MEMO

TO:	Bradford T. Atwood
FROM:	Isaac Old
CC:	Patrick Boylan
DATE:	March 13, 2019
SUBJECT:	Frito-Lay Distribution Facility Operational Noise

BART Industries owns a facility on 360 Route 12A, in Plainfield, New Hampshire, that is currently being leased to Frito-Lay as a distribution facility. The facility has recently been the subject of noise complaints from a neighboring resident. RSG was tasked with measuring sound levels from the facility, to assess the contribution of operational sound levels in the surrounding area. This memo includes:

- A description of how the facility is used;
- Monitoring procedures;
- Monitoring results;
- Discussion; and
- Conclusions.

A description of acoustical terms used in this memo is found in Appendix A. The Town of Plainfield does not have a quantitative sound level limit applicable to the facility.

Project Description

The Frito-Lay distribution facility is located in the Town of Plainfield, New Hampshire on a 3.55-acre lot and is used as a food and beverage distribution facility. There are two main sources of externally-visible activity at the facility. The first is the arrival of tractor trailers from a regional distribution facility. This occurs up to six times per week. The trucks arrive, spend approximately one to two hours unloading, and then depart. The arrival and departure times vary, with arrival times of between 3:11 am and 11:00 pm in the months of September through October 2018. In spite of this broad range, most arrivals were in the mid-to-late afternoon. The second type of activity is the departure and arrival of smaller delivery trucks. These trucks pack up goods in the early morning hours (typically about 4 am) and then arrive back at the facility sometime in the mid-afternoon.

The facility is currently permitted for operational hours of between 6 am and 6 pm and is seeking to have this range extended.

There have been recent noise complaints from a neighbor located just north of the facility, citing early morning and evening noise.

Monitoring Procedures

To assess facility sound levels in the context of the surrounding area, sound level monitoring was carried out at the site between Tuesday, March 5, and Friday, March 8, 2019. Sound levels were measured at the two locations near the facility shown in Figure 1. Weather during this period was generally clear, with temperatures ranging from -21 to 3 °C (-6 to 36 °F) and winds from 0 to 7 m/s (0 to 16 mph).

Sound levels were measured with two ANSI/IEC Type 1 Cesva SC310 sound level meters, logging A-weighted and 1/3 octave band sound levels once each second. Microphones were mounted at an approximate height of 1.4 meters (4 feet) and covered with 7-inch (180 mm) hydrophobic foam wind screens, to reduce the influence of wind-caused sound on measurements. Sound level meters were connected to audio recorders to aid in sound source identification. Both sound level meters were calibrated before and after the measurement period, to ensure equipment accuracy. Wind speed and temperature sensors were co-located with the East monitor.

Sound level data that occurred during equipment setup and takedown was removed, as were periods with microphone-height wind speeds exceeding 5 m/s (11 mph), as excess wind can produce false sound level readings. Most sound level meters are only certified for ambient temperatures between -10 and 40 °C (14 and 104 °F). Most of the nighttime periods during monitoring were below this level. RSG has tested our equipment in temperatures down to -18 °C (0 °F) and has found measurements reliable, so data from these periods is included shown.

East Monitor

The East monitor was located near the eastern tip of the parcel. The purpose of this location was to track sound from NH Route 12A and other area sound sources. A picture of the setup is shown in Figure 2.

West Monitor

The West Monitor was located directly north of the Frito-Lay facility. The purpose of this monitor was to track sound from the facility in combination with local sound sources, at a location between the facility and the closest residence to the north. A picture of the setup is shown in Figure 3.

