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## Wilmington School & Residence Sound Attenuation Program

# Report #2: Criteria and Prioritization Recommendations Report





Wilmington School & Residence  
Sound Attenuation Program

# **Report #2: Criteria and Prioritization Recommendations Report**

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## EXECUTIVE SUMMARY

This report presents recommendations for the criteria to be used to determine eligibility for the Harbor Community Benefit Foundation's (HCBF) Wilmington School and Residence Sound Attenuation Program along with a methodology for prioritizing implementation of the program. Considerable background information regarding the adverse environmental and health impacts from community noise exposures and noise impact criteria used by or recommended by various national and international entities are presented. This information was used to develop the criteria and prioritization recommendations along with the results of the noise measurements that were previously completed for this project and are presented in Report #1: Noise Measurement Report. In addition, noise contour maps, which are being prepared concurrently with the development of this report and will be delivered shortly after this report were used in developing the proposed criteria and prioritization.

To fulfill its mission to address the noise impacts from operations associated with the Port of Los Angeles, it is recommended that any residence or school that is exposed to noise from Port related operations that perceptibly affects the noise environment and whose interior noise levels exceed the WHO Interior Noise Level Guidelines should be eligible for the program. The use of this criterion results in many residences and schools being eligible for the program, and a method for prioritizing mitigation is necessary. A prioritization methodology is proposed in this report.

A single number priority scoring system is proposed. The priority scoring system considers the amount that the indoor noise levels exceed the criteria during both day and nighttime hours. Both average noise levels and maximum noise levels generated by Port related operations are considered. A Prioritization Score noted as  $P_{\text{Score}}$  is calculated. The homes with the highest  $P_{\text{Score}}$  are given the highest priority for implementation of sound attenuation. Noise impacts students and residents differently, and therefore, the ratings for residents and schools is not directly comparable. However, we believe that schools should be given priority since mitigation of schools benefits more people, especially young people, and results in more benefit for the money spent.

As discussed above, noise contour maps have been developed concurrently with this report. These contour maps, along with a report presenting the methodologies and assumptions used to develop the maps will be delivered shortly after this report. In addition to the noise contours, this deliverable will include maps showing  $P_{\text{Score}}$  estimates for eligible properties. The scores will group the properties into low, medium, and high impact categories.

After Reports #2 and #3 are reviewed and approved by the HCBF Board, the next step in the program is to perform a detailed inventory of the structures within the impact zones. A survey will be performed to identify residential housing types and school construction. This survey will document specific building characteristics that affect remediation. A report summarizing the results of the survey, presenting various approaches to providing additional attenuation, and identifying the home and school types that would benefit most from a sound insulation program will be delivered at the conclusion of the next task.

The final step in our program is to identify the sound mitigation measures for the typical building constructions in the neighborhood. The noise impact, building codes, noise goals and other concerns must be considered in determining the soundproofing features that will need to be employed. We will also look for other funding opportunities that might be tied in with the soundproofing program (i.e., energy conservation funds) to maximize the benefit of the dollars spent. The final result of this program is to provide a plan of what schools and/or homes should have first priority in sound-proofing and what sound mitigation measures will be needed for each building type.

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## 1.0 INTRODUCTION

This is the second report produced for the Harbor Community Benefit Foundation's (HCBF) Wilmington School and Residence Sound Attenuation Program. The first document, *Report #1: Measurement Report*, presented the results of a comprehensive noise-monitoring program to identify and preliminarily quantify noise sources associated with the Port of Los Angeles operations impacting the homes and schools of the Wilmington Community.

This second report has been prepared concurrently with the third deliverable for the project, Noise Impact Maps, which present quantified noise contours from the port, related noise sources identified in the first report overlaid on aerial mapping. The information and recommendations presented in this report include specific criteria for determining eligibility of schools and homes for the Sound Insulation Program and to prioritize implementation of the program.

The first report presented an overview of metrics (e.g., Leq, CNEL, Lmax) used to measure noise and criteria used to assess the impacts of noise on humans. The definitions of the noise metrics are presented in the Glossary at the end of this report. An overview of Noise Impact Criteria was also presented in the first report. In this report, the discussion is expanded considerably to present the latest information on what is known about the adverse impacts of noise on humans. Noise criteria used by local, state, federal, and international agencies were considered and are also presented in this report.

A consistent theme in the United States when establishing noise criteria is to strike a balance between the benefits provided by the noise generator and their impacts on persons. A private industrial facility will typically have stricter noise limits than a public roadway because of the public good provided by the roadway. Another example is the Federal Aviation Administration's airport noise criteria allows for up to 12% of exposed persons to be highly annoyed based on the rationale that the airport is providing a public service.

The World Health Organization's (WHO) Guidelines for Community Noise (World Health Organization, 1999) do not make this compromise and are based on a more broad definition of health. These guidelines, discussed in Section 3.1, are based the WHO's objective of the attainment of the highest possible level of health by all peoples with health defined as, "A state of complete physical, mental and social well-being not nearly the absence of disease or infirmity." As you will see, the WHO guidelines recommend considerably lower noise levels than the criteria used by federal, state and municipal agencies in the United States. These standards are based on a definition of health being an absence of disease. The WHO guidelines represent ideal noise levels that are not always achievable in developed areas.

The formation of the HCBF is a general acknowledgment that port related noise is a significant and long-term issue in the Wilmington Community. One of the primary functions of the HCBF is to reduce the impact of port related noise. However, as understood by many previously, and demonstrated in the noise measurement report, the port related noise impacts in the community are widespread. Further, the resources available to the HCBF to address these issues are limited. While the foundation will continue to search for additional funding resources to increase the amount available, it is very unlikely that there will not be enough resources to provide sound attenuation for all residences that result in ideal levels of noise.

Therefore, the implementation criteria, rather than trying to establish ideal noise conditions, needs to establish an equitable way to prioritize mitigation. A priority scoring system based on the average and maximum daytime and nighttime noise exposures is recommended Section 4.0. The score is based on how much the noise level at the home exceeds a criteria level. Weighting factors are applied to each of these noise metrics to characterize the impacts from each noise exposure type. While suggested criteria levels and weighting values are presented, they are subject to approval by the HCBF Board.

This report is intended to give the HCBF Board the best available information regarding the impacts on humans from various noise exposures in order to confirm that the scoring system recommended is appropriate and to select appropriate weighting and criteria values.

## 2.0 BACKGROUND INFORMATION

*If a tree falls in the forest and there is no one to hear it, does it make a noise?*

When phrased in this manner, the age old philosophical thought experiment becomes trivial. It does not matter what you believe about the nature of reality in the absence of an observer. The creation of noise requires an observer because noise is simply unwanted sound. It is the existence and judgment of the observer that determines whether or not the sound is noise or not. One person's music is another person's noise. However, many modern day sounds, traffic, aircraft, industry, are almost universally identified as noise. Further, recent research suggests that high community noise levels can result in adverse health effects that may or may not be related to an individual's conscious attitude towards the noise.

In the modern world, community noise is a fact of life that we cannot avoid, but we can minimize its impact. One of the side effects of our ability to harness energy and use it to do work for us, whether propelling a car or airplane, digging a ditch, or providing air conditioning, is that noise is generated as a byproduct. However, it is generally agreed that the benefit provided by this ability, increased mobility and opportunity, outweigh the negative side effects such as noise. Further we can use knowledge and technology to minimize the impacts of the side effects.

This section provides basic and advanced information useful in considering what noise is and how it can adversely impact persons. Subsection 2.1 discusses the qualities of sound and how they are perceived by humans. Subsection 0 provides an overview of the current state of knowledge regarding how noise adversely affects humans. Appendix A provides more in depth discussions of the individual adverse effects for the more technically interested reader. Finally, Subsection 3.0 gives summaries of international, national, state, and local criteria adopted to address noise impacts.

### 2.1 Sound, Noise, and Perception

Sound is created when mechanical vibrations from a sound source—your larynx, a loudspeaker, an engine, a horn—are transmitted to air creating rapid variations in air pressure that travel away from the source like a wave from a pebble dropped in a pond. These rapid pressure variations, or acoustic waves, enter our ear canals and cause our eardrum to vibrate in sympathy with the air pressure variations. These vibrations are transmitted through a series of bone levers in the middle ear to the fluid filled inner ear. The inner ear converts these vibrations into neural signals, which are perceived by our brain as sound. The rapid variations in air pressure are sound. Sound's primary qualities are amplitude (loudness) and frequency (pitch or tone).

#### 2.1.1 Sound Levels and Decibels

Amplitude is the change in air pressure above and below equilibrium sound pressure (typically about 101,300 Pascal (Pa)) caused by the sound. Human ears can detect air pressure changes as small as 20  $\mu$ Pa (micro Pascal =  $10^{-6}$  Pascal.). Pressure changes of 20 Pa induce pain. Therefore, amplitude of sound that is perceptible to humans has a range of 10,000,000 Pa. However, we never see sound levels in terms of pressure. This is because the large range makes working with pressure levels directly unwieldy. To compress this large range of perceptible sound levels the decibel is used (dB). Another advantage of the decibel is that it is better related to how humans perceive sound levels.

The decibel is most simply ten times the base ten logarithm of the ratio of two power quantities. Sound pressure in air is most correctly referenced as  $\text{dB}_{\text{SPL}}$  or dB SPL. The SPL subscript indicates that the level is the ratio of the air pressure of the sound being measured to the threshold of human hearing, 20  $\mu$ PA. However, when used in reference to noise the SPL subscript is often omitted. Further, pressure is not a unit of power but the square of pressure is proportional to power. So

$dB_{SPL}$  is ten times the logarithm of the ratio of the square of the air pressure fluctuation caused by the sound to the square of the threshold of hearing or, equivalently, twenty times the base ten logarithm of the ratio of the air pressure fluctuation caused by the sound to the threshold of hearing.

## 2.1.2 The Strange World of Decibels and Logarithms

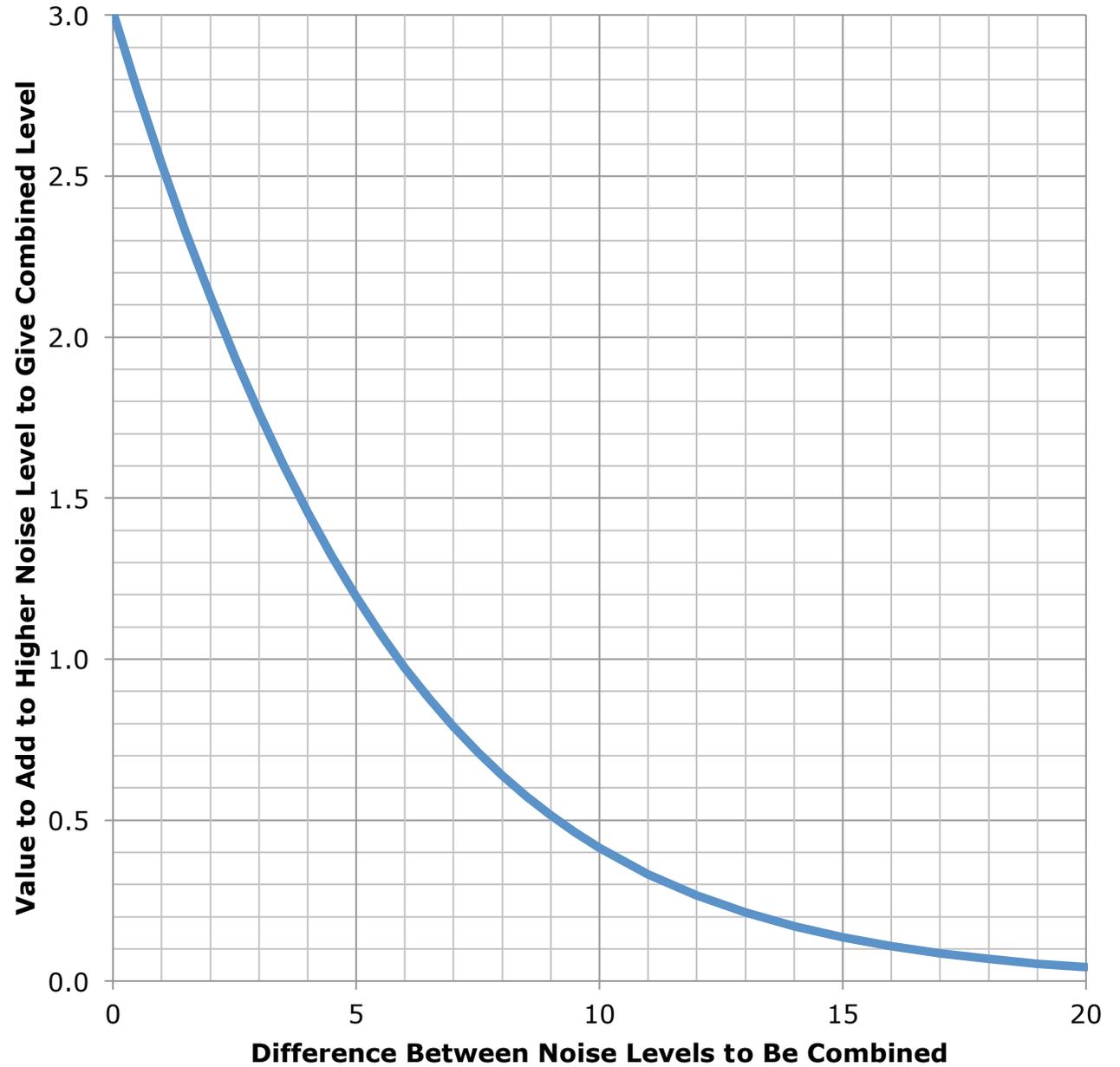
Logarithms are not easily understood as most of human experience is simply additive. A person takes one step forward and then another step, he has taken two steps forward. In our typical experience 50 plus 50 equals 100. However, in the world of logarithms, 50 dB plus 50 dB equals 53 dB. That is because in the world of noise you are adding the noise levels together logarithmically. If you've never been taught and studied logarithms, the logarithmic world of the dB is quite strange and unintuitive. However, it is much more usable since human perception of sound is logarithmic. That is, if you have one source of noise at 50 dBA and then you add another source of noise at 50 dBA, it doesn't actually sound like twice the noise. Try this simple exercise. Tap one fingernail on your desk, wall, book or other hard surface. Now tap two fingers at the same time; did it sound twice as loud? Most people would say "no". Now start the experiment again and keep adding more fingers tapping. How many fingers have to tap before the noise seems like it is twice as loud? Most people would say "all ten fingers." Our recommendation is that if you do not wish to study logarithms, take it on faith that the math works. The more important concepts are how noise levels are combined and how humans perceive sound levels in terms of decibels.

## 2.1.3 Decibel Arithmetic

As discussed above, when two equal sound sources are combined, the resulting noise level is 3 dB greater than for one source alone. Figure 1 presents a table and nomograph for the addition of two different sound levels. This graphic presents the value to be added to the higher of the two sound levels based on the difference in the sound levels to give the sound level of the two sources combined. For example, two noise sources are generating 57.0 dB and 60.0 dB at a location. The table shows that for noise levels with a 3 dB difference a value of 1.8 dB is added to the higher noise level to determine the combined noise level, 61.8 dB. The table and chart show that as the difference between the sound levels to be combined increases, the difference between the loudest noise level and the combined noise level decreases. The combined noise level for two sources with a 10 dB difference is only 0.4 dB greater than the higher noise level and adding a noise source that is 20 dB lower than another will not change the overall noise level.

The combination of ten equal sound sources results in a noise level 10 dB greater than one source alone. One hundred equal sound sources would generate 20 dB higher noise levels than a single source. This is the case for instantaneous noise levels from constant noise sources and for time averaged noise levels from intermittent sources. A piece of machinery that runs constantly will generate an  $Leq(H)$  noise level 3 dB higher than if the same piece of machinery runs for 30 minutes in an hour (i.e., one half of an hour). The noise level from the constant source will be 10 dB higher than if the machine only runs for 6 minutes in an hour (i.e., one tenth of an hour) and 20 dB louder if the machine only runs for 10 seconds in an hour (i.e., one hundredth of an hour). Similarly, a road with double the traffic volume of another will generate a 3 dB higher  $Leq(H)$  a road with 10 times the traffic volume will generate a 10 dB higher  $Leq(H)$  and a road with 100 times the traffic volume will generate a 20 dB higher  $Leq(H)$ .

Difference Between Noise Levels To Be Combined	Value to Add to Higher Level to Give Combined Level
0.0	3.0
0.5	2.8
1.0	2.5
1.5	2.3
2.0	2.1
2.5	1.9
3.0	1.8
3.5	1.6
4.0	1.5
4.5	1.3
5.0	1.2
5.5	1.1
6.0	1.0
6.5	0.9
7.0	0.8
7.5	0.7
8.0	0.6
8.5	0.6
9.0	0.5
9.5	0.5
10.0	0.4
11.0	0.3
12.0	0.3
13.0	0.2
14.0	0.2
15.0	0.1
16.0	0.1
17.0	0.1
18.0	0.1
19.0	0.1
20.0	0.0



**Figure 1 - Decibel Addition Table & Nomograph**



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### 2.1.4 The Decibel and Human Perception

The other advantage of using the decibel is that it correlates well with human perception. The smallest sound level difference perceptible by humans in the laboratory with a direct immediate comparison of the sounds is about 1 dB. Our ability to detect sound level differences is reduced to about 3 dB in typical community noise conditions. This is because a direct immediate comparison of the sounds is not easily made and the time between comparisons reduces our ability to discern sound level differences. Further, the frequency content of the sound levels to be compared is often different, further reducing this ability. In fact, it is generally accepted that a 5 dB change is required for it to be perceptible to most persons. A 10 dB change is described as a doubling, or halving, of noise levels.

### 2.1.5 Tossing One Rock or Many Rocks Into the Pond

Sound's other primary quality is frequency, the rate at which the air pressure varies. In the pond wave, the closer the peak of each individual wave is spaced the higher the frequency. Humans are able to detect air pressure changes with rates of 20 individual waves per second to 20,000 waves per second. The unit of waves (more correctly "cycles") per second is called Hertz (Hz). Below 20 Hz, humans perceive air pressure changes as individual pulses rather than a tone. The upper limit of hearing 20 kHz is representative of a younger listener with unimpaired hearing. As we age our ability to detect high frequency sounds is lower and one of the primary modes of hearing damage due to exposure to high sound levels is the reduction in the audibility of high frequency sounds.

The frequency range of a piano is from 32.7 Hz (C0) to 4,186 Hz (C8) with middle C having a frequency of 261.6 Hz. A typical adult male voiced speech has a fundamental (i.e., lowest) frequency of 85 to 180 Hz and a typical female has a fundamental frequency of 165 to 255 Hz. Human speech generates frequencies as high as 8 kHz but most of then energy is between 1 kHz and 3 kHz. Sources that generate sound that is primarily concentrated at one frequency are referred to as tonal or pure tones. When throwing one rock into the pond, all the waves generated are equally spaced and it represents a pure tone.

Most community noises are broadband in that, unlike a musical instrument, they generate sound equally within a relatively wide frequency range. The fuzz sound between radio stations is one example of broadband noise. Noise from traffic and aircraft is broadband and typically ranges from approximately 50 Hz to 5 kHz. When throwing many rocks of different sizes into the pond an odd irregular pattern forms that is similar to broadband noise. Tonal noise is generally found to be more annoying than broadband noise.

### 2.1.6 Human Perception of Frequency

The human ear is not able to perceive all frequencies the same. Three frequency-weighting schemes have been established to allow measured sound levels to account for our varied sensitivity to different frequencies. These frequency weightings are called A, B and C. The A-Weighting mimics human sound perception in the range of community noise. The B and C weightings mimic perception at higher levels with C-Weightings best representing human response for very high noise levels such as inside a loud factory or at a concert.

In community noise, most measurements and analysis are performed using the A-weighting and the resulting noise levels are noted dBA. Some noise metrics, such as LDN and CNEL are defined as A-weighted and the "A" may or may not be included in the dB notation.

## 2.2 Adverse Effects of Noise on Humans

Historically, the primary adverse effect associated with community noise has been annoyance. Higher noise levels, greater than 90 dBA averaged over 8 hours, are known to cause hearing damage, but these levels are not typically encountered in community noise situations. The Occupational Safety and Health Administration have established hearing protection standards to minimize workplace hearing damage and these standards are discussed in more detail below. It's been known that noise affects sleep, but again, this impact was thought to be reflected in annoyance reactions.

### 2.2.1 Physiological Effects

Several studies published in recent years indicate a correlation between community noise exposure and hypertension (high blood pressure), ischemic heart disease (reduced blood supply to the heart muscle) and even diabetes. Additionally, studies investigating nighttime sleep disturbance from noise event exposure, primarily aircraft, have indicated that nighttime noise events result in increased heart rate and blood pressure and excretion of stress hormones that may contribute to adverse health effects even if the noise event does not cause a perceived awakening. Research has also shown that increased average nighttime noise exposures (nearly constant average noise levels rather than noise events) can result in changes in sleep structure and increases in blood pressure and heart rate along with reductions in the perceived quality of sleep (difficulty in falling asleep, waking up during sleep, waking up too early, feelings of sleepiness one or more days a week). There is considerable evidence that undisturbed sleep of sufficient length is important for health and daytime performance and that sleep disturbance can have considerable effects beyond annoyance.

However, trying to identify, measure and quantify any potential effects of noise on human health is complex and difficult. A large amount of research on the health effects of noise on humans have been published in the past 30 years but the results of these studies have been quite variable, some very controversial and often produce conflicting results. This is largely due to variations in methodologies on how to identify and measure the noise exposure. It is not known if the health effects are related to single dose, long term average, number of events above a certain level, or another way of quantifying noise exposure. A lack of uniform methodology makes it difficult to compare the results of many of these studies. Further, cumulative noise exposures for a population are difficult to discern as people are exposed to various noise environments at home, work and elsewhere. Typically, studies only evaluate residential noise exposures, which can be quite variable depending on the person's habits. Residential noise exposures are affected by how much time a person spends outdoors vs. indoors, whether windows open or closed, and even which rooms in their home they spend time and sleep. Noise levels in a room facing a noise source such as a roadway can be much greater than in a room on the opposite side of the home. Additionally, it is difficult to separate other confounding effects such as exposure to air pollution levels, lifestyles, life stressors, hereditary factors, and genetic composition from the effects of noise. While there is considerable evidence that noise can have adverse health effects on humans our understanding of the specific effects or mechanisms of how this occurs is currently insufficient to make predictions of adverse health effects based on noise exposure.

