APPENDIX I
Noise and Vibration Technical Report

NOISE AND VIBRATION TECHNICAL REPORT

For the Proposed
Culver Studio Innovation Plan

Culver City, CA

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ACRONYMS AND ABBREVIATIONS

Acronym	Description
Caltrans	California Department of Transportation
CNEL	Community Noise Equivalent Level
dB	decibel
dBA	A-weighted dB scale
FTA	Federal Transit Administration
L_{eq}	Equivalent Sound Level
L_{max}	Maximum Noise Level
PPV	peak particle velocity
TeNS	Caltrans Technical Noise Supplement

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EXECUTIVE SUMMARY

The purpose of this Noise and Vibration Technical Report is to assess and discuss the impacts of potential noise and vibration impacts that may occur with the implementation of the proposed Innovation Plan ("Project"). The Studio proposes to technologically update and expand its facilities within the existing Studio Campus footprint, while retaining the Studio's unique ambiance and prominent place in the community. The Innovation Plan encompasses flexible and sustainable digital media space, adaptive reuse and reinvigoration of prominent buildings, inviting and collaborative landscaped open areas, sensitive treatment of neighborhood interfaces, and redesigned and improved access. The Innovation Plan is reflected in proposed Comprehensive Plan Amendment No. 7 (CPA No. 7) and includes some improvements approved under Comprehensive Plan Amendment No. 6 (CPA No. 6) but not yet constructed.

The analysis describes the existing noise environment in the vicinity of the Project Site, estimates future noise and vibration levels at surrounding land uses resulting from construction and operation of the Project, and identifies the potential for significant noise impacts based on applicable noise and vibration threshold of significance. Noise worksheets and technical data used in this analysis are provided in Appendices A-D of this report. The findings of the analyses are as follows:

- Construction activities would be required to comply with Culver City's allowable construction hours of between 8:00 A.M. and 8:00 P.M. Mondays through Friday, 9:00 A.M. and 7:00 P.M. Saturdays, and 10:00 A.M. and 7:00 P.M. Sundays, and would be temporary in nature. Through compliance with Culver City's allowable construction hours, Mitigation Measures MM-NOISE-1 through MM-NOISE-3, and project design features PDF-NOISE-1, PDF-NOISE-2, and PDF-NOISE-7 through PDF-NOISE-9, noise impacts related to on-site construction activities would be less than significant at noise sensitive receptor locations.
- Off-site haul truck trip would not substantially increase noise levels over the ambient condition. In addition, construction activities would occur only during daytime hours within the allowable hours specified in the City's Municipal Code. Therefore, noise impacts from off-site construction traffic would be less than significant and no mitigation measures are required.
- The Project's noise impacts on existing development from operational on-site stationary noise sources would be less than significant with implementation of project design features PDF-NOISE-3 through PDF-NOISE-6, and PDF-NOISE-10. Project operational traffic would increase noise levels at off-site noise-sensitive uses in the Project area. Increases in ambient noise levels due to operational traffic would not exceed the established thresholds. Operational traffic-related noise impacts would be less than significant.
- Project operation would not generate excessive vibration levels at nearby sensitive receptor locations. Thus, long-term vibration impacts would be less than significant.
- Temporary construction-related vibration would exceed the established threshold for structure damage and human annoyance to the adjacent residential uses south of the Project site and to on-site historical structures. However, vibration generated by on-site construction activities would have a less than significant impact on surrounding and on-site uses with incorporation of Mitigation Measures MM-NOISE-3 and MM-NOISE-4.

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1. PROJECT DESCRIPTION AND EXISTING NOISE SETTING

ESA PCR has conducted an acoustical study with respect to potential noise and vibration impacts from construction activities, surface transportation, and other aspects of Project operations that are noise and vibration intensive and that have the potential to impact existing off-site noise sensitive land uses and existing on- and off-site vibration-sensitive land uses. The objectives of this noise study are to:

a. Quantify the existing ambient noise environment at the Project site;
b. Evaluate construction related noise and vibration impacts and the traffic and operational noise and vibration impacts to noise sensitive receptors;
c. Provide, if needed, noise mitigation measures as required to meet applicable noise regulations and standards including interior sound level standards as specified by Culver City (City).

In addition, the compatibility of siting new noise- and vibration-sensitive land uses within a built, urban environment was assessed, and performance measures were specified to demonstrate the Project's ability to meet the applicable noise and vibration standards.