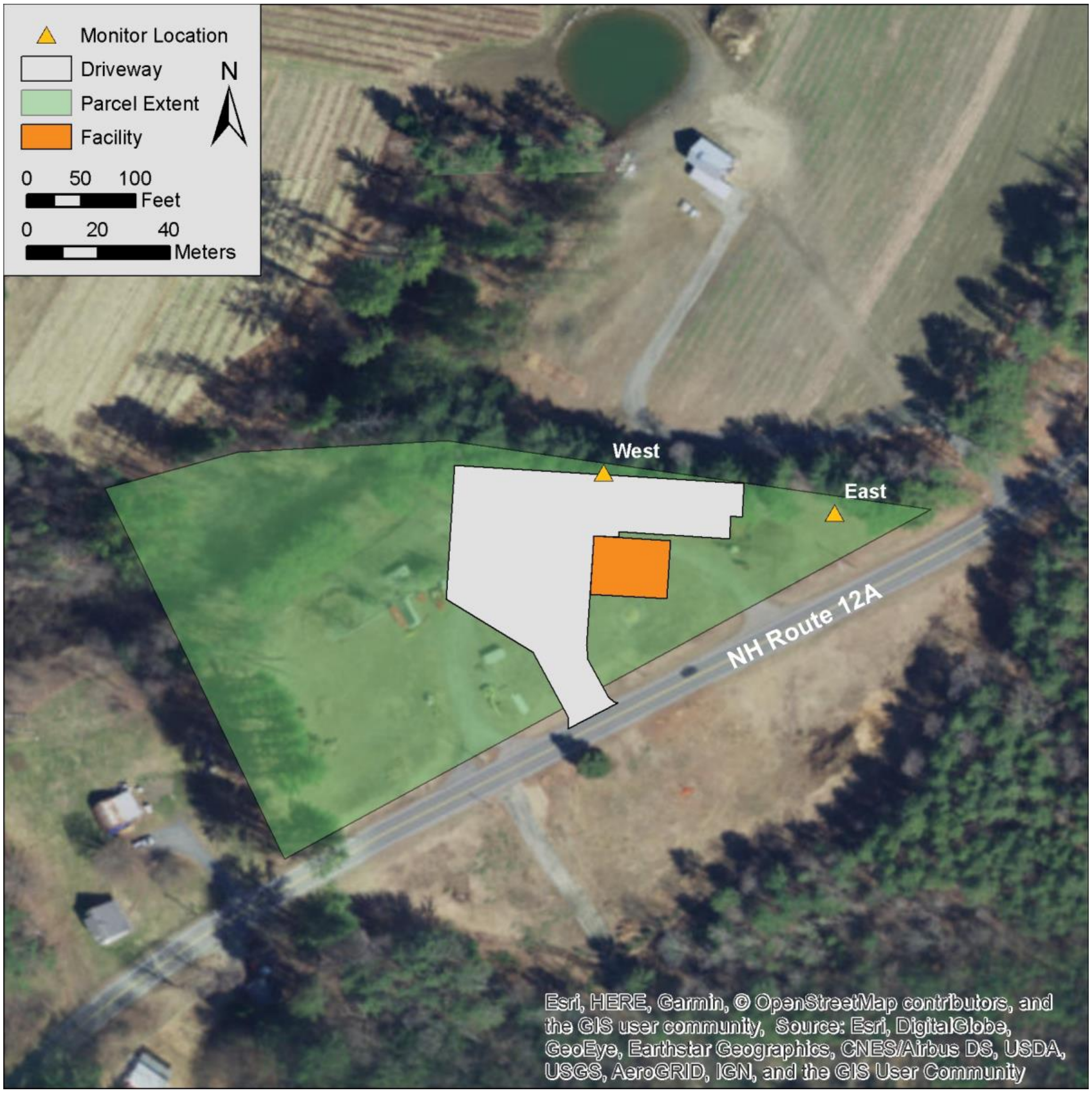

FIGURE 1: SITE MAP AND MONITOR LOCATIONS

FIGURE 2: EASTERN MONITOR LOOKING EAST TO NH ROUTE 12A

FIGURE 3: WESTERN MONITOR LOOKING EAST TOWARDS NH ROUTE 12A

Monitoring Results

Sound pressure levels from both monitoring locations are shown for three different periods in Figures 4 to 7. In each case, data from the West monitor (located at the facility) is compared with data from the East monitor. The idea is to separate out facility sound sources (measured at the west monitor) and compare them in overall level with non-facility sources.

Figure 4 shows a period between 4:00 and 4:35, which contains a delivery truck being loaded, followed by its departure (between about 4:05 and 4:20). At the West monitor, sound levels are elevated due to the vehicle operation and the movement of packages. Sound levels due to the activity range between 45 and 60 dBA with occasional spikes above 60 dBA. This is similar in level to vehicle pass-bys at the eastern monitor. Note that vehicle sound levels are much lower at the West monitor than the East monitor. This is due to the West monitor being further from NH Route 12A, and the facility partially screening the West monitor from the road. Since the East monitor is much closer to NH Route 12A than the closest residence to the north (18 versus 120 meters or 59 versus 394 feet), sound levels from traffic will be lower than what is measured by approximately 16 dB. The same goes for facility sound levels at the West monitor where the monitor is approximately 16 meters (52 feet) from the facility and the residence is 100 meters (328 feet) away, also resulting in a sound level difference of approximately 16 dB between the two locations. As an example, if a 64 dBA sound spike from road traffic is measured at the East monitor, the spike would be approximately 48 dBA at the residence.

Figure 5 shows a period, with another delivery truck loading, as well as a train traveling along the Connecticut River to the west. Sound levels are elevated for an extended period of time, and audio files indicate that site activity is audible. However sound levels from the Facility are not consistently in excess of sound from road traffic, and during this particular period the train pass-by was dominant.

Figure 6 shows arrival of a larger distribution truck. In this case sound levels exceed road traffic levels for a short period. Much of this is caused by the backup alarm. Figure 7 show just the 1 kHz 1/3 octave band for the same period at both monitors. The 1 kHz 1/3 octave band is the band that contains most of the backup alarm sound. While the time-history shows the same approximate shape, the arrival of the truck produces a larger increase in this band, due to the truck backup alarm, than the overall level. Backup alarms are, by design, more easily recognized among background sound, due to their tonal nature. Tonal sounds are also considered to be more annoying than broadband sounds of the same similar level.

The arrival times of the large distribution truck during this monitoring period is varied, occurring at 18:00 on March 6, 9:00 on March 7, and 0:15 on March 8. In contrast, the smaller delivery trucks are more consistent, departing in the early morning from 4:00 to 6:00 and arriving back in the early/mid-afternoon.

