

**STUDY OF
SOUND PROPAGATION**
For Proposed
OUTDOOR ACTIVITIES
Measurement Survey Report

**Wallace Township
Chester County, PA**



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I. EXECUTIVE SUMMARY

The Wallace Township Zoning Ordinance Section 1209.B.6 has established a not-to-exceed sound level criterion at residential lot lines of 55 dB(A) from 7:00 am – 10:00 pm, and 45 dB(A) from 10:00 pm to 7:00 am. A measurement survey was conducted to evaluate future compliance with the Ordinance for the propagation of sound levels from the proposed outdoor activities to adjacent property lines and communities.

The Planned Country Club Community (PCCC) Ordinance Standards for allowable sound levels for Non Residential Uses (§13 23.E.4.i.7) states that all equipment shall be sound insulated to reduce the decibel level of such equipment. Sound levels from any source proposed as a component of a PCCC development shall comply with the requirements set forth in Zoning Ordinance Section 1209.B.6.

A battery powered speaker was used to generate test tones for 1/1 octave band center frequencies from 250 Hz to 4 kHz. The speaker was oriented to simulate conditions associated with proposed outdoor activities. The nominal source level generated by the speaker was 110 dB / octave at 1 meter (3 feet). Each test tone 'sweep' was approximately 5 seconds in length with approximately 30 seconds between tones to allow the observers to document the ambient background sound level without, and with, the sound level generated by the test tones. The logarithmic difference between the 'with' and 'without' measured sound levels would represent the sound level contribution from the test tone propagating from the source to the measurement location.

Initial observation and measurement sites were proposed for the residential property line along Chalfont Road at Waterview Drive (0.4 mile), and at an elevated location along Marshall Road near Highspire Road (0.8 mile). (See Figure 1) Sound propagation tests conducted between 6 pm and 7 pm were nonproductive; sound source levels propagating from the outdoor site did not produce a discernable or measurable event for any of the octave bands at either of these observation locations.

The observers relocated to the gated entry along Marshall Road, approximately 1,200 feet from the proposed site of outdoor activities at Canyon Lake, to determine if the test tones were audible and measurable against the ambient background sound level. It should be noted that significant sound level contributions from aircraft and vehicles, especially motorcycles on Marshall and Creek Road, were both audible and measurable at the test site throughout the entire measurement survey. These events were so frequent and intrusive that collecting sound measurements unaffected by their influence was difficult to

achieve even though the entire test event was less than 2 minutes and 30 seconds in duration. Some frequencies, notably 250, 500, and 1,000 Hz, were occasionally audible at the gate if ambient background conditions were favorable, i.e., no aircraft flyovers or local traffic events.

In order to calibrate propagation characteristics for future sound level predictions, data from a minimum of two measurement sites are necessary. A second measurement site 'A' was established along the walkway to, and approximately 560 feet from, the test site. (See Figure 1) From this location, when ambient background sound levels were favorable, i.e., unaffected by aircraft or local vehicular operations, many, if not all, of the test tones were audible and measurable.

FIGURE 1
Proposed Outdoor Activities
Source, Observation, and Measurement Sites



An analysis of the successful measurements indicated that sound levels emanating from the Test Site (~120 dB(A) combined source strength) ranged from 41-47 dB (A) at Measurement Site 'A' (See Appendix B). The effective reduction of sound from the test site is due to several factors such as distance (dispersion), the height

of the Canyon Lake walls (barrier edge diffraction), absorption of mid and high frequencies due to heavy vegetative growth between the source and receivers, and absorption due to air [at higher frequencies]. Effects of inversions on sound level propagation are qualitatively discussed in Section III.D.3 and may be quantitatively evaluated during subsequent phases of the study if necessary.

The measured levels, even with a combined source strength of ~120 dB(A), are well below the daytime criteria of 55 dB(A) and are below or approach the nighttime criteria of 45 dB(A) at both measurement sites.

Actual sound levels from outdoor activities are not anticipated to exceed 100 dB(A), even if amplified sound reinforcement is used. Therefore, sound levels measured at sites 'A' and 'B' would be further reduce by approximately 20 dB(A) resulting in operational sound levels that are in compliance with both day and nighttime criteria.

II. COMPLIANCE WITH APPLICABLE ORDINANCE PROVISIONS

A. General Zoning Ordinance Standards (§12 09)

Environmental Performance Standards defining allowable noise levels are found in the Wallace Township Zoning Ordinance §12 09(B)(6), NOISE. The ordinance states the following conditions:

- a. Excessive noise shall be required to be muffled so as not to be objectionable due to intermittence, beat frequency, shrillness, or volume.
- b. The maximum permissible sound pressure level of any continuous, regular, or frequent source of sound produced by any activity regulated by this ordinance shall be as established by the time period and type of land use district listed below. Sound pressure levels shall be measured at all major lot lines, at a height of at least four (4) feet above the ground surface.
- c. Sound from any source controlled by this ordinance shall not exceed the following limits at the property line of said source.

Sound Pressure Level Limits Decibels (dB(A)'s)

	7a.m. - 10p.m.	10p.m. - 7a.m.
Industrial District	70	65
All Other Districts	55	45

1. Where the emitting and receiving premises are in different zones, the limits governing the stricter zone shall apply to any regulated noise entering that zone.
2. The level specified may be exceeded by 10 dB(A) for a single period, no longer than 15 minutes in any one day.

- d. Noise shall be measured with a sound level meter meeting the standards of the American National Standards Inst., ANSI S1.2 – 1962 *American Standard Meter for Physical Measurements of Sound*. [Current reference is ANSI 1.4-1983 (R 2006)]
- e. Exceptions. The noise standards stated in this section shall not apply to public or private school band and athletic activities; activities conducted and authorized by the Township on Township Parks and playgrounds; operation of municipal or public works vehicles or equipment; or usual and customary agricultural activities unless such activities bear a direct relationship to the public health and safety.