### 2.2.2 Sleep Disturbance – You Don't Have to Wake Up To Be Impacted

Most of the research on sleep disturbance due to noise is related to conscious awakenings from aircraft noise events. These studies have shown that an aircraft noise event with an indoor single event noise level of 80 dBA, maximum level of approximately 70 dBA, will result in a conscious awakening in approximately 10% of persons at most, and about 3% of persons on average. An aircraft flyover with a single event noise level of 105 dBA, Lmax of approximately 95 dBA, awoke approximately 20% of persons at most and approximately 9% of persons on average. However, these rates may not be applicable over large populations. It is not clear that all events with the

same noise level have the same probability of awakening a person. It is known that the recent sleep history, the amount of time a person has been asleep and how tired they were when they fell asleep, influences how susceptible a person is to awakenings from noise.

Habituation has been shown to be an important consideration in sleep disturbance. Much of the early research was conducted on subjects in laboratory conditions. When large field studies of awakenings in people's homes were compared to the laboratory experiments the rates of awakening were much lower for persons sleeping in their own homes. Some have suggested that awakenings are more related to unexpected sounds as the mind does not feel it necessary to awake for a common sound it has "heard" before. It is important to note that 80% to 90% of consciously recognized sleep disturbances in noisy environments are caused by something other than an outdoor noise source.

Most importantly, recent research has suggested that noise events that do not cause a conscious awakening can result in adverse impacts. Disturbance from noise events occurs in three successive stages. The initial response to a noise event during sleep is an increase in heart rate and blood pressure. A more substantial noise event will cause this initial response along with changes to sleep stage, going from a deeper sleep to a lighter sleep. The most substantial events result in the initial response and a conscious awakening, the most significant sleep stage change. It is theorized that even the initial response can contribute to the physiological effects discussed previously.

### **2.2.3 Communication Interference**

Aural speech communication interference is another adverse effect of noise. Speech intelligibility is highly dependent on the level of the signal relative to the level of noise (signal to noise ratio) but the frequency spectrum of the noise is also important. In high noise situations our brain automatically modifies our behavior to overcome the effects of noise on speech communication. This is referred to as the Lombard Effect. Not only do we automatically speak louder, but the pitch, rate, and durations of syllable sounds are also automatically modified to make them more intelligible. Our facial movements are also exaggerated in high noise conditions. While less important than the speech sound itself our brains also use visual cues from the speaker's facial movements in understanding speech. Speech recorded in a high noise environment is easier to understand when played back in a noisy environment compared to speech recorded in a quiet environment played back under the same conditions. Screaming reduces speech intelligibility because increased vocal energy produces decreased phonetic information used for understanding.

### **2.2.4 Annoyance**

There are strong indications that annoyance is only a part of the adverse effects of community noise but our understanding of these effects is incomplete at this time. Advances in neuroscience and further research into the effects of noise will surely increase our understanding and ability to predict the adverse health effects from noise in the future. It is possible that annoyance also contributes to and confounds the other health effects from noise. However, as discussed below, noise annoyance is quite complicated. Recent research has demonstrated annoyance rates appear to vary by community and it has been long understood that a person's attitude towards the source of noise will affect their level of annoyance and factors beyond noise level (i.e., non-acoustic factors) contribute to annoyance. Humans are cognitively biased to be more likely to be annoyed by someone or something that they don't like than someone they are favorable towards.

To some extent, annoyance is a cognitively chosen reaction to noise, but the primary annoyance reaction is likely due to the autonomic nervous system's (involuntary nervous system) response to noise that we can not cognitively control. However, our cognitive attitudes towards the noise source likely filter the annoyance inputs from the autonomic nervous system to determine our perceived annoyance, which is what has been measured in most noise effects studies. We have just begun to

understand how our bodies react to noise with or without annoyance and investigate the impacts of these responses.

From an evolutionary point of view it makes sense that not all sounds are cognitively processed, as hearing is our primary threat detector during sleep and an important threat detector when we are awake. Our mind perceives loud noise events as a potential threat and immediately begins preparing to respond the threat increasing blood pressure and heart rate likely through automatic instantaneous release of stress hormones. If we are asleep, the mind must decide if the noise represents enough of a probability of a threat to require a cognitive response (i.e., a change in sleep state or an awakening). As discussed above, adequate sleep is very important to human health and so the mind must balance the potential threat with the adverse effects of losing sleep to respond to a noise that is not a threat. The body does not stop preparing to respond to the threat until it has determined that the noise is not an actual threat. It is this threat response preparation that is most likely a primary contributor of the adverse health effects of noise.

When we are awake, the mind must decide if the potential threat from the noise is real enough to divert our attention from the task at hand to cognitively assess the threat of the noise. At the same time it prepares to respond to the threat with the release of stress hormones and increased heart rate and blood pressure. If the mind decides that the threat needs to be cognitively addressed and we are distracted from what we are doing to assess the threat we are likely annoyed by this distraction and our autonomic system responds to this annoyance as a stressor just like its initial reaction to the noise.

In environments with considerable levels of continuous noise, such as along a highway, our noise threat detection capabilities are likely reduced due to a lower signal (the potentially threatening noise event) to noise (the continuous noise source) ratio than in areas with low background noise levels. This results in an increased workload for the threat detection system and can delay or confuse the decision of whether the noise represents a real threat resulting in increased stress on the body. The increased difficulty in speech communication may also increase stress.

### **2.2.5 Impact on Children**

The primary impact of noise on children at school is communication interference and distraction. Effective speech communication is critical for the educational process. Further, as the students are learning new things, hearing new ideas and words, the comprehension portion of speech communication performed by them is more difficult and more likely to be impacted by high background noise levels and noise events that cause distractions. As discussed previously, we unconsciously speak louder as background noise levels increase. Other conversations in the room represent additional noise and cause one to speak louder. However, that increases the noise level at the other conversations creating a positive feedback loop and raising the overall noise level in the room. While background noise influences this, a stronger influence on this feedback loop is the amount of acoustical absorption in the room.

Noise from outdoor sources is only one acoustical property of many that affect classroom learning. HVAC systems and other equipment can also generate noise that affects children in the same way as outdoor noise. Further, the amount and placement of acoustically absorptive and reflective surfaces can enhance or diminish the acoustical performance of the classroom. Communication intelligibility is increased by a voice reflecting off nearby acoustically reflecting surfaces and reaching the ear shortly after (5 to 30 milliseconds) the sound directly from the person's mouth. This effectively increases the level of the sound reaching the ear. However, too many acoustically reflective surfaces in a room increase the amount of reverberation (i.e., sound bouncing around the room), which decreases intelligibility. The reverberation effectively increases the background noise level. The complete acoustical performance of a classroom, not just noise level from outdoor

sources, is involved in creating an effective learning environment. This concept is expanded in Section 3.1.2, which discusses the Acoustical Society of America's Classroom Acoustics standard.

### **2.2.6 Extreme Quiet or Where Did I Put My iPod?**

It should also be noted that too little noise is also undesirable. The anechoic chamber at Orfield Laboratories in South Minneapolis holds the Guinness World Record for the world's quietest place. The chamber absorbs 99.99% of the sound. Currently, the record for a person to remain in the chamber alone is 45 minutes. Apparently, the experience of only hearing the sounds your body is making can be quite disconcerting and induce hallucinations. This low level of noise would never be experienced in the natural environment but this effect points to the fact that our aural perception is disturbed by sound levels at both extremes.

### **2.2.7 For More Information**

More detailed and technical discussions of the adverse affects of noise on humans is presented in Appendix A of this report.

### 3.0 A REVIEW OF NOISE IMPACT CRITERIA

The following sections provide summaries of noise impact criteria used by and recommended by various agencies. We start with the World Health Organization's (WHO) *Guidelines For Community Noise* that presents recommended noise levels for various environments that represent the onset of health effects from noise exposure developed by an international expert task force. The City of Los Angeles noise criteria is presented in Section 3.1.1. Finally, the Acoustical Society of America's (ASA) American National Standard Institute (ANSI) standard for classroom acoustics is presented. This document gives recommendations for the acoustical qualities of a classroom to provide optimal acoustics for the learning environment.

Additional criteria were also considered and are included in Appendix B. We have presented the criteria that has most influenced our recommendations in the main body of the report. Additional standards that are presented in the appendix represent the policies of the following agencies:

- State of California
- Federal Highway Administration
- Federal Aviation Administration
- Department of Housing and Urban Development
- Federal Transit Authority
- U.S. Environmental Protection Agency

#### 3.1 WHO Guidelines

In 1992 the WHO Regional Office for Europe convened a task force to develop guidelines for community noise. A preliminary guidance document was published by the Karolinska Institute, Stockholm on behalf of WHO in 1995. This document served as a basis for the globally applicable *Guidelines For Community Noise* (World Health Organization, 1999), which was finalized by the expert task force in a March 1999 meeting in London, United Kingdom.

This document provides a good background discussion of the noise sources, their measurement and noise propagation and transmission. Adverse health effects from noise, as they were understood in 1999, are discussed in detail. The document recommends guideline noise levels for specific noise environments. The document states that these noise levels represent the onset of health effects from noise exposure. The expert group preferred the development of exposure-response relationships to indicate the expected effects of noise levels above the guideline values. However, the group concluded that the scientific literature was not sufficient to establish such relationships.

It should be noted that the WHO uses a different definition for health than is typically applied to environmental standards in the United States. The WHO defines health as "A state of complete physical, mental and social well-being not nearly the absence of disease or infirmity" whereas planning standards developed for use in the United States uses the absence of disease as the definition of health. Further, the standards based on speech intelligibility were based on an average conversation sound level of 45 dBA to 50 dBA. However, the EPA Levels document cites a study showing the average conversation level to be approximately 55 dBA and other sources assume 60 dBA or even 65 dBA.

Table 1 presents Guideline Noise Levels recommended in the WHO document for various environments. The guidelines are in terms of the energy average (Leq) noise level during the daytime and evening, Leq(16hr), during the nighttime, Leq(8hr) as well as other time periods applicable to the environment. The guidelines also specify Lmax noise levels for specific

environments. It should be noted that the WHO guidelines recommend the use of the “fast” meter response. Typically in the United States a “slow” meter response is used. The meter response determines how quickly the sound level meter responds to quickly changing sound levels. In the “slow” mode the meter will take approximately one second to read the noise level of a constant noise source just after it is switched on. In the “fast” mode it takes about three tenths of a second.

The guidelines note that because different critical health effects are related to different noise characteristics (e.g., long term average vs. instantaneous event maximum level) it is not enough to characterize the noise environment only in terms of noise metrics based only on energy summation (i.e., Leq). It recommends that maximum noise levels and the number of noise events be characterized separately along with nighttime noise levels.

### **3.1.1 City of Los Angeles**

The following sections provide a summary of the noise criteria used by the City of Los Angeles. Section 3.1.1.1 presents the land use noise compatibility guidelines adopted in the City’s General Plan that is nearly identical to those recommended by the state. Section 3.1.1.2 presents the City’s residential interior noise standard from its building code that mirrors the state’s code. Section 3.1.1.3 presents the City’s Noise Ordinance. Instead of adopting general noise standards applicable all noise sources, the City has opted to establish noise level standards for various equipment and activities. The City’s general noise standard is what is often referred to as a nuisance standard in that it prohibits noise that “causes discomfort or annoyance to any reasonable person of normal sensitiveness.” This type of standard is difficult to enforce because the courts are reluctant to establish ad hoc criteria for this determination.

#### **3.1.1.1 General Plan Noise Element**

The Noise Element of the City of Los Angeles General Plan was adopted in 1999 (City of Los Angeles, 1999). The Noise Element identifies land uses that are deemed “noise sensitive” uses: single-family and multi-unit dwellings, long-term care facilities (including convalescent and retirement facilities), dormitories, motels, hotels, transient lodgings and other residential uses; houses of worship; hospitals; libraries; schools; auditoriums; concert halls; outdoor theaters; nature and wildlife preserves, and parks. Table 2 presents The City’s adopted Noise Compatibility Guidelines. These guidelines are based on the Noise Compatibility Guidelines presented in Governor’s Office of Planning and Research “General Plan Guidelines” presented in Figure 10 in Appendix B. The guidelines categorize noise levels in four categories of acceptability for various land uses. A description of each of the four acceptability categories is presented at the bottom of the table. For land uses where the primary activities are indoors (residences, schools, libraries, churches, hospitals, motel/hotels, office buildings) are based on buildings being able to provide adequate outdoor-to-indoor sound isolation for acceptable interior noise levels.

#### **3.1.1.2 City of Los Angeles Municipal Code**

Chapter IX – Building Regulations, Article 1 – Buildings, Section 91.1207 – Sound Transmission Control of the City of Los Angeles Municipal Code requires new hotels, motels, dormitories, residential care facilities, apartment houses, dwellings, private schools, and places of worship to achieve an interior noise level of 45 dBA CNEL consistent with the State’s building code discussed in Section B.2.3. Acoustical reports demonstrating compliance with this standard are required for any new or substantially modified building that is exposed to noise levels exceeding 60 dBA CNEL prior to issuance of building permits.

**Table 1**  
**WHO Guideline Noise Levels For Community Noise In Specific Environments**

Specific Environment	Critical Health Effects	Guideline(s)
<b>Residential</b>		
Outdoor Living Areas	Serious Annoyance, Daytime And Evening	55 dBA Leq(16hr)
	Moderate Annoyance, Daytime And Evening	50 dBA Leq(16hr)
Dwelling, Indoors	Speech Intelligibility & Moderate Annoyance Daytime And Evening	35 dBA Leq(16hr)
Dwelling, Bedroom	Sleep Disturbance, Night-Time	30 dBA Leq(8hr)
		45 dBA Lmax(fast)
Outside Bedroom	Sleep Disturbance, Window Open (Outdoor Values)	45 dBA Leq(8hr) 60 dBA Lmax(fast)
<b>School</b>		
Classroom Indoors	Speech Intelligibility, Disturbance of Information Extraction, Message Communication	35 dBA Leq(During Class)
Pre-School Sleeping Rooms	Sleep Disturbance	30 dBA Leq(Sleep Time) 45 dBA Lmax(fast)
Playgrounds	Annoyance (External Source)	35 dBA Leq(During Play)
<b>Hospitals</b>		
Ward Room, Indoors	Sleep Disturbance Night-Time	30 dBA Leq(8hr) 45 dBA Lmax(fast)
	Sleep Disturbance, Daytime and Evenings	30 dBA Leq(16hr)
Treatment Room, Indoors	Interference with Rest and Recovery	As Low As Possible
<b>Industrial, Commercial, Shopping &amp; Traffic Areas</b>		
Indoors & Outdoors	Hearing Impairment	70 dBA Leq(24hr) 110 dBA Lmax(fast)
<b>Ceremonies, Festivals and Entertainment Events</b>		
Indoors & Outdoors	Hearing Impairment (patrons < 5 times/year)	100 dBA Leq(4hr) 110 dBA Lmax(fast)
<b>Public Addresses</b>		
Indoors & Outdoors	Hearing Impairment	85 dBA Leq(1hr) 110 dBA Lmax(fast)
<b>Music &amp; Other Sounds Through Headphones/Earphones</b>		
Indoors & Outdoors	Hearing Impairment (Free Field Vale)	85 dBA Leq(1hr) <sup>1</sup> 110 dBA Lmax(fast)
<b>Impulse Sounds From Toys, Fireworks, and Firearms</b>		
Indoors & Outdoors	Hearing Impairment (Adults)	140 dBA Peak SPL <sup>2</sup>
	Hearing Impairment (Children)	120 dBA Peak SPL <sup>2</sup>
<b>Parkland &amp; Conservation Areas</b>		
Outdoors	Disruption of Tranquility	See Note 3

1. Under headphones adapted to free-field values

2. Peak Sound Pressure measured 100 mm from the ear.

3. Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low

**Table 2**  
**City of Los Angeles Land Use Noise Compatibility Guidelines**

Land Use	Community Noise Exposure, CNEL, dBA			
	Normally Acceptable	Conditionally Acceptable	Normally Unacceptable	Clearly Unacceptable
Single Family, Duplex, Mobile Homes	50-60	55-70	70-75	Above 70
Multi-Family Homes	50-65	60-70	70-75	Above 70
Schools, Libraries, Churches, Hospitals, Nursing Homes	50-70	60-70	70-80	Above 80
Transient Lodging-Motels, Hotels	50-65	60-70	70-80	Above 80
Auditoriums, Concert Halls, Amphitheatres	--	50-70	--	Above 65
Sports Arena, Outdoor Spectator Sports	--	50-75	--	Above 70
Playgrounds, Neighborhood Parks	50-70	--	67-75	Above 72
Golf Courses Riding Stables, Water, Recreation, Cemeteries	50-75	--	70-80	Above 80
Office Buildings, Business and Professional Commercial	50-70	67-77	Above 75	--
Industrial Manufacturing, Utilities, Agriculture	50-75	70-80	Above 75	--

**Normally Acceptable:** Specified land use is satisfactory, based upon the assumption that any buildings involved are of normal conventional construction without any special noise insulation requirements.

**Conditionally Acceptable:** New construction or development should be undertaken only after a detailed analysis of the noise reduction requirements is made and needed noise insulation features included in the design. Conventional construction, but with closed windows and fresh air supply systems or air conditioning will normally suffice.

**Normally Unacceptable:** New construction or development should generally be discouraged. If new construction or development does proceed, a detailed analysis of the noise reduction requirements must be made and needed noise insulation features included in the design.

**Clearly Unacceptable:** New construction or development should generally not be undertaken.

### 3.1.1.3 City of Los Angeles Noise Ordinance

The Los Angeles Municipal Code (Chapter XI-Noise Regulation) establishes the City's noise standards for various noise sources generated on private property affecting neighboring properties. Article 1, General Provisions, provides definitions of various acoustical terms and procedures and criteria for sound level measurement. Penalties to be applied to measurements of noise sources with specific characteristics are specified. Measurements of tonal and repeated impulsive noises are increased by 5 dB. Measurements of noise occurring less than 15 minutes per hour during the daytime are reduced by 5 dB.

This article also defines “presumed ambient noise levels” which are presented in Table 3. The specific noise standards in presented in later sections are based on the ambient noise level. The code instructs that if the measured ambient level is less than the presumed ambient noise level presented in Table 3, the presumed ambient noise level shall be used as the ambient noise levels

**Table 3**  
**Noise Ordinance Presumed Ambient Noise Level**

<b>Zone</b>	<b>Daytime (7 am to 10 pm)</b>	<b>Nighttime (10 pm to 7 am)</b>
A1, A2, RA, RE, RS, RD, RW1, RW2, R1, R2, R3, R4, and R5 (Residential)	50 dBA	40 dBA
P, PB, CR, C1, C1.5, C2, C4, C5, and CM (Commercial)	60 dBA	55 dBA
M1, MR1, and MR2 (Light Manufacturing)	60 dBA	55 dBA
M2 and M3 (Manufacturing)	65 dBA	65 dBA

Article 2, Special Noise Sources, regulate specific noise sources; including radios, televisions, and similar devices (Section 112.01), air conditioning refrigeration, heating, pumping, and filtering equipment (Section 112.02) construction noise (Section 112.03), power equipment intended for repetitive use in residential areas and other machinery, equipment and devices (Section 112.04), maximum noise levels from powered equipment or hand tools (Section 112.05), and places of public entertainment (Section 112.06).

The first section of Article 2 restricts noise generated by radios, televisions and the like to not exceed the ambient noise level plus 5 dB. The section makes it unlawful to operate these devices “in such a manner, as to disturb the peace, quiet, and comfort of neighbor occupants or any reasonable person residing or working in the area or is audible more than 150 feet from the property line. The second section restricts noise generated by HVAC equipment, pumps and filters to not exceed the ambient noise level plus 5 dB.

The third section of Article 2 requires compliance with Section 41.40 of the Municipal Code titled, “Noise Due To Construction, Excavation Work – When Prohibited”. Section 41.40 prohibits any construction, building repair work, excavation, delivery of construction materials, or servicing of construction equipment that entails the use of a loud machine, tool or device between the hours of 9:00 A.M. and 7:00 A.M. Additionally, construction within 500 feet of a residential area is prohibited to the hours of 8:00 a.m. and 6:00 p.m. on any Saturday or national holiday. Individual homeowners working on their single-family homes are exempted from this restriction.

Emergency construction and construction within districts zoned for manufacturing and industrial uses are exempted from the construction hour restrictions as are several specific construction projects. Variances may be issued for work done in the public interest or where hardship, injustice, or unreasonable delay would occur because of the restrictions.

The fourth section of Article 2 prohibits the use of any “lawn mower, backpack blower, lawn edger, riding tractor, or any other machinery, equipment, or other mechanical or electrical device, or any hand tool which creates a loud, raucous or impulsive sound” within 500 feet of a residence between the hours of 10:00 p.m. and 7:00 a.m. The section also prohibits equipment noise from generating

a noise level that exceeds the ambient noise level plus 5 dB. The use of gas powered blowers is prohibited within 500 feet of a residence.

The fifth section limits the maximum noise levels from specific pieces of equipment as shown in Table 4. The code specifies that the maximum noise levels presented in Table 4 are superseded and replaced by any final noise regulations adopted by the EPA.