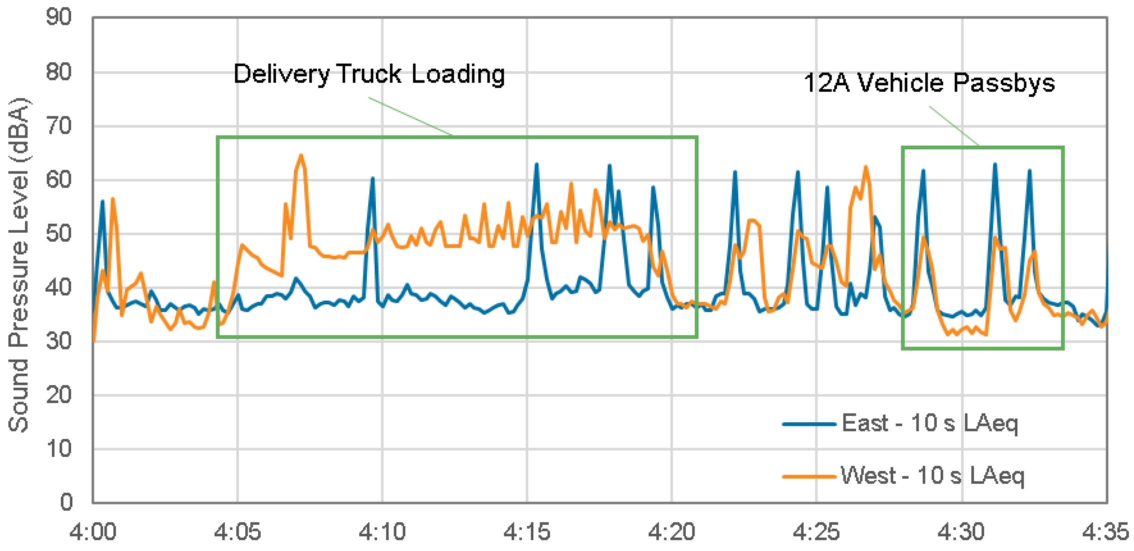

FIGURE 4: SOUND LEVEL COMPARISON - MARCH 6, 2019 BETWEEN 4:00 AND 4:35

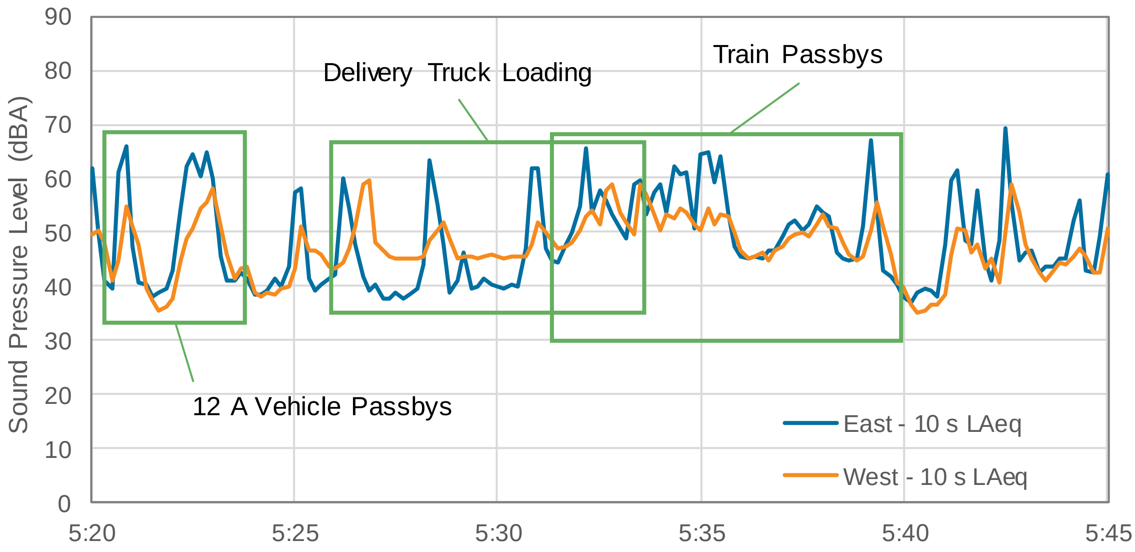

FIGURE 5: SOUND LEVEL COMPARISON - MARCH 6, 2019 BETWEEN 5:20 AND 5:45

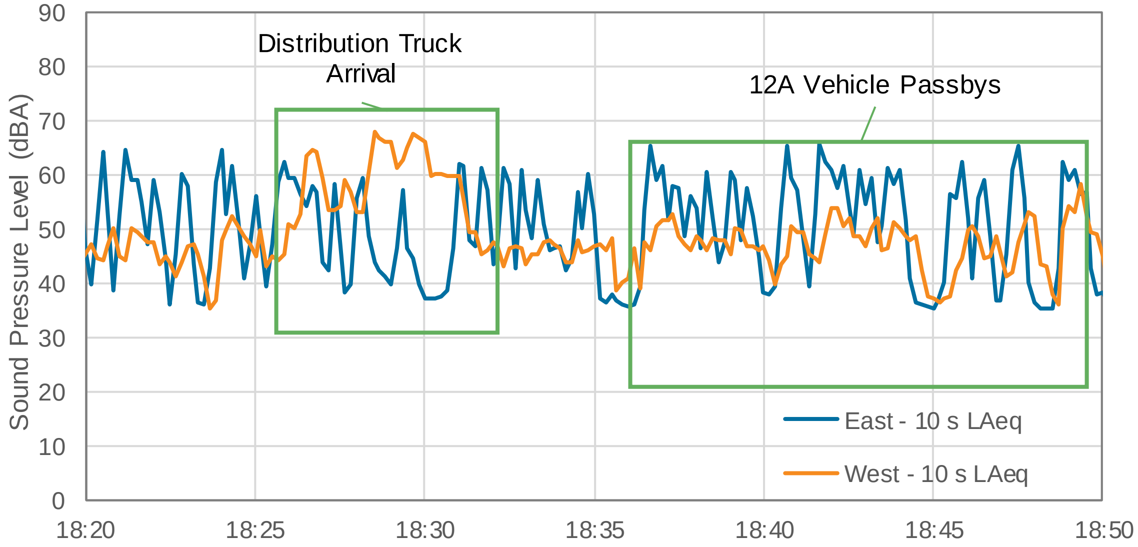

FIGURE 6: SOUND LEVEL COMPARISON - MARCH 6, 2019 BETWEEN 18:20 AND 18:50

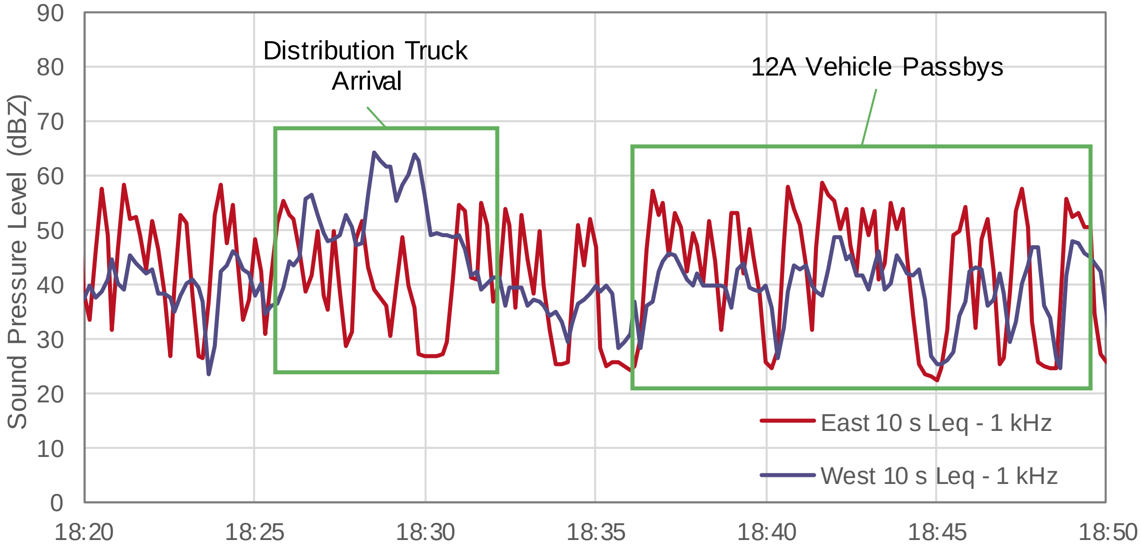

FIGURE 7: SOUND LEVEL COMPARISON AT 1 KHZ 1/3 OCTAVE BAND - MARCH 6, 2019 BETWEEN 18:20 AND 18:50

Discussion

Sound from the Frito-Lay distribution facility due to the *delivery* trucks, is approximately at the magnitude of other transportation sources in the area, such as trains traveling along the Connecticut River and cars traveling along NH Route 12A. These vehicles also have a relatively consistent schedule. Although they do have backup alarms, they seem to be used relatively infrequently.

The larger *distributio*n trucks tend to be louder than the delivery trucks and require more prolonged use of backup alarms than the delivery trucks. As a result, their arrival and departure is more prominent among background sounds and overall levels exceed other sound sources at times, particularly when deliveries are late at night or early in the morning.

Recommendations

The most effective way of reducing sound levels due to facility operation would be to install a sound barrier along the northern side of the driveway. An example is shown in Figure 8. The barrier should be continuous (without gaps or cracks), at least tall enough to break the line of site between the residence and the top of all trucks that will be using the facility (probably 12 feet tall or more) and it should extend long enough to cover the entire path of entering distribution trucks. Commercially available barriers can be used, such as are available from Sound Fighter and Kinetics. Alternatively, custom-made barriers can be used, assuming they are solid and continue all the way to the ground. What should be avoided are barriers with spaced wood slats, or other configurations with inherent gaps. If possible, barriers should be covered with acoustically absorptive material. Barriers can provide broadband sound level attenuation of up to about 10 dB. Effectiveness can vary depending on the sound source type. In this case the barrier would be more effective for backup alarm sound and less effective for low frequency exhaust sound. An earthen berm of equivalent height to a barrier can also be used if there is sufficient room at the site.

Backup alarm noise can be reduced and made less intrusive by installing broadband backup alarms on delivery and distribution trucks.

