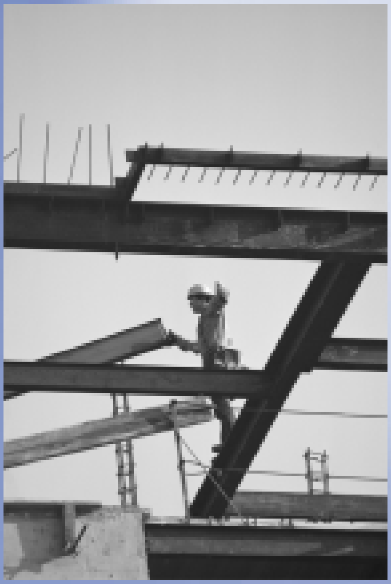


Environmental Noise

The Invisible Pollutant

Published in E2SC

Environmental Excellence in South Carolina

Volume 1 Number 1, Fall 1998

USC Institute of Public Affairs

(803)777-8157

William J. Cavanaugh and Gregory C. Tocci

From the moment of birth we are literally and figuratively immersed in a sea of sounds. We quickly learn that sound is essential for us to communicate with one another, to enjoy drama and musical performances, as well as recorded symphonies, jazz or rock music, and to appreciate countless other sounds we want to hear. Some loud sounds are necessary to warn us of oncoming potential danger, such as at a train crossing or at a construction site where a backing vehicle may be about to cross our path. One has only to be deprived of one's hearing, even temporarily, or to know someone who is severely hearing-impaired to realize how precious the gift of hearing truly is.

But some sounds around us may interfere with our ability to communicate. They may mask our enjoyment of desirable sounds; they may interfere with our ability to concentrate on a task or to learn a new one. Other sounds may startle us, interrupt our sleep, cause us psychological stress, contribute to physiological distress and, when sustained and loud enough, contribute to temporary or permanent loss of hearing. These latter sounds are "unwanted" and, by definition, are considered noise.

Environmental noise in and around buildings and communities in which people live and work has gradually and steadily increased in magnitude and diversity as civilization has advanced. The industrial growth and introduction of railroads in the 19th century accelerated the pervasiveness of environmental noise. In the 20th century, industrial growth even more dramatically exposed larger and larger segments of the population to noise, especially from the new mode of transportation—aircraft. In particular, the introduction of jet aircraft into the civil fleet in the late 1950s and early 1960s spurred the scientific–technical community, as well as the political leadership, to look for solutions to the growing problem of aircraft noise and environmental noise in general.

Protecting the health of the population is and continues to be the primary motive of all public efforts to control individual and community exposure to noise. The United States has adopted the World Health Organization's (WHO) broad definition of health as not the mere absence of disease, but as the total physiological and psychological well-being of the citizenry. Congress enacted the Environmental Protection Act of 1969 and the Noise Control Act of 1972 to mandate and implement practical and achievable standards and policies to ensure that the broad public health and environmental objectives with respect to individual and community noise are met. The United States Environmental Protection Agency (EPA), which grew out of the 1969 environmental legislation, assumed responsibility for coordinating the development of noise policies, standards, and guidelines in cooperation with several major federal agencies. Chief among them are the Federal Aviation Administration (FAA), the Federal Highway Administration (FHWA), the Department Of Housing and Urban Development (HUD), and others having cognizance over major sources or receptors of environmental noise.

The steadily growing concern for and adoption of means to control environmental noise are everywhere evident. The proliferation of highway noise barrier walls along the nation's interstates and major thoroughfares is but one visible manifestation of the success of this landmark environmental legislation of decades ago. Hundreds of residential communities near these major transportation routes are significantly quieter because of these noise abatement measures. Highway engineers and architects are even developing noise barrier walls and landscaped berms that are aesthetically pleasing to both motorists traveling the highways and the residents on the other side of these barriers. The fact that the noise output of the larger and more powerful jet engines necessary to serve the nation's insatiable demand for air travel has not increased with the increased mechanical power of the jet engines themselves is evidence that the nation's efforts to control noise have been productive. In fact, aircraft noise exposure in communities around airports has for the last ten years been on the decrease, as quieter aircraft become more prevalent, even though air traffic has been on the increase. The FAA's "quiet engine" research and development program begun long ago, and its multitude of other aircraft and airport noise abatement research programs, have led to vastly quieter aircraft operations than would have been the case without the continuing efforts to address the thorny issues of environmental noise.

This article reviews environmental noise descriptors and policy guidelines for abating environmental noise on which the scientific-technical community, governmental agencies, industry and consumer–public interest groups generally agree. Likewise those planners, architects, engineers and all involved in the design, specification, and construction of "built" environments need these noise guidelines and standards in order that they may provide effective controls of environmental noise when they are needed. Over the past several decades,

Environmental noise in and around buildings and communities in which people live and work has gradually and steadily increased in magnitude and diversity as civilization has advanced.