Compliance with the Zoning Ordinance: The results of the measurement survey documented in this report are offered to quantify (1) that the proposed Outdoor Activities will comply with the standards contained, or referred to, in the criteria above, and (2) that adequate provisions are available through proper design of facilities to reduce and minimize any potentially objectionable elements to the degree that the proposed Outdoor Activities will be muffled so as not to be objectionable due to intermittence, beat frequency, shrillness, or volume, as defined above.

B. Planned Country Club Community (PCCC) Ordinance Standards for Sound (§13 23)

Section §13 23.E (4)(j)(7) of the PCCC for Non Residential Uses states the following:

All equipment shall be sound insulated to reduce the decibel level of such equipment. Sound levels from any source proposed as a component of a PCCC development shall comply with the requirements set forth in Zoning Ordinance Section 1209.B.6.

This section shall not apply to sound levels associated with construction noise or emergency generator testing between the hours of 8:00 AM and 6:00 PM, or the use of emergency generators during periods of commercial power disruption.

Compliance with the PCCC Ordinance: Compliance with both the PCCC and the Zoning Ordinance are to be achieved during the design phase of the project. The commitment to comply is embodied in the reference to Section 1209.B.6.

III. TECHNICAL REPORT

A. Project Description

Valhalla Brandywine consists of a 600-acre retreat comprised of recreation facilities, a spa and wellness center, and comprehensive life enhancement programs in an idyllic natural setting. Valhalla Brandywine's Spa & Wellness center, as will some fine dining options, will be open to the public.

Valhalla Brandywine proposes an enclave of 275 country-style residences consisting of English cottages, carriage houses and manor homes. In addition, indoor and outdoor recreational opportunities will be integrated with the natural landscape to maximize open "green" space.

Valhalla Brandywine will also feature a golf clubhouse with an Audubon gold-certified golf course. All recreational facilities and homes will be designed to meet 'LEED' (Leadership in Energy and Environmental Design) certification requirements, ensuring these facilities have been planned and constructed according to strict environmental building standards.

B. The Physics of Sound

Sound is measured and described by units called decibels. Decibels are units which represent acoustic energy intensities. Because the range of energy found throughout the spectrum of normal hearing is so wide (whispers to jet engines) the scale necessary to define these levels must be capable of representing huge variations in energy.

The range of sensation to which the human ear can respond, from the barely discernable to the threshold of pain, is approximately seven orders of magnitude (10^7). Sound levels are depicted using the [base 10] logarithm of the ratio of the measured (or predicted) sound level to some reference level. For this purpose, the unit of the decibel has been borrowed from telephone technology to make the numbers more "normal". The sound intensity related unit of the decibel is abbreviated with 'dB'.

Sounds heard in the environment typically consist of a range of frequencies, each at a different level. Frequencies are airborne vibrations of varying wavelength described in cycles per second (cps) or Hertz (Hz). The more cycles per second (shorter wavelength) the higher the frequency. The normal range of healthy hearing is from 30 cps (very low) to 16,000 cps (very high). The human ear is most efficient in the mid and high range frequencies and has increasingly reduced efficiency below approximately 250 cycles (noted by the 'Bass Boost' or 'Loudness')

button on many stereo systems). The efficiency of the human ear to detect various frequency components of sound waves is also influenced by the overall amplitude (volume) of the frequency content of the source, i.e., at elevated sound pressure levels, low frequencies begin to be perceived at the same 'loudness' level as mid and high frequency components.

A method of correlating the response of the normal healthy human ear to equivalent sound levels at different frequencies is called "weighting". The weighting system used to correlate human hearing to frequency response is the "A-weighting" scale and the resultant sound pressure level is called the "A-weighted sound pressure level", identifiable by the abbreviated descriptor dBA or dB(A) (See Table III.B.1).

The A-weighted sound level adequately describes the acoustic environment at a particular instant. However, the level and frequency of sound varies constantly over time. Distant and continuous noise sources, such as traffic 1000 feet away, wind rustling leaves, and industrial activity, create a background, or ambient, sound level where no particular sound event can be readily identified. The level slowly changes with the daily cycle of human activity. Included with the background noise level is a succession of nearby noise events that are of short duration (aircraft flyovers, vehicle passbys, miscellaneous non-traffic events, e.g., dogs barking) and these cause more identifiable changes in the overall sound level.

The equivalent sound level, or Leq , is the representative 'steady state' level containing the same amount of energy as the 'time varying' levels throughout a defined period of time, typically, one hour. A 1-hour sample is denoted by $Leq(1h)$, or $Leq(h)$, while a 24-hour sample would be denoted as $Leq(24)$.

Measured 1/1 octave band sound levels in this report will be presented as sound pressure level, dB (linear or un-weighted) for prediction of sound propagation from the Test Site. Composite, full bandwidth, sound levels in this report will be presented as sound pressure level, dB(A), for comparison with the criteria in the Ordinance.

Table III.B.1
A-Weighting Adjustments for 1/1 Octave Band Sound Level, dB

1/1 Octave Band Center Frequency, Cycles/Sec.	63	125	250	500	1k	2k	4k	8k
Adjustment Factor	-26.2	-16.1	-8.6	-3.2	0	1.2	1.0	-1.1

C. The Affect of Distance On Sound Propagation

Two classic dispersion algorithms are presented to show the effect of distance on sound level propagation from a source to a receiver. The first algorithm converts the measured *Sound Pressure in a Free Field* at 50 feet to its associated *Sound Power Level*, L_w in dB at 1 m, for each octave-band contribution. Using the Sound Power values derived from the measurements, Sound Pressure Level, L_p in dB, can be predicted for any combination of receiver and distance using the *Sound Pressure in a Free Field* algorithm.

