APPENDIX 5.2.5-A

FUNDAMENTALS OF ACOUSTICS

Definition of Acoustical Terms

Acoustics is the study of sound and noise is defined as unwanted sound. Airborne sound is a rapid fluctuation or oscillation of air pressure above and below atmospheric pressure creating a sound wave. Acoustical terms are defined as follows.

Ambient sound level	The composite of the outdoor sound from all sources near and far. The normal or existing level of environmental sound at a given location.
A-scale	Scale of noise monitor in dBA units displaying A-weighted sound level
A-weighted sound pressure level, dBA	The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.
Background noise	The underlying level of noise present in the ambient noise, excluding the noise source under investigation, when extraneous noise is removed.
Baseline noise	A 90th percentile of the background noise (i.e., L_{90})
Continuous equivalent sound level	The steady A-weighted sound level over any specified period (not necessarily 24 hours) that has the same acoustic energy as the fluctuating noise during that period (with no consideration of night-time weighting).
dB (decibel)	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure, which is 20 micropascals.
dBA (decibel A)	Unit used for 'A-weighted' sound pressure levels. A-weighting is an adjustment made to sound-level measurement to approximate the response of the human ear.
Equivalent noise level (L_{eq})	The average A-weighted noise level, on an equal energy basis, during the measurement period.
Immision	The process of receiving sound coming from a source emitting sound.

L_{10}, L_{50}, L_{90}	Statistical values of the A-weighted sound pressure levels that are exceeded 10%, 50%, and 90% of the time during the measurement time.
L_{min}, L_{max}	The A-weighted lowest and highest noise levels recorded during the measurement time.
Noise attenuation	Noise reduction. The ability of a material, substance or medium to reduce the noise level from one place to another or between one room and another. Noise attenuation is specified in decibels.
Noise spectrum	Octave band noise components expressed in sound pressure levels; synonym of sound frequency spectra.
Octave band centre frequency	Groups of frequencies named by the centre frequency where the upper limit is always twice the lower limit of the range. Test data for performance of acoustical materials is standardized for easy comparison at the centre frequencies.
Octave band measurement	Measurement of octave band noise levels by spectrum analyzer that combines the features of sound level measurement instrumentation with the frequency selectivity capability of bandpass filters.
Sound frequency spectra	The frequency spectrum of a sound refers to the number of complete pressure fluctuations per second in the sound. The unit of measurement is the cycle per second (cps) or hertz (Hz). The name of the frequency and level content of a sound is its sound spectrum.
Sound power level (PWL)	Sound power level (PWL or Lw) is identified as the total sound power emitted by a source in all directions. Sound power is measured in watts. The reference selected for comparison is the picowatt (10^{-12} Watt).
Receiver	The location at which noise levels are computed and analyzed. Also referred to a as the observer.
Sound level meter	An instrument designed and calibrated to respond to sound and to give objective, reproducible measurements of sound pressure level. It normally has several features that would enable its frequency response and average times to be changed to make it suitable to simulate the response of the human ear.

Sound Intensity

There are several noise measurement scales that are used to describe the intensity or level of the sound in a particular location. The most common is the A-weighted sound level expressed in the decibel (dBA) unit. The dBA scale gives greater weight to the frequencies of sound to which the human ear is most sensitive. There is a relationship between the subjective noisiness or loudness of a sound and its intensity. Each 10 dBA increase in sound level is perceived as approximately a doubling of loudness over a fairly wide range of intensities (Bell 1994).

With regard to increases in noise level, the following relationships can be helpful in understanding the quantitative changes in noise levels (Cowan 1994):

- except in carefully controlled laboratory experiments, a change of only 1 dB in sound level cannot be perceived;
- a 3 dB change is considered a just-noticeable difference;
- an increase in level of at least 5 dB is required before any noticeable change in community response would be expected; and
- a 10 dB increase is subjectively heard as approximately a doubling in loudness, and would be expected to cause an adverse community response.

The measurement of sound level with standard instruments equipped with an A-weighting filter results in a de-emphasis of the very low and very high frequency components of sound in a manner similar to the frequency response of the human ear. This correlates well with subjective reactions to noise. All sound levels in this report are A-weighted, unless indicated otherwise.