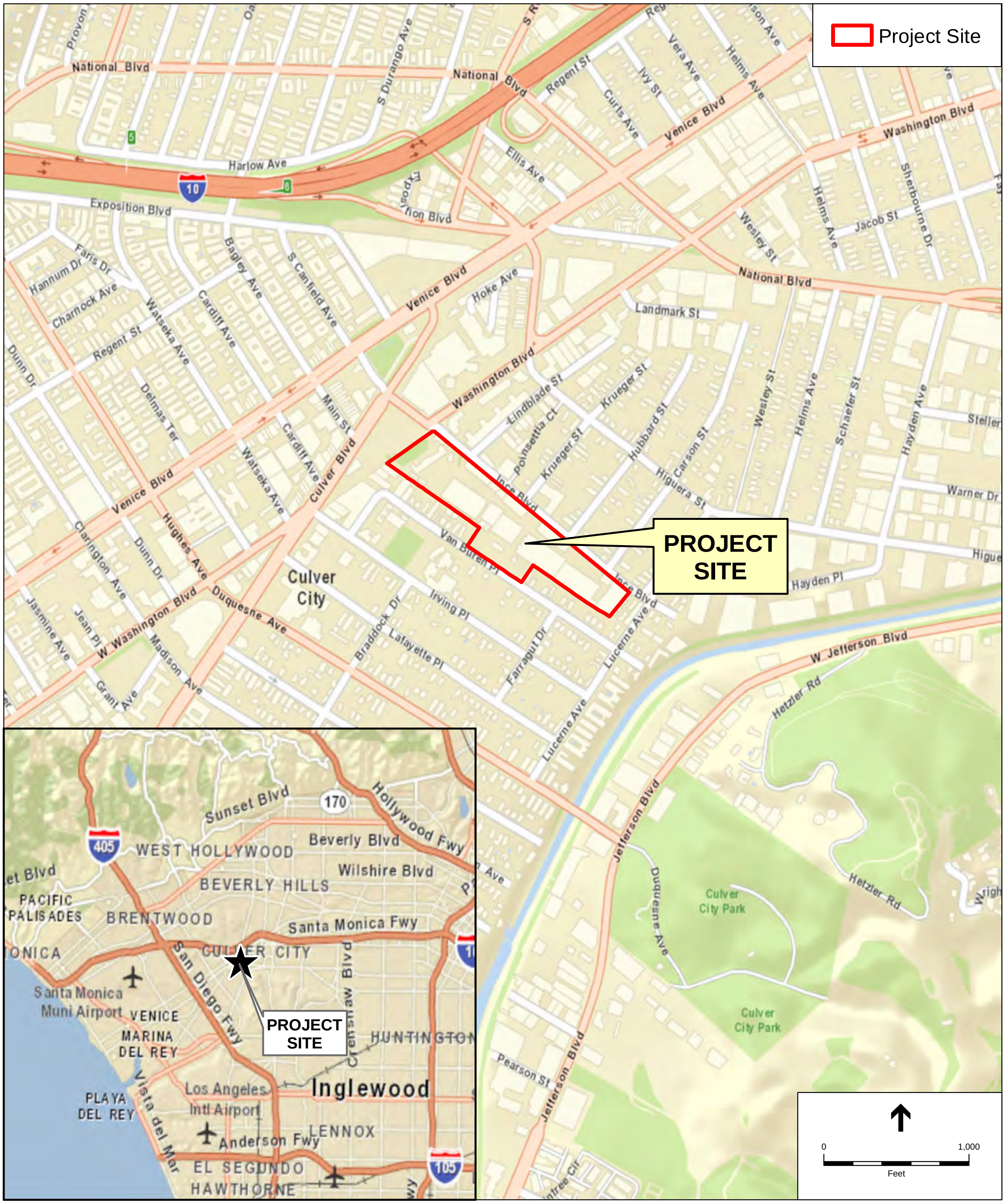
1.1 PROJECT LOCATION

The Project Site encompasses approximately 14 acres at 9336 W. Washington Boulevard in downtown Culver City. The Studio is generally bounded by the vacated portion of Washington Boulevard to the north, Ince Boulevard to the east, Van Buren Place and residential development to the west, and Lucerne Avenue to the south. **Figure 1**, *Regional and Project Vicinity Locations*, for the location of The Culver Studios.

1.2 EXISTING SITE CONDITIONS

Adjacent and surrounding land uses include, to the north, commercial retail uses, the Culver Hotel, and surface parking (Parcel B),[1] fronting on vacated Washington Boulevard and Culver Boulevard. To the east, across Ince Boulevard, are entertainment-related light industrial and studio facilities, including some affiliated with The Culver Studios, and single- and low-density multi-family residential uses. To the west, single- and low-density multi-family residential uses on Van Buren Place abut the Studio Campus, with Linwood E. Howe Elementary School located across Van Buren Place. To the south, multi-family residential uses abut the Studio Campus and primarily front on Lucerne Avenue.

[1] *The downtown Parcel B and Town Plaza Expansion is a mixed-use project that includes 74,600 square feet of office, 21,700 square feet of retail, and 21,700 square feet of restaurant uses with subterranean parking.*



SOURCE: ESRI Street Map, 2010.

The Culver Studios Innovation Plan

Figure 1

Regional and Vicinity Location Map

ESA PCR

1.3 PROJECT DESCRIPTION

The Culver Studios Innovation Plan proposes to modernize and expand the existing Central Area, encompassing the portion of the Studio Campus south of the Mansion and proposed Relocated Bungalow Area just south of the Mansion. Proposed improvements include the construction of six new Digital Media buildings which would house a flexible mix of creative space, production space, and digital media stages, and would replace six existing buildings housing offices and support services (Buildings L, O, X, Y, Z, and the Commissary) and four existing buildings housing sound stages, which would be demolished. The Project would also include: (1) the development of a new subterranean Central Parking Structure, and would replace the existing Van Buren Parking Structure with a new below- at- and above-grade Van Buren Parking Structure; (2) the decentralization of central plant (e.g., utility) facilities; (3) the accommodation of production vehicle staging and parking, service vehicle operation, deliveries, and trash activities, below grade where they currently occur above-grade; and (4) circulation and Studio gate improvements intended to improve overall vehicle queuing and backups on Ince Boulevard. **Figure 2**, *Site Plan Concept*, illustrates the site plan concept for the Project.

The Project would entail a multi-phased, approximate 31-month construction period. Construction is anticipated to start in the first quarter of 2018 and be completed in mid-2020.

1.3 NOISE AND VIBRATION BASICS

1.3.1 Noise

Sound can be described as the mechanical energy of a vibrating object transmitted by pressure waves through a liquid or gaseous medium (e.g., air). Noise is generally defined as unwanted sound (i.e., loud, unexpected, or annoying sound). Acoustics is defined as the physics of sound. In acoustics, the fundamental scientific model consists of a sound (or noise) source, a receiver, and the propagation path between the two. The loudness of the noise source and obstructions or atmospheric factors affecting the propagation path to the receiver determines the sound level and characteristics of the noise perceived by the receiver. Acoustics primarily addresses the propagation and control of sound.

Sound, traveling in the form of waves from a source, exerts a sound pressure level (referred to as sound level) that is measured in decibels (dB), which is the standard unit of sound amplitude measurement. The dB scale is a logarithmic scale that describes the physical intensity of the pressure vibrations that make up any sound, with 0 dB corresponding roughly to the threshold of human hearing and 120 to 140 dB corresponding to the threshold of pain. Pressure waves traveling through air exert a force registered by the human ear as sound.

