APPENDIX H-1

NOISE BACKGROUND INFORMATION

BACKGROUND INFORMATION ON NOISE

Noise Measurements and Terminology

Introduction. Sound is caused by vibrations that generate waves of minute air pressure fluctuations in the air. The number of pressure fluctuations per second is reported as cycles per second or Hertz (Hz). Different frequencies of vibration produce different tonal qualities for the resulting sound. Air pressure fluctuations that occur from 20 to 20,000 times per second can be detected as audible sound. Frequencies below 20 Hz are called infrasound frequencies. Frequencies above 20,000 Hz are called ultrasound frequencies. Although not audible, some infrasound frequencies can be felt as vibrations.

Human hearing varies in sensitivity for different acoustic frequencies. In addition, relative sensitivity to different acoustic frequencies also varies with the intensity of the sound. Peak sensitivity to pure tones typically occurs at frequencies between 2,000 Hz and 6,000 Hz. Relative sensitivity remains fairly high between about 250 Hz and 2,000 Hz. Relative sensitivity drops off above 7,000 Hz and below 200 Hz. Normal speech typically spans a frequency range from about 125 Hz to about 6,000 Hz, but is dominated by sounds in the range of 500 to 3,000 Hz. The frequency range for adult males tends to be lower than that for adult females, while the frequency range for children's speech tends to be higher than that for adult females.

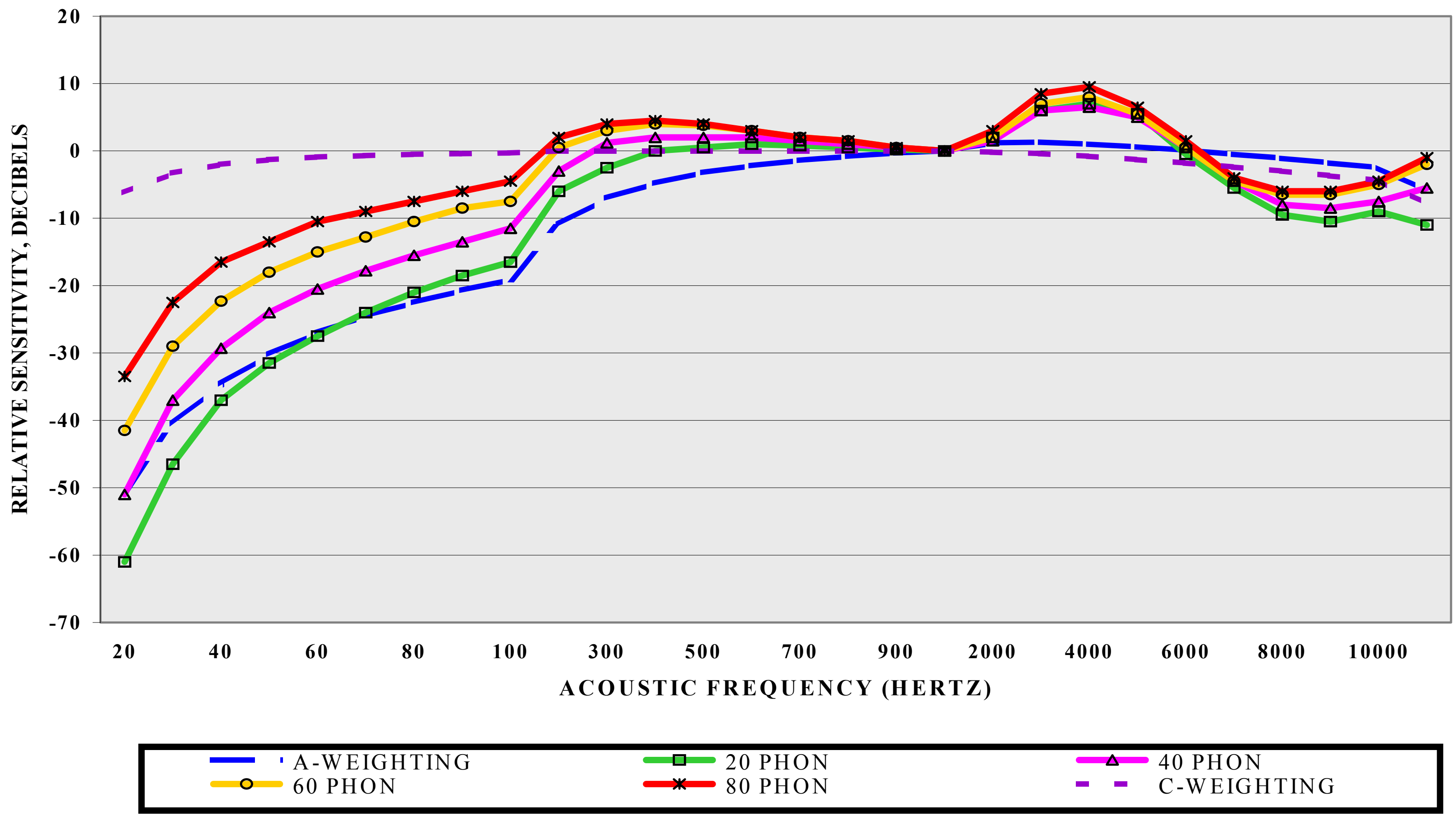
Figure 1 illustrates the relative sensitivity of human hearing to pure tones at various magnitudes. Hearing sensitivity is plotted as relative sensitivity to tones at "equal loudness" levels of 20, 40, 60, and 80 phons. The numerical value of an equal loudness curve in phons is equal to the loudness of a 1,000 Hz tone at the specified decibel level (for example, 60 phon is the loudness of a 1,000 Hz tone at 60 dB). Also shown for comparison are the two most commonly used decibel weighting systems (A-weighted and C-weighted). Decibel weighting systems are discussed in more detail below.

Measurements and descriptions of sounds are usually based on various combinations of the following factors:

- The vibration frequency characteristics of the sound, measured as sound wave cycles per second (Hertz); this determines the "pitch" of a sound;
- The total sound energy being radiated by a source, usually reported as a sound power level;
- The actual air pressure changes experienced at a particular location, usually measured as a sound pressure level; the frequency characteristics and sound pressure level combine to determine the "loudness" of a sound at a particular location;
- The duration of a sound; and
- The changes in frequency characteristics or pressure levels through time.

FIGURE 1

HEARING SENSITIVITY AT DIFFERENT LOUDNESS LEVELS



Data Sources: Scharf (1998, page 1185) and Ford (1987, page 2/14).

Sound level meters typically report measurements as a single composite decibel (dB) value. Decibel scales are a logarithmic index based on ratios between a measured value and a reference value. In the field of acoustics, decibel scales are proportional to the logarithm of ratios between the actual pressure fluctuations generated by sound waves compared to a standard reference pressure value of 20 micropascals (0.000000418 pounds per square foot or 0.0000000029 pounds per square inch). More specifically, a decibel is 10 times the logarithm of the squared pressure ratio, which is equal to 20 times the logarithm of the direct pressure ratio.

Modern sound level meters measure the actual air pressure fluctuations at a number of different frequency ranges, most often using octave or 1/3 octave intervals. The pressure measurements at each frequency interval are converted to a decibel index and adjusted for a selected frequency weighting system. The different adjusted decibel values for the octave or 1/3 octave bands are then combined into a composite sound pressure level for the appropriate decibel scale. Most sound level meters do not save or report the detailed frequency band pressure level measurements. A more sophisticated and expensive instrument (a spectrum analyzer) is required to obtain dB measurements for discrete frequency bands.

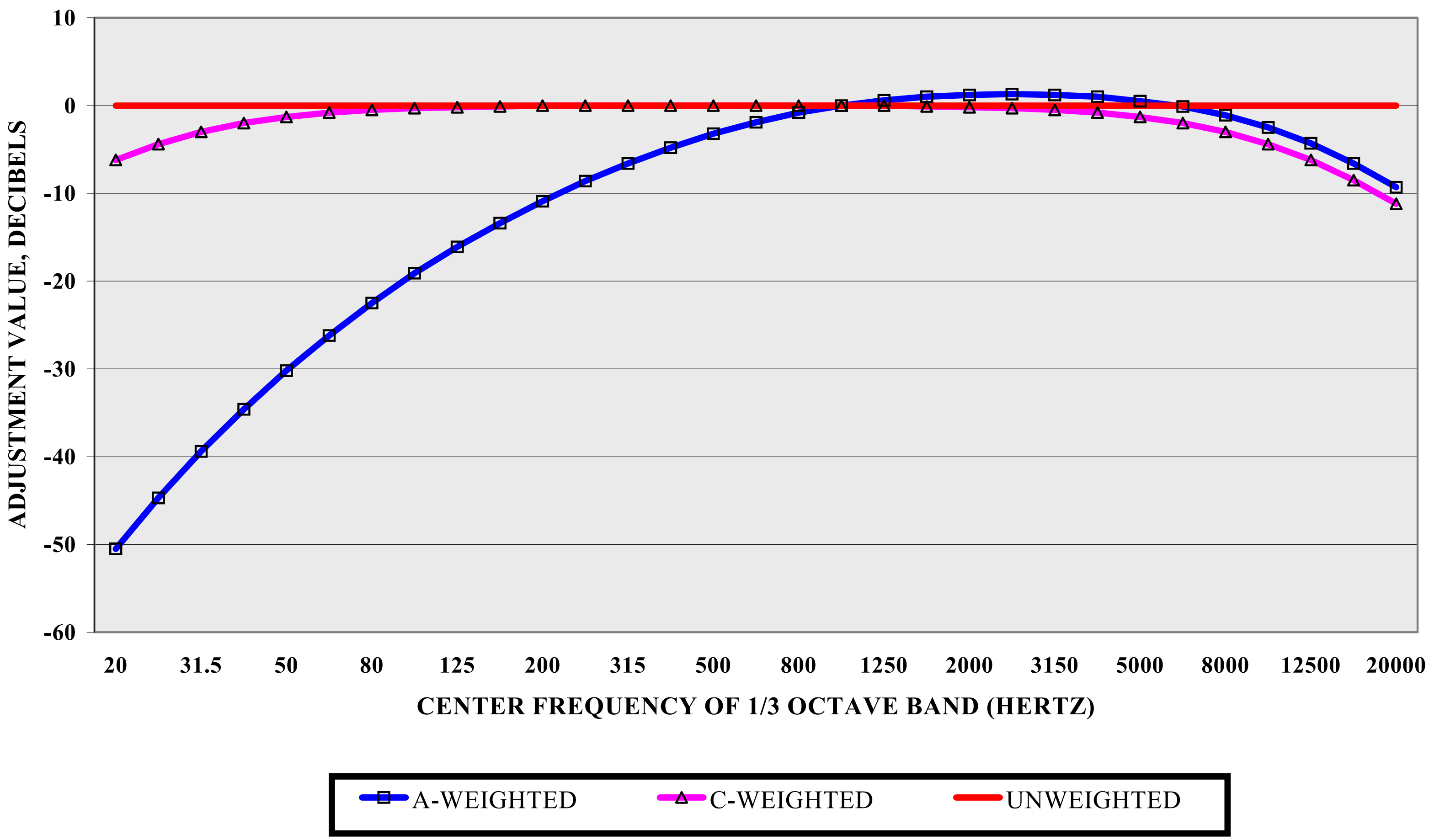
General Purpose Decibel Scales. Because the human ear is not equally sensitive to all audible sound frequencies, frequency weighting schemes have been developed to approximate the way the human ear responds to noise levels. The "A-weighted" decibel scale (dBA) is the most widely used for this purpose, with different dB adjustment values specified for each octave or 1/3 octave interval. The A-weighted scale significantly reduces the measured pressure level for low frequency sounds and slightly reduces the measured pressure level for some high frequency sounds.