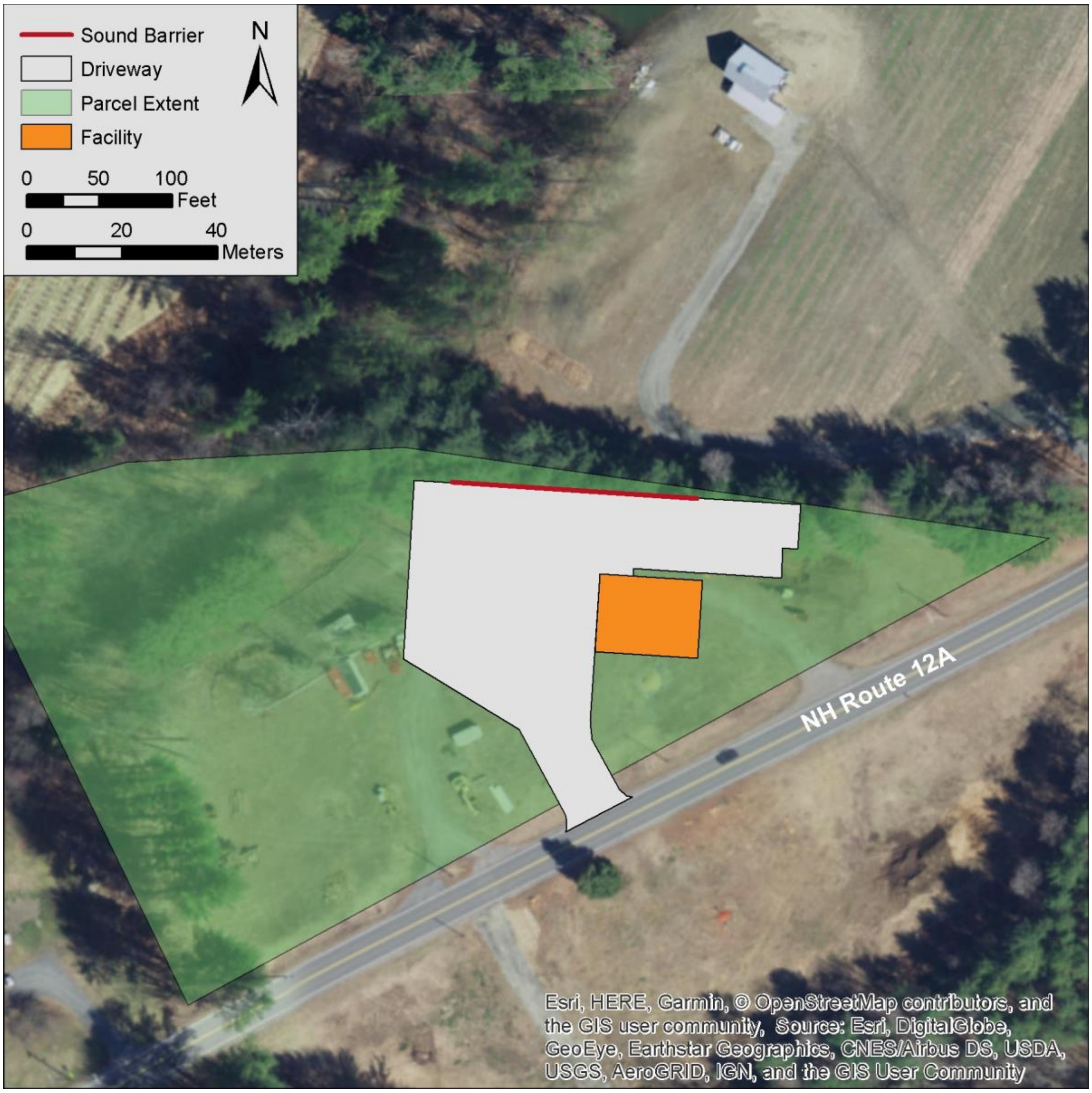

FIGURE 8: PROPOSED BARRIER CONFIGURATION

Conclusions

RSG measured sound levels at a Frito-Lay distribution facility, owned by BART Industries and located in Plainfield, New Hampshire, to assess facility sound emissions in relation to other area sound sources. Conclusions are as follows:

- Sound levels due to delivery trucks are typically at or below those due to other sound sources, such as trains and vehicles traveling along NH Route 12A.
- Sound levels due to distribution trucks can, at times, exceed sound levels caused by other sound sources. Distribution truck backup alarms are louder and used more extensively. Schedule of the distribution trucks is also more variable with arrivals sometimes occurring in the middle of the night.

- To reduce sound levels from the facility, a sound barrier could be installed along the northern edge of the facility of driveway. Backup alarm sound can also be reduced by use of broadband backup alarms.

Appendix A

Sound consists of tiny, repeating fluctuations in ambient air pressure. The strength, or amplitude, of these fluctuations determines the sound pressure level (SPL). "Noise" can be defined as "a sound of any kind, especially when loud, confused, indistinct, or disagreeable."

Expressing Sound in Decibel Levels

The varying air pressure that constitutes sound can be characterized in many different ways. The human ear is the basis for the metrics that are used in acoustics. Normal human hearing is sensitive to sound fluctuations over an enormous range of pressures, from about 20 micropascals (the "threshold of audibility") to about 20 pascals (the "threshold of pain").[1] This factor of one million in sound pressure difference is challenging to convey in engineering units. Instead, sound pressure is converted to sound "levels" in units of "decibels" (dB, named after Alexander Graham Bell). Once a measured sound is converted to dB, it is denoted as a level with the letter "L".

The conversion from sound pressure in pascals to sound level in dB is a four-step process. First, the sound wave's measured amplitude is squared and the mean is taken. Second, a ratio is taken between the mean square sound pressure and the square of the threshold of audibility (20 micropascals). Third, using the logarithm function, the ratio is converted to factors of 10. The final result is multiplied by 10 to give the decibel level. By this decibel scale, sound levels range from 0 dB at the threshold of audibility to 120 dB at the threshold of pain.

Typical sources of noise, and their sound pressure levels, are listed on the scale in Figure 9.

Human Response to Sound Levels: Apparent Loudness

For every 20 dB increase in sound level, the sound pressure increases by a *factor* of 10; the sound *level* range from 0 dB to 120 dB covers 6 factors of 10, or one million, in sound *pressure*. However, for an increase of 10 dB in sound *level* as measured by a meter, humans perceive an approximate doubling of apparent loudness: to the human ear, a sound level of 70 dB sounds about "twice as loud" as a sound level of 60 dB. Smaller changes in sound level, less than 3 dB up or down, are generally not perceptible.

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[1] The pascal is a measure of pressure in the metric system. In Imperial units, they are themselves very small: one pascal is only 145 millionths of a pound per square inch (psi). The sound pressure at the threshold of audibility is only 3 one-billionths of one psi: at the threshold of pain, it is about 3 one-thousandths of one psi.