Conversion of sound pressure to sound power in a free field is given by

$$L(w) = L(p) - Y \log \left(\frac{Q}{4 \times \pi \times r^2} \right) \text{ dB ref } 20 \text{ uPa}, \quad \text{eq. (1)}$$

Conversion of sound power to sound pressure in a free field is given by

$$L(p) = L(w) + Y \log \left(\frac{Q}{4 \times \pi \times r^2} \right) \text{ dB ref } 10^{-12} \text{ W}, \quad \text{eq.(2)}$$

where,

- $L(w)$ = Sound Power, dB
- $L(p)$ = Sound Pressure, dB
- Q = Directivity Factor, typically,
 - 1 = spherical (least directional)
 - 2 = hemispherical
 - 4 = quadral
 - 8 = octral (most directional)
- Y = Ground Impedance (Terrain Effect), typically,
 - 10 = hard surface (ignores terrain features)
 - 20 = soft surface (incorporates terrain features)
- π = 3.14
- r = distance from source to receiver in meters

Note that the distance variable, r^2 , is in the denominator of the dispersion equation, and indicates that, with all other variables being equal, the sound level will decrease as a function of the inverse square of the distance between the sound source and the listener.

D. Meteorological Effects On Sound Propagation

1. Absorption Due To Dispersion In Air

Meteorological effects can play a role in the dispersion of sound and, therefore, in the way sound amplitude and frequency content is perceived. The random nature of the variable content and the way in which these variables may combine is beyond the scope and capability of contemporary modeling techniques, e.g. predicting exacting weather conditions. However, certain aspects of how these variables affect sound propagation in a meteorologically 'neutral' envelope are discussed below.

- a. Temperature - (20° C/68° F) Generally, an increase in temperature results in a slight, barely measurable, decrease in sound levels. A decrease in temperature conversely results in a slight, barely measurable, increase in sound levels. Changes in temperature also affect the speed of sound.
- b. Humidity - (50%) Generally, an increase in humidity results in a slight decrease in sound levels, especially for frequencies above the 1 kHz octave band. A decrease in humidity conversely results in a slight increase in sound levels and a more uniform dispersion of acoustic energy throughout the audible frequency range.

2. Wind Speed and Direction

The effects of wind on sound propagation are complex and not well suited to existing modeling technologies. In general, what is understood is that light to moderate wind may slightly increase or decrease sound levels for receptors located immediately downwind from the source. If prevailing eddy currents are upward, sound levels may decrease slightly; if prevailing eddy currents are downward or propagating horizontally, sound levels may increase slightly. All of these effects are also variably dependant upon temperature and humidity effects.

As wind speed increases beyond moderate velocities, turbulence increases due to the interaction of wind currents with objects near the ground. The turbulence tends to randomize sound dispersion patterns and may decrease sound propagation for receptors both upwind and downwind from the source.

3. Inversions

Inversions occur when the upper air layer becomes more dense than the air layer near the surface. These effects are largely seasonal, are rarely predictable, and can undergo rapid changes in composition due to the variable effects of wind, temperature, and humidity. The propagation of sound may be affected by an inversion if the upper air layer is dense enough to act as a reflective plane and the angles of reflection are 'shallow'. The effect of inversions on sound propagation from Outdoor Activities will be evaluated during the prediction modeling phase of the study.

E. Methodology and Procedure

Guidance on how to evaluate the propagation of sound levels from proposed Outdoor Activities is provided in the Wallace Township zoning documents. The purpose of the measurement survey was to investigate how sound levels of a known amplitude and frequency composition, originating from the location of the proposed site, would propagate to the property lines of adjacent communities due to source orientation, distance, terrain, vegetation, and meteorological effects.



FIGURE 2 – Orientation of Sound Source at the Proposed Outdoor Activity Site

The 1/1 octave test tones used for the measurements were generated by a TEF20 analyzer and recorded to a Marantz Digital Audio Recorder. The test tones were transferred from the Digital Audio Recorder to a CD for playback using the Anchor Liberty CD player.

The test tones consisted of 5 second frequency sweeps for the 250, 500, 1k, 2k, and 4k Hz octave bands. The frequency sweeps were spaced at 30 second intervals to allow the

observers to record the measurements between successive sweeps. The entire test sequence was approximately 2 minutes and 30 seconds in length.

The volume of the speaker was adjusted for a nominal sound pressure level of 110 dB at 250 Hz. Speaker output volumes were measured for each test tone by manually holding a sound level meter approximately 1 meter from the transducers while precariously balancing on the edge of the berm. The Test Tone Source Levels were measured approximately once per hour during the measurement survey to verify battery condition. Results of these measurements are summarized in Table III.E.1 and indicate that Test Tone Source Levels deviated by only 1-2 dB throughout the measurement period. These minor variations are likely due more to the awkwardness of manually holding the sound level meter in front of the speaker than from a noticeable reduction in battery output.

Table III.E.1 Test Tone Sound Pressure Levels (SPL), dB, re 1 Meter							
Test Time (pm)	Sound Pressure Level (SPL)						
	Full Bandwidth		Octave Band Center Frequency, dB				
	dB	dB(A)	250	500	1000	2000	4000
7:10	119.9	120.2	110.0	109.1	112.0	114.8	115.4
8:00	119.8	120.1	108.8	108.5	112.4	115.4	114.5
9:00	118.6	118.4	109.7	109.6	112.5	112.5	112.5

Multiple locations are necessary to measure and analyze the propagation of sound from the proposed test site to property line locations. Primary conditions influencing whether a valid series of measurements could be obtained at the measurement site from the test tone sequence include:

1. Whether the test tone was audible at the measurement site,
2. Whether the test tone was measurable against the ambient background sound level or any local, intermittent, events such as aircraft flyovers or vehicle passbys,

3. Whether changes in temperature or humidity affected the propagation characteristics of the test tone, and
4. Whether local terrain features, such as natural barriers, affected the propagation characteristics of the test tone. See Figure 3.