**Table 4**  
**Powered Equipment and Hand Tools Maximum Noise Levels**

Equipment	Maximum Noise Level
Construction, Industrial, and Agricultural Machinery Including Crawler-Tractors, Dozers, Rotary Drills and Augers, Loaders, Power Shovels, Cranes, Derricks, Motor Graders, Paving Machines, Off-Highway Trucks, Ditchers, Trenchers, Compactors, Scrapers, Wagons, Pavement Breakers, Compressors And Pneumatic or Other Powered Equipment;	75 dBA
Powered Equipment of 20 HP or Less Intended For Infrequent Use In Residential Areas, Including Chain Saws, Log Chippers And Powered Hand Tools	70 dBA
Powered Equipment Intended for Repetitive Use In Residential Areas, Including Lawn Mowers, Backpack Blowers, Small Lawn And Garden Tools And Riding Tractors	65 dBA

The sixth section of article 2 prohibits the operation of equipment which result in the sound level in any place of public performance to exceed 95 dBA unless a conspicuous and legible sign stating, “WARNING: SOUND LEVELS WITHIN MAY CAUSE HEARING IMPAIRMENT” is located outside the place near each public entrance.

Article 3 prohibits the use of any refuse disposal truck, parking lot sweeper, or vacuum truck from operating within 200 feet of a residential building between 9:00 P.M. and 6:00 a.m.

Article 4 regulates noise associated with the repair and operation of vehicles as well as vehicle loading and unloading. Vehicle repair in or within 500 feet of any residential zone between the hours of 8:00 P.M. and 8:00 A.M. if it causes discomfort or annoyance to a reasonable person, is audible to the human ear at a distance of 150 feet or more from the property line, or generates a noise level exceeding the ambient noise level plus 5 dB. Unreasonable operation of any motor vehicle, including unreasonable acceleration of the engine, or operation of the horn or other device is also prohibited if it causes discomfort or annoyance to a reasonable person, is audible to the human ear at a distance of 150 feet or more from the property line, or generates a noise level exceeding the ambient noise level plus 5 dB.

The use of any audible signaling devices that can be heard for a distance greater than 200 feet is prohibited in or within 500 feet of residential zones. The use of any audible signaling device by a catering truck within 200 feet of a residential building is prohibited between the hours of 9:00 P.M. and 7:00 A.M. Vehicle theft systems must not use any audible status indicators and alarm activations must be automatically and completely silenced within 5 minutes.

Loading or unloading of vehicles including the operation of dollies, carts, forklifts or other wheeled equipment, which causes any impulsive sound, raucous or unnecessary noise within 200 feet of any residential building is also prohibited.

Article 5 prohibits the use of loudspeakers or sound amplifying equipment in public areas. Such equipment is prohibited at all times in and within 500 feet of residential zones or 200 feet from hospitals/ schools or churches. In all other zones the operation is prohibited between 9:00 P.M. and 8:00 A.M. When operation is not prohibited the amplified sound is limited to speech, music or the combination and shall not be audible at a distance exceeding 200 feet from the equipment and cannot be loud and raucous or unreasonably jarring, disturbing, annoying, or a nuisance to reasonable persons of normal sensitiveness.

Article 6 regulates general noise sources not addressed elsewhere in the code. This article specifies that it is unlawful “to willfully make or continue, or cause to be made or continued, any loud, unnecessary, and unusual noise which disturbs the peace or quiet of any neighborhood or which causes discomfort or annoyance to any reasonable person of normal sensitiveness residing in the area.” A list of characteristics of the noise that may be considered in this determination is provided but no specific criteria are established.

This section and similar noise ordinances are referred to as a “nuisance ordinance” in that it does not contain any specific noise limits that cannot be exceeded. In general, these types of ordinances are difficult to enforce because they do not define specific limits when the noise should be considered a nuisance and courts are reluctant to establish ad hoc criteria for this determination.

### **3.1.2 Acoustical Society of America Classroom Acoustic Recommendations**

Recognizing the importance of classroom acoustics in providing an effective learning environment the Acoustical Society of America developed recommendations for acoustical performance criteria for classrooms and had it adopted and published as an American National Standards Institute (ANSI) standard (Accredited Standards Committee, S12, Noise, 2010). In addition to the performance criteria, the document also includes guidance on achieving the standards along with commentary that provides additional information for non-experts.

The standard addresses interior classroom noise levels in three ways; a maximum noise level recommendation for exterior noise sources, a maximum noise level recommendation from interior noise sources (e.g. HVAC equipment), and building structure sound attenuation requirements. Interior noise levels from outdoor sources are not to exceed a  $Leq(H)$  of 35 dBA and 55 dBC for core learning spaces with enclosed volumes of less than 20,000  $ft^3$  and 40 dBA, 60 dBC for core learning spaces with greater enclosed volumes and all ancillary learning spaces. Core learning spaces are those where the primary functions are teaching and learning and include classrooms, instructional pods or activity areas, group instruction rooms, libraries, offices used for educational purposes, therapy rooms, and music rooms for instruction and practice. Ancillary learning spaces are those where the primary educational functions are informal learning, social interaction, or similar activity other than formal instruction.

As discussed previously in Section 2.1, the “A” and “C” indicate the frequency weighting used to determine the overall noise level. A-weighting is representative of human hearing in typical environments while C-weighting is more representative of human hearing at high noise levels. The purpose for its use in the standard is that C-weighting does not attenuate low frequencies like A-weighting. By specifying the 55 dBC limit, the standard ensures that a noise environment meeting the 35 dBA standard does not have excessive low frequency content that can be found annoying. While excessive low frequency content can be an issue with outdoor noise it is more likely to be caused by the HVAC system.

The standard applies the same two noise level limits, 35 dBA and 55 dBC Leq(H), to noise from interior sources including the HVAC system and lighting that are not directly controllable from the classroom. Classroom noise sources such as computers, audiovisual equipment, or exhaust fans, that can be controlled from within the classroom are not subject to this limit.

The standard provides minimum Outdoor-Indoor Sound Transmission Class (OITC) requirements for external walls and roofs based on the outdoor noise level and the proximity of playgrounds and exterior walkways. In addition, minimum Sound Transmission Class (STC) ratings are specified for interior partitions depending on the adjacent use. For multi-story schools, a minimum Impact Insulation Class (IIC) is specified for the floor/ceiling assemblies above learning spaces. OITC, STC, and IIC are standard methodologies for rating the sound transmission qualities of composite building elements with OITC for outdoor to indoor sound transmission, STC for sound transmission between interior rooms, and IIC for transmission of structure borne sound (i.e. footfalls) between levels.

The standard includes recommendations for maximum reverberation time. Reverberation is a measure of the time it takes the sound level to decay after sound stops being generated. Large rooms with acoustically hard, reflective, surfaces, such as a cathedral or empty warehouse or large public restroom, have high reverberation times as the sound bounces around the room off the hard surfaces that do not dissipate much energy. Acoustically absorptive surfaces absorb more energy from the sound that reflects from it resulting in a more rapid decay of the sound. In terms of speech intelligibility, high reverberation has the same effect as added noise and reduces understanding. However, this does not mean that acoustically reflective surfaces are undesirable. Acoustic reflections that arrive at the listener's ears within about 50 milliseconds of the direct sound increase intelligibility.

The maximum reverberation time specified for core learning spaces with an enclosed volume of less than 10,000 ft<sup>3</sup> is 0.6 seconds. However, the standard specifies that the design must include measures to lower the reverberation time to 0.3 seconds. The maximum recommended reverberation time for core learning spaces with an enclosed volume between 10,000 ft<sup>3</sup> and 20,000 ft<sup>3</sup> is 0.7 seconds. The standard includes an entire Annex that provides design guidelines for controlling reverberation.

## 4.0 ELIGIBILITY CRITERIA & PRIORITIZATION RECOMMENDATION

The HCBF was formed to address the negative cumulative environmental and public health impacts of the Port of Los Angeles' and port-related business operations on its neighbors. It is clear that excessive community noise degrades the environment resulting in speech interference, sleep disturbance and annoyance, which can impact a person's sense of well-being and productivity. The link between community noise and public health impacts is just now becoming more recognized.

Recent research suggests that community noise exposure is correlated with ischemic heart disease, hypertension and possibly diabetes but this correlation is not strong and the mechanism of how noise contributes to these diseases is not understood. As discussed in Section 0, our understanding of the dose-response relationship (i.e., the relationship between noise exposure level and its effect on persons) of the negative environmental impacts of community noise (annoyance, sleep disturbance, speech interference) is incomplete. In fact, it is not clear what quality or measure of community noise is best correlated with human response.

One potential explanation is that the environmental impacts of community noise (e.g., speech interference, sleep disturbance and annoyance) contribute to general stress, which is a known risk factor for these diseases. This suggests that the adverse health impacts from community noise exposure may be a secondary effect of the noise exposure. That is, the health impact arises from our response to community noise, both conscious and unconscious, and it is the mechanics of that response that contribute to disease rather than the disease being a direct result of the noise exposure as in hearing loss. This only increases the complexity in relating noise exposures to health impacts. Additional research is needed for a more complete understanding of the relationship between community noise exposures and adverse health impacts.

As discussed in Section 3.0, the noise criteria established in the United States are primarily based on annoyance, as that has been the most recognized and studied impact of community noise. However, even the typical 65 LDN outdoor noise standard would result in 10% to 13% of the population being highly annoyed. The World Health Organization guidelines are based on our best understanding of the spectrum of impacts of noise but the recommended noise levels represent a conservative estimate of the lowest noise level at which noise begins to adversely impact humans. The WHO outdoor residential guidelines are equivalent to a 55 LDN exposure for high annoyance and 52 LDN for moderate annoyance. The indoor guideline is equivalent to 37 LDN which is 8 dB less than the 45 LDN standard typically specified in America as an acceptable indoor noise level.

### 4.1.1 Indoor Noise Levels from Outdoor Sources

Older home construction of the type common in Wilmington typically achieves an outdoor-to-indoor noise reduction of at least 20 dB with windows closed. More modern construction that complies with energy efficiency standards typically achieves a reduction of approximately 23 dB. With open windows the noise reduction drops to about 12 dB. In order for windows to be able to remain closed, adequate ventilation is required per the Uniform Building Code. With acoustically upgraded windows, doors, and insulation, the noise reduction for older homes can typically be improved to approximately 28 dB or higher. By modifying the walls and roof of the structure (e.g.; adding a layer of gypsum board to the interior walls) the noise reduction can often be increased to 33 dB, but is often very expensive.

The largest reductions in interior noise levels (8 dB) resulting from upgrading a single building element are by providing mechanical ventilation to allow windows to remain closed, and upgrading older homes' windows. Note, that per the Uniform Building Code, mechanical ventilation can be provided by fans introducing the required amount of fresh air and air conditioning is not required. Ventilation alone would likely allow residents to comfortably keep their windows closed most of the year in Wilmington. Air conditioning is also an option, however, operating air conditioning can be prohibitively expensive for low-income households. In either case, it is also important to recognize

that the ventilation system can generate undesirable noise levels if the acoustics of the system are not considered during design.

Upgrading windows, doors and insulation provides approximately 16 dB additional noise reduction compared to open windows. A 5 dB reduction is considered the lowest that is readily perceptible in community noise situations and a 10 dB reduction is perceived as a halving of the sound level. The value of providing upgrades that achieve less than 5 dB of additional reduction is questionable.

Table 5 presents the maximum outdoor levels for the interior levels to not exceed the WHO Guideline Levels for the six levels of building noise reduction discussed above. Note that the noise levels are based on standard estimates of noise reduction and actual results will vary depending on the specific construction of the structure. This table shows that a daytime outdoor noise level must be 47 dBA (Leq) or less and the nighttime noise level must be 42 dBA (Leq) or less to meet the guidelines with windows open. Most residential areas in Wilmington do not experience noise levels as low as these.

The lowest measured Leq(H) levels during the measurement survey performed for this project were 55 dBA during the day at Site 18 (Hawaiian Avenue School) and 51 dBA during the night at Site 1 (Sandford at Sandison). Closed windows would be required to meet the WHO daytime Leq(H) indoor guideline and older homes may need upgraded windows to meet the nighttime WHO Leq(H) guideline. The highest measured Leq(H) levels were 71 dBA during the day measured at Site 11 (Avalon Road South) and 69 dBA during the night measured at Site 25 (Sandford Avenue). Table 5 shows that the maximum upgrade would result in an interior noise level exceeding the WHO Leq(H) guidelines.

In conclusion, most homes and schools in the Wilmington area do not meet the WHO indoor noise guidelines during either the day or nighttime unless their windows are closed. Even with windows closed, many homes do not meet the WHO guidelines of 35 dBA during the day and 30 dBA (Leq) during the night and would require building upgrades to meet these standards.

**Table 5**  
**Maximum Outdoor Noise Levels to Achieve WHO Interior Guideline Levels**

Building Noise Reduction	Interior Noise Level Guideline		
	Daytime Leq(H) (35 dBA)	Nighttime Leq(H) (30 dBA)	Nighttime Lmax (45 dBA)
Windows Open (12 dB)	47 dBA	42 dBA	57 dBA
Older Construction <sup>†</sup> (20 dB)	55 dBA	50 dBA	65 dBA
Newer Construction <sup>†</sup> (23 dB)	58 dBA	53 dBA	68 dBA
Upgraded Windows, Doors, & Insulation <sup>†</sup> (28 dB)	63 dBA	58 dBA	73 dBA
Maximum Upgrade <sup>†</sup> (33 dB)	68 dBA	63 dBA	78 dBA

† With windows closed

#### 4.1.2 Noise Reduction Requirements in Wilmington

Table 6 presents the modeled worst case outdoor noise levels in the areas of greatest impact identified in Figure 10 of the Noise Monitoring Results Report (Report #1). The top row presents noise levels experienced at the face of the homes located directly along a residential street with regular container truck activity and first row homes along the train tracks. Comparing these levels with those presented in Table 5 shows that upgraded windows and doors plus modifications are required to meet the WHO interior Leq(H) guidelines for homes exposed to the lowest noise levels from container trucks operating on residential streets (near Site 22-Opp Street). However, even with the maximum upgrades, the Leq(H) guidelines would be exceeded along streets with higher levels truck activity (near Site 2-Drumm Avenue, and Site 25 Sandford Ave). Nighttime Lmax levels would exceed the guidelines at all of these sites regardless of the level of building upgrades.

Table 6 presents noise levels for residences along railroad tracks near at-grade crossings that are subject to warning horn noise and for those away from these crossings where train-warning horns are not normally sounded. At this time there are no residential areas in Wilmington that are exposed to train noise without warning horns. The without horn noise levels are provided to demonstrate the noise levels that would be experienced if quiet zones were established. Comparing these levels with those in Table 5 shows that the homes along rail lines near at grade crossings would exceed the all of WHO guidelines even with the maximum building noise reduction upgrade. Homes along rail lines not exposed to warning horns would require the maximum upgrade for interior noise levels to be less than daytime Leq(H) guideline. However, the nighttime Leq(H) guideline would be exceeded with the maximum upgrade at homes closest to the tracks. All homes along the tracks would exceed the nighttime Lmax guideline even with the maximum upgrade.

**Table 6**  
**Modeled Worst-Case Outdoor Building Face Noise Levels in Areas of Greatest Impact**

Noise Source	Daytime Leq(H)	Nighttime Leq(H)	Nighttime Lmax
Container Trucks on Residential Streets	65-73 dBA	60-72 dBA	82-83 dBA
Train with Horn	75-80 dBA	72-77 dBA	112-117 dBA
Train w/o Horn	66-71 dBA	63-68 dBA	84-89 dBA

### 4.1.3 Criteria and Prioritization Reasoning

The selection of eligibility criteria and prioritization for the sound attenuation program is primarily a resource allocation decision because, at least initially, there are not sufficient funds available to provide sound attenuation for all homes and schools impacted by port related noise. However, the HCBF funding is not fixed and will increase as the number of containers processed at the port is increased. Further, additional funding opportunities may be available, and are being investigated by HCBF staff, making the long-term funding of the insulation program variable rather than fixed.

One option would be to limit eligibility for participation in the sound insulation program based on minimum noise exposure levels. However, the eligibility criteria selected by the program will be construed as determining which homes and schools are deserving of additional sound attenuation. Selecting the eligibility criteria based on available funds will suggest that some homes that are adversely impacted by noise are not deserving of additional sound attenuation. Therefore, the eligibility criteria should include all of the schools and residences exposed to port related noise whose cumulative noise exposures result in an adverse impact.

This leaves the prioritization criteria as the mechanism for allocating the limited resources. The prioritization criteria should result in the homes and schools that satisfy the eligibility criteria and are most impacted by noise to be the first structures upgraded by the sound attenuation program. As more funding becomes available, those structures with lower levels of noise exposure would then be treated with the eventual goal of treating all homes and schools meeting the eligibility criteria.

If the eligibility criteria are based on the WHO Guidelines it makes sense that the prioritization should be based on the guidelines as well. However, the prioritization criteria needs to provide a way to easily compare the relative level of noise impacts and the WHO Guidelines are given in terms of multiple noise metrics. Therefore, we propose that the prioritization criteria be based on a scoring system that is based on the amount the noise exposure exceeds each of the indoor WHO Guidelines (daytime Leq(H) and nighttime indoor Leq(H) and Lmax) multiplied by weighting factors to account for differences in the relative impacts represented by each of these metrics. This leads to a single number Priority Score ( $P_{Score}$ ) with the homes receiving the highest priority score being considered the most impacted and first in line for the attenuation program. The proposed Eligibility Criteria and  $P_{Score}$  determination are discussed in the following two sections. The  $P_{Score}$  should be viewed as a screening level analysis to determine prioritization for consideration of noise abatement.

## 4.2 Proposed Eligibility Criteria

Any residence or school that is exposed to noise from activity that is related to the operation of the Port of Los Angeles that perceptibly affects the noise environment and whose interior noise levels exceed the WHO Interior Noise Level Guidelines presented in Table 7 is eligible to participate in the sound attenuation program. Implementation of sound abatement upgrades will be dependent on available funding with the priority scoring system described below determining the order in which structures will be considered for acoustical upgrades.

**Table 7**  
**Minimum Interior Noise Levels for Sound Attenuation Program Eligibility**

	Leq(H)		Lmax Nighttime
	Daytime	Nighttime	
Residences	35 dBA	30 dBA	45 dBA
School	35 dBA	--	--

It should be noted that program eligibility does not guarantee implementation of sound abatement. Under Task 6 of the project, implementation criteria will be developed to determine the conditions required for the implementation of sound abatement as well as the scope of sound abatement. These criteria will consider the cost of the attenuation compared to the noise reduction benefit provided, as well as permanence of the noise sources impacting the structure and expected duration of the benefit (i.e. if the permanence of the structure).

## 4.3 Proposed Prioritization Scoring

The  $P_{score}$  formula is presented in Table 8. It would be used to determine priority for consideration of sound abatement implementation for residences. Although the formula looks complicated the basis for the equation is straightforward. The score is based on the amount that outdoor noise levels exceed the WHO outdoor noise criteria for average daytime noise, average nighttime noise, and nighttime peak noise levels. The levels of exceedance are multiplied by a weighting factor to account for whether the noise occurs during the day or night. Nighttime is weighted more heavily since sleep disturbance is a major concern. These values are then added together to determine the  $P_{Score}$ . Homes with the highest  $P_{Score}$  (the result of the formula) will be considered for sound attenuation implementation prior to homes with lower scores.

Both the Criteria Noise Levels and the Weighting Factors are policy decisions. The use of the WHO Guidelines for outdoor residential noise levels as the Criteria Noise Levels seems like an obvious choice. These are the outdoor noise levels that result in indoor noise levels that meet the WHO indoor guidelines with windows open. The appropriate Weighting Factors are less obvious.

The three Weighting Factors represent the relative impacts of the exceedances of the three criteria noise metrics. Because the current research on the impacts of noise on humans is not clear and often contradictory, these factors are subjective decisions that intuitively take into account the consequence of the impacts associated with each metric (e.g., annoyance, sleep disturbance, or disease), the impact of those consequences and the confidence that noise exposures cause these consequences (i.e., certainty that the associations between noise exposure and impacts found by the research are not just data correlations but that there is an actual causal relationship.)

**Table 8**  
**P<sub>Score</sub> Calculation**

$$P_{Score} = F_{Leq\ Day} \times MIN[(Leq_{Day} - C_{Leq\ Day}), 0] + F_{Leq\ Night} \times MIN[(Leq_{Night} - C_{Leq\ Night}), 0] + F_{Lmax\ Night} \times MIN[(Lmax_{Night} - C_{Lmax\ Night}), 0]$$

Where:

P<sub>Score</sub> = Prioritization Score

F<sub>Leq Day</sub> = Daytime Leq Weighting Factor (1 is recommended)

F<sub>Leq Night</sub> = Nighttime Leq Weighting Factor (2 is recommended)

F<sub>Lmax Night</sub> = Nighttime Lmax Weighting Factor (5 is recommended)

Leq<sub>Day</sub> = Daytime Outdoor Peak Hour Leq(H)

Leq<sub>Night</sub> = Nighttime Outdoor Peak Hour Leq(H)

Lmax<sub>Night</sub> = Nighttime Outdoor Maximum Noise Level

C<sub>Leq Day</sub> = Daytime Leq(H) Criteria Noise Level (50 dBA)

C<sub>Leq Night</sub> = Nighttime Leq(H) Criteria Noise Level (45 dBA)

C<sub>Lmax Night</sub> = Nighttime Leq(H) Criteria Noise Level (60 dBA)

Both the Criteria Noise Levels and the Weighting Factors are policy decisions. The use of the WHO Guidelines for outdoor residential noise levels as the Criteria Noise Levels seems like an obvious choice. These are the outdoor noise levels that result in indoor noise levels that meet the WHO indoor guidelines with windows open. The appropriate Weighting Factors are less obvious.

The three Weighting Factors represent the relative impacts of the exceedances of the three criteria noise metrics. Because the current research on the impacts of noise on humans is not clear and often contradictory, these factors are subjective decisions that intuitively take into account the consequence of the impacts associated with each metric (e.g., annoyance, sleep disturbance, or disease), the impact of those consequences and the confidence that noise exposures cause these consequences (i.e., certainty that the associations between noise exposure and impacts found by the research are not just data correlations but that there is an actual causal relationship.)

The primary impacts from average daytime noise levels are annoyance and speech interference. Daytime Leq levels are correlated with cardiovascular system health impacts and may be associated with metabolic disease (diabetes). Nighttime average noise levels have been correlated with perceived sleep quality disturbance and nighttime maximum levels are correlated with awakenings and unconscious sleep disturbance. These metrics are also associated with annoyance.