Sound pressure fluctuations can be measured in units of hertz (Hz), which correspond to the frequency of a particular sound. Typically, sound does not consist of a single frequency, but rather a broad band of frequencies varying in levels of magnitude, with audible frequencies of the sound spectrum ranging from 20 to 20,000 Hz. The typical human ear is not equally sensitive to this frequency range. As a consequence, when assessing potential noise impacts, sound is measured using an electronic filter that deemphasizes the frequencies below 1,000 Hz and above 5,000 Hz in a manner corresponding to the human ear’s decreased sensitivity to these extremely low and extremely high frequencies. This method of frequency filtering or weighting is referred to as A-weighting, expressed in units of A-weighted decibels (dBA), which is typically applied to community noise measurements. Some representative common outdoor and indoor noise sources and their corresponding A-weighted noise levels are shown in **Figure 3**, *Decibel Scale and Common Noise Sources*.

1.3.2 Noise Exposure and Community Noise

An individual's noise exposure is a measure of noise over a period of time; a noise level is a measure of noise at a given instant in time, as presented in Figure 3. However, noise levels rarely persist at that level over a long period of time. Rather, community noise varies continuously over a period of time with respect to the sound sources contributing to the community noise environment. Community noise is primarily the product of many distant noise sources, which constitute a relatively stable background noise exposure, with many of the individual contributors unidentifiable. The background noise level changes throughout a typical day, but does so gradually, corresponding with the addition and subtraction of distant noise sources, such as changes in traffic volume. What makes community noise variable throughout a day, besides the slowly changing background noise, is the addition of short-duration, single-event noise sources (e.g., aircraft flyovers, motor vehicles, sirens), which are readily identifiable to the individual.

These successive additions of sound to the community noise environment change the community noise level from instant to instant, requiring the noise exposure to be measured over periods of time to legitimately characterize a community noise environment and evaluate cumulative noise impacts. The following noise descriptors are used to characterize environmental noise levels over time, which are applicable to the Project.

L_{eq}: The equivalent sound level over a specified period of time, typically, 1 hour ($L_{eq(1)}$). The L_{eq} may also be referred to as the average sound level.

L_{max}: The maximum, instantaneous noise level experienced during a given period of time.

L_{min}: The minimum, instantaneous noise level experienced during a given period of time.

L_x: The noise level exceeded a percentage of a specified time period. For instance, L_{50} and L_{90} represent the noise levels that are exceeded 50 percent and 90 percent of the time, respectively.

L_{dn}: The average A-weighted noise level during a 24-hour day, obtained after an addition of 10 dB to measured noise levels between the hours of 10:00 P.M. to 7:00 A.M. to account nighttime noise sensitivity. The L_{dn} is also termed the day-night average noise level (DNL).

CNEL: The Community Noise Equivalent Level (CNEL) is the average A-weighted noise level during a 24-hour day that includes an addition of 5 dB to measured noise levels between the hours of 7:00 A.M. to 10:00 P.M. and an addition of 10 dB to noise levels between the hours of 10:00 P.M. to 7:00 A.M. to account for noise sensitivity in the evening and nighttime, respectively.

Note: Individual building square footages indicated are approximate and may shift as designs are refined, but will not exceed the total shown here and indicated in Table 2-2 of the Project Description.

SOURCE: Gensler, 2017

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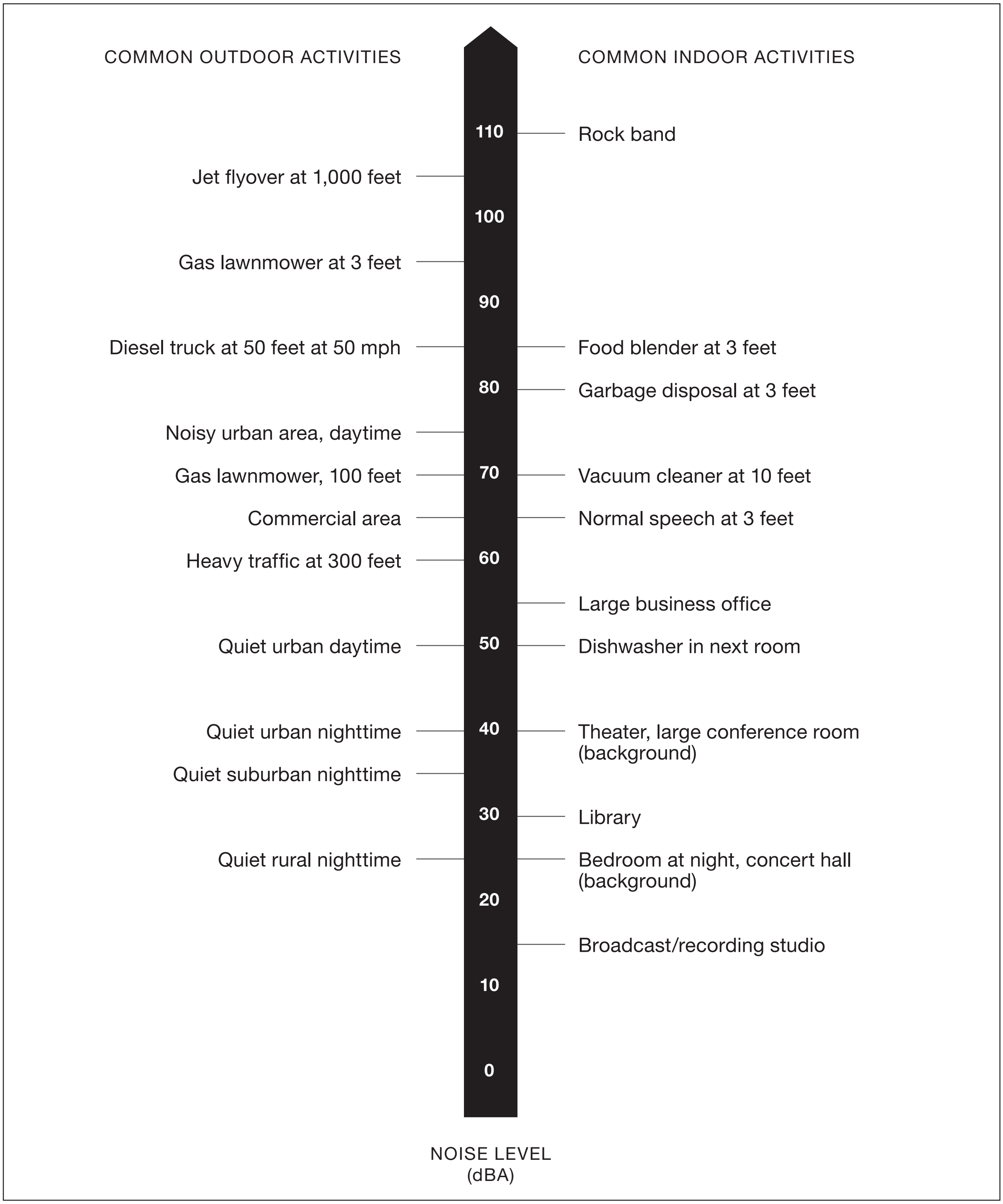
The Culver Studios Innovation Plan