Measurement sites were established based upon the observers' ability to discern and measure the test tones propagating from the speaker. It should be noted that significant sound level contributions from aircraft and vehicles, especially motorcycles on Marshall and Creek Road, were both audible and measurable at the proposed Test Site and measurement sites throughout the entire measurement survey. These events were so frequent and intrusive that collecting sound measurements uncolored by their influence was difficult to achieve even though the entire test event was less than 2 minutes and 30 seconds in duration. Some frequencies, notably 250, 500, and 1,000 Hz, were occasionally audible at the gate if ambient background conditions were favorable, i.e., no aircraft flyovers or local traffic events.

Concurrent measurements at a minimum of two different sites are necessary to calibrate the propagation characteristics for the prediction of future sound levels. The actual SPL contributions of individual test tones are obtained by calculating the Base 10 logarithmic difference between the measured sound pressure level with the test tone and the measured ambient background level without the test tone. Once the reference source level and two corresponding measurements at different distances are known, the following estimations for dispersion can be derived:

1. Changes in sound level due to Ground Impedance Effects (absorption and scattering)
2. Changes in sound level due to natural terrain barrier features (diffraction edge effects)

FIGURE 3 - View of rock walls to the right of the speaker which help to contain sound levels generated at the Canyon Lake test site



F. Measurement Procedure

The B&K 2230 (ANSI Type I) Integrating Sound Level Meter (SLM) was used to measure source levels generated at the Canyon Lake Test Site. Two RION Model NA-27 (ANSI Type I) Integrating SLMs were used to measure concurrent sound levels at both the 'A' and 'B' Measurement Sites. (See Figure 1.)

An acoustic calibrator was used to calibrate all the meters before and after the measurement period. A porous windscreen was used on the sound level meter during all measurement procedures. The sound level meter was operated on the Linear Network (dB) and the fast meter response for the 1/1 Octave Band Test Measurements.

The sound level meters were mounted approximately five feet above the ground surface. This height is generally considered representative of an observer's ear level. Wind speed during the measurement surveys was generally calm throughout the measurement period. Roadway pavement was dry.

G. Selection of Measurement Sites

Initial observation and measurement sites were attempted at the property line along Chalfont Road at Waterview Drive (0.4 mile), and at an elevated location along Marshall Road near Highspire Road (0.8 mile). Sound propagation tests conducted between 6 pm and 7 pm were nonproductive; test tones emanating from the Canyon River Test Site did not produce a discernable or measurable event for any of the octave bands at either of these locations. See Figure 1.

1. Description of Measurement Sites

Alternate 'sites of opportunity' were located much nearer to, and directly in line with, the orientation of the sound source. From these alternate observation and measurement sites the test tones from the sound source were audible when the background ambient sound level was not influenced by aircraft flyovers and traffic operations on Marshall and Creek Road.

- a. Measurement Site A

Measurement Site A (MS A) was established approximately 560 feet along the walkway midway between the gated entrance to Canyon Lake at Marshal Road and the Test Site. At this location, when ambient background sound levels were favorable, i.e., unaffected by aircraft or local vehicular operations, most, if not all, of the test tones were audible and measurable. At this distance, the effect of the Canyon Lake walls appeared to produce a measurable effect on the propagation of sound since MS A would be within the influenced of the shadow zone created by the diffraction edge at the top of the proposed seating area.

In addition to distance effects and barrier edge diffraction, other factors influencing the propagation of sound are absorption due to air (highly frequency dependent as a function of temperature and humidity) and a heavy vegetation canopy comprised of mature trees and dense undergrowth which can affect the propagation of sound both by diffusion and absorption (again, frequency dependent).

- b. Measurement Site B

Measurement Site B (MS B) was established along Marshal Road at the gated entrance to Canyon Lake. The distance from the Test Site to the measurement site was approximately 1,200 feet. This was a 'site of opportunity' selected to determine if the test tones were

audible and measurable against the ambient background sound level.

At a distance of 1,200 feet, the effect of the Canyon Lake walls would be less effective, relative to MS A, since the shadow zone created by the diffraction edge would be less effective. Some frequencies, notably 250, 500, and 1,000 Hz, were occasionally audible at the gate if ambient background conditions were favorable, i.e., no aircraft flyovers or local traffic events.

Other factors, in addition to distance effects, influencing propagation of sound levels are the more frequency dependent absorption due to air and, just like MS A, the area is heavily vegetated with mature trees and dense undergrowth which can affect the propagation of sound by both diffusion and absorption.

H. Meteorology at Measurement Site 'B'

Weather conditions were monitored during the measurement intervals when changes in temperature and humidity may result in changes in sound propagation due to inversion activity. These data are presented in Table III.H.1. Note that cloud cover and wind speed remained constant throughout the entire measurement survey. As expected, temperature decreased and humidity increased as photosynthesis reversed itself with decreasing sun light.

Table III.H.1 Meteorology, Site 'B'				
Time (pm)	Cloud Cover (%)	Temperature (°F)	Wind Speed (mph /Gust)	Humidity (%)
8:00	0	79.6	Calm /5	69±
8:30	0	70.5	Calm /5	85±
8:55	0	67.5	Calm /5	88±

This data will be further analyzed and used to calibrate future predictions of sound propagation from the proposed Outdoor Activity site.