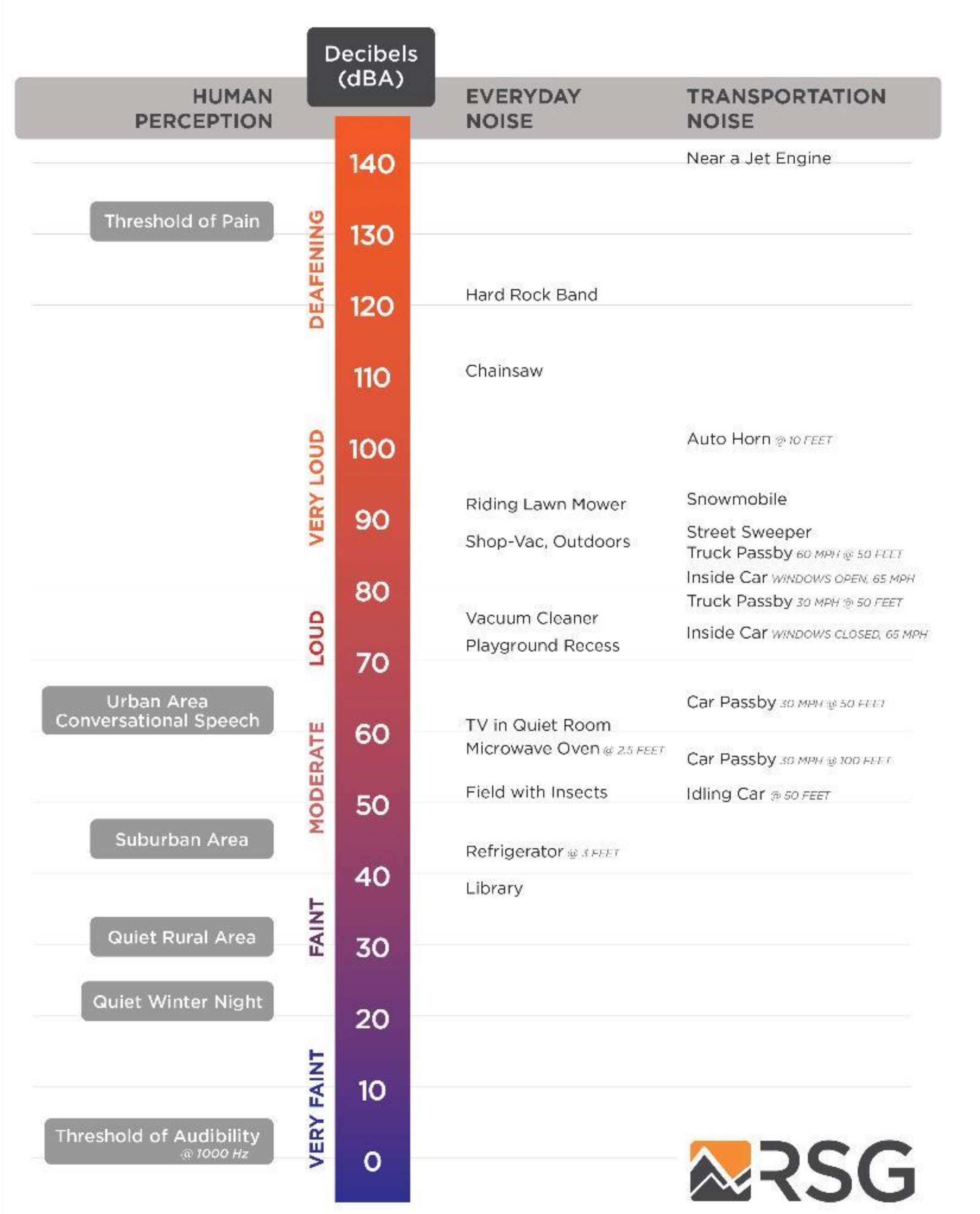

FIGURE 9: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL NOISE SOURCES

Frequency Spectrum of Sound

The “frequency” of a sound is the rate at which it fluctuates in time, expressed in Hertz (Hz), or cycles per second. Very few sounds occur at only one frequency: most sound contains energy at many different frequencies, and it can be broken down into different frequency divisions, or bands. These bands are similar to musical pitches, from low tones to high tones. The most common division is the standard octave band. An octave is the range of frequencies whose upper frequency limit is twice its lower frequency limit, exactly like an octave in music. An octave band is identified by its center frequency: each successive band's center frequency is twice as high (one octave) as the previous band. For example, the 500 Hz octave band includes all sound whose frequencies range between 354 Hz (Hertz, or cycles per second) and 707 Hz. The next band is centered at 1,000 Hz with a range between 707 Hz and 1,414 Hz. The range of human hearing is divided into 10 standard octave bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 8,000 Hz, and 16,000 Hz. For analyses that require finer frequency detail, each octave-band can be subdivided. A commonly-used subdivision creates three smaller bands within each octave band, or so-called 1/3-octave bands.

Human Response to Frequency: Weighting of Sound Levels

The human ear is not equally sensitive to sounds of all frequencies. Sounds at some frequencies seem louder than others, despite having the same decibel level as measured by a sound level meter. In particular, human hearing is much more sensitive to medium pitches (from about 500 Hz to about 4,000 Hz) than to very low or very high pitches. For example, a tone measuring 80 dB at 500 Hz (a medium pitch) sounds quite a bit louder than a tone measuring 80 dB at 60 Hz (a very low pitch). The frequency response of normal human hearing ranges from 20 Hz to 20,000 Hz. Below 20 Hz, sound pressure fluctuations are not "heard", but sometimes can be "felt". This is known as "infrasound". Likewise, above 20,000 Hz, sound can no longer be heard by humans; this is known as "ultrasound". As humans age, they tend to lose the ability to hear higher frequencies first; many adults do not hear very well above about 16,000 Hz. Most natural and man-made sound occurs in the range from about 40 Hz to about 4,000 Hz. Some insects and birdsongs reach to about 8,000 Hz.