TABLE 1

Principal Descriptors of Environmental Sound

Quantity	Symbol	Units	Definition
A-Weighted Sound Level	L_p	dBA	Single-number value of the magnitude of sound at a specific location and time which has been electronically filtered (or "weighted") to approximate the frequency sensitivity of the human ear.
Equivalent Sound Level	$L_{eq}(t)$	dBA	The level of a steady sound that has the same acoustical energy as does a time varying sound over a stated time period. "t" is the time period in seconds, minutes, or hours; e.g., the hourly equivalent sound level is symbolized as $L_{eq}(1h)$; the 20-minute equivalent sound level is symbolized as the $L_{eq}(20\ min)$.
Percentile Sound Level	$L_{n\%}$	dBA	The sound level exceeded "n" percent of the observation time interval; e.g., the level exceeded 90% of a 1 hour period is symbolized as the $L_{90}(1h)$ (often defined as the "background" or "residual" sound level); the level exceeded 10% of a 10 minute period is symbolized as the $L_{10}(10\ min)$.
Day-Night Average Sound Level	L_{dn}	dBA	The equivalent sound level for a 24-hour period that incorporates a +10dB penalty for all sound occurring between 2200 and 0700 hours.

Protecting the health of the population is and continues to be the primary motive of all public efforts to control individual and community exposure to noise.

standards and guidelines have been quite successfully applied on federally funded airport, highway, transit, and housing projects. More importantly, these standards and guidelines have served as a basis for enactment of standards and guidelines by state and local agencies throughout the country.

Quantifying Sound: A Bit About the Numbers

The principal descriptors for evaluating environmental sound are enumerated in Table 1 and discussed further below.

A-Weighted Sound Levels The full, audible frequency range for young, healthy ears extends from about 20 Hz (cycles per second) to about 20,000 Hz. However, the human hearing mechanism is most sensitive to sounds in the 500- to 8,000-Hz range. Above and below this range, the ear is inherently less sensitive. With increasing age, the ear becomes progressively less sensitive to sound over the entire frequency range (presbycusis). Persons who are exposed to loud noise over a long period of time can also incur a hearing loss that usually most significantly affects hearing acuity in the mid- and high-frequency ranges. To account for the varying sensitivity of the normal human ear to sound over the audible frequency range, sound level meters incorporate an electronic filter (or weighting network) that approximates the way the human ear perceives sound over the audible frequency range. Sound level values obtained using this weighting network are referred to as "A-weighted" sound levels and are signified by the identifying unit, dBA. To give some perspective to this simple sound level descriptor, Figure 1 shows A-weighted levels over the full dynamic range of human hearing, from very quiet concert halls and recording studios at about 20 dBA, up to levels of 130 dBA that would cause pain and potential hearing damage, even for short time exposures.

Another important feature of the human hearing mechanism is its ability to process sound over a tremendous dynamic range from the threshold of audibility to the threshold of pain, which is a million times as intense as sound at the threshold of hearing. With respect to detecting or perceiving changes in sound level, increases or decreases in sound level by 3 dBA or less are barely noticeable; an increase or decrease of 5 dBA is clearly apparent; and an increase or decrease of 10 dBA is perceived as a doubling or halving of loudness. Figure 1 also illustrates this effect using a loudness level scale alongside the A-weighted sound level scale. For example, selecting 60 dBA as a reference level, a sound level of 70 dBA would appear to be twice as loud. However, the ear being quite nonlinear in its response, a quartering or quadrupling of loudness more closely corresponds to a change of 15 dB, not 20 dB as the rule of thumb might suggest. Hence, an increase from the reference level of 60 dBA to a level of 80 dBA would be perceived as more than four times as loud. Some noise ordinances use this concept in specifying noise limits for new sound sources: for example, "…[A]ny new noise source should not increase the existing ambient sound level by more than 10 dBA…."

Time-Varying Sound Levels Both indoor and outdoor environmental sound levels usually vary markedly with time, whether in a relatively quiet setting such as in a remote rural area or in highly developed downtown urban community. With such time-varying sound, as with the weather, there is no simple convenient metric to completely describe the quality and quantity of sound energy present.

Figure 2, from an EPA report, shows a ten-minute time history of outdoor sound measured on a front lawn at a quiet suburban location on a typical, otherwise uneventful, afternoon. The maximum sound level, 73 dBA, occurs instantaneously when a sports car passes on the nearby street. Often, the "noise floor" or background sound of an area is expressed as the sound level exceeded 90 percent of the time, symbolized as the L_{90}. In Figure 2, the L_{90} is approximately 44 dBA; that is, the ambient sound level exceeds 44 dBA for about 90 percent of the time interval depicted. In other words, the background sound level is about as quiet as it gets at a particular location. The one percentile sound level, L_1, is generally taken to be representative of typically intrusive, high sound levels observed during a time interval. (one percent of the 10-minute interval in Figure 2 is six seconds).

Clearly, most outdoor sound like that of Figure 2 is best described in statistical terms in order to account for its time-varying character. Indeed, many community noise ordinances written only in terms of simple, unqualified limit values are not only difficult to evaluate, but encourage situations where the limits are unenforceable and largely ignored. Unrealistically low code limits often place normal human activities in violation and end up being disregarded.