I. Analysis of Sound Level Measurements

1. Summary of Measurement Results

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Table III.I.1 8:00 pm Measurement Sound Pressure Level, dB							
Octave Center (Hz)	Measurement Site 'A'			Measurement Site 'B'			Notes
	SPL _{TOT}	SPL _{BG}	SPL _{TT}	SPL _{TOT}	SPL _{BG}	SPL _{TT}	
250	41.5	40.5	34.6	*	37.8		
500	35.9	35.6	24.1	*	*		
1000	39.6	38.6	32.7	*	*		
2000	39.5	38.5	32.6	*	*		
4000	33.0	27.1	31.7	*	*		

TOT Measurement with Test Tone
BG Measurement without Test Tone
TT Sound Level of Test Tone (TOT-BG)
* Test Tone not measurable or discernable

Table III.I.2 8:30 pm Measurement Sound Pressure Level, dB							
Octave Center (Hz)	Measurement Site 'A'			Measurement Site 'B'			Notes
	SPL _{TOT}	SPL _{BG}	SPL _{TT}	SPL _{TOT}	SPL _{BG}	SPL _{TT}	
250	38.6	37.5	32.1	*	44.1		
500	41.5	40.1	35.9	47.5	39.2	46.8	
1000	38.8	33.5	37.3	46.0	42.0	43.8	
2000	40.5	33.0	39.6	*	35.9		
4000	*	27.0		*	*		

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Table III.I.3 8:55 pm Measurement Sound Pressure Level, dB							
Octave Center (Hz)	Measurement Site 'A'			Measurement Site 'B'			Notes
	SPL _{TOT}	SPL _{BG}	SPL _{TT}	SPL _{TOT}	SPL _{BG}	SPL _{TT}	
250	35.4	33.2	31.4	46.2	44.8	40.6	
500	37.1	30.9	35.9	31.8	*		
1000	36.4	31.3	34.8	32.2	*		
2000	32.2	30.9	26.3	21.2	*		
4000	*	27.1		*	*		

Table III.I.4 9:00 pm Measurement Sound Pressure Level, dB							
Octave Center (Hz)	Measurement Site 'A'			Measurement Site 'B'			Notes
	SPL _{TOT}	SPL _{BG}	SPL _{TT}	SPL _{TOT}	SPL _{BG}	SPL _{TT}	
250	38.3	34.0	36.3	46.8	38.2	46.2	
500	41.2	33.8	40.3	*	*		
1000	40.9	31.7	40.3	*	*		
2000	41.8	30.3	41.5	23.4	*		
4000	33.6	27.2	32.5	*	43.3		

Table III.I.5 9:10 pm Measurement Sound Pressure Level, dB							
Octave Center (Hz)	Measurement Site 'A'			Measurement Site 'B'			Notes
	SPL _{TOT}	SPL _{BG}	SPL _{TT}	SPL _{TOT}	SPL _{BG}	SPL _{TT}	
250	36.8	32.1	35.0	35.2	42.0		
500	41.4	30.0	41.1	36.7	32.2	34.8	
1000	39.8	30.8	39.2	*	35.5		
2000	47.9	30.7	47.8	*	*		
4000	33.8	27.2	32.7	*	*		

2. Analysis of Measurement Results

Summary of Ambient Conditions

- Aircraft flyovers occurred approximately every 2 minutes.
 - At approximately 6:30 pm a thirty second aircraft flyover resulted in an L_{max} of 64 dB(A) and an $L_{eq}(1/120)$ of 45 dB(A) at the Canyon Lake test location. This level exceeds the Ordinance criterion by 9 dB(A).
 - At approximately 6:34 pm a thirty second aircraft flyover resulted in an L_{max} of 55 dB(A) and an $L_{eq}(1/120)$ of 48 dB(A) at the Canyon Lake test location. This level approaches or exceeds the Ordinance criterion.
- Several measurement attempts had to be cancelled or discarded due to interference from traffic or aircraft noise.

- During the Source Measurements between 7:07 - 7:10 pm a very noticeable sound from a car or motorcycle on Creek Road was observed reflecting off the opposite rock walls at Canyon Lake.
- At approximately 8:55 pm, a very loud explosion-like sound occurred to our east.
- At approximately 9:26 pm, the 2000 Hz test tone was barely audible (< 40 dB) at Chalfont Road. In order for the observer to hear the tone, the speaker had to be rotated 90 degrees and aimed directly toward the observer located on Chalfont Road. None of the other test tones were perceptible above or within the ambient sound floor at all.

Potential Effect of Meteorology

During the late afternoon observation attempts when the ground surface was heated by the sun the test tones were not, or barely, audible. This may be due in part to reasonably strong vertical eddy currents directed up the sides of the 'bowl' created by the rock walls.

Trends within the data suggest that sound propagation *may* have improved after sunset. This may correlate to an observed increase in humidity, a decrease in vertical eddy currents, or the formation of a temporal inversion; *however*, a similar effect may also be caused by a decrease in the background ambient sound level which allowed a more accurate measurement of the test tone at the observer locations. Measured sound levels from the Test Site remained 5 dB(A) less than the Ordinance criterion even with the perceived increase in test tone levels.

Effect of the Canyon Lake Rock Walls

The rock walls did not result in echoing of the test tones within the bowl created by Canyon Lake, nor did the rock walls appear to have any audible or measurable effect on sound levels at the measurement or observer locations. The Canyon Lake walls did produce a rather soft 'musical' reverberation at lower frequencies that will enhance the entertainment experience for the local audience. This effect was not noticeable outside the Canyon Lake bowl.

J. Determination of A Quantitative Standard For Operation (DQSO)

The purpose of the Measurement Survey was to establish a measurable and verifiable threshold of sound levels that would allow Outdoor Activities to operate at or below this threshold to insure, to a reasonable level of certainty, compliance with the Township's Ordinance. This threshold, or Quantitative Standard, can then be used as the basis of design for the facilities and sound reinforcement systems.

Determination of A Quantitative Standard For Operation should also incorporate a reasonable (10 dB(A)) buffer level to account for anticipated variations in meteorology that may affect sound propagation, especially between 7 pm and 10 pm during the summer months when inversions may occur. A review of the measurement data *suggests* that a slight increase in measurable sound levels of 3-5 dB may have occurred during the evening measurements, however, this variation may also be attributable to less interference from the ambient background sound level resulting in more accurate readings.

The maximum cumulative (sum of all octave band sound level measurement data) level of 49.5 dB(A) was measured at Site A during the 9:10 pm measurement sequence. This level does not exceed the criterion contained in the Ordinance even though the cumulative Reference Source level was approximately 120 dB for that measurement sequence. If the DQSO was set at a not-to-exceed sound level of 100 dB, or 20 dB less than the Reference Source level, all factors being equal, the sound level at Site A would be approximately 30 dB which is well below the Ordinance, and not discernable within the existing ambient environment.