Other frequency weighting schemes are used for specialized purposes. The "C-weighted" decibel scale (dBC) originally was developed to approximate human hearing sensitivity to high sound pressure levels. In current practice, the C-weighted scale often is used to characterize low frequency sounds capable of inducing vibrations in buildings or other structures. The C-weighted scale makes only minor reductions to the measured pressure level for low frequency components of a sound while making slightly greater reductions to high frequency components than does the A-weighted scale. Figure 2 illustrates the 1/3 octave band weighting factors used for the A-weighted and C-weighted decibel scales.

The shape of the A-weighting curve in Figure 2 looks slightly different from that shown in Figure 1 because the figures have different X-axis scales. In addition, it is important to recognize that the relative hearing sensitivity curves shown in Figure 1 are for pure tones, not the broad spectrum ambient noise to which people normally are exposed. Although the A-weighted decibel scale illustrated in Figure 2 is only a very simplified approximation of relative hearing sensitivity, it has proven more useful than other decibel weighting schemes as an indicator of human response to general noise conditions. Table 1 summarizes typical dBA levels for various noise sources and noise conditions.

FIGURE 2

DECIBEL WEIGHTING SCALE CORRECTION FACTORS



Data Source: Ford (1987, page 2/14).

TABLE 1. A-WEIGHTED DECIBEL VALUES FOR EXAMPLE NOISE SOURCES

CHARACTERIZATION	dBA	EXAMPLE NOISE CONDITION OR EVENT	OTHER NOISE EXAMPLES
	145	---	---
	140	---	---
	135	---	---
Threshold of pain	130	Surface detonation, 30 pounds of TNT at 1,000 feet	---
	125	F/A-18 aircraft takeoff with afterburner at 470 feet	Mach 1.9 sonic boom under aircraft at 11,000 feet
Possible building damage	120	Mach 1.1 sonic boom under aircraft at 12,000 feet	Air raid siren at 50 feet; B-1 flyover at 200 feet
Threshold for immediate NIPTS	115	F/A-18 aircraft takeoff with afterburner at 1,600 feet	Commercial fireworks (5 lb charge) at 1,500 feet
	110	Peak crowd noise, pro football game, open stadium	Peak noise 50 feet behind firing position at rifle range
	105	Emergency vehicle siren at 50 feet	Pile driver peak noise at 50 feet
	100	F/A-18 aircraft departure climbout at 2,400 feet	Jackhammer at 10 feet; B-52 flyover at 1,000 feet
Extremely noisy	95	Locomotive horn at 100 feet; 2-mile range fog horn at 100 ft	Wood chipper processing tree branches at 30 feet
8-hour OSHA limit	90	Heavy truck, 35 mph at 20 ft; Leaf blower at 5 ft	Person yelling at 5 feet; Dog barking at 5 feet
Very noisy	85	Power lawn mower at 5 feet; City bus at 30 feet	Pneumatic wrench at 50 feet; Jet ski at 20 feet
	80	2-Axle commercial truck, 35 mph at 20 feet	Gas well drilling rig at 50 ft; Table saw at 50 feet
Noisy	75	Street sweeper at 30 feet; Idling locomotive, 50 ft	Beach with medium wind and surf
	70	Auto, 35 mph at 20 ft; 300 ft from busy 6-lane freeway	Stream bank at small/medium waterfall (10 feet)
Moderately noisy	65	Typical daytime busy downtown background conditions	Tree branches rustling in strong wind; Beach, light wind and surf
	60	Typical daytime urban mixed use area conditions	Normal speech at 5 feet
	55	Typical urban residential area away from major streets	Leaves/tall grass rustling in light/moderate wind
	50	Typical daytime suburban background conditions	Open field, summer night, insects

TABLE 1 (continued). A-WEIGHTED DECIBEL VALUES FOR EXAMPLE NOISE SOURCES

CHARACTERIZATION	dBA	EXAMPLE NOISE CONDITION OR EVENT	OTHER NOISE EXAMPLES
Quiet	45	Typical rural area daytime background conditions	---
	40	Quiet suburban area at night	---
	35	---	---
Very quiet	30	Quiet rural area, winter night, no wind	Quiet bedroom at night, no air conditioner
	25	---	---
	20	Empty recording studio	Barren area: no wind, water, insects, or animals
	15	---	---
Barely audible	10	Audiometric testing booth	---
	5	---	---
Threshold of Hearing	0	---	---

Notes:

NIPTS = noise-induced permanent threshold shift (permanent hearing damage)

OSHA = Occupational Safety and Health Administration

Indicated noise levels are average dBA levels for stationary noise sources or peak dBA levels for brief noise events and noise sources moving past a fixed reference point.

Average and peak dBA levels are not time-weighted 24-hour average CNEL or Ldn levels.

Decibel scales are not linear. Apparent loudness doubles with every 10 dBA increase in noise level, regardless of the dBA value.

Data compiled from various published sources, monitoring studies, and noise modeling analyses.

Source: Data compiled by Tetra Tech staff.

Other frequency weighting schemes that have been developed include the B-weighted and D-weighted decibel scales. The B-weighted scale was an attempt to approximate human perception of loudness for moderately high sound pressure levels. The D-weighted scale was developed as an attempt to correlate jet aircraft noise with annoyance. The B-weighted scale and the D-weighted scale are rarely used, although a few older models of sound level meters still provide for B-weighted or D-weighted measurements.

Unweighted decibel measurements are used for refined analyses that require data on the frequency spectrum of a sound (e.g., when determining the sound absorption or sound transmission properties of materials). As a direct measure of the pressure fluctuations associated with sound, unweighted decibel measurements also have considerable usefulness in evaluating noise-induced vibrations. Unweighted decibel measurements sometimes are termed flat or linear measurements. The term "overall sound pressure level" (OASPL) sometimes is used as a technical term to describe unweighted decibel measurements. Unfortunately, the phrase "overall sound pressure level" also is used in a generalized sense to refer to composite dBA or dBC measurements (combined measurements across the range of frequency bands being measured). For most noise sources, unweighted dB measurements are less than 1 dB higher than corresponding C-weighted dB measurements.

In practice, unweighted decibel measurements reflect the unmodified microphone response of a sound level meter. While most microphones provide a flat response across most of the frequency spectrum, there are no formal standards for unweighted decibel measurements. A formal Z-weighting scale is being adopted as an international standard that will replace unweighted decibel measurements with measurements adjusted to a flat response across the entire frequency spectrum from 10 Hz to 20,000 Hz. As a practical matter, this will have little effect on reported decibel measurements, but it will assure consistency among different measurement instruments.

Evaluations of blast noise or sonic boom events sometimes use a peak overpressure measurement. The peak overpressure normally is an unweighted decibel measurement for the dominant octave band or 1/3 octave band component of a sound. In most cases, the specific octave or 1/3 octave band for the peak overpressure measurement is not reported. The peak overpressure level will be slightly less than the corresponding composite unweighted decibel measurement.

Varying noise levels often are described in terms of the equivalent constant decibel level. Equivalent noise levels (Leq) are not a simple averaging of decibel values, but are based on the cumulative acoustical energy associated with the component decibel values. Leq values sometimes are referred to as energy-averaged noise levels. As a consequence of the calculation procedure, high dB events contribute more to the Leq value than do low dB events.

Leq values are used to develop single-value descriptions of average noise exposure over various periods of time. Such average noise exposure ratings often include additional weighting factors for potential annoyance due to time of day or other considerations. The Leq data used for these average noise exposure descriptors generally are based on A-weighted sound level measurements.