Energy-Equivalent Sound Levels The recent availability of inexpensive, yet sophisticated, sound level meters, as well as the adoption of improved standards and guidelines by federal and local agencies, has fostered the use of sound level descriptors that accommodate the time-varying character of environmental noise. Chief among these descriptors is the *energy-equivalent sound level* (L_{eq}). The L_{eq} is the hypothetical steady-state sound level that contains the same amount of acoustical energy as the actual time-varying sound over a specified time interval. In Figure 2, the L_{eq} for the 10-minute sample shown is 58 dBA. In other words, the acoustic energy of the sound sample in Figure 2 averages 58 dBA over the 10-minute interval. The duration of be observation period must always be stated or implied when using L_{eq}; for example, the equivalent sound level over a one-hour interval is symbolized as the L_{eq}(1h).

Environmental Noise from the Grand Canyon to the Freeways of Los Angeles An EPA study in 1971 produced an extremely valuable database of environmental sound at some eighteen locations throughout the United States (see Figure 3). The quietest location measured was at the north rim of the Grand Canyon

FIGURE 1
Loudness Ratio and A-Weighted Decibel Scale for Common Sounds

A – Loudness Level Ratio
B – A-Weighted Sound Pressure Level (dBA)

A	B	
128	130	Threshold of pain
64	120	Jet aircraft takeoff at 100 feet
32	110	Riveting machine at operator's position
16	100	Cutoff saw at operator's position
		Automobile horn at 10 feet
8	90	Industrial boiler room
		Bulldozer at 50 feet
4	80	Sports car interior at 60 m.p.h.
		Diesel locomotive at 600 feet
2	70	Quiet air compressor at 50 feet
1	60	Normal conversational speech at 5-10 feet
1/2	50	Open office area background level
1/4	40	Residential with soft radio music
		Residential background level
1/8	30	Soft whisper at 2 feet
		Recording studio
1/16	20	Concert hall

The steadily growing concern for and adoption of means to control environmental noise are everywhere evident.

Over the past several decades, standards and guidelines have been quite successfully applied on federally funded airport, highway, transit, and housing projects.

FIGURE 2

Typical Outdoor Sound Measured on a Quiet Suburban Street

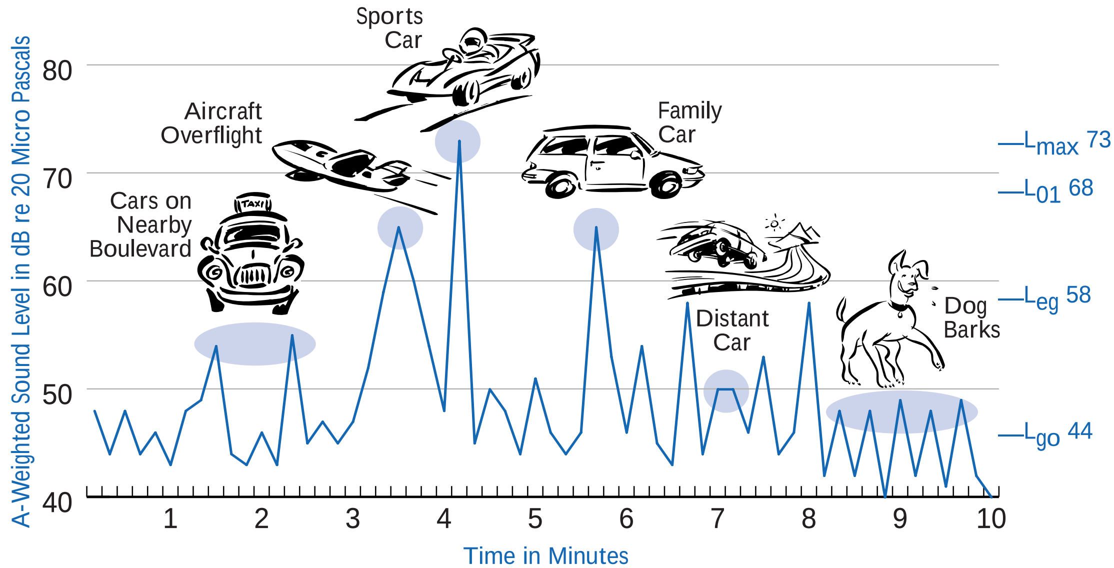
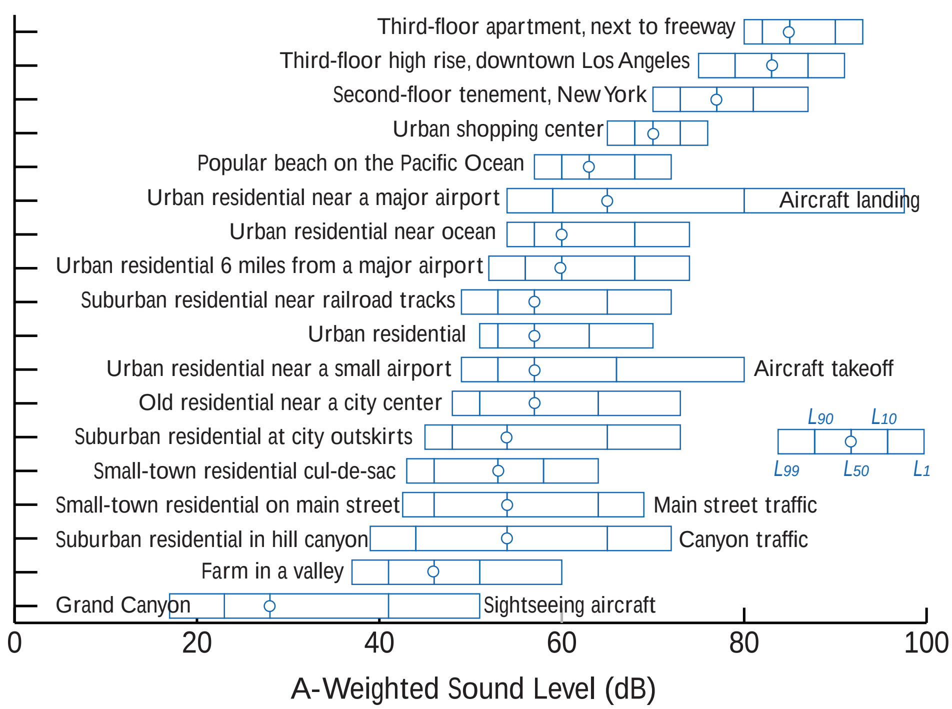