It is well accepted that nighttime noise levels are more impactful than daytime noise levels. The LDN and CNEL metrics weight nighttime noise by a factor of 10. That is, one noise event during the nighttime is equivalent to ten of the same noise events during the daytime. While these metrics were developed primarily to represent annoyance many consider them adequate proxies for the full range of impacts from noise. Therefore, it seems appropriate to base the nighttime weightings on this factor so that the product of F<sub>Leq Night</sub>, F<sub>Lmax Night</sub> should be about 10 times greater than F<sub>Leq Day</sub>.

If one thinks that nighttime average and maximum noise levels have an equal impact than the nighttime Weighting Factors should be equal, or about 3.16. However, the research suggests that maximum nighttime noise events result in a greater impact than average nighttime noise levels. However, these impacts are based on not only the maximum noise level but also the number of noise events. While the WHO Guidelines suggest that the number of nighttime noise events should also be considered, this information is included in the Leq noise level. Our recommendation is that

the nighttime Lmax factor should be about twice the Leq factor. An analysis of the P<sub>Score</sub>s based on noise exposures in the areas of greatest impact showed that the ranking of the P<sub>Score</sub>s did not vary much with the nighttime Weighting Factors set equal ( $F_{Leq\ Night}=F_{Lmax\ Night}=3.16$ ) and the with nighttime Lmax Weighting Factor 2.5 times greater than the Leq Weighting Factor ( $F_{Leq\ Night}=2 F_{Lmax\ Night}=5$ ). Under this assumption, nighttime Leq levels are twice as impactful and nighttime Lmax levels are five times as impactful than daytime Leq levels.

Table 9 presents the preliminary P<sub>Score</sub> priority rankings using and  $F_{Leq\ Day}$  of 1,  $F_{Leq\ Night}$  of 2, and  $F_{Lmax\ Night}$  of 5. This table shows the daytime and nighttime Leq levels and nighttime Lmax level resulting P<sub>Score</sub> and priority rank for each of the areas of greatest impact identified in Report #1. Table 10 presents the same information except it is sorted by priority from highest to lowest. These tables shows that the first rows and second rows of homes along rail lines would have top priority with the homes along residential streets with container truck activities being prioritized next. The results of this ranking agree intuitively with the level of noise impacts experienced in the community.

The P<sub>Score</sub> method provides an easily comparable single number rating to estimate the relative impacts of different residential noise exposures. The recommended residential weighting factors based on our understanding of the relative difference of the impacts related to different noise metrics results in prioritization rankings that intuitively make sense. The residences that we feel are most impacted are ranked the highest and the least impacted are ranked least.

The methodology does not provide a straightforward way to prioritize schools relative to residences as the impacts of noise on children at school are quite different than residents and the importance of reducing these impacts subjective. This will ultimately be a decision for the HCBF Board. The highest Leq(H) level measured near a school was adjacent to Normont School (Site 15). The noise exposure at the school is 13 dB greater than the criteria level, however, the P<sub>Score</sub> for schools is lower because it is only in session during the day. One option for a school P<sub>Score</sub> that is comparable to the residential P<sub>Score</sub> is to use a weighting factor that is equal to the product of the residential weighting factors, 10. This would result in a P<sub>Score</sub> of 130, which would rank the school as 9<sup>th</sup> in priority, behind the first and second rows of homes along rail lines and the first row homes along Drumm Street and Sandford Street. This seems reasonable based on the level of noise exposures. However, it does not take into the account the difference in impacts that residents experience long term versus the impact to approximately seven classrooms of children during school hours. Our recommendation is to give schools priority over residential areas. This recommendation is based on several factors. At roughly 30 students per classroom, more students are impacted in a classroom than in a residence. Therefore mitigation of schools provides benefits to more people. Second, school children are the future of the community. Helping to insure that students can be easily heard by the teacher and that they can concentrate on their lessons will help them obtain a good education which is a long term benefit to the community. A finally, due to the uniformity of building construction from one classroom to another, it is more cost beneficial to upgrade schools than it is residences.

**Table 9**  
**Preliminary Residential P<sub>Score</sub> Priority Ranking By Impact Area**

Noise Source Site	Site Description	Leq		Lmax Night	P <sub>Score</sub>	Priority Rank
		Day	Night			
<b>Rail Lines</b>						
4	McFarland Rail Line	78	75	115	292	1
	2nd Row of Homes	63	60	100	185	4
	3rd Row of Homes	52	49	89	105	13
	4th Row of Homes	44	41	81	67	22
1	Alameda Blvd	74	71	108	253	3
	2nd Row of Homes	64	61	98	182	5
	3rd Row of Homes	57	54	91	126	9
	4th Row of Homes	50	47	84	80	17
16	Northern Rail Line	78	75	112	282	2
	2nd Row of Homes	62	59	96	162	7
	3rd Row of Homes	53	50	87	104	14
<b>Container Trucks on Residential Streets</b>						
2	Drumm Street	73	68	87	176	6
	2nd Row of Homes	60	55	82	105	12
25	Sanford Street	66	63	83	141	8
	2nd Row of Homes	53	50	78	73	20
22	Opp Street	62	56	82	111	10
	2nd Row of Homes	57	51	77	75	18
<b>TraPac Operations</b>						
6	C Street @ Hawaiian Ave. <sup>1</sup>	62	57	80	108	11
6	C Street @ Hawaiian Ave. <sup>2</sup>	62	57	67	67	21
7	C Street @Wilmington Ave	65	58	71	86	15
19	C Street @ Gulf Ave	62	54	72	73	19
9	C Street @ McDonald Ave	64	52	67	53	23
8	C Street @ Bay View Ave	58	53	77	82	16

1. With train horns from current at grade crossing at Figueroa Street.

2. Without train horns. I.e., with the current TraPac entrance relocation currently under design by the Port of LA.

**Table 10**  
**Preliminary Residential P<sub>Score</sub> Priority Ranking By Rank**

Near Site	Description	Row of Homes	Noise Source	Leq		Lmax Night	P <sub>Score</sub>	Priority
				Day	Night			
4	McFarland Rail Line	1st	Rail Line	78	75	115	292	1
16	Northern Rail Line	1st	Rail Line	78	75	112	282	2
1	Alameda Blvd	1st	Rail Line	74	71	108	253	3
4	McFarland Rail Line	2nd	Rail Line	63	60	100	185	4
1	Alameda Blvd	2nd	Rail Line	64	61	98	182	5
2	Drumm Street	1st	Trucks	73	68	87	176	6
16	Northern Rail Line	2nd	Rail Line	62	59	96	162	7
25	Sanford Street	1st	Trucks	66	63	83	141	8
1	Alameda Blvd	3rd	Rail Line	57	54	91	126	9
22	Opp Street	1st	Trucks	62	56	82	111	10
6	C Street @ Hawaiian Ave.	1st	TraPac	62	57	80	108	11
2	Drumm Street	2nd	Trucks	60	55	82	105	12
4	McFarland Rail Line	3rd	Rail Line	52	49	89	105	13
16	Northern Rail Line	3rd	Rail Line	53	50	87	104	14
7	C Street @Wilmington Ave	1st	TraPac	65	58	71	86	15
8	C Street @ Bay View Ave	1st	TraPac	58	53	77	82	16
1	Alameda Blvd	4th	Rail Line	50	47	84	80	17
22	Opp Street	2nd	Trucks	57	51	77	75	18
19	C Street @ Gulf Ave	1st	TraPac	62	54	72	73	19
25	2nd Row of Homes	2nd	Trucks	53	50	78	73	20
6	C Street @ Hawaiian Ave.	1st	TraPac	62	57	67	67	21
4	McFarland Rail Line	4th	Rail Line	44	41	81	67	22
9	C Street @ Mc Donald Ave	1st	TraPac	64	52	67	53	23

## 4.4 Additional Implementation Considerations

Noise generated by port related operations change over time. For example, prior to our measurements we observed an operating distribution/consolidation facility operating north of Pacific Coast Highway between Sanford Avenue and the Watson Rail Yard (near Measurement Site #1). However, when the measurements were performed the business previously operating at the facility had left and the building was vacant leaving its future use and relation to port activities in question. The Port of Los Angeles is in the process of implementing two grade separation projects for the rail crossings of Fries Avenue and Avalon Boulevard south of Harry Bridges Avenue, which will eliminate train horn soundings at these intersections. However, these crossings are located quite a distance from residences and the benefit to the community will be from reduced numbers of distant train horn soundings regularly heard through out the community.

The Port also has plans to relocate the entrance to the TraPac facility from its current location south of Harry Bridges Boulevard at the Figueroa Street intersection. This will eliminate the rail line crossing at the entrance and eliminate the requirement for trains to sound their horns as they approach this intersection. Several resident's living along the west end of C Street indicated that these horn blasts were their primary noise concern due to sleep disturbance. This impact will be removed with the implementation of this project.

The City of Los Angeles and The Port are also working together to upgrade the crossing guards where the McFarland rail line (i.e., the rail line that connects the southern part of the Wilson Rail Yard with the port along McFarland Avenue) crosses Anaheim Boulevard to standards that would allow it to be a part of a quiet zone. However, the establishment of a quiet zone would require upgrading crossings at Denni Street, Grant Street, and L Street to the north. Alternatively, closing the street crossing the rail line would negate the need to upgrade the crossing guards. Discussions with the City and Port have indicated support for the establishment of a quiet zone along the McFarland rail line including closing the crossings at Grant Street and/or Denni Street and creating pocket parks between the crossings and the nearest cross street (Hyatt Avenue to the west and McFarland Avenue to the east). However, no funding mechanism for establishing such a quiet zone identified at this time. BNSF stated that it would be willing to contribute funds towards the establishment of a quiet zone as well.

Another issue to be considered is the permanence of the structure for which attenuation is provided. There are many areas in Wilmington where there existing residential land uses in areas zoned and planned for commercial development. The future existence of these non-conforming residential uses is uncertain as they could be replaced with commercial uses at any time.

Therefore, before any mitigation is implemented it will be important to review the source of noise for that area and confirm that it will be long-term problem.

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## 6.0 GLOSSARY

**A-WEIGHTING** - A frequency-weighting network used to account for changes in human auditory sensitivity as a function of frequency.

**ACTIGRAPH** - Wrist-watch-sized devices that record human movement and can provide an indication of sleep.

**AMPLITUDE** - The strength or magnitude of the pressure of a sound wave.

**ANNOYANCE** - Any bothersome or irritating occurrence.

**ANXIETY** - A feeling of apprehension, uncertainty, and fear without apparent stimulus. It is associated with physiological changes (tachycardia, sweating, tremor, etc.) - the source of which is often nonspecific or unknown to the individual.

**ARRHYTHMIA** - Any irregularity in the rhythm of the heart's beating.

**ATMOSPHERIC EFFECTS** - Sound absorption by air molecules and water vapor, sound refraction caused by temperature and near-ground wind gradients, and air turbulence are collectively called atmospheric effects. Although atmospheric effects are mostly responsible for substantial noise fluctuations at distant receivers, they also can have a significant effect at distances within 330 feet.

**AUDIBLE SPECTRUM** - The frequency range normally associated with human hearing, usually considered between 16 and 20,000 Hz. For noise control purposes, the audible spectrum of interest usually lies between 20 and 10,000 Hz.

**AUDIOMETRY** - Measurement/testing of the hearing, including aspects other than hearing sensitivity.

**AUDITORY THRESHOLD** - Minimum audible perceived sound.

**BACKGROUND NOISE** - The total noise in a system or situation independent of the presence of (i.e., without) the noise source of interest.

**BARRIER ATTENUATION** - The noise reduction from barrier diffraction only.

**BROADBAND NOISE** - Noise with components over a wide range of frequencies.

**CARDIOVASCULAR** - Pertaining to the heart and blood vessels.

**COMMUNITY NOISE EQUIVALENT LEVEL (CNEL)** – Used in California and is nearly identical to DNL, except that CNEL includes a 5 dB penalty for the evening time period from 7 pm to 10 pm.

**CROSS-SECTIONAL** - refers to data collected by observing many subjects (such as individuals,) at the same point of time. Analysis of cross-sectional data usually consists of comparing the differences among the subjects. For example, in airport noise studies, a cross-sectional study compares responses in one group to another group in a different location. Cross-sectional data differs from longitudinal data, which follows one subject's changes over the course of time.

**CURVILINEAR** – In the context used in this synthesis, curvilinear refers to a particular statistical method of plotting a smooth curve through scattered data.

**DAY-NIGHT AVERAGE SOUND LEVEL (LDN)** – The sound exposure level for a 24-hour day calculated by adding the sound exposure level obtained during the daytime (7 a.m. to 10 p.m.) to 10 times the sound exposure level obtained during the nighttime (10 p.m. to 7 a.m.). This unit is used throughout the U.S. for environmental impact assessment. Also written as DNL

**DECIBEL (unit dB)** - Unit of level when the base of the logarithm is the tenth root of ten, and the quantities are proportional to power.

**DOSE-RESPONSE** - The relationship that describes the change in effect on an organism caused by differing levels of exposure o a stressor, in this case, noise.

**EPINEPHRINE** - A hormone secreted by the adrenal medulla (inner or central portion of an organ) in response to stimulation of the sympathetic nervous system.

**EQUIVALENT SOUND LEVEL (Leq)** - The level of a steady sound which, in a stated time period and at a stated location, has the same sound energy as the time-varying sound. Ten times the logarithm to the base ten of the ratio of time-mean-squared instantaneous A-weighted sound pressure, during a stated time interval T, to the square of the standard reference sound pressure.

**FICON** – Federal Interagency Committee On Noise. A federal committee organized to coordinate federal policies on noise.

**FICAN** – Federal Interagency Committee on Aircraft Noise. A federal committee organized to coordinate federal research and policies on aircraft noise. See [www.FICAN.org](http://www.FICAN.org).

**FREQUENCY** - The number of oscillations per second of a periodic wave sound and of a vibrating solid, expressed in units of hertz, formerly cycles per second (cps). 1 Hz = 1 cps = 1 oscillation per second. The value is the reciprocal (1/x) of the period of oscillations in seconds. The symbol for frequency is *f*.

**FREQUENCY SPECTRUM** - The description of a sound wave's resolution into components of different frequency and usually different amplitude and phase.

**HOURLY EQUIVALENT SOUND LEVEL (Leq(H))** - Equivalent Sound Level (Leq) measured over a one hour period.

**GIS** – Geographic Information Systems. A computer software to analyze spatial data. Can be especially useful in examining noise distribution over a geographic area.

**GROUND ABSORPTION** – As sound propagates near the ground the interaction of the sound wave with the ground results in attenuation of the sound. Hard ground, like water, has less attenuation that soft ground (most other surfaces). Also known as Lateral Attenuation.

**HEARING IMPAIRMENT** - A decreased ability to perceive sounds as compared with what the individual or examiner would regard as normal. The result is an increase in the threshold of hearing.

**HEARING THRESHOLD** - For a given listener and specified signal, the minimum: (a) sound pressure level; or (b) force level that is capable of evoking an auditory sensation in a specified function of trials.

**HERTZ** - (abbreviation Hz) Unit of frequency, the number of times a phenomenon repeats itself in a unit of time.

**ISCHEMIC** - a *restriction in blood supply*, generally due to factors in the blood vessels, with resultant damage or dysfunction of tissue.

**LATERAL ATTENUATION** – As sound propagates near the ground the interaction of the sound wave with the ground results in attenuation of the sound. Hard ground, like water, has less attenuation that soft ground (most other surfaces). Also known as Ground Absorption.

**LDN** (see Day-Night Average Sound Level)

**Leq** – (see Equivalent Sound Level)

**Lday** – Equivalent noise level, Leq, computed for daytime hours, 7 am to 10 pm.

**Lnight** – Equivalent noise level, Leq, computed for nighttime hours, 10 pm to 7am.

**LX** - The SPL exceeded x percent of a specific time period. For example, L10 is the level exceeded 10% of the time, and L50 is the level exceeded 50% of the time.

**LONGITUDINAL** – A study which follows one subject's or groups changes over the course of time. Differs from a cross-sectional study in that the effect of a change in exposure is measured in same subjects while with a cross-sectional study the differences are observed by comparing different subjects. Longitudinal studies are superior to cross-sectional studies.

**LOUDNESS** - The judgment of intensity of a sound in terms of which sounds may be ranked on a scale from soft to loud. On this scale, a doubling of a reference sound energy is barely perceptible to the human ear, a tripling of the sound energy is readily perceptible, and 10 times the sound energy is about twice as loud. Decreasing the sound by the same factors has a reciprocal effect—reducing the reference sound energy to one-tenth of the original energy the sound is perceived as half as loud. Although loudness depends primarily on the intensity of the sound, it also depends on the sound's frequency and wave form.

**MASKING** - The action of bringing one sound, audible when heard by itself, to inaudibility or unintelligibility by the introduction of another sound.

**MAXIMUM NOISE LEVEL (Lmax)** - The maximum noise level, in A-weighted decibels, that occurs during a period of time or during a noise event.

**META-ANALYSIS** - In statistics, a meta-analysis combines the results of several studies that address a set of related research hypotheses.

**METRIC** – Measurement value, or descriptor.

**NEUROENDOCRINE** - cells are a specialized group of nerve cells (neurons) that produce hormones.

**NOISE** - Any unwanted sound.

**NOISE BARRIER** - A generic term for any feature that blocks or diminishes sound in its path from the source to receiver. Although the term can technically refer to any feature, manmade or natural, the two most common features included in noise barriers are soundwalls and earth berms. Almost all noise barriers in California are soundwalls; therefore, the terms “noise barrier” and “soundwall” are frequently interchanged, although soundwalls are a subset of noise barriers. See also “Soundwalls” and “Earth Berms.”

**NOISE INDUCED TEMPORARY THRESHOLD SHIFT** - Temporary hearing impairment occurring as a result of noise exposure, often phrased temporary threshold shift.

**NOISE INDUCED PERMANENT THRESHOLD SHIFT** - Permanent hearing impairment occurring as a result of noise exposure, often phrased permanent threshold shift.

**NOREPINEPHRINE** - A hormone produced by the adrenal medulla similar in chemical and pharmacological properties to epinephrine, but chiefly a vasoconstrictor with little effect on cardiac output.

**PARACUSIS** - Any abnormality or disorder of the sense of hearing.

**PASCAL** - A unit of pressure (in acoustics, normally RMS sound pressure) equal to 1 Newton per square meter (N/m<sup>2</sup>). The pascal is abbreviated Pa. A reference pressure for a sound pressure level of 0 dB is 20  $\mu$ Pa.

**PATHOLOGICAL** - Any condition that is a deviation from the normal.

**PEAK SOUND PRESSURE LEVEL** - Level of the peak sound pressure with stated frequency weighting, within a stated time interval.

**PERCENT TIME ABOVE AMBIENT** – Abbreviated %TAA, a noise metric developed for use in analyzing noise levels in National Parks.

**PHON** - Unit of loudness judged or calculated in definition of loudness level.

**PSYCHOLOGICAL MORBIDITY** – Incidence of mental health illness, including but not limited to depression and anxiety.

**PHYSIOLOGICAL** - Of the branch of biology dealing with the functions and vital processes of living organisms or their parts and organs.

**PRESBYACUSIA, PRESBYCUSIS** - Hearing deterioration occurring after middle age.

**PSYCHOPHYSIOLOGICAL** - Characteristic of or promoting normal, or healthy functioning of the mind or mental processes.

**REVERBERATION** - Sound that persists in an enclosed space, as a result of repeated reflection or scattering, after the source has stopped.

**REVERBERATION TIME** - Of an enclosure, for a stated frequency or frequency band, time that would be required for the level of time-mean-square sound pressure in the enclosure to decrease by 60 dB, after the sound source has stopped.

**SCHULTZ CURVE** – The dose-response relation curve that relates DNL to percent of the population highly annoyed. Named for Theodore Schultz, who first proposed and developed this curve. Has been updated by others and the updated curves are often also referred to as the Schultz Curve in honor of the original author.

**SHIELDING** - A noise reduction at the receiver because of the placement or existence of natural or artificial barriers (e.g., walls, berms, rows of buildings, or trees, if thick and dense enough).

**SOUND** - A vibratory disturbance created by a moving or vibrating source in the pressure and density of a gaseous, liquid medium or in the elastic strain of a solid that is capable of being detected by hearing organs. Sound may be thought of as mechanical energy of a vibrating object transmitted by pressure waves through a medium to the ears. The medium of main concern is air. Unless otherwise specified, sound will be considered airborne, not structureborne, earthborne, etc.

**SOUND EXPOSURE LEVEL (SEL)** - Over a stated time interval, T (where  $T=t_2-t_1$ ), ten times the base-10 logarithm of the ratio of a given time integral of squared instantaneous A-weighted sound pressure, and the product of the reference sound pressure of 20 micropascals, the threshold of human hearing, and the reference duration of 1 sec. The time interval, T, must be long enough to include a majority of the sound source's acoustic energy. As a minimum, this interval should encompass the 10 dB down points (see Figure). In addition, LAE is related to LAeqT by the following equation:

$$SEL = LAeqT + 10 \cdot \log_{10}(t_2 - t_1) \text{ (dB)}$$

where,

L<sub>AeqT</sub> = Equivalent sound level in dB (see definition above, also know as Leq).

**SOUND INSULATION** - The use of structures and materials designed to reduce the transmission of sound from one room or area to another, or from the exterior to interior of a building. Also, the degree by which sound transmission is reduced by means of sound-insulating structures and materials.

**SOUND PRESSURE LEVEL (SPL)** - Ten times the base-10 logarithm of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 micropascals.

**SOUND TRANSMISSION CLASS** - A single figure rating system designed to estimate sound insulation properties of a partition or a rank ordering of a series of partitions. It is intended for use primarily when speech and office noise constitutes the principal problem.

**STEADY-STATE** – Continuous, constant noise as compared to a noise that varies over time.

**STRESS** - The sum of the biological reactions to any adverse stimulus, physical, mental, or emotional, internal or external, that tends to disturb the organism's state of stability.