Figure 2

Site Plan Concept



SOURCE: Caltrans

Figure 3
Decibel Scale and Common Noise Sources

1.3.3 Effects of Noise on People

Noise is generally loud, unpleasant, unexpected, or undesired sound that is typically associated with human activity that is a nuisance or disruptive. The effects of noise on people can be placed into four general categories:

- Subjective effects (e.g., dissatisfaction, annoyance)
- Interference effects (e.g., communication, sleep, and learning interference)
- Physiological effects (e.g., startle response)
- Physical effects (e.g., hearing loss)

Although exposure to high noise levels has been demonstrated to cause physical and physiological effects, the principal human responses to typical environmental noise exposure are related to subjective effects and interference with activities. Interference effects interrupt daily activities and include interference with human communication activities, such as normal conversations, watching television, telephone conversations, and interference with sleep. Sleep interference effects can include both awakening and arousal to a lesser state of sleep.

With regard to the subjective effects, the responses of individuals to similar noise events are diverse and influenced by many factors, including the type of noise, the perceived importance of the noise, the appropriateness of the noise to the setting, the duration of the noise, the time of day and the type of activity during which the noise occurs, and individual noise sensitivity. Overall, there is no completely satisfactory way to measure the subjective effects of noise, or the corresponding reactions of annoyance and dissatisfaction on people. A wide variation in individual thresholds of annoyance exists, and different tolerances to noise tend to develop based on an individual's past experiences with noise. Thus, an important way of predicting a human reaction to a new noise environment is the way it compares to the existing environment to which one has adapted (i.e., comparison to the ambient noise environment). In general, the more a new noise level exceeds the previously existing ambient noise level, the less acceptable the new noise level will be judged by those hearing it. With regard to increases in A-weighted noise level, the following relationships generally occur[2]:

- Except in carefully controlled laboratory experiments, a change of 1 dBA in ambient noise levels cannot be perceived.
- Outside of the laboratory, a 3 dBA change in ambient noise levels is considered to be a barely perceivable difference.
- A change in ambient noise levels of 5 dBA is considered to be a readily perceivable difference.
- A change in ambient noise levels of 10 dBA is subjectively heard as doubling of the perceived loudness.

These relationships occur in part because of the logarithmic nature of sound and the decibel scale. The human ear perceives sound in a non-linear fashion; therefore, the dBA scale was developed. Because the dBA scale is based on logarithms, two noise sources do not combine in a simple additive fashion, but rather logarithmically. Under the dBA scale, a doubling of sound energy corresponds to a 3 dBA increase. In other words, when two sources are each producing sound of the same loudness, the resulting sound level at a given distance would be approximately 3 dBA higher than one of the sources under the same conditions. For example, if two identical noise sources produce noise levels of 50 dBA, the combined sound level would be 53 dBA, not 100 dBA. Under the dBA scale, three sources of

2 *California Department of Transportation (Caltrans), Technical Noise Supplement (TeNS), Section 2.2.1, September, 2013.*

equal loudness together produce a sound level of approximately 5 dBA louder than one source, and ten sources of equal loudness together produce a sound level of approximately 10 dBA louder than the single source. [3]

1.3.4 Noise Attenuation

When noise propagates over a distance, the noise level reduces with distance depending on the type of noise source and the propagation path. Noise from a localized source (i.e., point source) propagates uniformly outward in a spherical pattern, referred to as "spherical spreading." Stationary point sources of noise, including stationary mobile sources such as idling vehicles, attenuate (i.e., reduce) at a rate of between 6 dBA for acoustically "hard" sites and 7.5 dBA for "soft" sites for each doubling of distance from the reference measurement, as their energy is continuously spread out over a spherical surface (e.g., for hard surfaces, 80 dBA at 50 feet attenuates to 74 at 100 feet, 68 dBA at 200 feet, etc.). Hard sites are those with a reflective surface between the source and the receiver, such as asphalt or concrete surfaces or smooth bodies of water. No excess ground attenuation is assumed for hard sites and the reduction in noise levels with distance (i.e., distance loss) is simply the geometric spreading of the noise from the source. Soft sites have an absorptive ground surface, such as soft dirt, grass, or scattered bushes and trees, which in addition to geometric spreading, provides an excess ground attenuation value of 1.5 dBA (per doubling distance).[4] Most sites are a combination of both hard and soft surfaces; therefore, using the hard site criteria of 6 dBA is the more conservative approach.

Roadways and highways consist of several localized noise sources on a defined path, and hence are treated as "line" sources, which approximate the effect of several point sources. Noise from a line source propagates over a cylindrical surface, often referred to as "cylindrical spreading." Line sources (e.g., traffic noise from vehicles) attenuate at a rate between 3 dBA for hard sites and 4.5 dBA for soft sites for each doubling of distance from the reference measurement.[5] Therefore, noise due to a line source attenuates less with distance than that of a point source with increased distance.