FIGURE 3

A-Weighted Sound Levels Measured at 18 Locations in the United States



where background sound levels (L_{90}) were about 15 dBA. Even the sound level exceeded 50 percent of the time (L_{50}), sometimes referred to as the "time average" level, was as low as 20 dBA. Note however, that due to occasional sight-seeing aircraft flyovers, the level exceeded one percent of the time (L_1) reached 47 dBA, some 32 dBA above the background or generally quietest levels. This indicates the usefulness of percentile sound levels for describing environmental noise. Consultants in acoustics make extensive use of percentile sound levels as they give a comprehensive picture of how sound varies in the environment. The usefulness of percentile sound levels is becoming more widely recognized. For example, the U.S. National

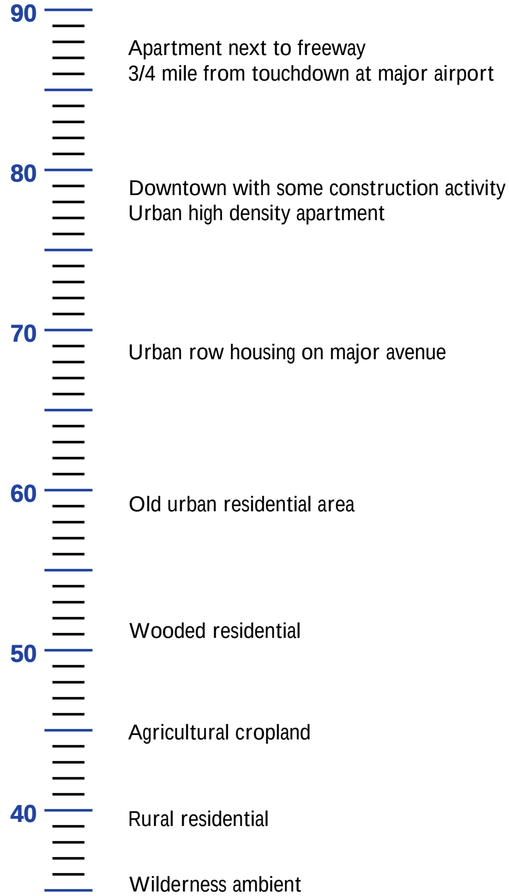
Park Service has become acutely aware of the noise resulting from excessive park development and from recreational vehicles and aircraft overflights. Policies and procedures are under development and are being implemented by the National Park Service to address these growing threats from environmental noise to the serenity of our national parks.

Figure 3 also shows the other extreme as well, a very noisy location on the third floor balcony of an apartment overlooking a heavily traveled multi-lane freeway. On this balcony, the background sound level (L_{90}) rarely falls below 78 dBA during the 7 A.M. to 7 P.M. observation period. Think of it: persons on this balcony would need to converse with raised voices at a distance of about two feet in order to be understood over the continuous din of traffic sound. Likewise, maximum sound levels during occasional truck pass-bys are in the order of 89 dBA. One expects that those residents rarely use their outdoor balconies; and, if so, spend only brief amounts of time there, preferring to escape the din of the balcony by entering the apartment and closing the sliding glass door behind to obtain 25 to 30 dBA of “quieting relief.”

Figure 3 also demonstrates that typical background sound levels (L_{90}) rarely fall below about 40 dBA, even for relatively quiet rural–suburban locations. Background sound levels (L_{90}) increase to the 45 to 50 dBA range in more densely populated urban locations that are not too close to major highways or airports. Figure 3 also indicates that intermittent, intrusive noise levels (L_1) are typically set by aircraft overflights near airports and by trucks near highways. It is quite likely that environmental sound conditions for almost all of South Carolina’s cities and towns could be characterized, without the benefit of a detailed acoustical measurement survey, simply by matching descriptions of these cities and towns with descriptions of the eighteen locations of Figure 3.