**STRUCTUREBORNE SOUND** - Sound that reaches the receiver over at least part of its path by vibration of a solid structure.

**TEMPORARY THRESHOLD SHIFT** - A temporary hearing loss, evidenced by an increase in the threshold of audibility (see "Threshold of Audibility") occurring after exposure to noise of high intensity. After a given time, usually up to several hours, the ear recovers to almost normal, but not quite so. After an excessive number of exposures of high intensity a hearing loss, or permanent threshold shift develops gradually.

**THRESHOLD OF AUDIBILITY** - (see Hearing Threshold)

**THRESHOLD OF HEARING** - (see Hearing Threshold)

**TINNITUS** - A sound of ringing or whistling in the ears, excluding hallucinations of voices. Otological condition in which sound is perceived by a person without an external auditory stimulation.

**TRANSMISSION LOSS** - The loss in sound energy at a specific frequency, expressed in decibels, as sound passes through a barrier or a wall. It may be expressed mathematically as:

$$TL = 10 \cdot \log_{10}(E_1/E_2)$$

Where:

TL = Transmission Loss

E<sub>1</sub> = sound energy leaving the back of the wall

E<sub>2</sub> = sound energy as it strikes the front of the wall

Transmission loss is not a reduction in total energy, only a transformation from sound energy into heat. Almost all highway noise barriers provide a loss of at least 25 dBA, which means that less than 1/3 of a percent of the sound energy travels through the wall.

**WAVE** - In acoustics, a propagation wave is a cyclic pressure variation in air. The waves move at a characteristic speed (e.g., the speed of sound) through the medium (e.g., air) as an elastic response to a pressure perturbation at a source.

**WAVE FRONT** - A portion of any wave, whether in compression or rarefaction state, that can be followed as it propagates throughout the medium, analogous to the crest of a tidal wave as it crosses the ocean. At all points on the wave front, the wave has equal amplitude and phase.

**WAVELENGTH** - For a non-periodic wave, such as sound in air, the normal distance between analogous points of any two successive waves. The wavelength of sound in air or water is inversely proportional to the frequency of the sound. Therefore, the lower the frequency, the longer the wavelength.

**VASOCONSTRICTION** - Tightening or compressing of the blood vessels.

## APPENDIX A – TECHNICAL DISCUSSION OF ADVERSE NOISE EFFECTS

The following subsections provide more detailed information about the specific adverse effects of noise, which are summarized above. The reader may choose to skip these subsections if they are not interested in the details of the impacts.

### A.1 Hearing Damage

Hearing damage due to noise is related to cumulative lifetime exposures to high noise levels. There are indications from animal experiments that children may be more vulnerable to noise induced hearing impairment than adults. Risk for noise induced hearing impairment may increase when combined with exposure to vibration, certain drugs (those classified as ototoxic), and, potentially, other chemicals. Very high instantaneous sound pressure levels may result in mechanical damage to the hearing mechanism. Occupational regulations limit peak sound pressure level exposures at 140 dB to prevent such damage. It is felt that children should not be exposed to peak sound levels exceeding 120 dB.

Historically, hearing damage has been an occupational noise exposure issue, however, increases in noise exposure from recreational activities (shooting, motorcycles, ATV's, personal watercraft, personal listening devices—headphones/earphones, loud toys, and musical performances) have increased the risk for non-occupational hearing damage. It is generally accepted that exposures greater than 90 dBA Leq(8) are required to induce hearing damage based on animal studies. This is equivalent to an Leq(24) noise level of 85 dBA. Epidemiological studies have failed to show hearing damage in populations exposed to noise levels less than 70 dBA Leq(24) that are not typically encountered in community noise situations.

Part 1910.95 of Title 29 of the Code of Federal Regulations (29 CFR 1910.95) presents the Occupational Safety and Health Administration (OSHA) occupational noise exposure regulations adopted to limit hearing loss from occupational noise exposures. These regulations require employers to reduce noise exposures when they exceed the permissible noise exposures presented in Table 11. Cumulative noise exposures to levels less than Table 11 are not anticipated to result in hearing damage. There are no areas of the Wilmington Community that have noise exposures from port-related activities exceeding the OSHA Permissible Noise Exposure.

**Table 11**  
**OSHA Regulation Permissible Noise Exposure**

Duration Per Day (Hours)	Sound Level
8	90 dBA
6	92 dBA
4	95 dBA
3	97 dBA
2	100 dBA
1-1/2	102 dBA
1	105 dBA
1/2	110 dBA
<1/4	115 dBA

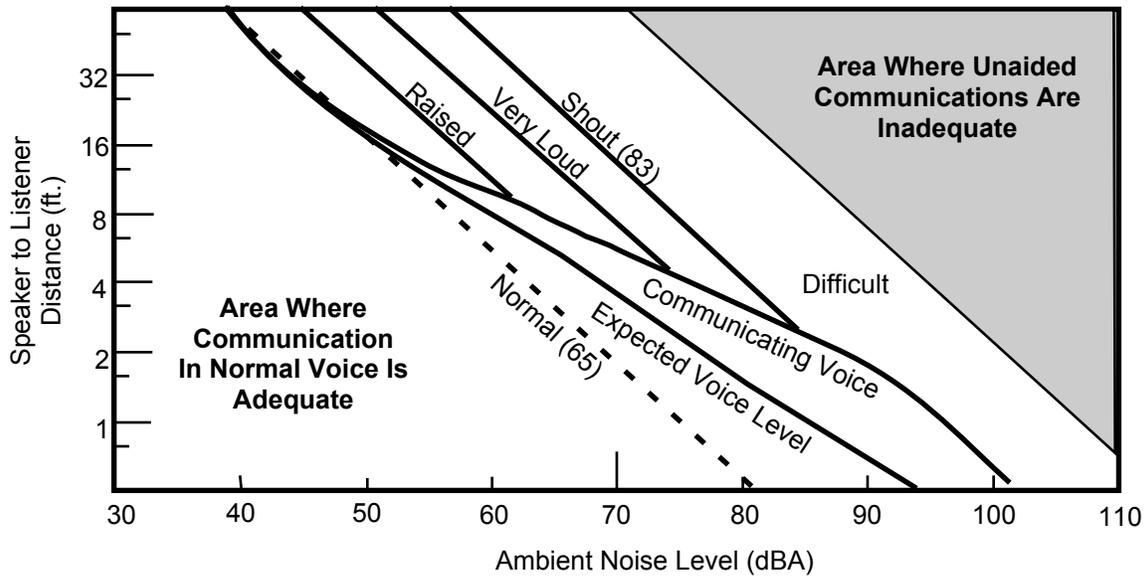
## A.2 Speech Interference

Speech intelligibility is influenced by speech level, pronunciation, talker-to-listener distance as well as the level and frequency characteristics of background noise. The environment and content of the speech and the capabilities of the listener also influence speech intelligibility. Our brains use visual queues and other available information, such as what we expect to be hearing, to fill in portions of speech that are not heard clearly enough to understand directly based on the sound alone. Therefore, a simple message with additional queues such as signs and gestures more likely to be comprehended than a complex message with no other queues. A phone conversation is more difficult to comprehend than a face-to-face conversation. The hearing acuity, language skills, and level of attention from the listener also effect speech interference. Persons listening to a second language or with less developed language skills (such as students) typically require more acoustic information for comprehension of speech than a native listener. It is more difficult for these people's brains to fill in the information not received acoustically because of the decreased familiarity with the language.

In 1977, the EPA published *Speech Levels in Various Noise Environments* (Karl S. Pearsons, 1977). This study showed that in a quiet environment less than 48 dBA, the sound level of typical average speech is 55 dBA at distance of 1 meter (3.3 feet). As background levels increase above 48 dBA, and up to 70 dBA people begin to raise their voice levels up to an average of 67 dBA at one meter. In addition to raising the volume of their voice in higher noise environments, the distance between speaker and listener drops. Communication distances average 1 meter (3.3 feet) at a low background noise levels of 45 dBA. As background noise levels are increased to 70 dBA this self-selected communication distance drops to an average of 0.4 meters (1.3 feet).

This relationship between speech level, background noise level and communication distance is shown in Figure 2. This figure shows the approximate maximum distance between the speaker and listener for just-reliable communication for various levels of vocal effort. In an environment with a background noise level of 70 dBA effective speech communication is limited to a distance of two feet with a normal voice. However, one's vocal effort will typically increase in this level of background noise, shown by the Expected Voice Level curve, allowing for communication at a distance of up to 4 feet. A very loud voice is required to effectively communicate up to 8 feet away and shouting is required to communicate at distances up to 16 feet. Effective communication at distances greater than 16 feet is difficult and nearly impossible at distances of more than 50 feet when the background noise level is 70 dBA.

The speech interference levels shown in Figure 2 are based on outdoor conditions with a steady-state noise. Indoors, acoustic reflections from surfaces can increase the effective level of the speech and increase the communication distance. However, high reverberation levels increase the effective noise level reducing communication distances. Intermittent noises, such as aircraft flyovers and train passes will only affect speech intelligibility during the noise event. If there are only a few relatively short noise events than speech can be paused during these events or repeated afterward without much impact. However, as the number and duration of events increase, the impact on speech communication increases. However, there has not been substantive research to characterize specifically how intermittent noise events impact speech.



**Permissible Distance Between a Speaker and Listeners for Specified Voice Levels and Ambient Noise Levels**  
 (Levels in parentheses refer to voice levels measured one meter from the mouth)

The WHO Guidelines recommend an interior noise level for schools of 35 dBA Leq for the time period that the class is in session to minimize speech interference. This is based on an assumed speech sound level of 45 to 50 dBA at 1 meter and a signal-to-noise ratio (i.e., the difference between the speech sound level and the background noise level) of 15 dBA being required for comprehension of complicated messages. This is generally consistent with the recommendations in *American National Standard for Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1, Permanent Schools* (Accredited Standards Committee, S12, Noise, 2010). However, the standard recommends a maximum interior noise level from exterior sources of 35 dBA Leq(H) as well as a maximum interior noise level from interior sources (such as HVAC systems and lighting) of 35 dBA Leq(H). This standard recognizes that it is the total interior noise level that impacts speech intelligibility.

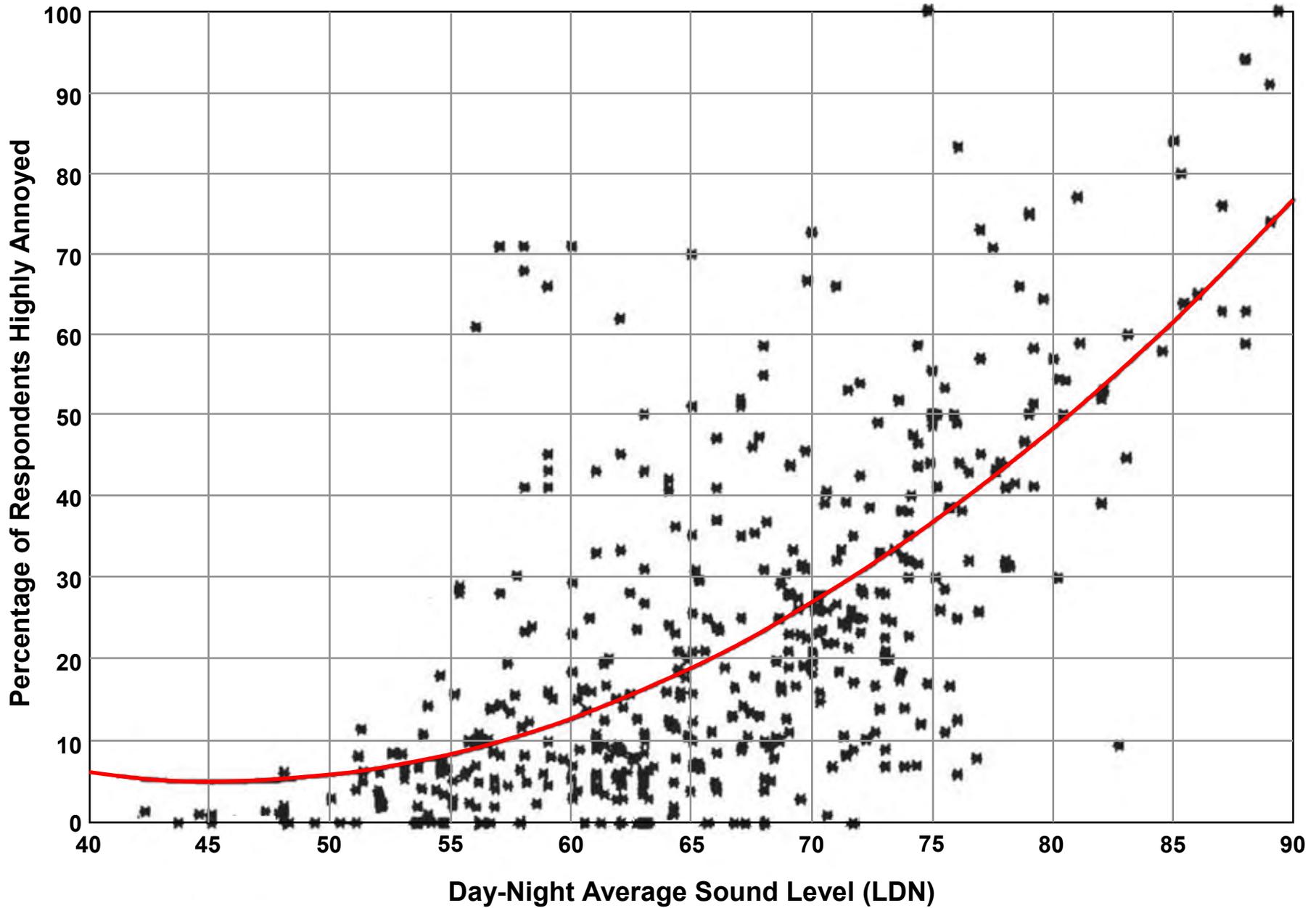
### A.3 Annoyance

Annoyance is one of the most studied effects of community noise. The Romans prohibited the movement of chariots in the streets at night and communities in the United States have enacted ordinances against excessive noise since its earliest days in response to complaints from residents. However, it was not until the birth of the jet age in the 1960's that the federal government recognized noise as a pollutant and began to support noise research and regulation, primarily due to increasing complaints of annoyance around airports. In the early research, the concept of "community annoyance" was developed to provide one comprehensive term to describe the overall community response to noise.

In 1978 Schultz published his seminal paper presenting the results of a meta-analysis of data from social surveys. He reviewed the original data to translate noise ratings to the LDN metric and determine the number of "highly annoyed" who responded on the upper 27%-29% of the annoyance scale (Schultz, 1978). For decades, environmental planners have relied heavily on the "Schultz Curve" and its later revisions to predict community annoyance from transportation noise. Schultz's recommended relationship has historically been the most widely accepted interpretation of the social survey literature on transportation noise-induced annoyance. In 1991 the U.S. Air Force commissioned an update to this important curve (Fidell, Barber, & Schultz, 1991). This research added 292 data points to the original 161 data points used originally.

In 1992, the Federal Interagency Committee on Noise (FICON) concluded that there were no new noise descriptors or metrics of sufficient understanding to substitute for the LDN exposure metric (Federal Interagency Committee on Noise, 1992). The committee also concluded that the dose-response relationship of LDN to the percentage of "Highly Annoyed" remains the best available approach for analyzing overall health and welfare effects for the vast majority of transportation noise analyses. However, there have long been questions regarding the methodology used to derive the Schultz Curve, including errors in measurement of both noise exposure and reported annoyance, data interpretation, and the problem of community response bias.

Figure 3 shows the updated Schultz Curve derived by Fidell, et. al. with the data points used to derive the curve. This data shows that the percentage of Highly Annoyed ranges from about 5% to more than 70% at 65 LDN. In later years, Fidell criticized the use of this simplistic curve in light of the high data variability, the effect of low- and high- noise exposures levels on the curve fit, and the lack of consideration of other variables in community response.



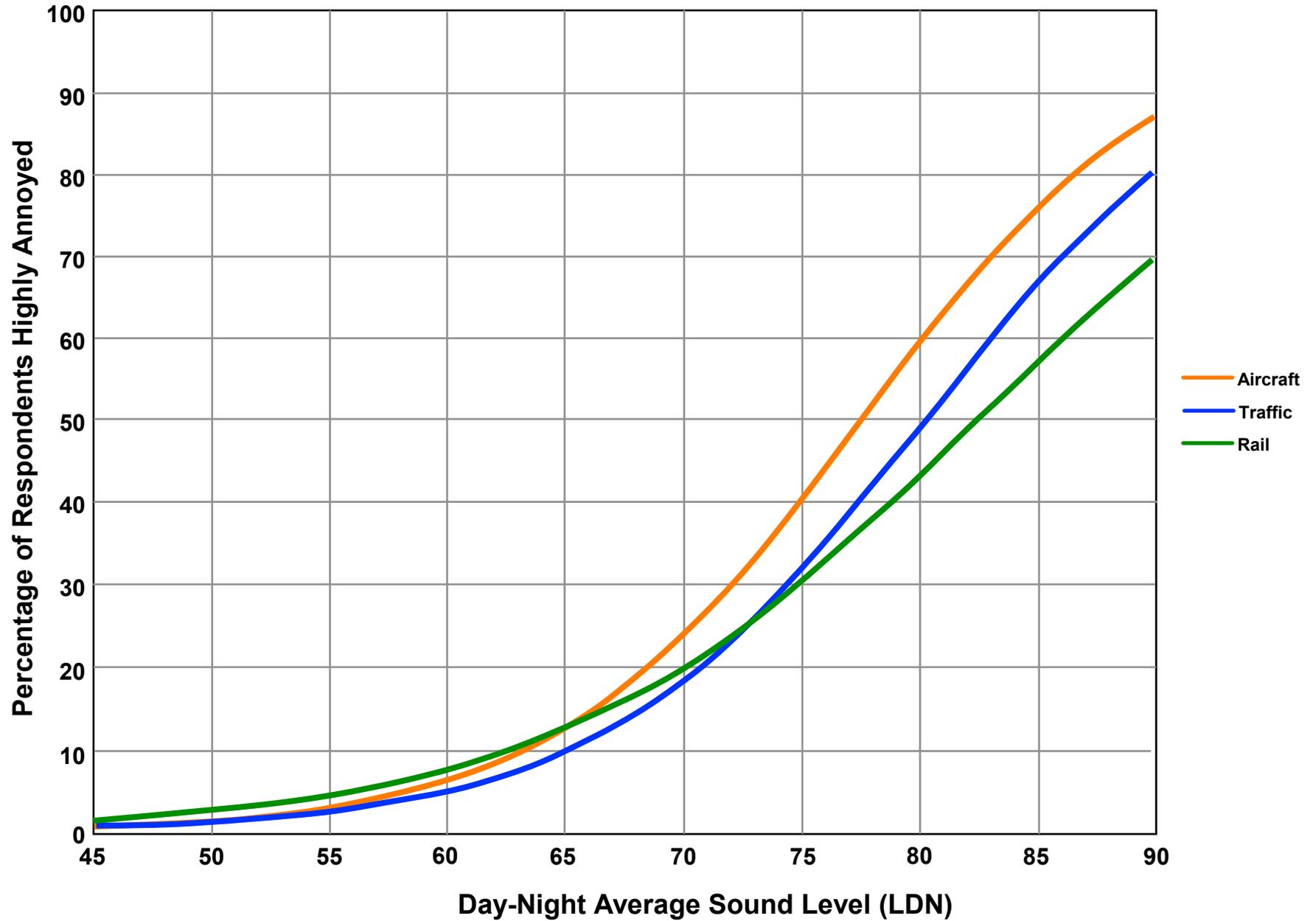
**Figure 3 - Community Noise Annoyance  
"Updated Schultz Curve"**

Because of several debatable methodological issues involved in the updated Schultz Curve, the data was reanalyzed and published (Feingold, Harris, & von Gierke, 1994). This reanalysis focused on the criteria for selecting which studies to include in the final database and the choice of data fitting algorithm. The resulting curve is presented in Figure 4. This curve was adopted by FICON for use by federal agencies in aircraft noise related environmental impact analysis and has been adopted as part of an American National Standards Institute (ANSI) Standard on community response to environmental noise. The figure also shows separate annoyance curves for different transportation noise sources (aircraft, roadway, and rail noise) based on the data specific to each noise source. These curves show that below about 64 LDN traffic noise is slightly more annoying than aircraft and rail noise but at higher noise levels, aircraft noise is perceived as most annoying. Rail noise is the least annoying noise below about 74 LDN and traffic is the least annoying noise above that level.