Statistical descriptions (Lx, where x represents the percent of the time when noise levels exceed the specified decibel level) also are used to characterize noise conditions over specified periods of time. L1, L5, and L10 descriptors can be used to characterize peak noise levels, while L90, L95, and L99 descriptors can be used to characterize "background" noise levels. It should be noted that the L50 value (the sound level exceeded 50 percent of the time) will seldom be the same as the Leq value for the period being analyzed. For relatively continuous noise conditions, the Leq value often is between the L30 and the L40 values for the measurement period. If impulse noise events are common, the Leq value may be close to the L10 value for the measurement period.

Decibel Scales Reflecting Annoyance Potential. Average noise exposure over a 24-hour period often is presented as a day-night average sound level (Ldn). Ldn values are calculated from hourly Leq values, with the Leq values for the nighttime period (10 p.m. - 7 a.m.) increased by 10 dB to reflect the greater disturbance potential from nighttime noises. Because of the time period weighting, an Ldn value will be 6.4 dB greater than the corresponding 24-hour Leq value for a constant noise level. For most real noise conditions, the corresponding Ldn and 24-hour Leq values will differ by less than this.

The community noise equivalent level (CNEL) also is used to characterize average noise levels over a 24-hour period, with weighting factors for evening and nighttime noise levels. Leq values for the evening period (7 p.m. - 10 p.m.) are increased by 5 dB while Leq values for the nighttime period (10 p.m. - 7 a.m.) are increased by 10 dB. Because of the time period weighting, a CNEL value will be 6.7 dB higher than the corresponding 24-hour Leq value for a constant noise level. For most real noise conditions, the corresponding CNEL and 24-hour Leq values will differ by less than this.

The CNEL value will be slightly higher than (but generally within 1 dB of) the Ldn value for the same set of noise measurements. Only in situations with high evening period noise levels will CNEL values be meaningfully different from Ldn values. Because of the small difference between them, CNEL and Ldn ratings normally are considered interchangeable.

Single-value average noise descriptors (such as Ldn or CNEL values) are applied most often to variable but relatively frequent sources of noise. Typical urban noise conditions, highway traffic, major rail yards, heavily used rail lines, and major commercial airports are examples where CNEL and Ldn descriptors are most appropriate.

A slightly modified version of the Ldn and CNEL calculations is used in some computer models that evaluate aircraft noise along low altitude military training routes. An additional penalty factor of up to 11 dB is added to the standard Ldn or CNEL calculation to account for startle effects and added disturbance caused by very rapid increases in noise level during low altitude flyover events. The resulting "onset rate adjusted" Ldn or CNEL value is often designated as Ldnmr. The magnitude of the added penalty factor depends on flight speed, flight altitude, and aircraft type. The maximum penalty factor (11 dB) is added for conditions in which noise levels increase from background conditions to the peak level in less than one second.

Noise Descriptors for Discrete Noise Events. Many people are skeptical about using 24-hour average noise descriptors to evaluate the annoyance potential of isolated short-duration noise events. Although this skepticism is often misplaced, other types of noise evaluations can be used. Lightly used rail lines, aircraft activity at small general aviation airports, testing of emergency generators, pile driving, and blasting activities sometimes are evaluated using other types of noise descriptors. Peak noise levels, the duration of individual noise events, and the repetition pattern of events often are used to describe intermittent or short duration noise conditions. Statistical descriptions (Lx values) and event-specific Leq values also can be used to characterize discrete noise events.

Impulse sounds usually are defined as noise events producing a significant increase in sound level but lasting less than two seconds (often less than one second). Examples of impulse noise sources include pile driving, punch presses, gunshots, fireworks, sonic booms, and blasting activities. Impulse noises usually are described using the sound exposure level (SEL) descriptor. In addition to impulse type noise events, the SEL descriptor often is used for a variety of longer duration discrete noise events (such as aircraft flyover events and train passby events). The SEL measure represents the cumulative (not average) sound exposure during a particular noise event, integrated with respect to a one-second time frame. The SEL descriptor sometimes is labeled SENEL (single event noise exposure level), LAE, LAX, or LE.

SEL measurements are equivalent to the Leq value of a one-second noise event producing the same cumulative acoustic energy as the actual noise event being analyzed. In effect, an SEL measure "spreads" or "compresses" the noise event to fit a fixed one-second time interval. If the actual duration of the noise event is less than one second, the SEL value will be less than the Leq value for the event. If the duration of the noise event exceeds one second, the SEL value will exceed the Leq of the event.

Impulse noises of substantial magnitude (e.g., blasting or sonic booms) often are characterized using unweighted (flat) or C-weighted SEL measures. Annoyance from such sources often involves induced structural vibrations as well as the loudness of the noise event. Unweighted and C-weighted decibel scales have proven more useful than the A-weighted scale for such evaluations. Less intense impulse noises often are characterized using an A-weighted SEL measure.

Most SEL measurements are performed using procedures that restrict the time interval over which actual measurements or subsequent calculations are made. Sometimes this involves defining the noise event as the period when sound levels exceed a particular threshold level. In other cases, the calculations are restricted to that portion of the noise event when sound levels are within a defined increment (generally 10 - 30 dB) of the peak sound level. The measurement restrictions noted above are done as a practical expediency to minimize manual computations, to accommodate monitoring instruments with a limited measurement range, or to systematically define discrete noise events against fluctuating background noise conditions. Due to the logarithmic nature of decibel units, these measurement restrictions normally have little effect on the calculated SEL value.

If individual noise events are repeated frequently, it is possible to calculate Ldn or CNEL values based on typical SEL values and the number of occurrence of such noise events during daytime, evening, and nighttime periods. Such computation procedures often are used to estimate noise levels around airports or railway lines.

Special Aircraft Noise Descriptors. The maximum dBA (Lmax), average dBA (Leq), and Ldn or CNEL measures are the most understandable descriptions of aircraft noise and the easiest to relate to land use compatibility criteria. In addition, Ldn and CNEL descriptions normally are used for airport land use compatibility studies. But for historical reasons and to maintain consistency with international aircraft certification procedures, most testing of aircraft noise levels is done as SEL values or as EPNL (effective perceived noise level) values.

The Federal Aviation Administration (FAA) sets most aircraft noise standards using EPNL values. The FAA sets noise standards for small propeller-driven aircraft using instantaneous peak dBA (Lpk) values, and allows small helicopters to be certified using SEL noise limits. The FAA requires testing to demonstrate compliance with adopted standards before issuing airworthiness certification for new or modified aircraft types.

EPNL values are not measured directly, but must be computed from other measurements. Calculation of EPNL values requires measurement of the time history of takeoff, landing approach, or other flyover events using a frequency spectrum analyzer that records average unweighted dB values for 1/3 octave bands during each 1/2 second interval of the flyover event. The 1/3 octave spectrum is recorded for 24 frequency bands with center frequencies ranging from 50 Hz to 10,000 Hz. The portion of the flyover event when noise levels are within 10 dB of the peak level is then used in the EPNL calculation. The unweighted dB values for each 1/3 octave band in each 1/2 second interval are converted to “perceived noisiness” (noy) values, which are another type of decibel scale. For each 1/2 second interval, the noy data are combined across the various 1/3 octave bands and converted into PNL (perceived noise level) values for that time interval. The noy data for each 1/3 octave band at each time interval are also evaluated to produce a correction factor that is added to the PNL value to generate tone-corrected perceived noise level (PNLT) values for each 1/2 second interval. The PNLT values for each 1/2 second time interval are then combined to produce the final EPNL value for the overall flyover event. EPNL values are essentially a type of time-averaged noise level, but the frequency weighting scheme is not like conventional A- or C-weighting schemes. The numerical values of EPNL data are substantially higher than the corresponding values of time-averaged dBA (Leq) measurements.

It should be noted that while most aircraft noise standards are set as EPNL values, the FAA uses Ldn and CNEL criteria for evaluating land use compatibility issues around airports.

Working With Decibel Values.

Numerical dB ratings for different noise sources cannot be added directly to give the dB rating of the combination of these sources. Decibel values are 10 times the logarithm of a squared pressure ratio, and must be converted back into squared pressure ratio values before being added together or averaged in a time-weighted manner. The resulting composite squared pressure ratio value can then be converted back into a composite decibel rating. For simplicity, the procedure for combining decibel values is often referred to as "energy averaging".

Time-Weighted Averages. The calculation procedure used for computing average noise levels (Leq values) results in high dB events contributing significantly more to the final Leq value than do background low dB conditions. For example, a single 1-second episode of 90 dBA introduced into a 1-hour constant background noise condition of 45 dBA will result in a 1-hour Leq value of 54.9 dBA. A 5-second episode of 90 dBA in a 1-hour background condition of 45 dBA results in a 1-hour Leq of 61.5 dBA. And a cumulative total of 20 seconds of 90 dBA in a 1-hour background condition of 45 dBA results in a 1-hour Leq of 67.5 dBA.

Even in the context of 24-hour averages, brief noise events have a noticeable effect. A 5-second episode of 90 dBA in a 24-hour background condition of 45 dBA raises the 24-hour Leq to 49.5 dBA. A cumulative total of 20 seconds of 90 dBA in a 24-hour background condition of 45 dBA results in a 24-hour Leq of 54.2 dBA.

Cumulative Effect of Multiple Noise Sources. Two noise sources producing equal dB ratings at a given location will produce a composite noise level 3 dB greater than either sound alone. When two noise sources differ by 10 dB, the composite noise level will be only 0.4 dB greater than the louder source alone.

Detectable Noise Level Changes. Hearing sensitivity to dB changes tends to increase at higher noise levels, except for very high frequency sounds (Scharf 1998, 1191). At moderate noise levels for sounds dominated by mid-range frequencies, the loudness discrimination threshold is typically between 1 and 2 dBA for sounds in the 30 to 50 dBA range and between 1 and 1.5 dBA for sounds in the 50 to 80 dBA range. For tones in the 1000 Hz octave band, the loudness discrimination threshold typically drops from about 1.5 dBA at 30 to 40 dB to between 0.5 and 1 dBA at 80 dBA. Outside a laboratory setting, most people have difficulty distinguishing the louder of two noise sources that differ by less than 1.5 dB.