It may be also observed from the statistical noise data of Figure 3 that the time average, L_{50}, sound levels are typically well below the L_{10} levels at nearly all eighteen locations. The gap is generally larger, on the order of 15 dBA, in quieter locations and in locations near airports. Based on examination of large sample of highway noise data, the FHWA has determined that the L_{eq} value for traffic noise is typically 3 dBA below the L_{10} value. Accordingly, the current FHWA standard allows the use of either L_{eq} or L_{10} in highway noise analyses and design of abatement measures, but not both an any single project (see Table 2 following).

FIGURE 4
Examples of Outdoor Day-Night Average Sound Levels in dB



Day/Night Average Equivalent Sound Levels

Noise levels occurring at night generally produce greater annoyance than do the same levels occurring during the day. It is generally agreed that people perceive intrusive noise at night as being 10 dBA louder than the same level of intrusive noise during the day, at least in terms of its potential for causing community annoyance. This perception is largely because background environmental sound levels at night in most areas are also about 10 dBA lower than those during the day.

This increased sensitivity to sound at night has been incorporated into the day-night average sound level, which is symbolized as the L_{dn}. The day-night average sound is the twenty-four-hour equivalent sound level that includes a 10 dBA “penalty” added to noise levels occurring between 10 P.M. and 7 A.M. to account for increased community sensitivity to nighttime noise. To help place day-night average sound level into perspective, Figure 4 contains a scale showing L_{dn} values for various types of outdoor locations.

Noise levels occurring at night generally produce greater annoyance than do the same levels occurring during the day.

TABLE 2

Guidelines for Acceptable Environmental Noise Levels

Authority and Specified Sound Levels (in dBA)	Criteria Objective
EPA Levels Document (1974)	
55 dB L_{dn}, outdoors 45 dB L_{dn}, indoors	For the protection of public health and welfare with an adequate margin of safety.
WHO Document (1980)	
50-55 dBA L_{eq}(15h), outdoor/day 45 dBA L_{eq}(9h), outdoor/night 30 dBA L_{eq}(24h), bedrooms 45 dBA L_{max}(24h), bedrooms	Recommended the guidelines for physiological and psychological well-being
U.S. Interagency Committee (FICON)	
65 dB L_{dn}, outdoors	Generally compatible for residential development.
>65-70 dB L_{dn}, outdoors	Residential use discouraged
HUD (ref. 24 CFR par 51.103)	
65 dB L_{dn}, outdoors	Acceptable for housing without special acoustical design consideration.
>65-75 dB L_{dn}, outdoors	Normally unacceptable, but acceptable with acoustical sound isolation.
>75 dB L_{dn}, outdoors	Unacceptable, but acceptable with acoustical sound isolation and the existence of overriding benefits of the project.
FHWA (ref. 23 CFR, par 772)	
57 dBA, L_{eq}(1h) 60 dBA, L_{10}(1h) outdoors	*Activity Category A* Lands on which serenity and quiet are of extraordinary significance.
67 dBA, L_{eq}(1h) 70 dBA, L_{10}(1h) outdoors	*Activity Category B* Picnic areas, recreation areas, residences, motels, schools, churches, libraries, hospitals
72 dBA, L_{eq}(1h) 75 dBA, L_{10}(1h) outdoors	*Activity Category C* Developed lands not in Categories A or B above.
FAA (ref. 14 CFR, par 150, Appendix A)	
65 dB L_{dn}, outdoors	Compatible for residential, public, and commercial building uses.
>65-70 dB L_{dn}, outdoors	Compatible for commercial building use. Compatible for public building use with 25 dBA building envelope aircraft noise reduction (NR). Not compatible for residential, but interior acceptable with 25 dBA building envelope NR.
>70-75 dB L_{dn}, outdoors	Compatible for commercial building use with 25 dBA building envelope NR. Compatible for public building use with 30 dBA building envelope aircraft noise reduction (NR). Not compatible for residential, but interior acceptable with 30 dBA building envelope NR.
>75-80 dB L_{dn}, outdoors	Compatible for commercial building use with 30 dBA building envelope NR. Not compatible for public building use. Not compatible for residential, but interior acceptable with 35 dBA building envelope NR.
>80 dB L_{dn}, outdoors	Not compatible for commercial, public, or residential use buildings.

HUD is the lead federal agency setting standards for interior and exterior noise for federally supported housing.

Acceptable Environmental Noise Levels

Because of their sensitivity to frequency and temporal characteristics of noise, both the L_{eq} and the L_{dn} have become widely used in environmental noise regulations and criteria. Among federal agencies using L_{eq} or L_{dn} are the EPA, the FHWA, HUD, the FAA, and the Department of Defense.