IV. CONCLUSIONS & RECOMMENDATIONS

- A. The Canyon Lake test site is effective in containing sound levels with a reference source oriented and positioned to represent the proposed operation.
- B. With proper orientation and positioning of the reference source, the Canyon Lake rock walls did not adversely amplify the test source levels.
- C. *However*, certain sound levels entering the bowl from traffic operations along Creek Road were amplified significantly at our testing location. This same, or similar, geometric relationship may be responsible for the annoyance expressed by local residents for operations at the Marsh Creek Speedway. If conditions permit, some of this effect may be abated with site work design.
- D. The 55 dB(A) criterion is routinely exceeded by aircraft and local traffic operations.
- E. Results of the Measurement Survey should be used as part of the Basis of Design (BoD) for the proposed facilities.
- F. A DQSO of 100 dB provides a measurable and verifiable reference for compliance, to a reasonable level of certainty, with the Ordinance.

GLOSSARY OF COMMON TERMINOLOGY

1. **A-Weighting:** The weighting network used to account for changes in level sensitivity as a function of frequency. The A-weighting network de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of the human ear. See also frequency weighting.
2. **"A" Weighted Sound Level** - a method of representing the human ear's interpretations of the loudness of an equal sound level throughout the audible frequency range. The scale is normally referenced to the loudness at 1 kHz.
3. **Acoustic Energy:** Commonly referred to as the mean-square sound-pressure ratio, sound energy, or just plain energy, acoustic energy is the square of the ratio of the mean-square sound pressure (often referred to as frequency weighted), and the reference mean-square sound pressure of 20 μPa , the threshold of human hearing. It is arithmetically equivalent to $10 (\text{SPL}/10)$, where SPL is the sound pressure level, expressed in decibels
4. **Acoustic Reflection:** The process by which the general direction of sound waves is reversed by bounding surfaces.
5. **Ambient Noise:** All-encompassing sound that is associated with a given environment, usually a composite of sounds from many sources near and far.
6. **Amplitude:** The maximum value of a sinusoidal quantity measured from peak to peak.
7. **Artificial Noise Source:** An acoustical source that is controlled in position and calibrated as to output power, spectral content, and directivity.
8. **Background Noise:** All-encompassing sound of a given environment without the sound source of interest.
9. **Building Attenuation:** The reduction in the energy of a sound field resulting from its passages through a building's structural elements.

10. Community Noise Equivalent Level (CNEL, denoted by the symbol, L_{den}): A 24-hour time-averaged L_{AE} adjusted for average-day sound source operations. In the case of highway traffic noise, a single operation is equivalent to a single vehicle pass-by. The adjustment includes a 5-dB penalty for vehicle pass-bys occurring between 1900 and 2200 hours, local time, and a 10-dB penalty for those occurring between 2200 and 0700 hours, local time. The L_{den} noise descriptor is used primarily in the State of California. L_{den} is computed as follows:

$$L_{den} = L_{AE} + 10 \cdot \log_{10}(N_{day} + 3 \cdot N_{eve} + 10 \cdot N_{night}) - 49.4 \quad (\text{dB})$$

where:

L_{AE} = Sound exposure level in dB ;

N_{day} = Number of vehicle pass-bys between 0700 and 1900 hours, local time;

N_{eve} = Number of vehicle pass-bys between 1900 and 2200 hours, local time;

N_{night} = Number of vehicle pass-bys between 2200 and 0700 hours, local time;

and

49.4 = A normalization constant which spreads the acoustic energy associated with highway vehicle pass-bys over a 24-hour period, i.e., $10 \cdot \log_{10}(86,400 \text{ seconds per day}) = 49.4 \text{ dB}$.

11. Contour: Graphical plot consisting of a smooth curve, statistically regressed through points of equal level.
12. Day-Night Average Sound Level (DNL, denoted by the symbol, L_{dn}): A 24-hour time-averaged L_{AE} , adjusted for average-day sound source operations. In the case of highway traffic noise, a single operation is equivalent to a single vehicle pass-by. The adjustment includes a 10-dB penalty for vehicle pass-bys occurring between 2200 and 0700 hours, local time. L_{dn} is computed as follows:

$$L_{dn} = L_{AE} + 10 \cdot \log_{10}(N_{day} + 10 \cdot N_{night}) - 49.4 \quad (\text{dB})$$

where:

L_{AE} = Sound exposure level in dB;

N_{day} = Number of vehicle pass-bys between 0700 and 1900 hours, local time;

N_{night} = Number of vehicle pass-bys between 1900 and 0700 hours, local time; and
49.4 = A normalization constant which spreads the acoustic energy associated with highway vehicle pass-bys over a 24-hour period, i.e., $10 \cdot \log_{10}(86,400 \text{ seconds per day}) = 49.4 \text{ dB}$.

13. Decibel (dB): A unit of measure of sound level. The number of decibels is calculated as ten times the base-10 logarithm of the square of the ratio of the mean-square sound pressure (often referred to as frequency weighted), and the reference mean-square sound pressure of 20 μPa , the threshold of human hearing.
14. Developed Land - those tracts of land or portions thereof which contain improvements or activities devoted to frequent human use of habitation.
15. Diffracted Wave: A sound wave whose phase and direction have been changed by an obstacle in the propagation medium. The medium is air for the purposes of this document.
16. Degradation: The increase in noise levels at receivers due to conditions such as reflections from a single barrier, multiple reflections of the noise between parallel barriers, noise leaks in a barrier, etc.
17. Divergence: The spreading of sound waves from a source in a free field environment. In the case of highway traffic noise, two types of divergence are common, spherical and cylindrical. Spherical divergence is that which would occur for sound emanating from a point source, e.g., a single vehicle pass-by. Cylindrical divergence is that which would occur for sound emanating from a line source, or many point sources sufficiently close to behave as a line source, e.g., a continuous stream of roadway traffic.
18. Energy: See Acoustic energy.
19. Equivalent Sound Level (TEQ, denoted by the symbol, L_{AeqT}): Ten times the base-10 logarithm of the square of the ratio of time-mean-square, instantaneous A-weighted sound pressure, during a stated time interval, T (where $T=t_2-t_1$), divided by the squared reference sound pressure of 20 μPa , the threshold of human hearing, e.g.,

1HEQ, denoted by the symbol, L_{Aeq1H} , represents the hourly equivalent sound level.