To adjust measured sound pressure levels so that they mimic human hearing response, sound level meters apply filters, known as "frequency weightings", to the signals. There are several defined weighting scales, including "A", "B", "C", "D", "G", and "Z". The most common weighting scale used in environmental noise analysis and regulation is A-weighting. This weighting represents the sensitivity of the human ear to sounds of low to moderate level. It attenuates sounds with frequencies below 1000 Hz and above 4000 Hz; it amplifies very slightly sounds between 1000 Hz and 4000 Hz, where the human ear is particularly sensitive. The C-weighting scale is sometimes used to describe louder sounds. The B- and D- scales are seldom used. All of these frequency weighting scales are normalized to the average human hearing response at 1000 Hz: at this frequency, the filters neither attenuate nor amplify. When a reported sound level has been filtered using a frequency weighting, the letter is appended to "dB". For example, sound with A-weighting is usually denoted "dBA". When no filtering is applied, the level is denoted "dB" or "dBZ". The letter is also appended as a subscript to the level indicator "L", for example "L_A" for A-weighted levels.

Time Response of Sound Level Meters

Because sound levels can vary greatly from one moment to the next, the time over which sound is measured can influence the value of the levels reported. Often, sound is measured in real time, as it fluctuates. In this case, acousticians apply a so-called “time response” to the sound level meter, and this time response is often part of regulations for measuring noise. If the sound level is varying slowly, over a few seconds, “Slow” time response is applied, with a time constant of one second. If the sound level is varying quickly (for example, if brief events are mixed into the overall sound), “Fast” time response can be applied, with a time constant of one-eighth of a second.[2] The time response setting for a sound level measurement is indicated with the subscript “S” for Slow and “F” for Fast: L_S or L_F. A sound level meter set to Fast time response will indicate higher sound levels than one set to Slow time response when brief events are mixed into the overall sound, because it can respond more quickly.

In some cases, the maximum sound level that can be generated by a source is of concern. Likewise, the minimum sound level occurring during a monitoring period may be required. To measure these, the sound level meter can be set to capture and hold the highest and lowest levels measured during a given monitoring period. This is represented by the subscript “max”, denoted as “L_{max}”. One can define a “max” level with Fast response L_{Fmax} (1/8-second time constant), Slow time response L_{Smax} (1-second time constant), or Continuous Equivalent level over a specified time period L_{EQmax}.

Accounting for Changes in Sound over Time

A sound level meter’s time response settings are useful for continuous monitoring. However, they are less useful in summarizing sound levels over longer periods. To do so, acousticians apply simple statistics to the measured sound levels, resulting in a set of defined types of sound level related to averages over time. An example is shown in Figure 10. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured, the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 28 dB in the figure) to the maximum (about 65 dB in the figure). The simplest descriptor is the average sound level, known as the Equivalent Continuous Sound Level. Statistical levels are used to determine for what percentage of time the sound is louder than any given level. These levels are described in the following sections.

Equivalent Continuous Sound Level - L_{eq}

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{eq}. The L_{eq} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{eq} is the most commonly used descriptor in noise standards and regulations. L_{eq} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{eq} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent noises. For

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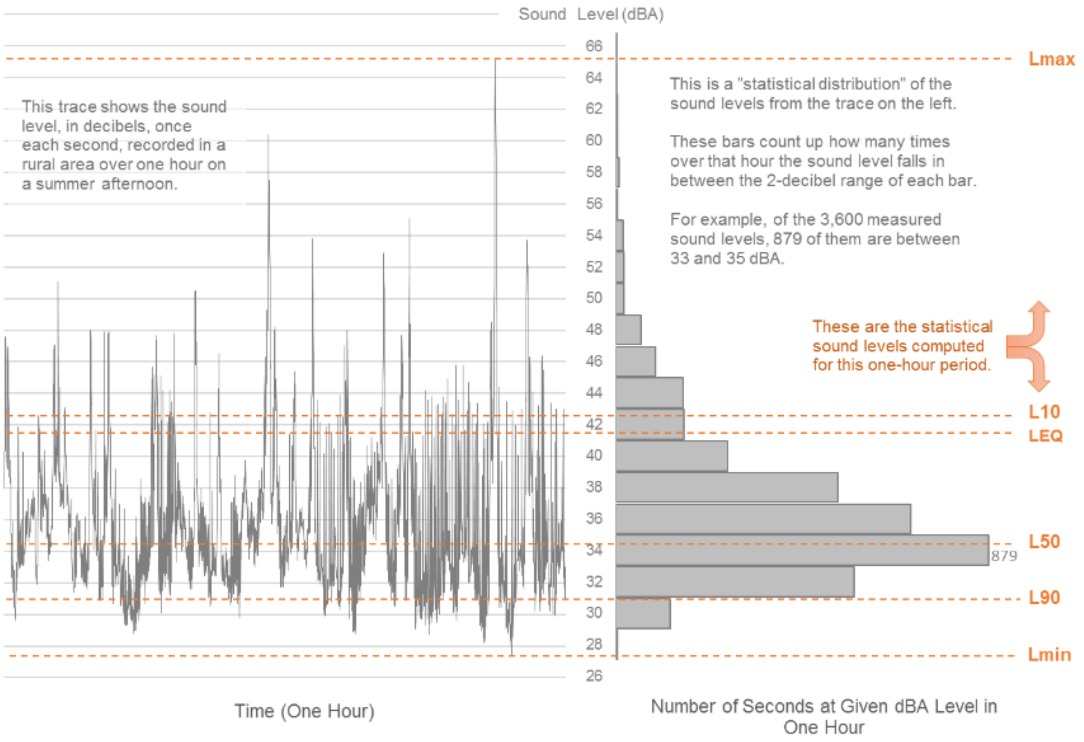
[2] There is a third time response defined by standards, the “Impulse” response. This response was defined to enable use of older, analog meters when measuring very brief noises; it is no longer in common use.

example, in Figure 10, even though the sound levels spends most of the time near about 34 dBA, the L_{eq} is 41 dBA, having been “inflated” by the maximum level of 65 dBA.