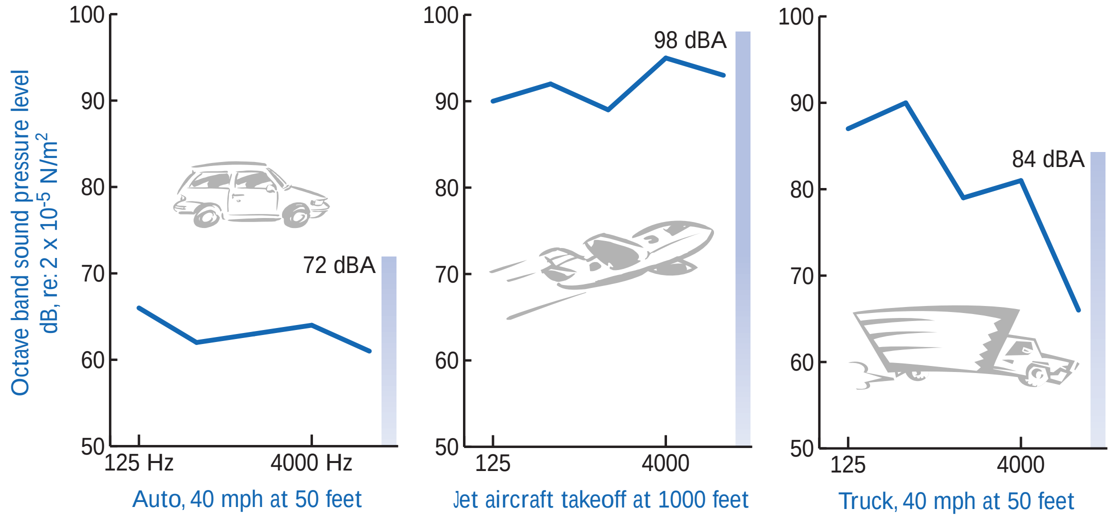
U.S. Department of Housing and Urban Development HUD is the lead federal agency setting standards for interior and exterior noise for federally supported housing. The standards, outlined in 24 CFR part 51, establish Site Acceptability Standards based on day-night equivalent sound levels. These standards are presented in Table 2.

In Table 2, ranges of L_{dn} values are correlated with various dispositions of HUD acceptability categories for housing and associated need for noise abatement, either at the site property line or in the construction of the building exterior envelope. These have been devised to achieve the HUD goal for interior noise levels not exceeding an L_{dn} of 45 dB. “Acceptable” sites are those where noise levels do not exceed an L_{dn} of 65 dB. Buildings on acceptable sites do not require additional noise attenuation other than that provided in customary building techniques. “Normally unacceptable” sites are those where the L_{dn} is above 65 dB but does not exceed 75 dB. Housing on normally unacceptable sites requires some means of noise abatement, either at the property line or in the building exterior, to ensure that interior noise levels are acceptable. From a practical standpoint, this requirement usually means that buildings must be air-conditioned so that windows can be closed to reduce exterior sound transmission into interior spaces.

“Unacceptable” sites are those where the L_{dn} is 75 dB or higher. The term “unacceptable” does not

FIGURE 5

Typical Exterior Transportation Noise Sources



necessarily mean that housing cannot be built on these sites, but rather that more sophisticated sound attenuation would likely be needed, and that there must exist some benefits that outweigh the disadvantages caused by high noise levels. Most often, housing on unacceptable sites requires high sound transmission loss (TL) glazing and air conditioning so that windows can be kept closed to obtain the full building envelope noise reduction. And it requires approval at the higher HUD departmental levels and only if housing on these sites fills a pressing regional need.

Federal Highway Administration Among criteria established by the FHWA for the design of highways is a set of design goals for traffic noise exposure. The FHWA traffic noise abatement criteria are given in 23 CFR Part 772, which classifies land areas according to use and ascribes corresponding maximum equivalent (L_{eq}) and tenth percentile (L_{10}) sound levels. Table 2 presents FHWA limits that cover most land uses and are applicable to the "worst regularly occurring traffic noise hour," usually rush hour. These limits are viewed by FHWA as goals in the design and evaluation of noise produced by traffic on certain types of highway projects.

Since most federal highway supported highway projects are designed, constructed, and managed by states, the strategy of the FHWA has been to step back from the environmental noise assessment of highway projects and require states to develop their own policies on highway noise abatement that are consistent with the recommendations of FHWA. Most states have instituted their own policies. These policies typically incorporate the FHWA noise abatement criteria for evaluating highway traffic noise. But, in addition, many of the policies also include guidelines for assessing traffic noise impact on the basis of the expected change in noise levels at receptor locations resulting from a highway project. Most policies that incorporate such limits indicate that a substantial noise impact occurs if sound levels at a receptor location increase by 10 to 15 dB, depending on the state. When highway traffic noise levels in an impact assessment situation are determined to be high enough to require the consideration of highway noise barriers, these policies require that the noise barrier pass certain feasibility and reasonability tests. These tests ascertain the constructability of barriers, the acceptability of their cost-benefit ratio, the impact of barriers on wildlife migration, the impact on road safety, and also whether the community desires them.

The prediction of highway noise is extremely complicated. To promote uniformity and accuracy in the calculation of highway traffic noise, the FHWA has developed and distributed computer programs that are used to calculate traffic sound levels at nearby receptor locations. The programs use as inputs traffic speed, volume, truck mix, number of lanes, distance to receptors, and other factors, which are used to calculate the L_{eq} and L_{10} sound levels at receptor locations. The original program available

The prediction of highway noise is extremely complicated.