L_{AeqT} is related to L_{AE} by the following equation:

$$L_{AeqT} = L_{AE} - 10 \cdot \log_{10}(t_2 - t_1) \quad (\text{dB})$$

where

L_{AE} = Sound exposure level in dB .

20. Existing Sound - that sound which is characteristic of an area before the construction of the proposed [highway] project.
21. Existing Level: The measured or calculated existing noise level at a given location.
22. Exponential Time-Averaging: A method of stabilizing instrumentation response to signals with changing amplitude over time using a low-pass filter with a known, electrical time constant. The time constant is defined as the time required for the output level to reach 63.4 percent of the input, assuming a step-function input. Also, the output level will typically reach 100 percent of an input-step function after approximately five time constants.
23. Far Field: That portion of a point source's sound field in which the sound pressure level (due to this sound source) decreases by 6 dB per doubling of distance from the source, i.e., spherical divergence. For a line source, the far-field is the portion of the sound field in which the sound pressure level decreases by 3 dB per doubling of distance.
24. Free Field: A sound field whose boundaries exert a negligible influence on the sound waves. In a free-field environment, sound spreads spherically from a source and decreases in level at a rate of 6 dB per doubling of distance from a point source, and at a rate of 3 dB per doubling of distance from a line source.
25. Frequency: The number of cycles of repetition per second or the number of wavelengths that have passed by a stationary point in one second.
26. Frequency Weighting: A method used to account for changes in sensitivity as a function of frequency. Three standard weighting networks, A, B, and C, are used to account for different responses to sound pressure levels. Note: The absence of frequency weighting is referred to as "flat" response. See also A-weighting.

27. **Ground Effect:** The change in sound level, either positive or negative, due to intervening ground between source and receiver. Ground effect is a relatively complex acoustic phenomenon, which is a function of ground characteristics, source-to-receiver geometry, and the spectral characteristics of the source. A commonly used rule-of-thumb for propagation over soft ground (e.g., grass) is that ground effects will account for about 1.5 dB per doubling of distance. However, this relationship is quite empirical and tends to break down for distances greater than about 30.5 to 61 m (100 to 200 ft).
28. **Ground Impedance:** A complex function of frequency relating the sound transmission characteristics of a ground surface type. Measurements to determine ground impedance must be made in accordance with the ANSI Standard for measuring ground impedance, scheduled for publication in 1999.
29. **Hard Ground:** Any highly reflective surface in which the phase of the sound energy is essentially preserved upon reflection; examples include water, asphalt, and concrete.
30. **Hertz (Hz):** Frequency in cycles per second.
31. **Insertion Loss (IL):** The sound level at a given receiver before the construction of a barrier minus the sound level at the same receiver after the construction of the barrier. The construction of a noise barrier usually results in a partial loss of soft-ground attenuation. This is due to the barrier forcing the sound to take a higher path relative to the ground plane. Therefore, barrier IL is the net effect of barrier diffraction, combined with this partial loss of soft-ground attenuation.
32. L_{AE} : See Sound exposure level.
33. L_{AeqT} : See Equivalent sound level.
34. L_{den} : See Community noise equivalent level.
35. L_{dn} : See Day-night average sound level.
36. L_{10} : See Ten-percentile exceeded sound level.
37. **Line-of-Sight:** Refers to the direct path from the source to receiver without any intervening objects or topography.

38. Line Source: Multiple point sources moving in one direction, e.g., a continuous stream of roadway traffic, radiating sound cylindrically. Note: Sound levels measured from a line source decrease at a rate of 3 dB per doubling of distance.
39. Lower Bound to Insertion Loss: The value reported for insertion loss when background levels are not measured or are too high to determine the full attenuation potential of the barrier.
40. Maximum Sound Level (MXFA or MXSA, denoted by the symbol, L_{AFmx} or L_{ASmx}): The maximum, A-weighted sound level associated with a given event (see Figure 14). Fast-scale response (L_{AFmx}) and slow-scale response (L_{ASmx}) characteristics effectively damp a signal as if it were to pass through a low-pass filter with a time constant of 125 and 1000 milliseconds, respectively.

Note: Fast response is typically used for measuring individual highway vehicle pass-bys. Slow response is recommended for the measurement of long-term impact due to highway traffic noise, where impulsive noises are not dominant, and is also used for measurements of sound source levels which vary slowly as a function of time, such as aircraft.
41. Near Field: The sound field between the source and the far field. The near field exists under optimal conditions at distances less than four times the largest sound source dimension.
42. Noise: Any unwanted sound. The perception of 'noise' varies greatly among individuals and populations.
43. Noise Barrier: The structure, or structure together with other material, that potentially alters the noise at a site from a BEFORE condition to an AFTER condition.
44. Noise Reduction Coefficient (NRC): A single-number rating of the sound absorption properties of a material; it is the arithmetic mean of the Sabine absorption coefficients at 250, 500, 1000, and 2000 Hz, rounded to the nearest multiple of 0.05.
45. Noise Reduction Goal: The amount of noise reduction that is desired. This value should be defined by a respective State Highway Agency and should typically be in the range of 5-10 dB(A). Noise barriers must provide at least a 5-dB(A) reduction in

highway traffic noise levels in order to provide noticeable and effective attenuation. A noise barrier should be designed to achieve the greatest reduction possible, but in no instance less than 5 dB(A).