Decibel Changes Versus Perceived Loudness. In general, a 10 dB increase in noise level is perceived as a doubling (100% increase) in loudness. A 1.5 dB increase represents an 11% increased in loudness, 2 dB increase is a 15 percent increase in loudness, a 3 dB increase is a 23 percent increase in loudness, and a 5 dB increase is a 41 percent increase in loudness. Conversely, a 1.5 dB reduction represents a 10% decrease in loudness, 2 dB reduction is a 13% decrease in loudness, a 3 dB reduction is a 19% decrease in loudness, a 5 dB reduction is a 29% decrease in loudness, and a 10 dB reduction is a 50% decrease in loudness. The sensitivity of the human ear to changes in loudness varies somewhat according to both the acoustical frequencies of the sound and the intensity (dB range) of the sounds. But in general, most people cannot distinguish noise level changes that vary by less than 10% in relative loudness.

Sound Attenuation Considerations. When distance is the only factor considered, sound levels from an isolated noise source would be expected to decrease by about 6 dB for every doubling of distance away from the noise source. When the noise source is essentially a continuous line (e.g., vehicle traffic on a highway), noise levels would be expected to decrease by about 3 dB for every doubling of distance, due to the additive effects of a linear array of noise sources. Ground conditions that absorb sound often result in noise drop-off rates of about 4.5 dB for every doubling of distance from a linear noise source such as highway traffic.

Sound levels at various locations away from a noise source are influenced by factors other than just distance from the noise source. Ground surface conditions, topographic features, and structural barriers can absorb, reflect, or scatter sound waves, resulting in lower noise levels (increased sound attenuation rates). Atmospheric conditions (wind speed and direction, humidity levels, temperature, and air pressure) and the frequency characteristics of the sound itself also affect sound attenuation rates. The vertical variation in wind, temperature, pressure, and humidity conditions also affects sound attenuation rates.

The atmosphere absorbs some of the energy content of sound waves, thus increasing sound attenuation rates over long distances. Such atmospheric absorption is greatest for high frequency components of a sound, resulting in a lower pitch to the sound at greater distances. Atmospheric absorption is most strongly dependent on temperature and humidity conditions, with a somewhat complex relationship among temperature, humidity, and the frequency components of the sound. Overall, atmospheric absorption is greatest for high frequency sounds under conditions of low relative humidity and moderately cool temperatures. Atmospheric absorption is least for low frequency sounds at high relative humidity and moderate temperatures.

Sound waves reflected by topographic features, buildings, or other structures can result in higher sound levels than expected in front of the reflecting object. The effects of reflected sound waves can be important in urban areas, partially off-setting the shielding effect of buildings and other structures.

Temperature inversions and altitudinal changes in wind conditions can at times diffract and "focus" sound waves to a location at considerable distance from the noise source. In such situations, the vertical changes in atmospheric conditions affect sound waves much the way lenses and prisms can bend and focus light rays.

Effects of Noise

There are numerous ways to categorize the environmental and health effects of noise. Most effects of noise can be categorized as:

- physiological effects on people;
- human psychological or behavioral effects;
- human activity interference effects;
- physical effects on buildings and structures; or
- physiological and behavioral effects on wildlife and livestock.

Several of the categories outlined above overlap to various degrees. There are various degrees of cause-effect interactions between physiological effects and psychological or behavioral effects. And activity interference is, to a certain extent, a behavioral effect. Nevertheless, the five categories listed above provide a convenient context for discussing the effects of noise.

Physiological Effects. Physiological effects of noise on people can be grouped into three broad categories: noise-induced hearing loss, sleep disturbance, and general stress-related physiological effects. Noise-induced hearing loss and sleep disturbance are the most thoroughly studied and most easily documented effects. Most information on the physiological effects of noise relates to audible sounds. Effects of infrasound (acoustic frequencies below 20 Hz) and ultrasound (acoustic frequencies above 20,000 Hz) have received less study, although exposure to intense infrasound frequencies may induce damaging vibrations in body tissues. Ward (1998, 1200) notes that a physical sensation of sound in the middle ear often occurs when unweighted sound pressure levels reach about 105 dB; physical discomfort often is reported for unweighted sound pressure levels of about 120 dB; a pain sensation typically occurs at an unweighted sound pressure level of about 140 dB; and the eardrum can be ruptured by unweighted sound pressure levels above 170 dB. Corresponding dBA thresholds normally would be several dB lower than the unweighted dB values.

Noise-Induced Hearing Loss. Hearing loss generally is measured as a change in audibility thresholds over a range of standard octave band frequencies (e.g., at 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz). Humes (1998, 1210) notes that for hearing loss determinations in adults, the normal threshold of hearing for pure tones generally is assumed to be:

- 45 dB at 125 Hz,
- 25.5 dB at 250 Hz,
- 11.5 dB at 500 Hz,
- 7 dB at 1000 Hz,
- 9 dB at 2000 Hz,
- 9.5 dB at 4000 Hz, and
- 13 dB at 8000 Hz.

Initial hearing loss typically appears in the 4000 Hz octave band. Over time, progressive hearing loss increases in this octave band and spreads to higher and lower octave bands. The extent of hearing loss in any octave band typically is characterized as (Humes 1998, 1212):

- normal (threshold loss of up to 25 dB);
- mild (threshold loss of 26 to 40 dB);
- moderate (threshold loss of 41 to 55 dB);
- moderately severe (threshold loss of 56 to 70 dB);
- severe (threshold loss of 71 to 90 dB); or
- profound (threshold loss of more than 90 dB).

A distinction often is made between temporary and permanent hearing threshold shifts. A temporary hearing threshold shift occurs if normal hearing sensitivity returns after a period without exposure to high noise levels. The period required for recovery from temporary threshold shift effects can range from minutes to several hours, depending on the intensity and duration of the noise exposure that produced the threshold shift. Even when recovery from temporary threshold shifts routinely occurs, permanent loss of hearing sensitivity still can occur as a result of long term cumulative noise exposure. Permanent loss of hearing sensitivity (a permanent increase in the hearing threshold at one or more frequency bands) occurs in two ways:

- as a progressive, long term result of cumulative noise exposure; and
- as an immediate result of exposure to high noise levels, regardless of exposure duration.

The U.S. Environmental Protection Agency (EPA) identified an annual average 24-hour Leq of 70 dBA as a long term noise exposure limit that should protect the general public against hearing damage with an adequate margin of safety (EPA 1974, 28-32). Noise levels obviously vary during the course of a day, but a 24-hour Leq of 70 dBA implies that there would not be any extended periods of exposure to high noise levels. To put a 24-hour Leq of 70 dBA in perspective, each of the following noise exposure conditions would generate a 24-hour Leq of 70 dBA or more:

- an 8-hour work day with an average noise exposure of 74.8 dBA (for example: 21 minutes at 85 dBA, 30 minutes at 80 dBA, 30 minutes at 75 dBA, and 6 hours 39 minutes at 70 dBA) and 16 hours at any noise level below 70 dBA;
- 2 hours 25 minutes at 80 dBA and 21 hours 35 minutes at any noise level below 70 dBA;
- 46 minutes at 85 dBA and 23 hours 14 minutes at any noise level below 70 dBA;
- 15 minutes at 90 dBA and 23 hours 45 minutes at any noise level below 70 dBA;
- 5 minutes at 95 dBA and 23 hours 55 minutes at any noise level below 70 dBA; or
- 1.5 minutes at 100 dBA and 23 hours 58.5 minutes at any noise level below 70 dBA.

The National Institute for Occupational Safety and Health (NIOSH) has determined that above a critical sound intensity, the mechanism of hearing damage changes from one based on cumulative noise exposure (the combination of magnitude and duration of sound) to a mechanism based on sound intensity alone, regardless of duration (NIOSH 1996). NIOSH estimates 115 to 120 dBA as the critical noise level at which human hearing is subject to instantaneous permanent damage effects. Without adequate hearing protection, any exposure to noise levels above 115 dBA is likely to cause some degree of permanent hearing threshold shift.

Sleep Disturbance. Sleep is made up of a cycle through a succession of stages having fairly distinctive physiological and neural activity patterns. It is customary to recognize five stages of sleep based on neural activity patterns: stages 1 through 4 are progressively deeper stages of sleep without dream activity, and REM (rapid eye movement) sleep is the stage in which dreams occur. The initial period of sleep typically involves a progression from sleep stage 1 to sleep stage 4, followed by a return to sleep stage 2, and then a period of REM sleep. There may be a brief period of awakening at the end of REM sleep. This basic sequence typically is repeated four or five times during the night, although the distribution of time spent in different sleep stages changes as the sleep stage episodes are repeated. The amount of stage 3 and stage 4 sleep generally declines and the amount of REM sleep generally increases toward the end of the overall sleep cycle.

Sleep disturbance can occur as inappropriate awakening from sleep or as a non-typical change in sleep stage. Most research has focused on awakening from sleep, since that is the easiest sleep disruption to recognize. It is important to note that periodic awakening from sleep during the night is a normal part of the sleep cycle for many people. It also is important to recognize that there are many different causes for sleep disruption, ranging from medical conditions to psychological problems to physical disturbance conditions. Sleep disruption is most likely to occur during sleep stages 1 and 2 or during REM sleep. Sleep stages 3 and 4 are less sensitive to disruption than are other sleep stages. Children exhibit a significantly higher proportion of stage 3 and stage 4 sleep than do adults, and consequently tend to experience less sleep disruption than adults. Noise is only one of may factors that can disrupt normal sleep cycles. But whatever the cause, sleep disturbance can result in a variety of physiological, behavioral, and activity interference consequences.