Additionally, receptors located downwind from a noise source can be exposed to increased noise levels relative to calm conditions, whereas locations upwind can have lowered noise levels. Atmospheric temperature inversion (i.e., increasing temperature with elevation) can increase sound levels at long distances (e.g., more than 500 feet). Other factors such as air temperature, humidity, and turbulence can also have significant effects on noise levels. [6]

1.3.2 Vibration

Vibration can be interpreted as energy transmitted in waves through the ground or man-made structures, which generally dissipate with distance from the vibration source. Because energy is lost during the transfer of energy from one particle to another, vibration becomes less perceptible with increasing distance from the source.

As described in the Federal Transit Administration's (FTA) *Transit Noise and Vibration Impact Assessment*, groundborne vibration can be a serious concern for nearby neighbors of a transit system route or maintenance facility, causing buildings to shake and rumbling sounds to be heard.[7] In contrast to airborne noise, groundborne vibration is not a common environmental problem, as it is unusual for vibration from sources such as buses and trucks to be

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[3] *Caltrans, Technical Noise Supplement (TeNS), Section 2.2.1.1, September, 2013.*

[4] *Caltrans, Technical Noise Supplement (TeNS), Section 2.1.4.2, September, 2013.*

[5] *Caltrans, Technical Noise Supplement (TeNS), Section 2.1.4.1, September, 2013.*

[6] *Caltrans, Technical Noise Supplement (TeNS), Section 2.1.4.3 September, 2013.*

[7] *FTA, Transit Noise and Vibration Impact Assessment, Section 7.1.3, May, 2006.*

perceptible, even in locations close to major roads. Some common sources of groundborne vibration are trains, heavy trucks traveling on rough roads, and construction activities, such as blasting, pile-driving, and operation of heavy earth-moving equipment.

There are several different methods that are used to quantify vibration. The peak particle velocity (PPV) is defined as the maximum instantaneous peak of the vibration signal in inches per second (in/sec), and is most frequently used to describe vibration impacts to buildings.

The effects of groundborne vibration include movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings. Building damage is not a factor for most Projects, with the occasional exception of blasting and pile-driving during construction. Annoyance from vibration often occurs when the vibration levels exceed the threshold of perception by only a small margin. A vibration level that causes annoyance will be well below the damage threshold for normal buildings. The FTA measure of the threshold of architectural damage for conventional sensitive structures is 0.2 in/sec PPV.[8]

In residential areas, the background vibration velocity level is usually around 0.0013 in/sec PPV, which is well below the vibration velocity level threshold of perception for humans, which is approximately 0.035 in/sec PPV.[9]

1.4 EXISTING NOISE ENVIRONMENT

1.4.1 Noise-Sensitive Receptor Locations

Some land uses are considered more sensitive to noise than others due to the amount of noise exposure and the types of activities typically involved at the receptor location. Residences, schools, motels and hotels, libraries, religious institutions, hospitals, nursing homes, and parks are generally more sensitive to noise than commercial and industrial land uses. Existing noise sensitive uses within 500 feet of the Project Site include the following:

- North: The Culver Hotel
- East: Single- and low-density multi-family residential uses and studio facilities
- West: Single- and low-density multi-family residential uses on Van Buren Place abut the Studio Campus, with Linwood E. Howe Elementary School located across Van Buren Place
- South: Multi-family residential uses abut the Studio Campus and primarily front on Lucerne Avenue

All other noise-sensitive uses are located at greater distances from the Project Site and would experience lower noise levels associated with the Project. Therefore, additional sensitive receptors beyond those identified above are not evaluated.

1.4.2 Ambient Noise Levels

The existing noise environment at the Project Site is comprised primarily of vehicle traffic including trucks, buses, etc. on Ince Boulevard, Van Buren Place, Lucerne Avenue, and Washington Boulevard. Secondary noise sources include nearby commercial and residential activities. To quantify the existing noise environment, short-term (15-

8 *FTA, Transit Noise and Vibration Impact Assessment, Section 12.2.2, May. 2006 .*

9 *Caltrans, Transportation and Construction Vibration Guidance Manual, Chapter 6.B, June, 2004.*

minute) measurements were conducted at four locations, identified as R1 through R4 in **Figure 4**, *Noise Measurement Locations*. A 15-minute measurement is a reasonable duration for sampling ambient noise levels where street traffic is the dominant source, as traffic noise generally does not vary significantly within an hour. Ambient sound measurements were conducted on Thursday, May 4, 2017, to characterize the existing noise environment in the Project vicinity.

- Measurement Location R1: The noise measuring device (sound level meter) was placed on the northern boundary of the Project Site approximately 250 feet east of the northeastern corner of Ince Boulevard and Krueger Street. Location R1 represents the existing general noise environment at the Project Site and nearby single-family residential uses along Ince Boulevard.
- Measurement Location R2: This measurement location represents the noise environment of the Project Site and residential uses along Lucerne Avenue. The sound level meter was placed on the northwestern corner of Ince Boulevard and Lucerne Avenue.
- Measurement Location R3: This measurement location represents the noise environment of the single family residential uses along Van Buren Place. The sound level meter was placed on the northeastern corner of Van Buren Place and Farragut Drive.
- Measurement Location R4: This measurement location represents the noise environment of the single-family residential uses and school uses along Van Buren Place. The sound level meter was placed near the Linwood E Howe Elementary school across the street from the existing Van Buren parking garage.

Noise measurements were conducted using Larson-Davis LxT1 Sound Level Meters (SLM). The Larson-Davis LxT1 SLM is a Type 1 standard instrument as defined in the American National Standard Institute (ANSI) S1.4. All instruments were calibrated and operated according to the applicable manufacturer specification. The recording microphones were placed at a height of 5 feet above the local grade elevation. The sound level meters were setup to collect the hourly average noise level (L_{eq}).

TABLE 1
SUMMARY OF AMBIENT NOISE MEASUREMENTS

Location, Duration, Existing Land Uses, and, Date of Measurements	Measured Ambient Noise Levels, dBA
R1 5/4/17(9:54 a.m. to 10:09 a.m.)/Thursday	66
R2 5/4/17(9:34 a.m. to 9:49 a.m.)/Thursday	67
R3 5/4/17(9:14 a.m. to 9:29 a.m.)/Thursday	57
R4 5/4/17(10:17 a.m. to 10:32 a.m.)/Thursday	56

SOURCE: ESA PCR, 2017.