Engine exhaust noise from most passenger automobiles is so well muffled that, except for very low speeds, automobile noise is dominated by noise generated at the tire–pavement interface.

since the mid-1970s is STAMINA 2.0. A later program, OPTIMA has been introduced to facilitate noise barrier evaluation. In 1998, FHWA introduced a new Microsoft Windows-based program called Traffic Noise Model (TNM). It is to replace the STAMINA/OPTIMA model that is to be phased out over the following two years.

Figure 5 compares spectra (the variation of sound energy over the audible frequency range) for sound produced by passing automobiles, trucks, and aircraft. The differences in shapes among these three frequency spectra explain why these sound sources are audibly different. Engine exhaust noise from most passenger automobiles is so well muffled that, except for very low speeds, automobile noise is dominated by noise generated at the tire–pavement interface. Auto noise increases with the speed of the vehicle. Wet pavement increases tire noise, but most of the change that is perceived between automobiles passing on dry and wet pavement is associated with a change in frequency content of tire noise.

You may have noticed that tire noise on new asphalt pavement is noticeably quieter than on worn pavement. This phenomenon is a result of venting at the surface of the road, which eliminates the entrapment of air between the tire tread and pavement. Unfortunately, this beneficial effect lasts for only a few weeks; then the pavement becomes filled and smooth, thus eliminating the efficient venting of air otherwise entrapped as the tire rolls over the pavement surface, rapidly entrapping, compressing, and then releasing air. This train of “pops” produces the broadband noise you hear as characteristic tire noise.

Truck noise is dominated by noise produced by the engine. Engine noise has three components: exhaust noise, casing-radiated noise (directly off the engine block and covers), and engine cooling-fan noise. Which of these three dominates depends on the engine speed, engine load, and type of exhaust muffling, but most often engine cooling-fan noise dominates, particularly in new trucks outfitted with more efficient mufflers. Truck tire noise—even at great distances from a highway—also remains a continuing problem, as anyone who has heard “singing tire tones” at night can tell you. Truck noise is often more noticeable at night, and often more annoying, because the higher background sound levels created by the continuous flow of auto traffic disappear at night, leaving the sound of discrete truck pass-by noise more evident. In actuality, noise produced by a passing truck is no different in the daytime from that in the night, but without the masking noise produced by automobile traffic during the day, truck noise more obviously stands out.

Practically speaking, once FHWA design criteria are exceeded, the only noise control method available to the highway designer is the use of noise barriers. These barriers may be of wood, metal, masonry units, or concrete planks; they may also be in the form of an earthen berm, or some combination of berm and wall. These barriers reduce sound levels at receptor locations only if they block the line of sight between receptors and highway vehicles. A highway noise barrier constructed along a major interstate highway in Newton, Massachusetts, for example, protects a well-developed suburban residential community; measurement showed that the residents are enjoying, on the average, 12 dB less highway noise than they experienced prior to the barrier construction.

Federal Aviation Administration The FAA does not specify aircraft noise exposure limits for communities near airports. Instead, the FAA sets limits on noise emissions from individual types of aircraft and sets deadlines for permitted operation of aircraft at U.S. airports that do not conform to these limits. Aircraft noise emission limits are important to communities around airports, but they are also important to airport planners who need to evaluate the noise impact of changes in airport operations produced by changes in facilities and normal growth in air traffic. Most airports, even smaller general aviation airports, maintain an airport master plan. An airport master plan is a written document that outlines all aircraft operations, assesses environmental effects including noise, and forecasts future airport growth.

Airport noise exposure information is normally presented as yearly day-night average sound level contours overlain on a map of the area. L_{dn} contours are normally presented in 5 dB increments beginning with the 65 dB contour. Some major airports have L_{dn} contours as high as 80 dB close to the ends of major departing runways. These maps are used by architects and engineers to interpolate aircraft day-night average sound levels at their project sites in the vicinity of airports. This information is used to evaluate the need for special sound isolation wall and window constructions to protect interior spaces of the building from excessive aircraft noise.

Table 2 indicates recommended compatible use zones for various kinds of building and land uses. For example, residential buildings, public buildings (such as schools, hospitals, churches, and auditoriums), and

TABLE 3

Possible Airport Noise Abatement Actions

Airport Feature and Activity	Possible Noise Abatement Actions
Flight tracks	Direct aircraft away from populated areas
Preferential runways	Foster use of runways with least impact
Restrict noisy aircraft	Minimize operations during day or night
Noise abatement flight procedures	Require use of noise abatement throttle and flap management procedures for takeoff and/or approach
Airport layout	Extend or build new runways and taxiways to make best use of compatible land and water
Shielding barriers	Shield people from noise of ground operations.
Building soundproofing	Soundproof schools, homes, and churches
Land use control	Ensure compatible land use through acquisition of property or other rights
Monitor and model	Monitor airport noise and flight tracks to provide data to the public and for evaluating proposed alternatives
Communications	Listen to complaints and suggestions; develop and institutionalize continuing effective dialogue and information transfer among all concerned parties

commercial buildings are compatible where the L_{dn} is below 65 dB. With each 5 dB increase in aircraft noise exposure, there is an increasing need for sound isolation to offset the aircraft noise exposure. For example, in the 75 to 80 dB range of L_{dn}, residential buildings are incompatible with respect to outside use; however, interior spaces can be made compatible if the exterior construction of the building can provide at least 35 dB of aircraft noise reduction. Correspondingly, commercial office buildings need to provide at least 30 dB of aircraft noise reduction. A chapter by Kenneth Eldred in the recently published *Handbook of Acoustics*[1] summarizes the kinds of actions that might be taken by airports to address the concerns of surrounding communities. These actions are outlined in Table 3.