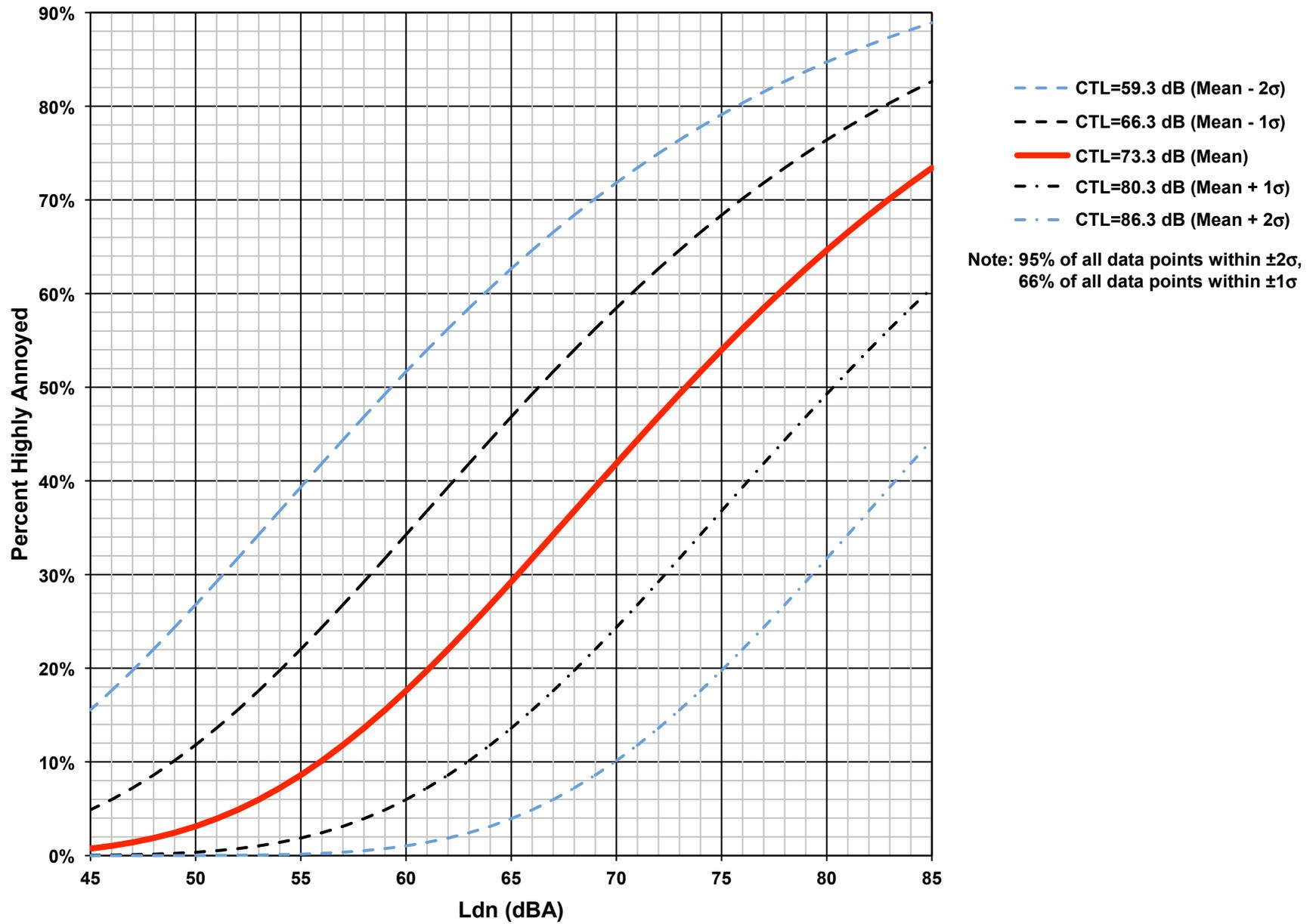
In 2011, Fidell *et al.* re-examined the relationship between annoyance and airport noise to address the wide variability in annoyance levels (Fidell, et al., 2011). In addition, this research also addressed the well recognized issue that noise related annoyance is not only related to its acoustical properties but was influenced by non-acoustic factors as well. Earlier research suggested that the rate of change of annoyance with LDN due to aircraft noise exposure closely resemble the rate of change of loudness with sound level (e.g., a 10 dB change being perceived as a halving or doubling of the loudness) and that differences from this assumed rate of change can be attributed to non-acoustic factors. Fidell used this assumption to develop a mathematical model to predict annoyance from LDN that assumed that the rate of change of annoyance from the noise exposure was the same as loudness is perceived as well as a factor to account for non-acoustic influences of annoyance.

The mathematical model effectively moved the annoyance curve based on the assumed relationship between LDN and the rate of change of annoyance by a constant called the Community Tolerance Level (CTL). This model was compared with survey data from communities around 34 individual airports. The value of the CTL was adjusted to minimize the difference between the model and the field data (least squares fit). It was found that the model provided excellent predictions of annoyance for three quarters of the airport communities it was applied to. Further, when applied to all of the data from multiple airports using the grand mean CTL value, the model's predictions agreed well with previous models developed from the data. The CTL value was arbitrarily selected to represent the noise level at which 50% of the community is expected to be highly annoyed (it could be anchored to any percentage of highly annoyed persons). A community that is more tolerant of noise will have a higher CTL than a community with less tolerance to the noise. CTL's for the airport communities analyzed in ranged from 62.6 dB to 86.3 dB with an average of 73.3 and a standard deviation of 7.0 dB. The 24 dB range in all of the data and 14 dB range within one standard deviation demonstrate the wide variability in annoyance by noise by the general population shown previously in Figure 3.

Figure 5 shows the aircraft noise annoyance levels predicted using the mean CTL levels as well as the mean plus and minus one and two standard deviations ( $\sigma$ ). Two thirds of the individual community data points fit in the area bounded by the curves for the mean plus and minus one standard deviation. 95% of the points fit within the area bounded by the curves for the mean plus and minus two standard deviations. This along with other data strongly suggests that the CTL values for communities have a Gaussian distribution.



**Figure 4 - FICON/ANSI Community Noise Annoyance**



**Figure 5 - Community Noise Annoyance – Community Tolerance Model**

On average, the non-acoustic factors represented by the CTL value account for one-third of the variance in the annoyance levels for all of the airport communities. The CTL value accounts for one-half of the variance in annoyance level three-quarters of the individual studies. That is, for three quarters of the communities, the level of noise accounts for half of the annoyance and non-acoustic factors account for the other half. Non-acoustic factors may include attitudes towards noise source operators, the familiarity of certain noises, and expectations about noises that may or may not be considered appropriate in a particular setting.

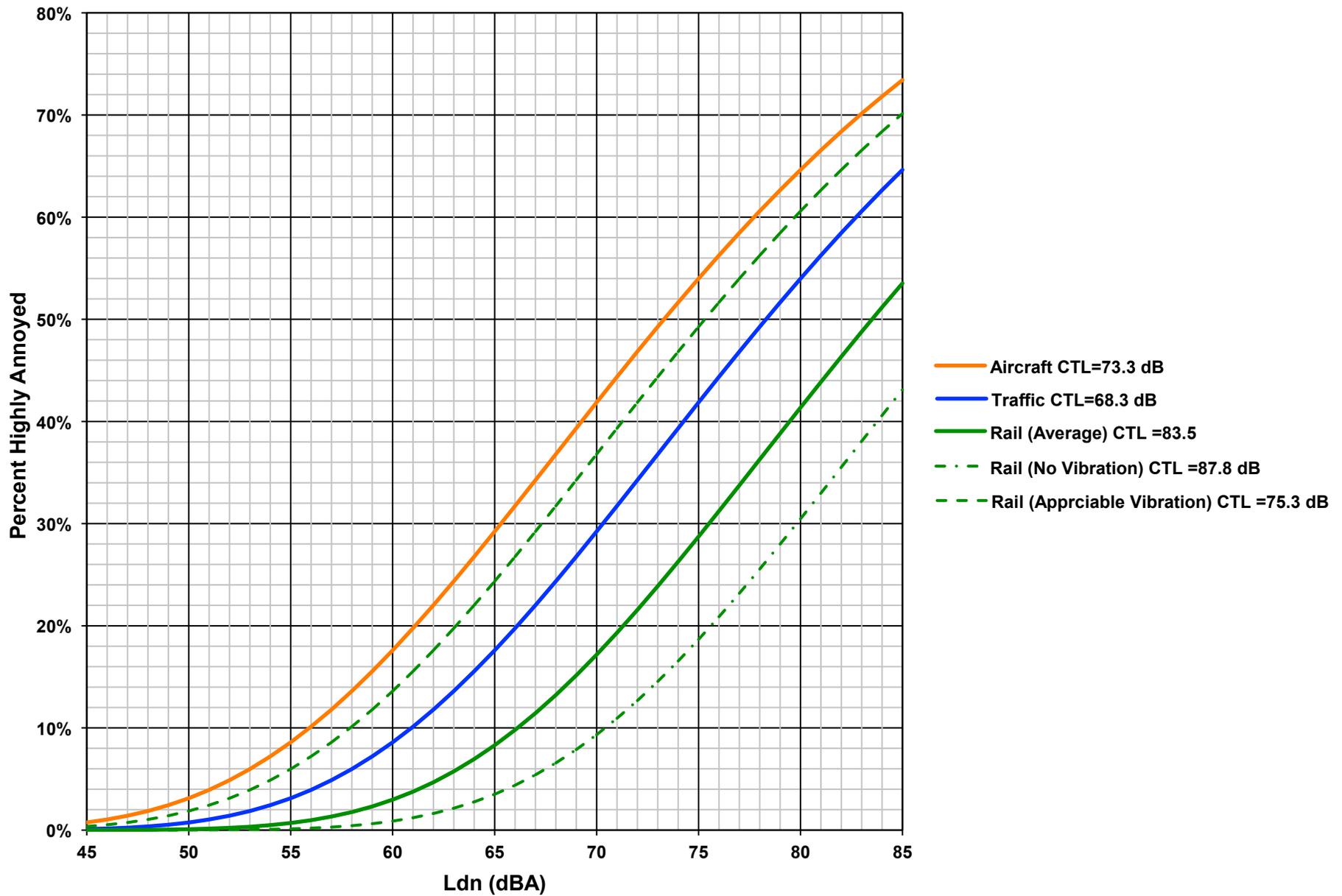
There are to considerable issues with applying this model. First there is no methodology to determine a community's CTL value without performing social surveys in that community. The authors suggest that this should be further researched and suggested the possibility of airports using complaints to derive this value. Further, what constitutes a community is ambiguous. However, the model is useful in providing an explanation for the considerable variations in annoyance among different communities. Once a CTL value is determined for a community the model can also be used to predict changes in annoyance due to changes in noise level. Further, the model allows for a comparison of annoyance from noise resulting from different sources.

In 2012, Schumer *et al.* examined the use of Community Tolerance Model to project annoyance of traffic and rail noise (Schomer, et al., 2012). The results of this analysis were that the model matched survey data from individual communities for road noise annoyance. Further, the annoyance predictions using the mean CTL value matched curves previously derived from all of the data. The CTL's for the traffic noise surveys ranged from 69.3 dB to 87.6 dB with a mean of 78.3 dB and a standard deviation of 5.1.

Initially the model did not match survey data for rail annoyance in some communities. However, when the respondents who were exposed to high vibration levels from the train (e.g., rattling windows and dishes) were separated as a different community from those who were not, the modeled predictions of annoyance agreed well with the survey results. Surveys from communities without high vibration levels had CTL values ranging from 83.6 dB to 92.0 dB. The mean CTL for these communities was 87.8 dB with a standard deviation of 3.5 dB. High vibration communities had CTL values ranging from 68.6 dB to 79.3 dB with a mean of 75.3 dB and a standard deviation of 4.2 dB. The 12.5 dB difference in mean CTL values means that, on average, people are 12.5 dB less tolerant of train noise when accompanied by high vibration levels. On, average, the same percentage of the population exposed to rail noise without vibrations will be highly annoyed as those with vibrations exposed to 12.5 dB lower LDN noise levels from the trains.

The mean CTL values for the aircraft, traffic, and rail noise sources are 73.3 dB, 78.3 dB and 83.5 dB respectively. The annoyance curves for each of these sources are presented in Figure 6. The annoyance curves for rail noise with and without vibration with mean CTL values of 87.8 dB and 75.3 dB are shown as well.

The difference in the CTL values between each source indicate how much more or less tolerant communities are to noise generated by these sources. On average communities are 5 dB more tolerant of traffic noise compared to aircraft noise, and 10 dB more tolerant of rail noise compared to aircraft noise. These values compare well to recommendations in the international standard for description, assessment and measurement of environmental noise, ISO 1996-1 (ISO, 2003). This standard recommends applying a +3 to +6 dB penalty to aircraft noise and a -3 to -6 dB bonus for train noise.



**Figure 6 - Comparison of Average Annoyance by Noise Source**

The curves show the considerable difference in annoyance from rail noise when it is accompanied with appreciable vibration. This finding correlates well with other research that has found increased noise annoyance in the presence of vibration. The CTL values indicate that communities are about 2.5 dB less tolerant of rail noise with vibration compared to traffic noise and about 2.5 dB more tolerant of rail noise with vibration than aircraft noise. Without appreciable vibration, communities are 9.5 dB more tolerant of rail noise compared to traffic noise and 14.5 dB more tolerant compared to aircraft noise.

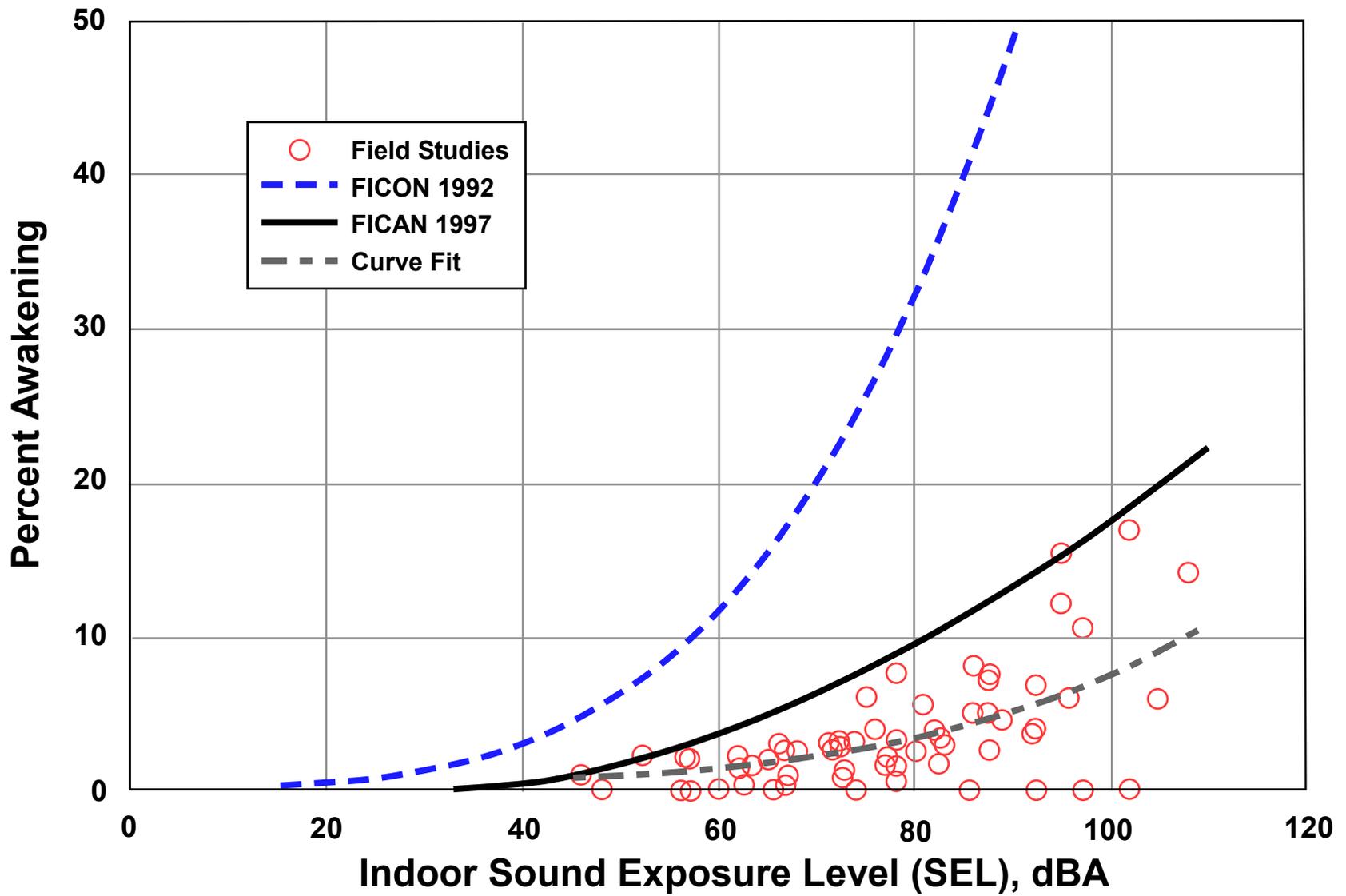
## A.4 Sleep Disturbance

An ever-increasing body of research demonstrates the importance of sleep in maintaining good physical and mental health. It has been long known that noise can adversely affect sleep. However, it is estimated that 80% to 90% of consciously recognized sleep disturbances in noisy environments are caused by something other than an outdoor noise source. Laboratory studies have shown that noise affects sleep in three successive stages; (1) the autonomic nervous system increases heart rate and blood pressure, (2) sleep stage changes, and (3) perceived awakening. This correlates well with viewing noise-induced awakenings as an event-detection process.

An awakening can be viewed as the result of a subconscious decision that a change in the short-term noise-environment is sufficient to warrant awakening to respond to a threat or other need (e.g., a crying infant). As a person is exposed to the same noise environment (i.e., habituated) the number of perceived awakenings decreases. This can be thought of the unconscious brain using prior information, hearing the same sound and remembering that an awakening was not previously warranted, in the decision making to reduce awakenings. The number of sleep stage changes are also reduced by habituation but not by the extent that the perceived awakenings. The autonomic nervous system response is not affected by habituation.

The earliest understanding of noise induced sleep disturbance was based on laboratory studies. However, subsequent epidemiological and in-home field studies have demonstrated that awakening rates in one's home are much less than in the laboratory. In 1992, the Federal Interagency Committee on Noise (FICON) recommended a dose-response relationship curve to estimate awakenings based on laboratory studies. In 1997, the Federal Interagency Committee on Aircraft Noise (FICAN) updated these recommendations based on in-home field studies. Figure 7 presents these two curves along with the data points from the field studies used to establish the 1997 recommended curve. The difference between the 1992 and 1997 curves shows a substantial reduction in the percent of expected awakenings based on field studies compared to laboratory studies. Further, the data points show that the 1997 curve is the upper-bound of the number of awakenings and represent the maximum likelihood that an awakening will occur.

In 2002 Finegold and Elias (Finegold, 2002) performed a meta-analysis of field studies of behavioral awakenings and developed the curve fit of the data shown in **Error! Reference source not found..** Note that this curve is based on the average numbers of expected awakenings rather than the FICAN curve which represents the upper bound. This curve predicts that there is approximately a 5% chance of awakening due to a indoor noise exposure of 90 dBA SEL (L<sub>max</sub> approximately 80 dBA). In a home with windows closed this equates to an outdoor noise level of 105 dBA SEL (L<sub>max</sub> approximately 95 dBA). The 1997 FICAN curve would predict an almost 15% chance, three times greater, of awakening due to the same noise exposure.



Note: Lmax is approximately 10 dBA less than SEL

**Figure 7 - Sleep Disturbance Dose Response Relationship**



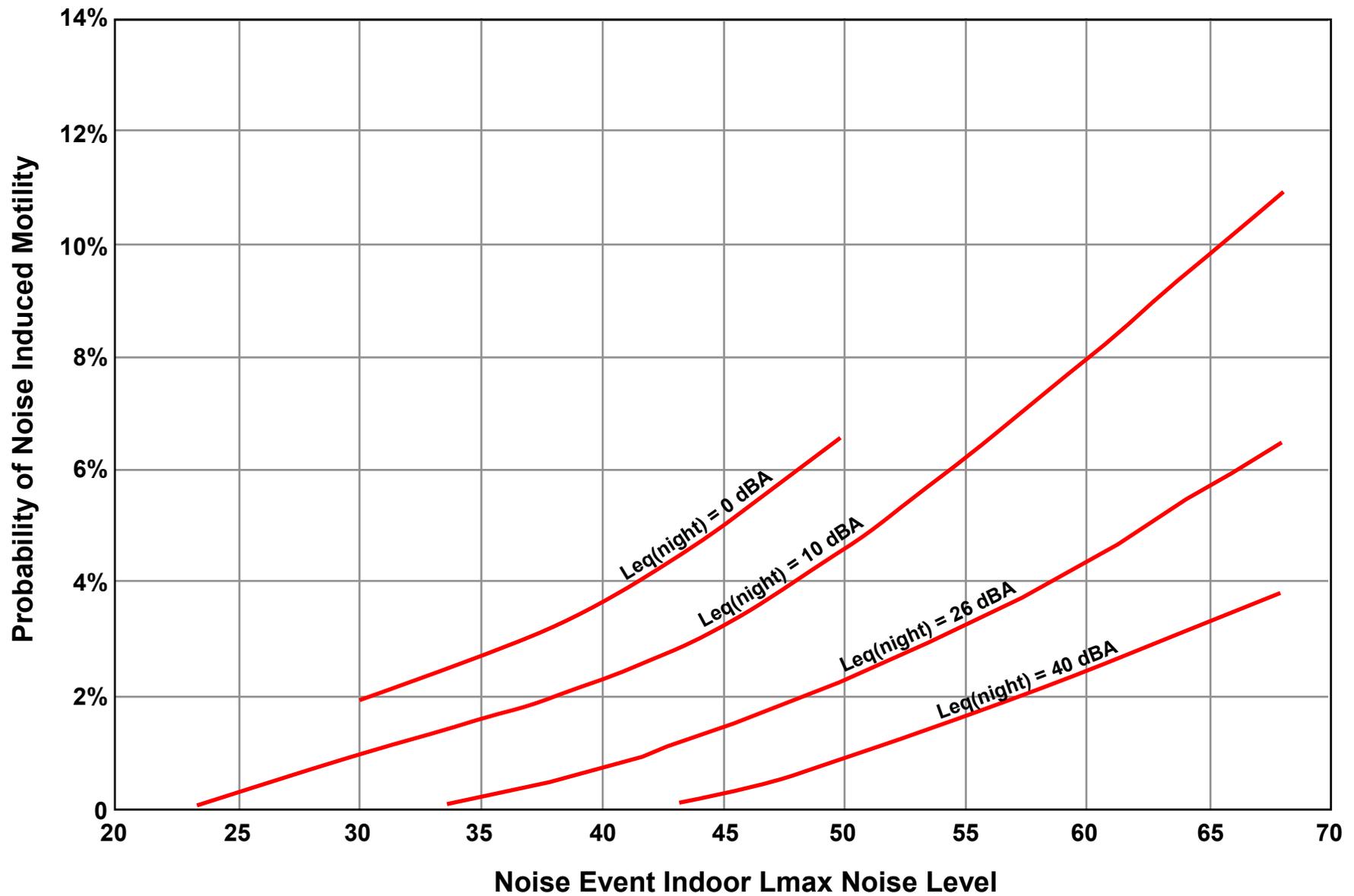
ANSI/ASA Standard S12.9-2008 Part 6 (Accredited Standards Committee, S12, Noise, 2008) recommends the use of a curve very similar to the curve fit shown developed by Finegold and Elias in Figure 7. This document notes that this provides an estimate of the number of behavioral awakenings from noise events in “steady state” situations where the noise has been present in both level and in frequency of occurrence for a long time (on the order of one year). It has been recognized that awakenings from newly introduced sources will have a higher rate of awakening than a “steady state” source. This is because after a new source is introduced some portion of the population acclimates, at least in part, to the new source, others will develop coping strategies such as closing windows at night and others will determine that they cannot cope or acclimate and will move away from the source. The ANSI/ASA standard recommends the use of the 1997 FICAN curve to estimate awakenings from newly introduced noise sources. It should be noted that these are only predictions of behavioral awakenings and do not predict sleep stage changes or autonomic nervous system responses.