The results of the ambient sound measurements are summarized in **Table 1**, *Summary of Ambient Noise Measurements*. As shown therein, the measure noise levels ranged from 56 dBA L_{eq} at R4 to 67 dBA L_{eq} at R2 in which the primary source of noise was traffic along roadways as recorded by ESA PCR technician.

1.4.3 Existing Roadway Noise Levels

To further characterize the Project area's ambient noise environment, CNEL noise levels attributed to existing traffic on local roadways were calculated using a traffic noise prediction model, which was developed based on calculation methodologies provided in the Federal Highway Administration (FHWA) Traffic Noise Model Technical Manual,[10] and traffic data provided in the Project's Traffic Impact Study[11] (see Appendix K of this Draft EIR). The FHWA's methodology, considered a noise industry standard, allows for the definition of roadway configurations, barrier information (if any), and receiver locations.

Existing roadway noise levels were calculated for 39 roadway segments located in the vicinity of the Project Site. The roadway segments selected for analysis are those expected to be most directly impacted by Project-related traffic, which, for the purpose of this analysis, includes the roadways located near and immediately adjacent to the Project Site. These roadways, when compared to roadways located further away from the Project Site, would experience the greatest percentage increase in traffic generated by the Project (as distances are increased from the Project Site, traffic is spread out over a greater geographic area and its effects are reduced).

Because the monitoring data validates the use of a Project-specific traffic noise prediction model, the ambient noise environment of the Project vicinity can be characterized by 24-hour CNEL levels attributable to existing traffic on local roadways. As indicated in **Table 2**, *Predicted Existing Vehicular Traffic Noise Levels*, the calculated CNEL (at the roadway right-of-way) from actual existing traffic volumes on the analyzed roadway segments ranged from 59.1 dBA to 70.2 dBA.

TABLE 2
PREDICTED EXISTING VEHICULAR TRAFFIC NOISE LEVELS

Roadway Segment	Adjacent Land Use	Existing CNEL (dBA) at Adjacent Land Use a
Culver Boulevard		
Between Venice Boulevard and Ince Boulevard	Commercial	65.4
Between Ince Boulevard and Main Street	Commercial	69.4
Between Main Street and Cardiff Avenue	Commercial	68.9
Between Cardiff Avenue and Washington Boulevard	Commercial	69.0
Between Washington Boulevard and Lafayette Place	Commercial	66.2
Between Lafayette Place and Duquesne Avenue	Commercial	67.0
Between Duquesne Avenue and Madison Avenue	Residential/ Commercial	67.9
Between Madison Avenue and Overland Ave	Residential/ Commercial	69.2
Ince Boulevard		
Between Washington Boulevard and Culver Studio Gate 2	Commercial	64.6
Between Culver Studio Gate 2 and Culver Studio Gate 3	Commercial	59.4
Between Culver Studio Gate 3 and Lucerne Avenue	Residential/ Commercial	59.1
Lucerne Avenue		
Between Higuera Street and Ince Boulevard	Residential	61.5
Between Ince Boulevard and Duquesne Avenue	Residential	62.4

[10] *Federal Highway Administration, Traffic Noise Model Technical Manual, February, 1998.*

[11] *Fehr & Peers, Culver Studios Modified Comprehensive Plan Update #7, May, 2017.*

Roadway Segment	Adjacent Land Use	Existing CNEL (dBA) at Adjacent Land Use a
Venice Boulevard		
Between La Cienega Avenue and Cattaraugus Avenue	Lodging/Commercial	67.9
Between Cattaraugus Avenue and National Boulevard	Residential/Commercial	67.8
Between National Boulevard and Robertson Boulevard	Commercial	69.0
Between Robertson Boulevard and Culver Boulevard	Commercial	70.2
Between Culver Boulevard and Main Street/Bagley Avenue	Commercial	69.1
Between Main Street/Bagley Avenue and Hughes Avenue	Residential/Commercial	68.4
Between Hughes Avenue and Clarington Avenue	Residential/Commercial	68.5
Between Clarington Avenue and Motor Avenue	Commercial	68.5
Between Motor Avenue and Overland Avenue	Residential/Commercial	68.9
Washington Boulevard		
Between La Cienega Boulevard and National Boulevard	Commercial	68.7
Between National Boulevard and Higuera Street	Commercial	68.8
Between Higuera Street and Ince Boulevard	Commercial	68.9
Between Ince Boulevard and Culver Boulevard	Lodging/Commercial	68.1
Between Culver Boulevard and Duquesne Avenue	Commercial	67.6
Between Duquesne Avenue and Clarington Avenue	Residential/Commercial	67.6
Between Clarington Avenue and Motor Avenue	Religious/Commercial	69.6
Between Motor Avenue and Overland Avenue	Commercial	69.3
Higuera Street		
Between Washington Boulevard and Lucerne Avenue	Residential/Commercial	66.6
Between Lucerne Avenue and Jefferson Boulevard	Residential/Commercial	66.1
Duquesne Avenue		
Between Jefferson Boulevard and Lucerne Avenue	Residential/Commercial	68.7
Between Lucerne Avenue and Culver Boulevard	Residential/Commercial	66.8
National Boulevard		
Between Robertson Boulevard and I-10 EB On-Ramp	Commercial	69.5
Between I-10 EB On-Ramp and Venice Boulevard	Commercial	68.4
Between Venice Boulevard and Washington Boulevard	Commercial	67.3
Between Washington Boulevard and Hayden Avenue	Residential/Commercial	69.0
Between Hayden Avenue and Jefferson Boulevard	Residential/Park/Commercial	66.7

[a] Calculated based on existing traffic volumes.

SOURCE: ESA PCR, 2017.