Stationary Sources of Environmental Noise

Stationary, or fixed, sources of environmental sound abound in and around practically all communities, large and small. Industrial plants, outdoor rooftop air-conditioning equipment, electrical transformers, power plants, waste processing plants, and, yes, even outdoor concert amphitheaters, can and do produce unwanted sound. This noise interferes with the enjoyment of residential property and with sleep, and detracts from the general physiological and psychological well-being of the community. Most often, the regulation of noise produced by these sources is the responsibility of the municipality or state. Most communities in the U.S. do not have noise codes or guideline standards that establish specific limits, but, rather, they have nuisance clauses against noise. These clauses are vague and nearly impossible to enforce efficiently, and often require court action. Detailed discussion of effective community noise codes and standards, however, is beyond the scope of this article.

It goes without saying that no new source of environmental noise, whether it be associated with the expansion of an existing facility or an entirely new facility, should be approved by local jurisdictions without an adequate review of its environmental impacts (including noise impact). Guidelines for environmental impact statements and analyses are principally outlined in 40 CFR Part 1500, which was preceded by and draws upon the Environmental Policy Act of 1969 and the Noise Control Act of 1972. Federal agencies—FAA, FHWA, and others—necessarily deal only with noise sources that have national, even international, implications and therefore must maintain a suitably wide perspective on noise regulation recognizing that the specific needs and interests of states and localities vary. As noted earlier, the FHWA has addressed the varying interests and needs of states by requiring them to establish their own policies in accordance with the broad guidelines they have set for such facilities. The FHWA, along with many other federal agencies, has expended tremendous amounts on research to provide technical tools that states and other jurisdictions need to enact meaningful and worthwhile guidelines and standards to protect the environment. We are now, by and large, well-equipped to define acceptable environmental noise limits and to control cost-effectively practically any type of community noise source. Fortunately, most if not all sources of environmental sound fall into the “annoy-

Industrial plants, outdoor rooftop air-conditioning equipment, electrical transformers, power plants, waste processing plants, and, yes, even outdoor concert amphitheaters, can and do produce unwanted sound.

Understanding these general community-wide reactions to environmental noise is helpful in establishing noise control design goals for individual facilities as well.

The good news is that community noise exposure levels are well below those that cause hearing damage or even sleep disturbance. The bad news is that the range of acceptable noise exposure is exceedingly broad: "one person's noise is another's music" is often the case, and not just with outdoor concert amphitheaters.

ance" category. The good news is that community noise exposure levels are well below those that cause hearing damage or even sleep disturbance. The bad news is that the range of acceptable noise exposure is exceedingly broad: "one person's noise is another's music" is often the case, and not just with outdoor concert amphitheaters.

A recent Federal Transit Administration publication (*Transit Noise and Vibration Impact Assessment*, April, 1995, p. 2-3) gives an indication of expected community reaction when a new environmental noise source is introduced. If the new source does not result in a significant increase in the communities' pre-existing day-night average sound level (L_{dn}), little or no reaction is expected. With up to a 10 dB increase in L_{dn}, sporadic to widespread complaints would be anticipated. Greater than a 10 dB increase in L_{dn} results in increasingly strong community reaction including threats and initiation of legal action. Understanding these general community wide reactions to environmental noise is helpful in establishing noise control design goals for individual facilities as well.

Conclusion

Addressing and solving any environmental noise problem involves two initial steps:

- Quantify the problem using noise measurements or analytical means
- Determine the applicable criteria, goals, or noise limits.

The first step—quantifying sound—is usually straightforward; the second step—finding an applicable limit—is also made simple if the community affected has in place a well-written and workable environmental noise ordinance or guideline. With "global" environmental noise sources, such as highways, railroads, and aircraft, the primary responsibility lies with federal authorities to provide the necessary regulatory guidelines. The task of establishing applicable guidelines and limits is increasingly being delegated to state authorities under the supervision of the appropriate federal agencies. The knowledge of how to measure and control environmental noise is a professional expertise that is readily available throughout the country. Most practicing acoustical consultants, architects, and engineers, and those working at universities and federally supported research centers around the country, agree that we are well-prepared to make the 21st century a "quiet" one. Yes, the invisible pollutant of environmental noise can be tamed. ESC

[1] *Handbook of Acoustics*, Malcolm J. Crocker, editor; John Wiley and Sons, New York, 1998.

William Cavanaugh and Gregory Tocci are acoustical consultants based in Sudbury, MA. Their company is Cavanaugh Tocci Associates, Inc.