One criticism of the dose-response relationship using single event exposure levels is that some studies suggest that it is the difference in sound level between noise event and the background noise level that determines the reaction probability. Figure 8 presents a graph showing the probability of motility (muscle movement) within 15 seconds of a noise event as a function of the maximum noise level from the event from a study prepared by The Netherlands Organization for Applied Scientific Research (TNO) (Passchier-Vermeer W, 2003). Four curves are shown representing different nighttime background noise levels, L<sub>night</sub> (Leq during the sleeping period).

The graphic shows that as the background noise level increases the probability of motility induced by a noise event is reduced. This data also showed the relationship is also dependent on the time of the noise event relative to the start of the sleep period. For example, the probability for noise-induced motility is approximately 1.3 times higher in the seventh hour of sleep than it is in the first hour. This correlates well with the event detection model of noise-induced awakening discussed above. The “cost” of an awakening is greater early in the sleep period because, after some period of time, additional sleep provides diminishing returns. Sleeping twice as much as normal does not allow you to stay awake for twice as long with the same performance as two separate sleep/awake periods. Further, an awakening early in the sleep period is more likely to affect the quality of later sleep.

There is also evidence that increased background noise levels also adversely affect sleep. A Japanese Study found a significant correlation on perceived sleep quality (difficulty in falling asleep, waking up during sleep, waking up too early, and daytime sleepiness) and traffic volume (Kageyama T, 1997). Traffic noise levels are proportional to the traffic volume and nearly constant especially compared to train and aircraft noise events. Other studies have confirmed this association. A laboratory study that examined the effects of road, rail and aircraft noise on sleep concluded that perceived sleep quality was well correlated with the average nighttime noise level (Greifhan, Marks, & Robens, 2006). However, physiological response (sleep latency, and the amount of deep sleep) was impacted more by rail noise than aircraft and traffic noise. This exposes the importance of the content of the noise. It is generally accepted that the “meaning of the sound” to the individual, such as a child crying, is a strong predictor of awakenings.

Most likely the effects of noise on sleep are a complex relationship between background noise levels and content, the noise levels and content from individual noise events, and the attitudes and experiences of the subject. It appears that the characteristics of the noise; level, frequency content, constant vs. intermittent, frequency of events, time of occurrence, and the content or meaning of the sound may impact different aspects of sleep quality. Some effects may be dependent on a single characteristic of the noise while others may depend on multiple characteristics.



**Figure 8 - Probability of (Aircraft) Noise Induced Motility**



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Most of our knowledge of noise effects on sleep stage changes or autonomic response is based on laboratory studies. The experimental techniques and equipment used to study these effects precluded their use in large field studies. As shown above, response to noise during sleep in an unfamiliar laboratory situation is quite different from the response at home. Recent improvements in technology have now made large-scale field studies possible. The Partnership for AiR Transportation Noise and Emissions Reduction (An FAA/NASA/Transport Canada-sponsored Center of Excellence) published a design for a field study on the effects of aircraft noise on sleep (Basner, 2012). This study will use actigraphy to measure body movement, an Electrocardiogram to measure heart rate, and a button to signal conscious awakenings. In addition participants will fill out a brief questionnaire each morning. The methodology will allow for comparison with previous field studies as well as unobtrusively measure both subtle and more obvious changes in sleep caused by various noise exposures. If this methodology is successful then it will likely be extended to examine the effects of road and rail noise on sleep.

## A.5 Physiological Response

As discussed in Section 0, community noise is unlikely to be of sufficient level to result in hearing damage. Research has also examined the relationship between noise exposure during pregnancy and birth weight and found no relation. Exposures to high occupational noise levels have been associated with development of neurosis and irritability. However, there has been no association found between community noise exposure and psychiatric disorders. It is believed that noise can accelerate and intensify latent mental illness. One study showed a weak association between road noise and minor psychiatric disorders. However, the association was found to disappear after adjustment for the baseline trait anxiety.

There is an increasing body of evidence that long-term community noise exposures can have adverse effects on the cardiovascular system, specifically increasing the risk of hypertension (high blood pressure) and ischemic heart disease (reduced blood flow to the heart). However, the associations are weak and there is no consensus on what levels of noise increase this risk or even what noise metrics are best associated with the risk. Most of these studies have been based on compilations of and/or re-review of previous data. Criticisms of these studies include that the reviews were not carried out in a systematic way, which noise exposures were not adequately reported, and that adjustments were not made or improperly made to account for important confounding influences. The influence of publication bias (the tendency not to publish study results that do not support the hypothesis) has also been cited as a deficiency in the certainty of the association for cardiovascular disease.

Some analyses conclude that cardiovascular system impacts require noise exposures to exceed 70 dBA LDN while others predict effects from as low as 50 dBA Leq(24). The WHO guidelines concluded that, "cardiovascular effects are associated with the long-term exposure to Leq(24) values in the range of 65 to 70 dB or more. Some studies relate the risk to the maximum noise level or sound energy from individual events at night and others examine the effect between average daytime noise levels.

Section 0, discussed the impact of noise on school children in terms of speech communication interference and attention distraction and how these effects can impact learning. Although children are typically identified as a vulnerable group, there have been no studies associating children's noise exposure directly to adverse physiological health outcomes. One study looked at mental effects of noise on two communities of children and adolescents, one living near a military base and the other not impacted by loud military aircraft flying as low as 75 m. Neither psychiatric disorders nor environmental factors showed any relationship to noise; however, psychophysiological parameters (e.g., heart rate and muscle tension) demonstrated some relationship to noise. Direct physiological effect of noise resulting in adverse health outcomes in children is understudied and requires further research.

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## **APPENDIX B – TECHNICAL REVIEW OF ADDITIONAL NOISE IMPACT CRITERIA**

### **B.1 Federal Agencies**

In 1972 the Noise Control Act was passed which required the U.S. Environmental Protection Agency (EPA) to establish noise standards on a gamut of motor vehicles, industrial machinery, and household appliances. Noise emissions standards were adopted for motor vehicles traveling on public roads, and train locomotives and cars. The Federal Aviation Administration (FAA) originally adopted noise standards new aircraft in 1960. Over the years these standards have been revised downward as technological advancements to reduce noise have been developed. For the most part these standards establish maximum noise levels that cannot be exceeded by specific vehicle categories and operating conditions. These standards are largely based on noise emission levels that are considered technologically feasible to achieve considering cost, reliability and safety among other factors. The standards are intended to minimize noise impacts but do not prevent them from occurring. These standards largely preempt state and local agencies from adopting more stringent noise regulations.

In 1969 congress passed the National Environmental Protection Act (NEPA). NEPA requires federal agencies to document and address the environmental impacts of their actions, including noise impacts. The three federal agencies charged with regulation of the three major transportation noise sources have established noise regulations for assessing compliance with the National Environmental Protection Act (NEPA) as well as other purposes. In addition, the Department of Housing and Urban Development has established criteria for its housing projects. The noise regulations adopted by each of these agencies is discussed below. It is notable how much lower the WHO guideline values are. A residential area meeting the WHO outdoor guidelines would have a DNL level of 56.0 dBA with serious daytime/evening annoyance and 53.2 dBA with moderate daytime/evening annoyance. In comparison, the rail, aircraft, and housing DNL based federal standards are based on a 65 dBA DNL noise criterion.

#### **B.1.1 Environmental Protection Agency Noise Assessment Guidelines**

In March 1974, in response to a federal statutory mandate, the EPA published what is often referred too as the EPA Levels document (Environmental Protection Agency, 1974). This document was intended to "provide State and Local governments as well as the Federal Government and the private sector with an informational point of departure for the purpose of decision-making". The analysis presented in document concluded that 55 dB DNL was the requisite level to protect public health and welfare with an adequate margin of safety for areas with outdoor uses, including residences and recreational areas. Note that these levels were developed for suburban type uses. In some urban settings, the noise levels will be significantly above this level, while in some wilderness settings, the noise levels will be well below this level. The EPA "levels document" does not constitute a standard, specification or regulation, but identifies safe levels of environmental noise exposure without consideration for achieving these levels or other potentially relevant considerations. These EPA guidelines have not been adopted or recommended for use by the FAA, the State of California, or the City of Los Angeles.

## B.1.2 Freight Trains –Federal Railroad Administration/Federal Transit Administration

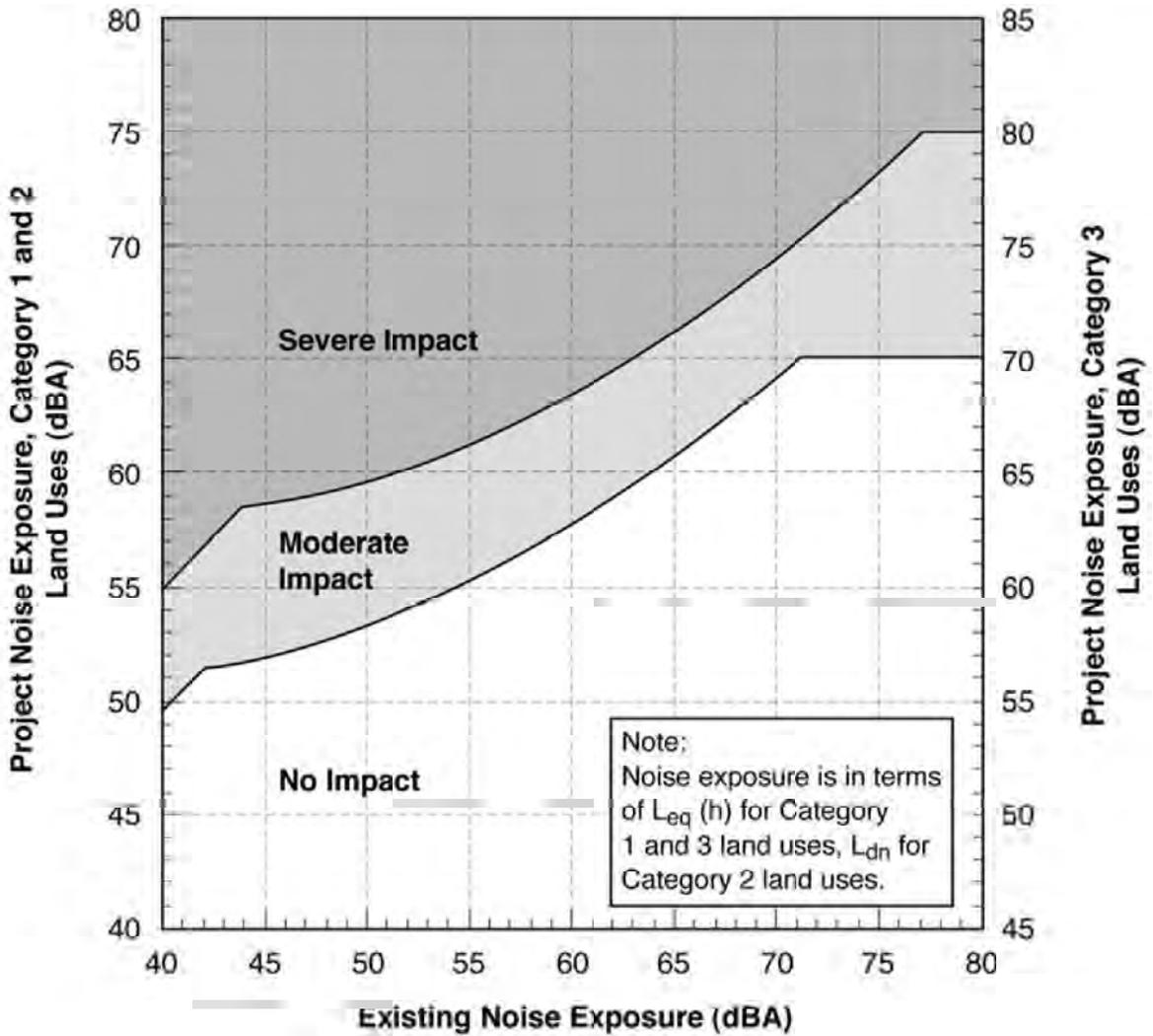
The Federal Railroad Administration (FRA) is one of ten agencies under the Department of Transportation concerned with intermodal transportation and primarily safe, reliable, and efficient transportation of goods and people by rail. The FRA has developed guidance for the assessment of noise and vibration impacts from high-speed rail (i.e., greater than 90 mph) for compliance with NEPA (Carl E. Hanson P. J., 2012). For conventional rail operations (i.e., less than 90 mph) the FRA uses the Federal Transit Administration’s (FTA) Transit Noise and Vibration Impact Assessment (Carl E. Hanson D. A., 2006). This document specifies the Noise Impact Criteria used by the FRA and FTA for conventional rail projects along with a screening procedure and detailed analysis methodology for modeling rail noise levels and determining impacts and mitigation. Figure 9 presents the noise impact criteria for the three land-use categories listed in Table 12.

**Table 12**  
**FTA Noise Impact Land Use Categories**

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor Leq(H)*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheatres and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor LDN	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor Leq(H)*	Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, and churches where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.

\* Leq for the noisiest hour of transit-related activity during hours of noise sensitivity.

The FTA noise impact criteria are defined by the two curves shown in Figure 9. If the existing and with project noise levels intersect below the lower curve on Figure 9 then a project is not considered to have a noise impact and according to the FTA guidance “the introduction of the project will result in an insignificant increase in the number of people highly annoyed by the new noise.” Note that for Land Use Category 2, this curve stops increasing at 65 LDN, “a standard limit for an acceptable living environment defined by a number of Federal agencies.” Existing and project noise levels intersecting above the top curve are considered Severe Impacts “since a significant percentage of people would be highly annoyed by the new noise.” The Severe Impact curve flattens out at 75 LDN, “a level associated with an unacceptable living environment.”



**Figure 9 - FTA Transit Noise Impact Criteria**

For residential uses, Land Use Category 2, impacts are measured based on the LDN metric. If the existing noise levels are less than 43 LDN a projected noise level increase between 10 and 15 dB results in a moderate impact and an increase greater than 15 dB results in a severe impact. For higher existing noise levels, a lower increase in noise level will result in impacts. At an existing noise level of 56 LDN, a project would need to have no change in noise to not result in a noise impact while an increase of 6 dB would result in a severe impact. At an existing noise level of 67 LDN, the project would need to have no increase or a reduction in noise to not result in a severe impact. At this level the project would need to reduce noise level by 4 dB to not result in a noise impact.

Schools are included in Land Use Category 3 where impacts are based on the noisiest hourly equivalent noise level (Leq(H)) under existing and with project conditions. The allowable with project noise levels are increased by 5 dB compared to residential uses discussed above. While the category description describes these areas as “where it is important to avoid interference with such activities such as speech” it would allow a noise level up to 70 dBA Leq(H) outdoors at a school. Based on Figure 9 above, this noise level would limit effective raised voice conversation to less than 2 meters (6 feet), which is often not practical for a schoolyard. Further, this would allow for an interior noise level of up to 50 dBA in classrooms even if windows remain closed which is 15 dB higher than the WHO and ANSI/ASA recommendations.

The residential noise impact standards used by the FTA are consistent with what is understood about annoyance and transportation noise. However, they do not address the sleep disturbance or speech interference impacts from single train event. In their guidance, the FTA argues that because the Lmax levels and number of events are included in the determination of LDN and Leq and they correlate well with annoyance that these metrics are appropriate. However, it is likely that these conclusions will need to be reassessed based on current research in the near future.

### **B.1.3 Federal Highway Administration - Highway Noise**

Title 23, Part 772 of the Code of Federal Regulations (23 CFR 772) presents the FHWA's Procedures For Abatement Of Highway Traffic Noise And Construction Noise (Federal Highway Administration, 2010). The highway noise criteria is based on the peak noise hour Leq(H) (i.e., the highest hourly average noise level in a day). However, Noise Abatement Criteria (NAC) specified by the FHWA is not intended to be noise level goals but thresholds above which noise abatement must be considered. The regulation is applied to two types of projects and these projects must demonstrate compliance with the regulation prior to implementation. Type I projects are those that create new highways, or considerably alter the alignment or increase the capacity of an existing highway. Type II projects are sound barrier retrofit programs where the NAC are used to determine eligibility. These retrofit programs are operated by state and local transportation agencies.

Type I projects on federal highways or involving federal funds must prepare an analysis demonstrating compliance with the FHWA regulation. This involves measurement and modeling of existing noise levels along with modeling of future (design year) noise levels with the project. A noise impact is identified if the projected noise levels at sensitive receptors approach or exceed the NAC or if the future with project noise level is projected to increase substantially over existing conditions. The regulation does not define what “approach” or “substantial” increase but leaves these definitions to the States which are required to prepare policies that are reviewed and approved by the FHWA that define these values as well as specify how other parts of the regulation are to be implemented. California's policies are presented in Caltrans' Traffic Noise Analysis Protocol (TNAP) (California Department of Transportation, 2011). This document defines approach as “come within 1 dB of” and a substantial exceedance as 12 dB.

Table 13 presents the FHWA's NAC. The NAC are focused on abating outdoor noise levels and the criteria are applicable in areas of “outdoor frequent human use that would benefit from a

reduced noise level.” More generally, these are areas where people are exposed to traffic noise for an extended period of time on a regular basis. The only interior NAC is applicable to very sensitive indoor uses that often do not have outdoor activity areas. The three primary activity categories, A-Residential, C-Sensitive Uses and F-commercial, have criteria of 67 dBA Leq(H) for residential and sensitive uses and 72 dBA Leq(H) for commercial uses. In California, if the projected noise level with a Type I project at a sensitive receptor is more than 1 dB less than the applicable NAC or of the noise level is projected to increase more than 12 dBA a noise impact is identified.

The regulation requires that noise abatement be considered for all impacted receptors. Most often the noise abatement considered is noise barriers (walls and/or berms). However, federal funding can be used for traffic management measures (vehicle and/or speed restrictions), alteration of the proposed alignment, acquisition of property to serve as a buffer zone. If the noise abatement is found to be reasonable and feasible it must be incorporated in the project. The regulation leaves the definition of “feasible” and “reasonable” to state transportation agencies.

**Table 13**  
**FHWA Noise Abatement Criteria (NAC)**

Activity Category	NAC <sup>1</sup> / Evaluation Location	Description of Activities
A	57 dBA Leq(h) /Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose
B <sup>2</sup>	67 dBA Leq(h) /Exterior	Residential
C <sup>2</sup>	67 dBA Leq(h) /Exterior	Active sport areas, amphitheatres, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools, television studios, trails, and trail crossings.
D	52 dBA Leq(h) /Interior	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios.
E	72 dBA Leq(h) /Exterior	Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A–D or F.
F	--	Agriculture, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing.
G	--	Undeveloped lands that are not permitted.

1. The Leq(h) activity criteria values are for impact determination only and are not design standards for noise abatement measures. All values are A-weighted decibels (dBA).
2. Includes undeveloped lands permitted for this activity category

Feasibility of noise abatement is an engineering consideration to ensure that the abatement results in a discernable effect. Caltrans’ requires noise abatement to provide at least 5 dB of noise reduction (compared to conditions without the abatement) in order to be considered feasible. Reasonableness is based on three factors, a noise reduction design goal, the cost of the abatement,

and the opinions of the receptors benefitted by the abatement. Caltrans' has established a noise reduction design goal of 7 dB. That is, to be considered reasonable, noise abatement must provide at least 7 dB of noise reduction for at least one benefitted receptor. A benefitted receptor is one that receives at least 5 dB of reduction from the abatement. Caltrans has established a reasonableness allowance of \$55,000 per benefitted receptor. In order to be considered reasonable, the cost of implementing the sound abatement must be less than the total reasonableness allowance. If more than 50% of benefitted receptors responding to a survey oppose a noise abatement measure implemented in the public right of way it is not considered reasonable.

The FHWA NAC are based on speech communication interference and annoyance. Peak noise hours occur during the hour of the greatest traffic volume flowing freely. Slowing caused by congestion decreases traffic noise levels considerably more than increases in traffic volumes during these periods. For highways without congestion, the peak noise hour is concurrent with the peak traffic hour. For highways with congestion, the peak noise hour can be repeated four times a day before and after the AM and PM peak traffic volume periods as traffic transitions from uncongested to congested and back. In Southern California, daytime noise levels along freeways are typically near the peak hour levels throughout the daytime when there is free flow dropping 5 dB or more during congested periods. During the evening, traffic volumes and noise levels begin to decrease with the lowest noise levels experienced in the late night/early morning hours and then increasing again as the morning commute begins.

One effect of increased congestion is that the increase in noise from the late night minimums begins earlier in the morning as more commuters decide to avoid the congestion by starting their commute earlier. Peak noise levels along an uncongested urban or suburban highway would typically occur near the 8:00 a.m. and 5:00 p.m. hours. Traffic noise levels on many freeways in Southern California can start increasing from their late night/early morning levels around 4:00 a.m. and approach peak noise hour levels as early as 5:00 a.m.

#### **B.1.4 Federal Aviation Administration - Aircraft**

In 1976 the Federal Aviation Administration (FAA) adopted its Aviation Noise Abatement Policy. This policy sets for the authorities and responsibility of the Federal Government, airport proprietors, State and Local governments, the air carriers, air travelers and shippers, and airport area residents and prospective residents. This policy states that it is the role of State and Local governments and airport proprietors to undertake land use and operation actions necessary to promote compatibility. The primary role of the FAA described in the policy is to regulate the noise at its source (i.e., the aircraft) as well as supporting local efforts to develop airport noise abatement plans. The policy requires the FAA to give high priority in the allocation of federal Airport Improvement Project (AIP) funds to projects designed to ensure noise compatible land uses near airports.