The sound level of 0 dBA corresponds roughly to the threshold of hearing (see chart in Appendix A). The sound level of quiet countryside can be expected to be at the 20 dBA level while calm environments correspond to a level of 30 to 50 dBA. Beyond 70 dBA, sounds become very disruptive (ISO 1969; EPA 1974). Construction sources, like a pneumatic hammer, produce a noise level of around 100 dBA.

Sound Frequency Spectrum

The frequency of a sound refers to the number of complete pressure fluctuations per second in the sound waves. The unit of measurement is the cycle per second (cps) or hertz (Hz). Most sounds in the environment do not consist of a single frequency, but of a broad band of frequencies, differing in levels. The name of the frequency and level content of a sound are its sound spectrum. A sound spectrum is typically described in terms of 1/3 or 1/1 octave bands, which separate the audible frequency range (for human beings, from about 20 to 20,000 Hz) into ten segments.

Most environmental noise is a conglomeration of distant noise sources that results in a relatively steady background noise having no identifiable source. These distant sources may include aircraft, industrial activities, wind in trees, birds and animal noise, etc. and are relatively constant from moment to moment. As natural forces change or as human activity follows its daily cycle, the sound level may vary slowly from hour to hour. Superimposed on this slowly varying background is a succession of identifiable noisy events of brief duration. These may include nearby activities such as a single helicopter or aircraft flyover or snowmobile operation which cause the environmental noise level to vary from instant to instant.

A presence of prevailing specific discrete frequency in the broadband noise results in a specific perception of noise loudness and noise character such as rumble, roar, or hiss. The individual octave band noisiness estimates are combined to give an overall perceived noise level (PNL) that is intended to accurately estimate subjective evaluations of the same sound. PNL values will vary with time, for example, when an aircraft flies by a measuring point. The frequency spectrum values add both a duration correction and a tone correction to PNL values. The duration correction ensures that longer duration events are rated as more disturbing. Similarly, noise spectra that seem to have prominent tonal components are rated as more disturbing by the tone-correction procedure.

Time-Varying Character of Sound

Many environmental noises vary over time, at different times of day or from season to season. For example, service road traffic noise may be considerably louder during some hours of the day but much quieter at night. Aircraft noise may vary with the season due to different numbers of aircraft operations. It is usually not possible to measure sound pressure levels continuously over a long enough period of time to completely define the environmental noise exposure. In practice, measurements usually only sample some part of the total exposure.

To describe the time-varying character of environmental noise, statistical noise descriptors were developed. "L_{10}" is the A-weighted sound level equalled or exceeded during only 10% of the measurement time. The L_{10} provides a good measure of the maximum sound levels caused by intermittent or intrusive noise. "L_{50}" is the A-weighted sound level that is equalled or exceeded 50% of the measurement time period; it represents the median sound level. The "L_{90}" is the A-weighted sound level equalled or exceeded 90% of the time. Since this represents "most" of the time, L_{90} generally has been adopted as a good measure of the ambient baseline noise of the measurement site. Therefore, the baseline noise is defined as L_{90} of the background noise recorded at the surveyed site.

Due to variations in sound levels over time, a method for describing the average character of the sound must be utilized to compare two locations or time periods. Most commonly, environmental sounds are described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events. This energy equivalent sound/noise descriptor is called equivalent level (L_{eq}). The most common averaging period is hourly; however, L_{eq} can describe any series of noise events for any selected duration such as daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.). The L_{eq} is particularly useful in describing the subjective sound change in an environment where the source of sound remains the same but there is change in the level of activity (Passchier and Passcier-Vermeer 2000).

In determining the daily measure of environmental noise, it is important to account for the different response of people to daytime and nighttime noise. During the nighttime, exterior background noise levels are generally lower than in the daytime; however, most household noise also decreases at night, thus exterior noise intrusions again become noticeable. Furthermore, most people trying to sleep at night are more sensitive to noise. To account for human sensitivity to nighttime noise levels, a special descriptor was developed. The descriptor is called the Day / Night Average Sound Level ($L_{eq,day}$ / $L_{eq,night}$).