Sleep disturbance from noise is influenced by many factors, including whether sleep is occurring in familiar or unfamiliar locations; the magnitude, duration, and variability of intruding noises; and the predictability of intruding noise conditions. Many studies of sleep disturbance have focused on aircraft flyover noise events near commercial and military airfields. The Federal Interagency Committee on Noise (1992) developed an equation to predict the probability that discrete aircraft flyover events would awaken adults during normal sleep. An updated analysis of available data recently produced a revised equation (Federal Interagency Committee on Aviation Noise 1997). These equations used indoor SEL values for individual flyover events as the predictive noise measure.

Stress-Related Physiological Effects. Noise is a recognized contributor to generalized stress conditions, but it is difficult to distinguish the contribution of noise exposure versus other factors to overall stress conditions at any given time. General physiological indicators of stress, such as changes in cardiovascular and endocrine conditions, undoubtedly accompany any stress reactions related to noise exposure. Loud noises in general tend to produce dilation of the pupil of the eye, increased heart rate, and vasoconstriction of the extremities (Ward 1998, 1197).

Psychological and Behavioral Effects. General annoyance is the most common reaction to noise, although stress-related behavioral changes or reactions also occur. Annoyance related to noise conditions depends on many factors in addition to the magnitude, duration, variability, and time of day of noise events. Personal attitudes and opinions concerning recognizable noise sources can be an important influence. A person's previous exposure to various noise conditions also is important in shaping personal reaction to ongoing or new noise conditions. Nevertheless, numerous studies and surveys have been performed to characterize the extent of annoyance associated with various noise sources and noise levels. Most of these studies and surveys have evaluated annoyance to noise from transportation sources (highway traffic, rail traffic, and aircraft flight operations) because those are the dominant noise sources affecting urban areas.

Several different equations have been developed to estimate the fraction of the population that will rate itself as "highly annoyed" under different average noise level exposure conditions. Other equations have been developed to relate average noise exposure conditions for high energy impulse noise events to the fraction of the population that will be highly annoyed. Most of these equations use the 24-hour Ldn noise value as the predictor of annoyance.

Startle reactions to sudden, unexpected loud noises produce an immediate contraction of the orbital eye muscles and the flexor muscles of the legs, arms, and back; this results in an automatic eyeblink and crouching movement (Ward 1998, 1199). If loud impulse noise events are repetitive and relatively predictable, the intensity of the startle reaction tends to be significantly reduced. Startle reactions can pose a safety hazard under some conditions.

Insomnia (chronic difficulty in falling asleep or chronic difficulty staying asleep) is a symptom of other medical or psychological conditions. Underlying medical problems can include use or withdrawal from various medicines or drugs, endocrine disturbances, biorhythm disruption such as jet lag, or diseases such as arthritis. Psychological conditions such as anxiety or depression also can cause insomnia. The extent to which noise conditions actually produce insomnia (as opposed to occasional awakening from sleep) is not clear.

Activity Interference Effects. Annoyance and noise-related stress conditions can result in a wide range activity interference including speech and communication interference, interference with cultural activities, reduced work productivity, and disruption of leisure activities. If such activity interference is a long-term condition, then noise conditions can lead to land use compatibility problems. Noise-related land use compatibility problems have led various federal, state, and local agencies to develop a wide range of noise guidelines and regulations (see section 3.6.4, below).

Physical Effects on Buildings and Structures. Physical effects of noise on buildings and other structures occur primarily through airborne or ground vibrations. Most ground vibrations are generated by underground sources or by sources in physical contact with the ground surface. Open air noise sources rarely generate detectable ground vibrations. Although many people attribute building vibration and object shaking to ground vibrations, most such events are caused by vibrations induced by airborne sound. Direct ground vibration is important only at locations close to the vibration source. Sonic booms and blast noise events are the major sources of airborne vibrations that can be strong enough to create detectable vibrations in buildings or structures.

Vibration intensities can be measured in many different ways, but movement velocity units (such as inches per second) are commonly used. Common vibration criteria and guidelines can be summarized as follows (U.S. Army Center for Health Promotion and Preventive Medicine 1999). Most people can detect structural vibrations at an intensity of 0.08 inches per second. Vibrations become noticeable at an intensity of 0.20 inches per second. Many people rate a vibration intensity of 0.38 inches per second as unpleasant, and an intensity of 0.8 inches per second as disturbing. A vibration intensity of 0.1 inches per second can cause loose objects to rattle. A vibration intensity of 0.5 inches per second often is used as a guideline for avoiding minor cracking in poorly fitted loose glass windows or in stressed plaster. A vibration intensity limit of 2 inches per second often is used as a guideline for avoiding damage to lightweight structures. Cracking of concrete may occur at vibration intensities above 4 inches per second. Minor structural damage is likely at a vibration intensity of 5.4 inches per second.

A peak unweighted noise level of 120 dB is likely to induce a structural vibration intensity of about 0.1 inches per second, which is detectable and can cause loose objects to rattle. A peak unweighted noise level of 134 dB can produce a vibration intensity of 0.5 inches per second. A peak unweighted noise level of 175 dB can produce a vibration intensity of 2 inches per second, which is near the threshold for damage to lightweight structures. The peak unweighted noise level must exceed 185 dB to produce vibration intensities of 4 inches per second or more.

Physiological and Behavioral Effects on Wildlife and Livestock. Because several aspects of underwater acoustics are significantly different from open air acoustics, it is useful to separate the discussion of the effects of noise on terrestrial wildlife and livestock from the discussion of effects of noise on aquatic and marine species. Differences in sound level measurement conventions and differences in the physics of sound propagation also make it convenient to separate the discussion of noise impacts in aquatic and marine environments from noise impacts on terrestrial species.

Terrestrial Wildlife and Livestock. Noise effects on wildlife and livestock are similar in most respects to noise effects on people, with potential physiological, behavioral, and activity interference effects. Potential physiological effects include a generalized increase in stress conditions, loss of hearing sensitivity, and effects of sleep disturbance. In general, loss of hearing sensitivity from prolonged exposure to loud noises or from short term exposure to intense impulse noise is likely to be the most important physiological effect. Potential behavioral effects of noise are best categorized as general disturbance and potential disruption or reproductive and brood rearing behaviors. Potential activity interference effects include changes in habitat use patterns and interference with vocal or non-vocal communication and signaling.

Although the acoustic frequency range for hearing and relative sensitivity to different acoustic frequencies vary among species, the hearing range for most terrestrial vertebrates broadly overlaps that of people. The hearing range for some species extends beyond the frequency range for people at either high or low frequencies. Most species also show a relative sensitivity pattern of peak sensitivity to mid range frequencies, with reduced sensitivity to low and high frequencies.

Many reports of apparent noise disturbance to terrestrial wildlife fail to distinguish between disturbance from noise per se and disturbance from visible activity. In general, most terrestrial wildlife are more easily disturbed by visible activity than by noise alone. Behavioral accommodation to noise conditions is common among vertebrates, especially when noise occurs in isolation from visible activity. It should be noted, however, that behavioral accommodation to noise conditions does not preclude physiological effects from noise exposure. When animals learn to associate particular noises with active disturbance conditions (such as snowmobile, vehicle, aircraft, or boat activity), noise per se can become an important disturbance factor. Migratory waterfowl, in particular, seem to be relatively sensitive to noise disturbance, especially when noise is associated with potential active disturbance factors such as boats, aircraft, or helicopters.

Aquatic and Marine Wildlife. Much of the research on noise effects on aquatic and marine species has focused on marine mammals rather than on fish, amphibians, reptiles, or invertebrates. Richardson, Greene, Malme, and Thomson (1995) provide a useful review of underwater noise as it affects marine mammals. Although the general concerns regarding noise effects on aquatic and marine species are similar to those for terrestrial species, aquatic and marine conditions tend to make sound and vibration relatively more important than in terrestrial environments. Except in shallow water areas, light penetration is limited in aquatic and marine environments. Consequently, vision is typically a short-range sense in aquatic and marine species. Sound and vibration, on the other hand, can be transmitted long distances in aquatic and marine conditions. As a result, sound production, hearing, and vibration detection tend to be more important to marine and aquatic species than to terrestrial species.

Various factors that distinguish underwater acoustics from open air acoustics need to be recognized in order to properly interpret data from underwater sound level measurements. Absorption of acoustic energy occurs for all acoustic frequencies in air, but is negligible for low acoustic frequencies in pure water. Some dissolved minerals, such as magnesium sulfate and boric acid, absorb energy from low frequency sounds in water, but the extent of low frequency sound absorption is much less in marine conditions than in air. In most cases, low frequency sounds can be transmitted over substantial distances in aquatic and marine environments. Sound propagation underwater also tends to be more complicated than sound propagation in open air. Water pressure, density, temperature, and salinity conditions have a more pronounced effect on sound propagation in underwater conditions than do temperature and humidity conditions in the open air. Sound transmission underwater can be channeled in depth zones that are bounded by strong salinity and density gradients.

Standard conventions for measuring sound underwater differ significantly from the conventions used for measuring airborne sound. Underwater sound measurement conventions were developed primarily in the context of geophysical studies, physical oceanographic studies, and military sonar system development studies. In contrast, measurement conventions for airborne sound were developed primarily in the context of studies related to hearing and acoustic communication. Although decibel units are used for both airborne and underwater sound, the standard reference pressure used to compute decibel values is different. The reference pressure for computing decibel values for airborne sounds is 20 micropascals. The reference pressure used for computing decibel values for underwater sound is 1 micropascal. As a result, a sound pressure level measured underwater yields a decibel value 26 dB higher than if the same physical sound pressure were measured as airborne sound.