1.4.4 Vibration-Sensitive Receptor Locations

Typically, ground-borne vibration generated by man-made activities (i.e., rail and roadway traffic, operation of mechanical equipment, and typical construction equipment) diminishes rapidly with distance from the vibration source. The FTA uses a screening distance of 50 feet for residential uses and historic buildings. When vibration-sensitive uses are within these distances from a project site, vibration impact analysis is required. The Mansion, Bungalows, Building D, E, H, I, and Stage 11/12/14 and 15/16) are located within the area of potential vibration impact (within 50 feet) and could be affected by vibration caused by short-term construction. Low-density multi-family residential uses to the east of the Project Site , single- and low-density multi-family residential uses on Van Buren Place abut the Studio Campus, with Linwood E. Howe Elementary School located across Van Buren Place, and multi-family residential uses abut the Studio Campus and primarily front on Lucerne Avenue are located within the area of potential perceptible vibration generated on the Project Site (i.e., within 50 feet) and could be affected by vibration caused by short-term Project construction and long-term Project operation.

SOURCE: Google Earth, 7/8/2016 (Aerial)

The Culver Studios Innovation Plan

Figure 4

Noise Measurement Locations

ESA PCR

1.5 REGULATORY SETTING

Many government agencies have established noise standards and guidelines to protect citizens from potential hearing damage and various other adverse physiological and social effects associated with noise and ground-borne vibration. Federal and local policies and/or standards such as those of the FTA, U.S. Environmental Protection Agency (USEPA), and regulations in the City of Culver City General Plan Noise Element, and the Culver City Municipal Code (CCMC) would be applicable to the Project, as summarized below.

1.5.1 Federal

Federal Noise and Vibration Standards

Under the authority of the Noise Control Act of 1972, the USEPA established noise emission criteria and testing methods published in Parts 201 through 205 of Title 40 of the Code of Federal Regulations (CFR) that apply to some transportation equipment (e.g., interstate rail carriers, medium trucks, and heavy trucks) and construction equipment. In 1974, USEPA issued guidance levels for the protection of public health and welfare in residential land use areas[12] of an outdoor L_{dn} of 55 dBA and an indoor L_{dn} of 45 dBA. These guidance levels are not considered as standards or regulations and were developed without consideration of technical or economic feasibility. Groundborne vibration levels resulting from construction activities at the Project Site were estimated using data published by FTA in its *Transit Noise and Vibration Impact Assessment* (2006). The potential vibration levels at off-site sensitive locations resulting from implementation of the Project are analyzed against the vibration thresholds established by the FTA to determine whether an exceedance of allowable vibration levels would occur. The FTA has adopted vibration standards that are used to evaluate potential building damage impacts related to construction activities, which are shown in **Table 3**, *Construction Vibration Damage Criteria*.

TABLE 3
CONSTRUCTION VIBRATION DAMAGE CRITERIA

Building Category	PPV (in/sec)
I. Reinforced-concrete, steel, or timber (no plaster)	0.5
II. Engineered concrete and masonry (no plaster)	0.3
III. Non-engineered timber and masonry buildings	0.2
IV. Buildings extremely susceptible to vibration damage	0.12

SOURCE: FTA 2006.

In addition, the FTA has also adopted standards associated with human annoyance for groundborne vibration impacts for the following three land-use categories: Vibration Category 1 – High Sensitivity, Vibration Category 2 – Residential, and Vibration Category 3 – Institutional. The FTA defines Category 1 as buildings where vibration would interfere with operations within the building, including vibration-sensitive research and manufacturing facilities, hospitals with vibration-sensitive equipment, and university research operations. Vibration-sensitive equipment includes, but is not limited to, electron microscopes, high-resolution lithographic equipment, and normal optical microscopes. Category 2 refers to all residential land uses and any buildings where people sleep, such as hotels and hospitals. Category 3 refers to institutional land uses such as schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference. The vibration

[12] *USEPA, EPA Identifies Noise Levels Affecting Health and Welfare, April, 1974.*

thresholds associated with human annoyance for these three land-use categories are shown in **Table 4**, *Groundborne Vibration Impact Criteria for General Assessment*. No thresholds have been adopted or recommended for commercial and office uses.

TABLE 4
GROUNDBORNE VIBRATION IMPACT CRITERIA FOR GENERAL ASSESSMENT

Land Use Category	Frequent Events[a]	Occasional Events[b]	Infrequent Events[c]
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[d]	65 VdB[d]	65 VdB[d]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB

a “Frequent Events” is defined as more than 70 vibration events of the same source per day.
b “Occasional Events” is defined as between 30 and 70 vibration events of the same source per day.
c “Infrequent Events” is defined as fewer than 30 vibration events of the same kind per day.
d This criterion is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes.

SOURCE: FTA 2006.

1.5.2 Local

City of Culver City General Plan Noise Element

The City of Culver City Noise Standards are developed from those of several Federal and State agencies including the Federal Highway Administration, the Environmental Protection Agency, the Department of Housing and Urban Development, the American National Standards Institute, and the State of California Department of Health Services. These standards set limits on the noise exposure level for various land uses. **Table 5**, *City of Culver City Exterior Noise Standards*, lists exterior noise level standards and the type of occupancy to which they should be applied.

TABLE 5
CITY OF CULVER CITY EXTERIOR NOISE STANDARDS

Zone	dBA CNEL
Residential	65
Commercial	65

SOURCE: City of Culver City Noise Element.

Policy 2.A Create a comprehensive ordinance establishing noise regulation criteria, and standards for noise sources and receptors to include but not be limited to the following:

- Noise reduction features during site planning to mitigate anticipated noise impacts on affected noise sensitive land uses, such as schools, hospitals, convalescent homes, and libraries.
- Temporary sound barrier installation at construction site if construction noise is impacting nearby noise sensitive land uses.
- Noise abatement and acoustical design criteria for construction and operation of any new development.

City of Culver City Municipal Code

Chapter 9.07 of the City of Culver City Municipal Code (CCMC) provides specific noise restrictions and exemptions for noise sources within the City. Several of these requirements are applicable to the proposed Project and are discussed below.