Addition of Sound Levels

Sound levels in decibels are logarithmic quantities and do not follow normal algebraic rules for addition. Instead, the sound levels in decibels are first converted to energy equivalents, the energy equivalents are added algebraically, and then the total energy equivalent is converted back to its decibel values. The formula for addition of sound levels is:

$$L_{total} = 10 \log \{\Sigma 10^{Li / 10}\}$$

where: Li = individual component sound level in dBA

Typical air attenuations at 20ºC and 70% relative humidity are as follows:

Frequency (Hz)	31.5	63	125	250	500	1 k	2 k	4 k	8 k
Attenuation (dB per 1 km)	0.0	0.1	0.3	1.0	2.7	5.4	9.7	23.2	74.8

Equivalent Sound Level (L_{eq})

A single-number representation of the cumulative acoustical energy measured over time intervals is expressed as L eq. The daytime/nighttime ambient sound levels and the frequency analysis was calculated using the following formula which incorporates the logarithmic definition of sound units:

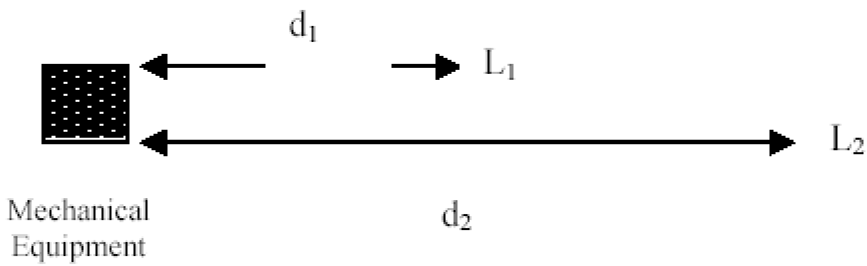
$$L_{eq} = 10 \log \{\Sigma\, fi\, 10^{Li / 10}\}$$

where: f i = fraction of total time the constant level Li is present
L i = sound level in dBA

Sound Level at Specified Location

The noise level L_2 (in dBA) at distance d_2 can be computed from the noise level L_1 (in dBA) measured at distance d_1 by the equation:

$$L_2 = L_1 - 20 \log (d_2 / d_1)$$



Frequency Weighted Metrics (dBA)

In order to simplify the measurement and computation of sound loudness levels, frequency weighted networks have obtained wide acceptance. The A-weighting (dBA) scale has become the most prominent of these scales and is widely used in community noise analysis. This metric has shown good correlation with community response and may be easily measured. The metrics used in this study are all based upon the dBA scale.

The effects of noise on people can be listed in three general categories:

- subjective effects of annoyance, nuisance, dissatisfaction;
- interference with activities such as speech, sleep, learning; and
- physiological effects such as startling and hearing loss.

In most cases, environmental noise produces effects in the first two categories only. However, workers at industrial facilities typically experience noise effects in the last category. No completely satisfactory way exists to measure the subjective effects of noise, or to measure the corresponding reactions of annoyance and dissatisfaction. This lack of a common standard is primarily due to the wide variation in individual thresholds of annoyance and habituation to noise. Thus, an important way of determining a person's subjective reaction to a new noise is by comparing it to the existing or ambient environment to which that person has adapted. In general, the more the level or the tonal (frequency) variations of a noise exceed the previously existing ambient noise level or tonal quality, the less acceptable the new noise will be, as judged by the exposed individual.

Sound Pressure Levels

The following table shows the relative A-weighted noise levels of common sounds measured in the environment and in industry for various sound levels.

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130 (Threshold of pain)	Blasting	Extremely noisy - intolerable
120	Jet take-off	
110	Rock concert	
100	Pneumatic hammer	Very noisy
90	Heavy truck	
80	Busy street traffic	Loud
70	Loud radio or television	
60	Department store	Moderate to quiet
50	General office	
40	Living room	Quiet to very quiet
30	Bedroom	
20	Unoccupied recording studio	Almost silent
< 10 (Threshold of hearing)	Anechoic chamber	Silent