in terms of displacement (inches or meters), velocity (inches per second or meters per second) or acceleration (inches per second squared or meters per second squared).

Noise is unwanted sound that may interfere with communications or disturb a person. There is no mathematical or scientific distinction between noise and sound, the only difference is how they are perceived by humans.

Decibel (abbreviation "dB") is a mathematical expression used for expressing the magnitude of sound levels. The human ear is capable of hearing pressure variations from 0.00002 Pascals to 20 Pascals. Decibels are used to compress this large range of values to a more manageable range that varies from about 0 to 120. A decibel is defined as $10\log_{10}\left(P^2_{ref}/P^2_{ref}\right)$

"p" is the sound pressure magnitude generated by a source, and "P^2_{ref}" is a reference pressure of 20 microPascals (μPa). Note that decibels are logarithmic quantities. Therefore, 60 dB + 60 dB = 63 dB, not 120 dB

Frequency is the number of cyclical variations in sound pressure that occur over one second. Humans perceive a change in frequency as a change in pitch. For example, a low frequency sound ("bass") will be perceived has having a low pitch, and a high frequency sound ("treble") will be perceived as having a high pitch. Frequency is expressed in units of Hertz, abbreviated as Hz.

Octave (or octave band) is a range of frequencies where the upper frequency limit is twice the lower frequency limit. For example, the frequency range of 25 Hz to 50 Hz is one octave. Octave bands are identified by their "center" frequencies.

A-Weighting simulates the response of the human ear to sound by attenuating low and high frequencies, and amplifying the midrange frequencies. A-weighted sound levels are abbreviated as "dBA." The following gives an indication of how A-weighted sound levels are perceived by humans under normal conditions:

- A 1 decibel difference in sound level can only be detected in carefully controlled laboratory experiments.
- A 3 decibel change is the minimum difference in noise level that is perceptible to humans outside of controlled testing environments
- A change of at least 5 decibels is required before a community would perceive a significant change in the noise environment.
- A 10 decibel change in sound level is usually perceived as a doubling in the loudness of sound.

The following table gives common A-weighted sound levels:

Typical Noise Source dBA Levels	
Noise from rustling leaves	20 dBA
Room in a quiet dwelling at night	32 dBA
Soft whisper at 5 ft	34 dBA
Refrigerator at 3 ft	45 dBA
Air conditioner indoor at 3 ft	55 dBA
Passenger car at 50 ft	69 dBA
Television at full volume at 5 ft	70 dBA
Lawn mower at 50 ft	73 dBA
Bus idling at 50 ft	75 dBA
Bulldozer at 50 ft	82 dBA
Jackhammer at 50 ft	89 dBA
Heavy diesel propelled vehicle at 25 ft	92 dBA
Lawn mower at 5 ft	93 dBA
Jet aircraft at 500 ft overhead	115 dBA
Human pain threshold	120 dBA

L_{90} is the sound level that is exceeded 90% of the time during the measurement period. L_{90} is the metric commonly associated with the background noise, and is used by several agencies and municipalities to assess background noise.

L_{eq} is the level of steady sound that has the same energy as a fluctuating sound measured over the same time period. L_{eq} is indicative of the average sound level during the measurement period.

L_{max} is the maximum sound pressure level of an event. L_{max} is often used to characterize the loudness of a single event

References:

Martin Hirschorn, *Noise Control Reference Handbook*, Industrial Acoustics Company, New York, NY, 1989

U.S. Department of Transportation, Federal Highway Administration, FHWA Roadway Construction Noise Model User's Guide, FHWA-HEP-05-054 DOT-VNTSC-FHWA-05-01, January 2006

U.S. Department of Transportation, Federal Transit Administration, Transit Noise and Vibration Impact Assessment Manual, FTA Report No. 0123, September 2018

Appendix B: Noise Measurement Site Photographs

Figure B1. Trotting Park Noise Measurement Site N1

Figure B2. Trotting Park Noise Measurement Site N2

Figure B3. Trotting Park Noise Measurement Site N3

Figure B4. Thomas B Landers Road Noise Measurement Site N4

Figure B5. Thomas B Landers Road Noise Measurement Site N5

Figure B6. Nathan Ellis Highway Noise Measurement Site N6

Figure B7. Nathan Ellis Highway Noise Measurement Site N7

Figure B8. Nye Park Pickleball Noise Measurement

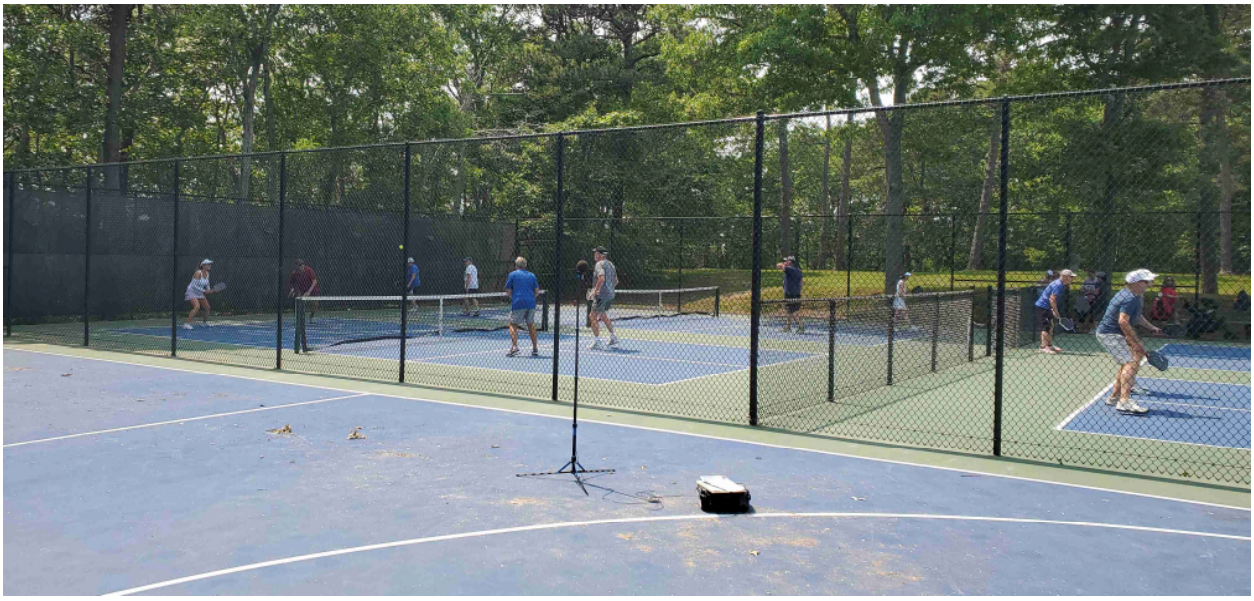


Figure B9. Nye Park Pickleball Noise Measurement