This trace shows the sound level, in decibels, once each second, recorded in a rural area over one hour on a summer afternoon.

This is a "statistical distribution" of the sound levels from the trace on the left.

These bars count up how many times over that hour the sound level falls in between the 2-decibel range of each bar.

For example, of the 3,600 measured sound levels, 879 of them are between 33 and 35 dBA.

These are the statistical sound levels computed for this one-hour period.

FIGURE 10: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

Percentile Sound Levels – Ln

Percentile sound levels describe the statistical distribution of sound levels over time. “L_N” is the level above which the sound spends “N” percent of the time. For example, L_{90} (sometimes called the “residual base level”) is the sound level exceeded 90% of the time: the sound is louder than L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the “median level”) is exceeded 50% of the time: half of the time the sound is louder than L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{eq} (mean) are not always the same, for reasons described in the previous section.

L_{90} is often a good representation of the “ambient sound” in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that aren’t part of the source being investigated. L_{10} represents the higher, but less frequent, sound levels. These could include such events as barking dogs, vehicles driving by and aircraft flying overhead, gusts of wind, and work operations. L_{90} represents the background sound that is present when these event noises are excluded.

Note that if one sound source is very constant and dominates the noise in an area, all of the descriptive sound levels mentioned here tend toward the same value. It is when the sound is varying widely from one moment to the next that the statistical descriptors are useful.

Sound Levels from Multiple Sources: Adding Decibels

Because of the way that sound levels in decibels are calculated, the sounds from more than one source do not add arithmetically. Instead, two sound sources that are the same decibel level increase the total sound level by 3 dB. For example, suppose the sound from an industrial blower registers 80 dB at a distance of 2 meters (6.6 feet). If a second industrial blower is operated next to the first one, the sound level from both machines will be 83 dB, not 160 dB. Adding two more blowers (a total of four) raises the sound level another 3 dB to 86 dB. Finally, adding four more blowers (a total of eight) raises the sound level to 89 dB. It would take eight total blowers, running together, for a person to judge the sound as having “doubled in loudness”.

Recall from the explanation of sound levels that a difference of 10 decibels is a factor of 20 in sound pressure and a factor of 10 in sound power. (The difference between sound pressure and sound power is described in the next Section.) If two sources of sound differ individually by 10 decibels, the louder of the two is generating *ten times* more sound. This means that the loudest source(s) in any situation always dominates the total sound level. Looking again at the industrial blower running at 80 decibels, if a small ventilator fan whose level alone is 70 decibels were operated next to the industrial blower, the total sound level increases by only 0.4 decibels, to 80.4 decibels. The small fan is only 10% as loud as the industrial blower, so the larger blower completely dominates the total sound level.

The Difference between Sound Pressure and Sound Power

The human ear and microphones respond to variations in sound *pressure*. However, in characterizing the sound emitted by a specific source, it is proper to refer to sound *power*. While sound pressure induced by a source can vary with distance and conditions, the power is the same for the source under all conditions, regardless of the surroundings or the distance to the nearest listener. In this way, sound power levels are used to characterize noise sources because they act like a “fingerprint” of the source. An analogy can be made to light bulbs. The bulb emits a constant amount of light under all conditions, but its perceived brightness diminishes as one moves away from it.

Both sound power and sound pressure levels are described in terms of decibels, but they are not the same thing. Decibels of sound pressure are related to 20 micropascals, as explained at the beginning of this primer. Sound power is a measure of the acoustic power emitted or radiated by a source; its decibels are relative to one picowatt.

Sound Propagation Outdoors

As a listener moves away from a source of sound, the sound level decreases due to “geometrical divergence”: the sound waves spread outward like ripples in a pond and lose energy. For a sound source that is compact in size, the received sound level diminishes or attenuates by 6 dB for every doubling of distance: a sound whose level is measured as 70 dBA at 100 feet from a source will have a measured level of 64 dBA at 200 feet from the source and 58 dBA at 400 feet. Other factors, such as walls, berms, buildings, terrain, atmospheric absorption, and intervening vegetation will also further reduce the sound level reaching the listener.

The type of ground over which sound is propagating can have a strong influence on sound levels. Harder ground, pavement, and open water are very reflective, while soft ground, snow cover, or grass is more absorptive. In general, sounds of higher frequency will attenuate more over a given distance than sounds of lower frequency: the “boom” of thunder can heard much further away than the initial “crack”.

Atmospheric and meteorological conditions can enhance or attenuate sound from a source in the direction of the listener. Wind blowing from the source toward the listener tends to enhance sound levels; wind blowing away from the listener toward the source tends to attenuate sound levels. Normal temperature profiles (typical of a sunny day, where the air is warmer near the ground and gets colder with increasing altitude) tend to attenuate sound levels; inverted profiles (typical of nighttime and some overcast conditions) tend to enhance sound levels.