46. Noise Sensitive Areas or Locations - general areas of similar land use or specific locations having activities that may be affected by sound levels.
47. Normal Incident (Sound): (Also referred to as 0-degrees incidence) Sound waves that strike a receiver at an angle perpendicular, or normal, to the angle of incidence.
48. Parapet: Parapets are low walls, or railings or a combination of both which are located along the outside edges of (typically) roof tops of buildings or bridge decks.
49. Point Source: Source that radiates sound spherically. Note: Sound levels measured from a point source decrease at a rate of 6 dB per doubling of distance.
50. Random Incident (Sound): Sound waves that strike a receiver randomly from all angles of incidence. Such waves are common in a diffuse sound field.
51. Receiver - a location at which sound levels are predicted and analyzed.
52. REMEL: Reference Energy Mean Emission Level.
53. Retaining Wall: A structure built to hold back earth or water
54. Right-of-Way (ROW): The entire strip or area of land used for highway purposes
55. Sabine Absorption Coefficient (Sab): Absorption coefficient obtained in a reverberation room by measuring the time rate of decay of the sound energy density with and without a patch of the sound-absorbing material under test laid on the floor. These measurements are performed in accordance with the American Society of Testing and Materials (ASTM) Standard C 423-90a.ref.15
56. Sensitive Receptor - Continually occupied sites where worst-case noise impact is typically found.
57. Shoulder: The part of a roadway contiguous to the traffic lanes for accommodating stopped vehicles, bickeways, and cleared snow.
58. Soft Ground: Any highly absorptive surface in which the phase of the sound energy is changed upon reflection; examples include terrain covered with dense vegetation or

freshly fallen snow. (Note: at grazing angles greater than 20 degrees, which can commonly occur at short ranges, or in the case of elevated sources, soft ground becomes a good reflector and can be considered acoustically hard ground).

59. Sound Absorption Coefficient (SAC): (See also Sabine Absorption Coefficient): The ratio of the sound energy, as a function of frequency, absorbed by a surface, and the sound energy incident upon that surface.
60. Sound Contours - areas along a roadway within which sound levels will exceed a specified sound level. (Not to be interpreted as any single line.)
61. Sound Energy: See Acoustic energy.
62. Sound Exposure Level (SEL, denoted by the symbol, L_{AE}): Over a stated time interval, T (where $T=t_2-t_1$), ten times the base-10 logarithm of the ratio of a given time integral of squared instantaneous A-weighted sound pressure, and the product of the reference sound pressure of 20 μPa , the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10 dB down points.

In addition, L_{AE} is related to L_{AeqT} by the following equation:

$$L_{AE} = L_{AeqT} + 10 \cdot \log_{10}(t_2 - t_1) \quad (\text{dB})$$

where:

$$L_{AeqT} = \text{Equivalent sound level in dB}$$

63. Sound Pressure: The root-mean-square of the instantaneous sound pressures during a specified time interval in a stated frequency band.
64. Sound Pressure Level (SPL): Ten times the base-10 logarithm of the square of the ratio of the mean-square sound pressure, in a stated frequency band (often weighted), and the reference mean-square sound pressure of 20 μPa , the threshold of human hearing.

$$\text{SPL} = 10 \cdot \log_{10}(p^2 / p_{\text{ref}}^2) \quad (\text{dB})$$

where:

$$p = \text{mean-square sound pressure; and}$$

p_{ref} = reference mean-square sound pressure of 20 μPa .

65. Sound Transmission Class (STC): A single-number rating used to compare the sound insulation properties of barriers. STC is derived by fitting a reference rating curve to the sound transmission loss (TL) values measured for the 16 contiguous one-third octave frequency bands with nominal mid-band frequencies of 125 Hz to 4000 Hz inclusive, by a standard method. The reference rating curve is fitted to the 16 measured TL values such that the sum of deficiencies (TL values less than the reference rating curve), does not exceed 32 dB, and no single deficiency is greater than 8 dB. The STC value is the numerical value of the reference contour at 500 Hz.
66. Spectrum: A signal's resolution expressed in component frequencies or fractional octave bands.
67. Ten-Percentile Exceeded Sound Level: The sound level exceeded 10 percent of a specific time period. For example, from a 50-sample measurement period, the fifth (10% of 50 samples) highest sound level is the 10-percentile exceeded sound level. Other similar descriptors include L50 (the sound level exceeded 50 percent of a specific time period), L90 (the sound level exceeded 90 percent of a specific time period), etc.
68. Transmission Loss (TL): The loss in sound energy, expressed in decibels, as sound passes through a barrier or a wall. Measurements to determine a barrier's TL should be made in accordance with ASTM Recommended Practice E413-87.ref.16 TL is determined as follows:

$$TL = 10\log_{10}[10^{(SPL_s/10)} / 10^{(SPL_r/10)}] \quad (\text{dB})$$

where:

SPL_s is the sound pressure level on the source side of the surface; and

SPL_r is the sound pressure level on the receiver side of the surface.

69. Undeveloped Land - those tracts of land or portions thereof which contain no improvements or activities devoted to frequent human use or habitation.
70. Wavelength: The perpendicular distance between two wave fronts in which the displacements have a difference in phase of one complete period.

71. Wind Classes: Near-ground wind effects are generally separated into three wind classes: upwind, calm, and downwind. When sound is propagating during upwind conditions, sound waves tend to refract upward away from the ground, which may result in a decrease in sound levels at a receiver. When sound is propagating during downwind conditions, sound waves tend to refract downward towards the ground, which may result in an increase in sound levels at a receiver.
72. Wrap - The process of turning or curving the terminus of a barrier segment to help compensate for barrier insertion loss degradation due to physical openings in the barrier; or, to help extend the effective length of a barrier by physically reducing the viewing angle from a receiver to the roadway.