Additional differences in measurement conventions also complicate comparison of sound level data for airborne and underwater sound. Various frequency weighting schemes (especially A-weighting and C-weighting) are commonly employed with airborne sound measurements. Frequency weighting schemes are rarely employed with underwater sound measurements. Sound level measurements integrated across a broad spectrum of acoustic frequencies are used for most airborne sound measurements, but are less common in data for underwater sound level measurements. In many cases, underwater sound level measurements are made for a single acoustic frequency or a narrow band of frequencies. Many underwater sound level measurements are restricted to frequencies below 1,000 Hz.

Differences in reference distances used for conventional data reporting further complicate the comparison of data from underwater measurements with those from open air measurements. Many reported underwater noise measurements are presented as an equivalent "source level" value: the unweighted dB value that would be measured at a distance of 1 meter (3.3 feet) if the total acoustic energy produced by the source was generated by an idealized point. Except in occupational noise studies, most data on airborne noise generation is standardized to distances of 50 feet (15.2 meters) or more from the source without conversion to an equivalent point source. Adjustments to a common measurement convention must be made when trying to compare noise data from open air measurements with data from underwater measurements, but can be difficult to do for physically large sources of sound. The combination of a low reference pressure value and the convention of presenting data as equivalent source level values results in high numerical values for underwater sound data compared to data for airborne sounds. The equivalent source level convention is very useful for mathematical modeling purposes, but it overstates the true physical sound pressure levels experienced in underwater environments when the noise source is physically large.

There is considerable variation in the range of acoustic frequencies involved in hearing and sound production among aquatic and marine species. While the dominant communication frequencies overlap with the range of human hearing, some species are sensitive to very high ultrasound frequencies or to very low infrasound frequencies. Whales and dolphins that use echolocation signals produce and respond to sound frequencies as high as 60,000 Hz or more. Some seals also produce clicks and other high frequency sounds above 20,000 Hz. At the other extreme, some whales produce very low frequency sounds in the infrasound range below 20 Hz.

As with terrestrial wildlife, noise effects on aquatic and marine species include physiological effects, general disturbance, disruption of reproductive behavior, and other activity interference. Potential physiological effects include a generalized increase in stress conditions, loss of hearing sensitivity, and effects of sleep disturbance. In general, loss of hearing sensitivity from prolonged exposure to loud noises or from short term exposure to intense impulse noise is likely to be the most important physiological effect. Potential activity interference effects include changes in feeding or resting habitat use patterns, changes in migration or other travel routes, and interference with vocal or non-vocal communication and signaling.

There is ample evidence that underwater noise can cause general disturbance of most marine mammal species. Vessel noise, drilling platform noise, geophysical survey noise sources, and underwater construction noise have all been implicated in marine mammal disturbance. The distance at which behavioral changes occur provides clear evidence that noise, as opposed to visible activity, is the primary disturbance trigger. Visible activity also can be an additional disturbance factor, especially for species that spend time at the water surface. Disturbance of fully submerged animals by airborne noise sources (such as aircraft and helicopters) is much less common, since most airborne sound is reflected from the water surface. Only when an airborne sound source is essentially overhead will airborne noise effectively penetrate below the water surface. Species that spend part of their time out of the water react to airborne sound in much the same way as terrestrial wildlife. As is the case for terrestrial wildlife, many marine and aquatic species develop tolerance to noise sources that do not create other adverse interactions.

Regulatory Context

Federal Legislation. The Noise Pollution and Abatement Act of 1970 (Title IV of the Clean Air Act, 42 USC 7627) established an Office of Noise Abatement and Control within EPA. EPA was directed to investigate and identify the effects of noise levels on public health and welfare, including: psychological and physiological effects on humans; effects of sporadic extreme noise as compared with constant noise; effects on wildlife and property; effects of sonic booms on property; and such other matters as may be of interest in the public welfare. Title IV of the Clean Air Act also requires other federal agencies and departments to consult with EPA regarding methods for abating objectionable or nuisance condition noise impacts that result from activities they carry out or sponsor.

The federal Noise Control Act of 1972 (42 USC 4901 *et seq.*) established a requirement that all federal agencies must administer their programs in a manner that promotes an environment free from noise that jeopardized public health or welfare. EPA was given the responsibility for: providing information to the public regarding identifiable effects of noise on public health or welfare, publishing information on the levels of environmental noise that will protect the public health and welfare with an adequate margin of safety, coordinating federal research and activities related to noise control, and establishing federal noise emission standards for selected products distributed in interstate commerce (construction equipment; transportation equipment; motors and engines; and electrical or electronic equipment). Aircraft, aircraft engines, military weapons, military combat equipment, rockets and other equipment used by the National Aeronautics and Space Administration, and various other items were excluded from the definition of products distributed in commerce. States and political subdivisions thereof retain the right to establish and enforce controls on environmental noise through the licensing, regulation, or restriction of the use, operation, or movement of products or combinations of products. The federal Noise Control Act also directed all federal agencies to comply with federal, state, interstate, and local noise control and abatement requirements to the same extent that any person is subject to such requirements.

Although the EPA can require other federal agencies to justify their noise regulations with respect to the policy requirements of the federal Noise Control Act, each federal agency retains authority to adopt noise regulations pertaining to agency programs. The Occupational Safety and Health Administration (OSHA) has primary authority for setting workplace noise exposure standards. Due to aviation safety considerations, the FAA has primary jurisdiction over aircraft noise standards.

Federal Interagency Noise Committees. The Federal Interagency Committee on Urban Noise (FICUN) was formed in 1979 to review various federal agency programs related to noise impacts on land use. The committee included representatives of the Department of Transportation, Department of Housing and Urban Development, Environmental Protection Agency, Department of Defense, and the Veterans Administration. The 1980 report issued by FICUN summarized federal agency noise policies and programs. In addition, it identified the Ldn noise metric as the most appropriate noise descriptor to use for evaluating noise in the context of land use compatibility issues. The 1980 FICUN report also included a chart of compatible and incompatible noise levels for various categories of land use.

The Federal Interagency Committee on Noise (FICON) was formed in 1990 to review federal agency policies concerning the assessment of airport noise issues. Participating agencies included the Department of Transportation, Department of Defense, Department of Justice, Department of Housing and Urban Development, Environmental Protection Agency, Veterans Administration, and the Council on Environmental Quality. The 1992 report prepared by the committee confirmed the use of the Ldn noise metric as the primary basis for assessing land use compatibility issues, but also recognized that supplementary noise descriptors could be useful to further explain noise impacts on a case-by-case basis. The 1992 FICON report recognized the maximum A-weighted decibel level (Lmax) as useful for evaluating short-term individual aircraft flyover events.

The Federal Interagency Committee on Aviation Noise (FICAN) was established in 1993 to provide an on-going forum for coordination and review of federal agency activities related to aviation noise issues. Agency participation in FICAN includes the Federal Aviation Administration, the Department of Transportation (Office of the Secretary), U.S. Army, U.S. Navy, U.S. Air Force, National Aeronautics and Space Administration, National Park Service, Department of Housing and Urban Development, Environmental Protection Agency, and the Centers for Disease Control and Prevention (National Center for Environmental Health). Periodic reviews conducted by FICAN have continued to support the use of Ldn values as the primary indicator of land use compatibility conditions in terms of aviation noise. FICAN has, however, also supported the use of supplemental noise descriptors (such as Lmax, SEL, or time above a threshold level) to provide information that is not easily communicated by Ldn values (FICAN 2002).

Department of Defense Noise Guidelines. The Department of Defense began development of noise evaluation programs in the early 1970s. Initial program development involved the Air Installation Compatible Use Zone (AICUZ) program for military airfields. Early application of the AICUZ program emphasized Air Force and Navy airfields. The Army implemented the program as the Installation Compatible Use Zone (ICUZ) program by addressing both airfield noise issues and other major noise sources such as weapons testing programs and firing ranges. Joint Air Force, Army, and Navy planning guidelines were issued in 1978 (Department of Defense 1978). The 1978 guidelines use annual average Ldn values to categorize noise exposure conditions on military installations. Three broad noise exposure zones are used as the basis for characterizing various land use compatibility conditions:

- Zone 1 = areas with Ldn levels below 65 dB
- Zone 2 = areas with Ldn levels of 65-75 dB
- Zone 3 = areas with Ldn levels above 75 dB

The guidelines indicate that all land uses are compatible with Zone 1 noise levels. Educational, medical, and residential land uses generally are not compatible with Zone 2 noise levels unless special acoustic treatments and designs are used to ensure acceptable interior noise levels. Acoustical insulation also may be needed for administrative and office facilities located in Zone 2 areas. Residential, medical, and educational land uses are not compatible with Zone 3 noise levels. Industrial, manufacturing, and office land uses may be acceptable in Zone 3 areas if special building designs and other measures are implemented.

The Army has recently supplemented the original 1978 guidelines to develop a more comprehensive Environmental Noise Management Program (ENMP). The ENMP program incorporates ICUZ evaluations as one component of the program. Other components of the EMP include programs for handling noise complaints and undertaking supplemental noise evaluations when warranted by the nature of discrete noise events. Criteria for evaluation of noise levels have been expanded beyond the normal A-weighted Ldn descriptor to include the use of C-weighted Ldn values to characterize major blast noise sources and the use of peak unweighted decibel values to characterize small arms firing (Table 2).

More recent guidance for ENMP evaluations (U.S. Army 2002) notes that "average busy day" noise contours may be more appropriate than annual average noise contours for installations where activity levels vary significantly over the course of a year. In addition, the recent guidance recommends the use of A-weighted Ldn values for evaluating land use compatibility issues related to small arms ranges.