The Aviation Safety and Noise Abatement Act of 1979 further established the FAA's supporting role in noise compatibility planning. The law establishes funding for noise compatibility planning and sets the requirements by which airport operators can apply for funding. This law also mandated the FAA to develop an airport community noise metric to be used by all federal agencies assessing or regulating aircraft noise. The FAA determined that the LDN metric was best correlated with annoyance. The FAA expressly allows the CNEL metric in lieu of the LDN California had been using the CNEL metric for airports and the metrics are so similar.

As a means of implementing the Aviation Safety and Noise Abatement Act, the FAA developed and adopted the Airport Noise Compatibility Planning Program regulation. The program is codified in Part 150 of Title 14 of the Code of Federal Regulations (14 CFR 150) and often referred to as Federal Aviation Regulation (FAR) Part 150. This regulation includes guideline recommendations to local authorities for determining acceptability and permissibility of land uses, which are presented below in Table 14. These guidelines were derived from case histories involving aircraft noise

problems at civilian and military airports and the resultant community responses and conclude that residential uses are acceptable with noise exposures up to 65 dB DNL. However, the regulation guidelines state, “the responsibility for determining the acceptability and permissible land uses remains with the local authorities.”

FAR Part 150 prescribes the procedures, standards, and methodology governing the development, submission, and review of airport noise exposure maps and airport noise compatibility programs. Airports are not required to prepare noise exposure maps and noise compatibility programs but doing so is required for the use of federal funds or passenger facility charge (PFC) funds to implement these programs. Noise compatibility programs are required to assess several noise abatement options but are not limited to these options. However, the regulation presents a list of requirements for any adopted policies or programs. The options that are required to be analyzed are; acquisition of land and interests therein, construction of barriers and acoustical shielding, soundproofing of public buildings, the implementation of a preferential runway system, modification of flight tracks to limit noise exposure in sensitive areas, and, implementation of restrictions on aircraft that can use the airport. It should be noted that these programs are required to examine both existing incompatible land use and consider remedial actions to address existing land-use noise compatibility issues as well as examining potential future land uses and consider preventative actions to avoid future issues.

In 1990, as a part of the FAA’s reauthorization the FAA was prohibited from approving noise compatibility programs that call for the use of Airport Improvement Program (AIP) funds to mitigate noise impacts from exposures below 65 LDN.

The Airport Noise And Capacity Act of 1990 (PL 101-508,104 Stat 1388), also known as ANCA or the Noise Act, required that the FAA establish a method to review aircraft access restrictions proposed by airport proprietors and to institute a program to phase out older, noisier Stage 2 aircraft over 75,000 pounds (B737-200, B727, and DC9) by December 31, 1999. Stage 2 is the first aircraft certification standard applicable to aircraft certified after 1969. Stage 3 aircraft are newer quieter aircraft (B737-300, B757, MD80/90). All aircraft certified after 1977 were required to achieve the Stage 3 standard. In 2001, Stage 4 noise standards were adopted but most aircraft complying with the Stage 3 requirements also complied with the Stage 4 standard. Stage 2 aircraft fitted with “hush kits” to meet the Stage 3 standard generally were not compliant with Stage 4 standards. All aircraft certified after 2006 are required to meet the Stage 4 noise standards. In early 2013, the International Civil Aviation Organization (ICAO) recommended the adoption of Chapter 5 standards 7 dB less than the current Stage 4 standards. Note that ICAO refers to the “Stage” categories as Chapters. Typically, the FAA, which is a member of ICAO, adopts the equivalent ICAO aircraft noise standard but uses the term “Stage” to identify the categories.

To implement ANCA, the FAA adopted two regulations, Part 91 and Part 161. Part 91 implemented the ban Stage 2 aircraft over 75,000 pounds after December 31, 1999. The domestic airline fleet in the mainland US became all Stage 3 in the year 2000. The ban was not applicable in the States of Hawaii or Alaska. Part 161 sets out the requirements and procedures for implementing any new airport use and access restrictions by airport proprietors. Airports with use and access restrictions adopted prior to 1990, such as those at Orange County’s John Wayne Airport and Long Beach Airport, are ‘grandfathered’ under the terms of the act.

**Table 14**  
**FAA Part 150 Noise Compatibility Guidelines**

Land use	Yearly day-night average sound level (L <sub>dn</sub> ) in decibels					
	<65	65-70	70-75	75-80	80-85	> 85
<b>Residential</b>						
Residential, other than mobile homes and transient lodgings	Y	N <sup>1</sup>	N <sup>1</sup>	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N <sup>1</sup>	N <sup>1</sup>	N <sup>1</sup>	N	N
<b>Public Use</b>						
Schools	Y	N <sup>1</sup>	N <sup>1</sup>	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y <sup>2</sup>	Y <sup>3</sup>	Y <sup>4</sup>	Y <sup>4</sup>
Parking	Y	Y	Y <sup>2</sup>	Y <sup>3</sup>	Y <sup>4</sup>	N
<b>Commercial Use</b>						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware and farm equipment	Y	Y	Y <sup>2</sup>	Y <sup>3</sup>	Y <sup>4</sup>	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y <sup>2</sup>	Y <sup>3</sup>	Y <sup>4</sup>	N
Communication	Y	Y	25	30	N	N
<b>Manufacturing and Production</b>						
Manufacturing, general	Y	Y	Y <sup>2</sup>	Y <sup>3</sup>	Y <sup>4</sup>	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y <sup>6</sup>	Y <sup>7</sup>	Y <sup>8</sup>	Y <sup>8</sup>	Y <sup>8</sup>
Livestock farming and breeding	Y	Y <sup>6</sup>	Y <sup>7</sup>	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
<b>Recreational</b>						
Outdoor sports arenas and spectator sports	Y	Y <sup>5</sup>	Y <sup>5</sup>	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

**Key:**

Y (Yes)=Land Use and related structures compatible without restrictions.

N (No)=Land Use and related structures are not compatible and should be prohibited.

(Key Continued on Next Page)

25, 30, or 35=Land use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structure  
NLR=Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.

**Notes:**

- (1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus, the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.
- (2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
- (3) Measures to achieve NLR of 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.
- (4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal level is low.
- (5) Land use compatible provided special sound reinforcement systems are installed.
- (6) Residential buildings require an NLR of 25.
- (7) Residential buildings require an NLR of 30.
- (8) Residential buildings not permitted.

One of the major purposes of ANCA was to discourage local airport use restrictions more stringent than the Stage 2 phase out required by ANCA. Correspondingly, the Part 161 requirements to implement an airport use restriction program are considerable. To date, only one airport, Naples Airport in Florida, has received approval to implement a use restriction program. However, the approval was for only a part of the plan proposed by the airport. Plans developed for Burbank and Van Nuys Airports have not been approved by the FAA.

FAA Order 5050.4B presents the agency's policies for implementing NEPA for airport actions (Federal Aviation Administration, 2006). FAA Order 1050.1E, CHG1 presents the agency's policies and procedures for assessing environmental impacts (Federal Aviation Administration, 2006) and provides the FAA's definition of a significant noise impact. The FAA considers an airport action to have a significant noise impact if it results in a 1.5 dB or greater increase in LDN and results in a noise level exceeding 65 dB LDN in noise sensitive areas. For example, an increase from 63.5 dB to 65 dB is considered a significant impact. The policy goes on to state that if a screening analysis shows that noise sensitive uses will be significantly impacted using the criteria above, an examination of potential noise impacts to sensitive areas exposed to noise level between 60 and 65 dB LDN should be performed. The policy potential for mitigation in areas projected to be exposed to noise levels between 60 and 60 dB LDN and experiencing an increase of 3 dB LDN or more should be considered. The policy directs that the same range of mitigation options available for areas exposed to 65 dB LDN and higher should be considered along with eligibility for federal funding. However, the policy states, "This is not to be interpreted as a commitment to fund or otherwise implement mitigation measures in any particular area."

One of the sound abatement alternatives under the FAR Part 150 program is a sound insulation program. The Federal Aviation Administration (FAA) guidelines for these programs are identified in the FAA's "*Airport Improvement Program Handbook*", Order 5100.38C, Chapter 8, Section 2 – Noise Compatibility Projects, paragraph 812. It should be noted that a draft of Order 5100.38D has been released and is currently under review. The FAA approves assistance to airports by the funding of sound insulation programs when structures (which include residences, schools and places of worship) are located within the 65 dB DNL contour (CNEL in California) of the approved Noise Exposure Maps that are developed as part of an airport's FAR Part 150 Study. These guidelines require that the sound insulation for residences should provide an improvement of the sound reduction provided by the structure of at least 5 dB and a resulting interior noise level of 45 LDN in all habitable rooms. For schools, the program is required to improve the sound reduction provided by the structure by at least 5 dBA and an interior noise level of 45 Leq(day).

## **B1.5 Department of Housing and Urban Development**

Part 51, Subpart B of Title 24 of the Code of Federal Regulations (24 CFR 51.B) presents the noise exposure requirements for residential uses receiving funding from the U.S. Department Housing and Urban Development (HUD). These requirements effectively set an outdoor residential noise standard of 65 dB LDN (or CNEL) and an indoor standard of 45 dB LDN. Projects exposed to noise levels less than 65 dB LDN are considered compatible and require no additional review. Projects with noise exposures between 65 and 75 dB LDN are considered normally unacceptable. Projects with this level of noise exposure are required to implement sound barriers (walls, berms or wall/berm combination) to reduce exterior noise exposures to less than 65 dB LDN and demonstrate that the outdoor-to-indoor noise reduction is sufficient to achieve an interior noise level of 45 dB LDN or less. Projects with noise exposures exceeding 75 dB Ldn are considered unacceptable. However, projects with these exposures can be implemented if it can be demonstrated that the outdoor and indoor noise levels meet the 65 dB LDN and 45 dB LDN standards and require special approval by the Assistant Secretary for Community Planning and Development.

## **B.2 State of California**

The State of California has historically been forward thinking in regulating environmental impacts. As discussed above, California established 65 dB CNEL as the noise impact boundary for airports prior to the Federal Government promulgating airport noise standards. The current California Airport noise standard is presented in Section B.2.1. Every city and county in California is required to prepare a comprehensive General Plan and one of the required elements of these plans is a Noise Element to ensure that noise is considered in municipal planning. The Governor's Office of Planning and Research has prepared guidelines for the content of these plans including providing recommended land use noise compatibility recommendations. These are discussed in Section B.2.2. The state's building code contains requirements for interior noise levels in new residential buildings are discussed in Section B.2.3. In the 1960's and 1970's the California Department of Health included an Office of Noise Control. In 1977 this office published a Model Noise Ordinance for cities and counties to use in developing their own noise ordinances. The recommendations from the Model Noise Ordinance are presented in Section B.2.4.

### **B.2.1 Airport Noise Standards**

Subchapter 6, Noise Standards, of Title 21, Division of Aeronautics, of the California Code of Regulations provides noise standards for all airports operating under a valid permit issued by the Department of Transportation. This regulation establishes "the level of noise acceptable to a reasonable person residing in the vicinity of an airport" to be 65 dB CNEL. The regulation continues, "This criterion level has been chosen for reasonable persons residing in urban residential areas where houses are of typical California construction and may have windows partially open. It has been selected with reference to speech, sleep, and community reaction."

The regulation defines the Noise Impact Area as the area exposed to noise levels exceeding 65 dB CNEL that is comprised of incompatible land use. Residences are considered incompatible land uses unless; (1) an aviation easement has been acquired, (2) the dwelling unit was constructed prior to January 1, 1989 and has adequate acoustic insulation so that interior levels do not exceed 45 dB CNEL and the residence does not have a exterior normally occupiable private habitable area such as a backyard, balcony, or patio exposed to an aircraft noise level exceeding 75 dB CNEL, (3) the residence is a high rise apartment or condominium with an air circulation or air conditioning system and an interior noise level less than 45 dB CNEL, (4) the airport proprietor has made a genuine effort to acoustically treat residences with an exterior exposure less than 80 dB CNEL (75 dB CNEL if the residence has a private outdoor area) or acquire aviation easements, or both, for the impacted residences but the property owners have declined to take part in the program, or (5) the residence is owned by the airport proprietor. Public and private schools, hospitals,

convalescent homes, churches, synagogues, temples and other places of worship are also identified as incompatible land uses if interior noise levels exceed 45 dB CNEL and no aviation easement has been acquired.

Airports with incompatible land uses exposed to aircraft noise levels exceeding 65 dBA CNEL are identified by Counties as Noise Problem Airports. Designated noise problem airports are required to establish noise-monitoring plans to validate the location of the noise impact boundary. Furthermore, each airport is required to submit quarterly reports showing the location of the noise impact boundary as validated by measurement data along with other information regarding the noise measurements and airport operations. The regulation prohibits operating a designated noise problem airport with a noise impact area unless a variance is obtained from the division of aeronautics. Variances require the airport proprietor to prepare and implement programs to reduce the noise impact area to an acceptable degree in an orderly manner over a reasonable period of time. Variances are granted if to do so would be in the public interest considering the economic and technological feasibility of complying with the noise standards, the noise impact that would occur with the variance, and the value to the public of the services granted under the variance, and whether the airport proprietor is taking good faith measures to the best of its ability to achieve airport noise standards.

## **B.2.2 General Plan Guidelines**

Each City and County in California must prepare a comprehensive, long-term general plan for the development of its community. The Governor's Office of Planning and Research (OPR) are required to adopt and periodically revise guidelines for the preparation and content of local general plans (Governor's Office of Planning And Research, 2003). One of the required general plan elements is a Noise Element. Appendix C of the OPR Guidelines presents specific guidelines for preparation of a noise element along with recommended land-use noise compatibility guidelines along with factors recommended to adjust the guideline noise levels based on the specific source. Figure 10 presents the recommended land-use noise compatibility guidelines and Table 15 shows the recommended adjustments. Table 2 presented in Section 3.1.1.1 presents the land-use noise compatibility guidelines adopted in the City of Los Angeles Noise Element.

The objective of the noise compatibility guidelines is to provide communities with a means of judging the noise environment they deem to be generally acceptable. A range of values is given to accommodate the variability in perceptions of environmental noise that exist between communities and within a given community. The adjustment factors can be applied to account for some of the factors that may cause the noise to be more or less acceptable than the mean response.

Land Use Category	Community Noise Exposure LDN or CNEL, dB					
	55	60	65	70	75	80
Residential - Low Density Single Family, Duplex, Mobile Homes						
Residential - Multi. Family						
Transient Lodging - Motels Hotels						
Schools, Libraries, Churches, Hospitals, Nursing Homes						
Auditoriums, Concert Halls, Amphitheaters						
Sports Arena, Outdoor Spectator Sports						
Playgrounds, Neighborhood Parks						
Golf Courses, Riding Stables, Water Recreation, Cemeteries						
Office Buildings, Business Commercial and Professional						
Industrial, Manufacturing, Utilities, Agriculture						

**INTERPRETATION:**



**Normally Acceptable**

Specified land use is satisfactory, based upon the assumption that any buildings involved are of normal conventional construction, without any special noise insulation requirements



**Conditionally Acceptable**

New construction or development should be undertaken only after a detailed analysis of the noise reduction requirements is made and needed noise insulation features included in the design. Conventional construction, but with closed windows and fresh air supply systems or air conditioning will normally suffice.



**Normally Unacceptable**

New construction or development should generally be discouraged. If new construction or development does proceed, a detailed analysis of the noise reduction requirements must be made and needed noise insulation features included in the design.



**Clearly Unacceptable**

New construction or development should generally not be undertaken.

**Figure 10 - California Land-Use Noise Compatibility Guidelines**



HARBOR COMMUNITY  
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**Table 15**  
**Noise Compatibility Adjustment Factors**

Type of Correction	Description	Amount of Correction*
<b>Seasonal Correction</b>	Summer (or year-round operation)	<b>0</b>
	Winter only (or windows always closed)	<b>-5</b>
<b>Correction for Outdoor Residual Noise Level</b>	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	<b>+10</b>
	Quiet suburban or rural community (not located near industrial activity)	<b>+5</b>
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial uses)	<b>0</b>
	Noisy urban residential community (near relatively busy roads or industrial areas)	<b>5</b>
	Very noisy urban residential community.	<b>-10</b>
<b>Correction for Previous Exposure and Community Attitudes</b>	No prior experience with the intruding noise.	<b>-5</b>
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but people are aware that bona fide efforts are being made to control the noise.	<b>0</b>
	Community has had some previous exposure to intruding noise and the noisemaker's relations with the community are good.	<b>-5</b>
	Community aware that operation-causing noise is very necessary and will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances	<b>-10</b>
<b>Pure Tone or Impulse</b>	No pure tone or impulsive character.	<b>0</b>
	Pure Tone or impulsive character present.	<b>5</b>

\* Value to be added to measured CNEL in dB.

### B.2.3 Building Code (Title 24)

Section 1207.11 of the 2010 California Building Code (State of California, 2010) requires that residential structures located where the noise level exceeds 60 dBA LDN (or CNEL) require an acoustical analysis demonstrating that the proposed design will limit interior noise from exterior sources to 45 dBA LDN (or CNEL). If the interior noise limits are met by requiring that windows remain closed, the design for the structure must also specify a ventilation or air conditioning system to provide a habitable interior environment. The ventilation system is required to not compromise the noise reduction, that is, the noise generated by the ventilation system must not result in the combined noise level to exceed 45 dBA LDN (or CNEL). It should be noted that prior to the 2010 revision to the building code the interior noise level requirement was restricted to multi-family dwelling units

## B.2.4 Model Noise Ordinance

In 1977 the California Department of Health's Office of Noise Control prepared a guidance document for municipalities wishing to enact noise control ordinances to regulate noise generated on one property from significantly impacting adjacent properties. (Office of Noise Control, 1977). Table 16 presents the recommended base exterior noise limits from the Model Noise Ordinance. These represent the maximum noise levels that cannot be exceeded for more than 30 minutes per hour or L50. Allowable noise levels would be further restricted to the base noise limit + 5 dB not to be exceeded for more than 15 minutes per hour (L25), the base limit +10 dB for more than 5 minutes in any hour (L8.3), the base +15 dB for more than 1 minute in any hour (L1.6) and the base +20 dB for any period of time.

Multiple noise limits are specified for residential uses depending on their setting. Most often municipalities choose one of these classifications for their noise ordinance. If the measurement location is on the boundary of land use categories it is recommended that the lower standard +5 dBA be applied. The limits should be reduced by 5 dBA if the offending noise source is a pure tone or impulsive. Additionally, the allowable noise level is to be adjusted upward in 5 dB increments if the ambient noise level, without the offending source, exceeds the noise level limits. If the ambient maximum noise level exceeds the limit then the limit should be increased to the maximum ambient noise level.

It should be noted that the hourly Leq noise level from a source operating just within the recommended noise ordinance limits would be 8.3 dBA higher than the base noise level shown in Table 16. However, it is unlikely that a noise source would operate in such a manner. In most cases the hourly Leq noise level near a source just complying with the standards would be approximately 5 dBA higher than the base noise levels.

The Model Ordinance also suggests interior noise standards to be applied to multi-family residential units. The recommended nighttime (10:00 p.m. to 7:00 a.m.) interior noise levels are not to exceed 35 dBA for more than 5 minutes in any hour (L8.3), 40 dBA for more than one minute in an hour (L1.6) and 45 dBA for any period of time (Lmax). The recommended allowable daytime interior noise levels are 10 dB higher. A noise source just complying with the standards would generate a Leq noise level of 36.1 dB during the nighttime and 46.1 dB during the daytime.

The Model Ordinance also suggests a "noise disturbance" provision, "No person shall unnecessarily make, continue, or cause to be made or continued, any noise disturbance." However, it is suggested that enforcement actions under this provision should be used with caution because the nuisance must be shown to be a public disturbance, which is difficult to prove in court.

Specific standards are recommended for noise sources that would be difficult, if not impossible, to enforce because of the variability and intermittency such as barking dogs, street sales, or loading/unloading activities or are best controlled with specific noise level limits or time restrictions. Typically noise from loading/unloading activities, construction and property maintenance, powered model vehicles, non-emergency signaling devices and testing of emergency signaling devices is most effectively regulated by limiting these activities to daytime hours and the model ordinance presents recommendations. Recommendations for noise limits from HVAC equipment are also given, limiting HVAC system noise to 55 dBA at any point on a neighboring property and 50 dBA at any patio or outside the nearest neighboring window.

**Table 16**  
**Model Noise Ordinance Recommended Exterior Noise Limits**  
**(Levels Not to be Exceeded for More than 30 Minutes in Any Hour)**

Receiving Land Use Category	Time Period	Noise Zone Classification*		
		Rural Suburban	Suburban	Urban
One & Two Family Residential	10 pm - 7 am	40 dBA	45 dBA	50 dBA
	7 am - 10 pm	50 dBA	55 dBA	60 dBA
Multiple Dwelling Residential Public Space	10 pm - 7 am	45 dBA	50 dBA	55 dBA
	7 am - 10 pm	50 dBA	55 dBA	60 dBA
Limited Commercial Some Multiple Dwellings	10 pm - 7 am		55 dBA	
	7 am - 10 pm		60 dBA	
Commercial	10 pm - 7 am		60 dBA	
	7 am - 10 pm		65 dBA	
Light Industrial	Any Time		70 dBA	
Heavy Industrial	Any Time		75 dBA	

\* The classification of different areas of the community in terms of the environmental noise zones shall be determined by the Noise Control Office(r), based on assessment of community noise survey data. Additional area classifications should be used as appropriate to reflect both lower and higher existing ambient levels than those shown. Industrial noise limits are intended primarily for use at the boundary of industrial zones rather than for noise reduction within the zone.

It is suggested that certain activities be exempted from the noise limits. These include emergency operations, occasional outdoor gatherings, public dances, shows, and sporting and entertainment events conducted pursuant to a permit or license issued by the municipalities and certain agricultural operations.