The Army Center for Health Promotion and Preventive Medicine (CHPPM) assists Army installations in development of environmental noise management plans. In addition, CHPPM also undertakes special noise studies to evaluate noise problems associated with various types of noise sources. When investigating noise conditions related to weapons firing or ordnance detonations, CHPPM typically measures peak unweighted decibel levels and/or C-weighted SEL levels. Table 3 summarizes the noise criteria most often used by CHPPM when evaluating blast noise issues.

Executive Order 13045. Executive Order 13045 (issued on April 21, 1997) requires federal agencies to review their programs and actions in order to identify and assess environmental health risks and safety risks that might disproportionately affect children. The executive order notes that children may be disproportionately sensitive to environmental health and safety risks because:

- children's neurological, immune, digestive, and other bodily systems are still developing;
- children consume more food and fluids in proportion to their body weight than do adults;
- children breathe more air in proportion to their body weight than do adults;
- children's size and weight may diminish the degree of protection they receive from standard safety features; and
- children's behavior patterns may make them more susceptible to accidents because they are less able to protect themselves.

Although noise is not expressly mentioned in the executive order, noise is a routine consideration in environmental health and safety programs.

TABLE 2. NOISE ZONES DEFINED IN ARMY REGULATION 200-1

NOISE ZONE	GENERAL NOISE SOURCES, A-WTD Ldn RANGE	SMALL ARMS, PEAK UNWEIGHTED dB RANGE	OTHER IMPULSE NOISE SOURCES, C-WTD Ldn RANGE	PERCENT OF POPULATION HIGHLY ANNOYED	ACCEPTABILITY FOR NOISE-SENSITIVE LAND USES
I	Up to 65 dBA	up to 87 dB Pk	up to 62 dBC	less than 15%	Acceptable
II	65 - 75 dBA	87 - 104 dB Pk	62 - 70 dBC	15% - 39%	Normally Unacceptable
III	over 75 dBA	over 104 dB Pk	over 70 dBC	over 39%	Unacceptable

Notes:

Noise levels from all sources should be evaluated in terms of annual averages of the identified noise metric.

Noise from transportation sources (aircraft and vehicles) and common industrial sources should be evaluated using A-weighted Ldn values.

Noise from small arms ranges should be evaluated using peak unweighted dB values until the Z-weighting standard is adopted, at which time peak Z-weighted decibel values should be used.

Noise from other impulsive sources (such as armor, artillery, and demolition activities) should be evaluated using C-weighted Ldn values.

Noise-sensitive land uses include housing, schools, and medical facilities.

Compatibility determinations for existing conditions and proposed actions should be supplemented by descriptions of projected noise increases and potential public reaction where:

(1) the noise environment is determined by a few infrequent but very high level noise sources (such as blast events over 110 dBC SEL);

(2) single event noise levels from the proposed action are 10 dB or more greater than existing levels;

(3) where the A-weighted Ldn is between 60 and 65 dBA and the proposed action would increase the Ldn value by 3 dB or more;

(4) where the A-weighted Ldn is above 65 dBA and the proposed action would increase the Ldn value by 1.5 dB or more.

Source:

Department of the Army. 1997. Army Regulation 200-1: Environmental Protection and Enhancement. Chapter 7: Environmental Noise Management Program.

TABLE 3. CHPPM BLAST NOISE ASSESSMENT CRITERIA

PREDICTED IMPULSE SOUND LEVEL			
PEAK UNWEIGTED dB LEVEL	**C-WEIGHTED SEL VALUE**	**RISK OF COMPLAINT**	**RECOMMENDED ACTION**
less than 115 dB	less than 90 dBC	low risk of complaints	No restrictions
115 - 130 dB	90 - 105 dBC	moderate risk of compaints	Postpone non-critical tests if possible
130 - 140 dB	105 - 115 dBC	high risk of complaints; possiblility of damage	Postpone all but extremely important tests
over 140 dB	over 115 dBC	threshold for permanent hearing damage; high risk of physiological and structural damage claims	Postpone all explosive operations

Notes:

CHPPM normally uses peak unweighted dB measurements to investigate blast noise complaint issues.
For rapid-fire test events with major weapons, noise level criteria should be reduced by 15 dB.
C-weighted SEL values often are used to predict the potential for sleep disturbance.

Source:

U.S. Army Center for Health Promotion and Preventive Medicine. 2001. Environmental Noise Management: An Orientation Handbook for Army Facilities. Page A-6.

State and Local Regulations. The State of Hawai'i has adopted statewide noise standards that apply to fixed noise sources, construction equipment, and similar sources. The noise standards are phrased as property line noise limits, and vary according to the zoning district of the impacted property. Separate noise standards have been established for non-impulse noise and impulse noise. The standards for non-impulse noise are summarized in Table 4. The standards for impulse noise are summarized in Table 5. All of the noise limits are specified as noise levels which can be exceeded no more than 10% of the time in any 20-minute period.

TABLE 4. STATE OF HAWAI'I COMMUNITY NOISE STANDARDS FOR NON-IMPULSE NOISE

ZONING DISTRICT GROUP	EXAMPLE ZONES	DAYTIME NOISE LIMIT FOR NON-IMPULSE NOISE (7 a.m. to 10 p.m.)	NIGHTTIME NOISE LIMIT FOR NON-IMPULSE NOISE (10 p.m. to 7 a.m.)
CLASS A	Residential Conservation Preservation Open Space Public Space	L_{10} less than or equal to 55 dBA during any 20-minute period	L_{10} less than or equal to 45 dBA during any 20-minute period
CLASS B	Multi-Family Dwellings Apartments Business Commercial Hotel Resort	L_{10} less than or equal to 60 dBA during any 20-minute period	L_{10} less than or equal to 50 dBA during any 20-minute period
CLASS C	Agriculture Country Industrial	L_{10} less than or equal to 70 dBA during any 20-minute period	L_{10} less than or equal to 70 dBA during any 20-minute period

Notes:

L_{10} = noise level exceeded 10% of the time during the specified time interval.

Noise limits are based on the zoning district of the property affected by a noise source.

Class A, Class B, and Class C noise limits apply to any lands having zoning designations equivalent to the listed example zones.

For mixed zoning districts, the primary land use designation shall be used to determine the applicable noise limits.

Noise limits apply to any point at or beyond the property line of the noise source.

Noise sources covered by these noise limits include stationary noise sources and equipment used for agricultural, construction, or industrial activites.

Compliance with the non-impulse noise limits shall be based on A-weighted noise level measurements made with the instrument in the slow response setting (1 second integration).

Source: Hawai'i Administrative Rules, Title 11, Chapter 46.

TABLE 5. STATE OF HAWAI'I COMMUNITY NOISE STANDARDS FOR IMPULSE NOISE

ZONING DISTRICT GROUP	EXAMPLE ZONES	DAYTIME NOISE LIMIT FOR IMPULSE NOISE (7 a.m. to 10 p.m.)	NIGHTTIME NOISE LIMIT FOR IMPULSE NOISE (10 p.m. to 7 a.m.)
CLASS A	Residential Conservation Preservation Open Space Public Space	L_{10} less than or equal to 65 dBA during any 20-minute period	L_{10} less than or equal to 55 dBA during any 20-minute period
CLASS B	Multi-Family Dwellings Apartments Business Commercial Hotel Resort	L_{10} less than or equal to 70 dBA during any 20-minute period	L_{10} less than or equal to 60 dBA during any 20-minute period
CLASS C	Agriculture Country Industrial	L_{10} less than or equal to 80 dBA during any 20-minute period	L_{10} less than or equal to 80 dBA during any 20-minute period

Notes:

L_{10} = noise level exceeded 10% of the time during the specified time interval.

Noise limits are based on the zoning district of the property affected by a noise source.

Class A, Class B, and Class C noise limits apply to any lands having zoning designations equivalent to the listed example zones.

For mixed zoning districts, the primary land use designation shall be used to determine the applicable noise limits.

Noise limits apply to any point at or beyond the property line of the noise source.

Noise sources covered by these noise limits include stationary noise sources and equipment used for agricultural, construction, or industrial activities.

Compliance with the impulse noise limits shall be based on A-weighted noise level measurements made with the instrument in the fast response setting (125 millisecond integration).

Source: Hawai'i Administrative Rules, Title 11, Chapter 46.

ACRONYMS AND ABBREVIATIONS

AICUZ	Air Installation Compatible Use Zones
CHPPM	Army Center for Health Promotion and Preventive Medicine
CNEL	Community Noise Equivalent Level
dB	Decibel
dBA	A-Weighted Decibel
dbC	C-Weighted Decibel
ENMP	Environmental Noise Management Program
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FICAN	Federal Interagency Committee on Aviation Noise (1993 – present)
FICON	Federal Interagency Committee on Noise (1990-1992)
FICUN	Federal Interagency Committee on Urban Noise (1979-1980)
Hz	Hertz
ICUZ	Installation Compatible Use Zones
Ld	Daytime Average Sound Level
Ldn	Day-Night Average Sound Level
Le	Evening Average Sound Level
Leq	Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level)
Lmax	Maximum Sound Pressure Level
Lmin	Minimum Sound Pressure Level
Ln	Nighttime Average Sound Level
Lpk	Instantaneous Peak Sound Pressure Level
Lx	Percentile Sound Pressure Level
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
SEL	Sound Exposure Level

GLOSSARY OF COMMON NOISE LEVEL DESCRIPTOR DESIGNATIONS

CNEL	*Community Noise Equivalent Level.* A 24-hour average noise level rating with a 5 dB penalty factor applied to evening noise levels and a 10 dB penalty factor applied to nighttime noise levels. Lden is a seldom-used alternative unit designation.
dB	*Decibel.* A generic term for measurement units based on the logarithm of the ratio between a measured value and a reference value. Decibel scales are most commonly associated with acoustics (using air pressure fluctuation data); but decibel scales sometimes are used for ground-borne vibrations or other types of measurements.
dBA	*A-Weighted Decibel.* A frequency-weighted decibel scale that approximates the relative sensitivity of human hearing to different frequency bands of audible sound.
dBC	*C-Weighted Decibel.* A frequency-weighted decibel scale that correlates well with the physical vibration response of buildings and other structures to airborne sound.
dBP	*Peak Unweighted Decibel (or Linear Peak Decibel)* . A unit designation for the peak unweighted decibel level. The peak unweighted decibel measurement sometimes is designated as LFpk (for flat-weighted peak level).
DNL	*Day-Night Average Sound Level.* A 24-hour average noise level rating with a 10 dB penalty factor applied to nighttime noise levels. Ldn is an alternative unit designation.
EPNL	*Effective Perceived Noise Level.* A complex weighted decibel scale used internationally for aircraft and aircraft engine noise certification requirements. EPNL values cannot be measured directly, but must be calculated from other data.
Hz	*Hertz.* A standard unit for describing acoustical frequencies measured as the number of air pressure fluctuation cycles per second. For most people, the audible range of acoustical frequencies is from 20 Hz to 20,000 Hz.
LAE	*Sound Exposure Level.* An alternative unit designation for SEL. Might be confused with A-weighted Leq, which sometimes is designated as LAeq
LAX	*Sound Exposure Level.* An alternative unit designation for SEL, but could be confused with the Lx designation for A-weighted measurements.

Ld — *Daytime Average Sound Level.* An Leq value based either on a 15-hour time period between 7:00 a.m. and 10:00 p.m. (used for Ldn calculation) or on a 12-hour time period between 7:00 p.m. and 7:00 a.m. (used for CNEL calculation). Also used for specifying noise limits in some local noise ordinances (time period may vary).

Ldn — *Day-Night Average Sound Level.* A 24-hour average noise level rating with a 10 dB penalty factor applied to nighttime noise levels. DNL is an alternative unit designation.

Ldnmr — *Onset Rate Adjusted Day-Night Average Sound Level.* A modified version of the Ldn descriptor that is used for evaluation of low altitude aircraft flight noise. Additional penalty factors of up to 11 dB are added to the basic Ldn calculation, with the precise value dependent on both the magnitude of noise level increase during a flyover event and the duration of the noise level rise from background noise levels to the maximum instantaneous noise level.

Le — *Evening Average Sound Level.* An Leq value based on a 3-hour time period between 7:00 p.m. and 10:00 p.m. (used primarily for CNEL calculation).

LE — *Sound Exposure Level.* An alternative unit designation for SEL, but easily confused with the Le descriptor.

Leq — *Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level).* The decibel level of a constant noise source that would have the same total acoustical energy over the same time interval as the actual time-varying noise condition being measured or estimated. Leq values must be associated with an explicit or implicit averaging time in order to have practical meaning. The use of A-weighted, C-weighted, or unweighted (flat) decibel units sometimes is indicated by LAeq, LCeq, or LFeq, respectively.

Lmax — *Maximum Sound Pressure Level.* The highest decibel level measured during a stated or implied monitoring period or noise event. The Lmax value recorded by a sound level meter depends on the time factor used for integration of instantaneous sound pressure level measurements. For most modern sound meters, this is 1 second when the instrument is set for the slow sampling rate and 1/8 second when the instrument is set for the fast sampling rate. The use of A-weighted, C-weighted, or unweighted (flat) decibel units sometimes is indicated by LAmax, LCmax, or LFmax, respectively.

Lmin *Minimum Sound Pressure Level.* The lowest decibel level measured during a stated or implied monitoring period or noise event. The Lmin value recorded by a sound level meter depends on the time factor used for integration of instantaneous sound pressure level measurements. For most modern sound meters, this is 1 second when the instrument is set for the slow sampling rate and 1/8 second when the instrument is set for the fast sampling rate. The use of A-weighted, C-weighted, or unweighted (flat) decibel units sometimes is indicated by LAmin, LCmin, or LFmin, respectively.

Ln *Nighttime Average Sound Level.* An Leq value based on a 9-hour time period between 10:00 p.m. and 7:00 a.m. (used for both Ldn and CNEL calculations). Also used for specifying noise limits in some local noise ordinances (time period may vary).

Lp *Sound Pressure Level.* An alternative unit designation for SPL, but might be confused with the Lpk descriptor. Weighting system confusion with the dBP unit designation also is possible. The Lp or SPL designation typically is used for the current sound pressure level as displayed on an operating sound level meter.

Lpk *Instantaneous Peak Sound Pressure Level.* The highest instantaneous decibel level detected during a monitoring interval. The reported value depends somewhat on the instrument detector setting (slow, fast, or impulse sampling rate). Some sound level meters allow the decibel weighting for the Lpk measurement to be set independently from the decibel weighting used for the normal time-integrated monitoring. Lpk will differ from Lmax when the instrument samples more frequently than the minimum integration time. For many modern sound level meters, the slow sampling rate is 8 readings per second and the fast sampling rate is either 16 or 32 readings per second. A separate impulse sampling rate also may be available (typically at the fast sampling rate but with a special detector that can track a noise level rise over time intervals as short as 20 to 60 microseconds (0.02 to 0.06 milliseconds). The use of A-weighted, C-weighted, or unweighted (flat) decibel units sometimes is indicated by LApk, LCpk, or LFpk, respectively.

Lx *Percentile Sound Pressure Level.* The decibel level exceeded x percent of the time during a monitoring episode. Sometimes designated as Ln or Lnn, although those designations are easily confused with the nighttime average noise level descriptor used for Ldn and CNEL estimates.

Noy *Noy.* A linear scale of perceived noiseness developed in connection with the PNL decibel weighting system. The noy scale is linear with respect to 40 dB PNL; consequently, a noise rated at 3 noy is perceived to be three times as noisy as a sound of 40 dB PNL.

Phon — *Phon.* A unit of equal perceived loudness for pure tones. Phon values are indexed to the unweighted decibel value for tones at 1000 Hz. The phon value for any given tone is based on the dB value of a 1000 Hz tone that has the same perceived loudness as the tone under consideration.

PNL — *Perceived Noise Level.* A decibel weighting system originally developed for evaluation of aircraft noise levels. In current practice, the PNL descriptor is used primarily as a step in the computation of EPNL values which are used for aircraft noise level certification purposes. PNL values sometimes are designated as PNdB. Lpn is a seldom-used alternative designation for PNL.

PNLT — *Tone-Corrected Perceived Noise Level.* A decibel weighting system originally developed for evaluation of aircraft noise levels by adjusting PNL values for the presence of dominant pure tones. In current practice, the PNLT descriptor is used primarily as a step in the computation of EPNL values which are used for aircraft noise level certification purposes.

OASPL — *Overall Sound Pressure Level.* This term is used in two different contexts. As a technical term, it is a composite unweighted decibel value based on measurements across a broad spectrum of acoustical frequencies. In more generic usage, it simply means a composite sound pressure level (typically an A-weighted level) that reflects the overall spectrum of acoustical frequencies associated with a given sound.

rms — *Root Mean Squared.* A mathematical calculation technique that determines the average of absolute deviations (whether positive or negative) from a reference or mean value. The numerical deviation from the reference value is squared to generate a positive numerical value; the mean of a sequence of such squared deviation values is then determined; and the square root of that mean value is then taken to provide the average of the numerical deviations. This is the technique used in sound level meter circuitry to measure physical air pressure fluctuations so that sound pressure levels can be calculated.

SEL — *Sound Exposure Level.* The SEL measure represents the cumulative (not average) sound exposure during a particular noise event, integrated with respect to a one-second time frame. SEL measurements are equivalent to the Leq value of a one-second noise event producing the same cumulative acoustic energy as the actual noise event being analyzed. In effect, an SEL measure "spreads" or "compresses" the noise event to fit a fixed one-second time interval. If the actual duration of the noise event is less than one second, the SEL value will be less than the Leq value for the event. If the duration of the noise event exceeds one second, the SEL value will exceed the Leq of the event. SEL values can have any specified decibel weighting. Blast noise SEL values frequently are given as C-weighted decibels. SEL values for sources such as aircraft flyover events or train passby events typically are given as A-weighted decibels.

SENEL *Single Event Noise Exposure Level.* An older term identical to SEL, but implying the use of A-weighted decibels. In current practice, the SEL.designation is used more often than the SENEL designation.

Sone *Sone.* A linear scale of equal perceived loudness indexed to the perceived loudness of a 40 dB tone at 1000 Hz. The sone scale is linear with respect to a 40 dB tone at 1000 Hz; consequently, a noise rated at 3 sones is perceived to be three times as loud as a 40 dB tone at 1000 Hz.

SPL *Sound Pressure Level.* A decibel level calculation based on the measurement of instantaneous pressure fluctuations over and under the prevailing barometric pressure. The root mean squared (rms) pressure measurements are converted to a pressure ratio using 20 micropascals as the reference pressure. The sound pressure level in decibels is calculated as 10 times the logarithm of the square of the pressure ratio. Most sound level meters integrate the SPL readings over minimum time intervals that depend on user-set detector sampling rates. Most sound level meters also allow the user to specify a decibel weighting for the SPL measurements. Modern sound level meters typically sample 8 times per second at a slow setting and 16 or 32 times per second at a fast setting. When set to the slow sampling setting, modern sound level meters average SPL readings over a 1 second interval and use those 1-second Leq values for other time period integrations. The basic data integration period will be 1/8 of a second when a fast sampling rate setting is used. SPL (Lp), Lmax, Lmin, and Lx data typically are based on the 1-second (slow response) or 1/8 second (fast response) Leq values.

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