Chapter 9.07 of the CCMC provides specific noise restrictions and exemptions for noise sources within the City. CCMC noise regulations state that construction activity shall be prohibited, except between the hours of 8:00 A.M. and 8:00 P.M. Mondays through Fridays; 9:00 A.M. and 7:00 P.M. Saturdays; 10:00 A.M. and 7:00 P.M. Sundays. It is prohibited for any person to operate any radio, disc player or cassette player or similar device at a construction site in a manner that results in noise levels that are audible beyond the construction site property line.

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2. THRESHOLDS OF SIGNIFICANCE

The significance thresholds below are derived from the Environmental Checklist questions in Appendix G of the State CEQA Guidelines. Accordingly, a significant impact associated with noise would occur based on the following thresholds described below:

- Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies;
- Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels;
- A substantial permanent increase in ambient noise levels in the vicinity of the Project above levels existing without the Project;
- A substantial temporary or periodic increase in ambient noise levels in the Project vicinity above levels existing without the Project.
- For a Project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the Project expose people residing or working in the Project area to excessive noise levels?
- For a Project within the vicinity of a private airstrip, would the Project expose people residing or working in the Project area to excessive noise levels?

As discussed in the Initial Study, provided in Appendix A-2 of this Draft EIR, and in Chapter 6, Other CEQA Considerations, the Project Site is not located within an airport land use plan or within two miles of an airport. The nearest airports are the Santa Monica Municipal Airport and the Los Angeles International Airport (LAX), located approximately three miles to the west and five miles to the south of the Project Site, respectively. Therefore, the Project would not expose people in the Project vicinity to excessive noise levels from airport use. Per the Initial Study, no further analysis of these topics in this EIR section is necessary. Besides these topics, the other noise topics were determined to have a potentially significant impact in the Initial Study.

The following significance criteria are used to evaluate potential noise and vibration impacts of the Project based on the regulatory framework described above. The Project would result in potentially significant impacts under the following circumstances:

- Project construction activities occur between the hours of 8:00 P.M. and 8:00 A.M. Monday through Friday; 7:00 P.M. and 9:00 A.M. on Saturdays; 7:00 P.M. and 10:00 A.M. on Sundays.
- Project construction activities would not incorporate noise reduction techniques as specified in the City's General Plan Policy 2.A of the Noise Element.
- The Project-related operations would cause ambient noise levels to increase by 5 dBA, L_{eq} or more.
- The Project-related operation of the loading dock, or refuse collection area exceeds the average ambient noise level by 10 dBA.
- Potential Building Damage – Project construction activities cause ground-borne vibration levels to exceed 0.2 inch-per-second PPV at the nearest residential and school buildings.
- Potential Building Damage – Project construction activities cause ground-borne vibration levels to exceed 0.12 inch-per-second PPV at historic structures (the Mansion, Bungalows, Building D, E, H, I, and Stage 11/12/14 and 15/16).

- Potential Human Annoyance – Project construction activities cause ground-borne vibration levels to exceed 80 VdB at nearby residential uses or 83 VdB at nearby school uses.

3. IMPACT ANALYSIS

3.1 METHODOLOGY

3.1.1 On-Site Construction Noise

On-site construction noise impacts were evaluated by determining the noise levels generated by the different types of construction activity anticipated, calculating the construction-related noise level at nearby sensitive receptor locations, and comparing these construction-related noise levels to existing ambient noise levels (i.e., noise levels without construction noise) at those receptors. More, specifically, the following steps were undertaken to assess construction-period noise impacts.

1. Ambient noise levels at surrounding sensitive receptor locations were estimated based on field measurement data (see Table 1)
2. Typical noise levels for each type of construction equipment were obtained from the Federal Highway Administration roadway construction noise model;
3. Distances between construction site locations (noise sources) and surrounding sensitive receptors were measured using Project architectural drawings and site plans and Google Earth;
4. The construction noise level was then calculated, in terms of hourly L_{eq}, for sensitive receptor locations based on the standard point source noise-distance attenuation factor of 6.0 dBA for each doubling of distance; and
5. Construction noise levels were then compared to the construction noise significance thresholds identified below.

3.1.2 Off-Site Roadway Noise (Construction and Operations)

Roadway noise impacts have been evaluated using the Caltrans TeNS method based on the roadway traffic volume data provided in the Traffic Study prepared for the Project and included in Appendix K of this Draft EIR. This method allows for the definition of roadway configurations, barrier information (if any), and receiver locations. Roadway noise attributable to Project development was calculated and compared to baseline noise levels that would occur under the "Without Project" condition.

3.1.3 Stationary Point-Source Noise (Operations)

Stationary point-source noise impacts were evaluated by identifying the noise levels generated by outdoor stationary noise sources, such as rooftop mechanical equipment, parking structure, special events and outdoor programming, and loading area activity, calculating the hourly L_{eq} noise level from each noise source at sensitive receptor property lines, and comparing such noise levels to existing ambient noise levels. More specifically, the following steps were undertaken to calculate outdoor stationary point-source noise impacts:

1. Ambient noise levels at surrounding sensitive receptor locations were estimated based on field measurement data (see Table 1);
2. Distances between stationary noise sources and surrounding sensitive receptor locations were measured using Project architectural drawings, Google Earth, and site plans;
3. Stationary-source noise levels were then calculated for each sensitive receptor location based on the standard point source noise-distance attenuation factor of 6.0 dBA for each doubling of distance;

4. Noise level increases were compared to the stationary source noise significance thresholds identified below; and
5. For outdoor mechanical equipment, the maximum allowable noise emissions from any and all outdoor mechanical equipment were specified such that noise levels would not exceed the significance threshold identified below.

Parking related noise levels were estimated using the methodology recommended by FTA for the general assessment of stationary transit noise source. Using the methodology, the Project's peak hourly noise level that would be generated by the onsite parking levels was estimated using the following FTA equation for a parking lot:

$L_{eq}(h) = SEL_{ref} + 10\log(NA/1000) – 35.6$, where

$L_{eq}(h)$ = hourly L_{eq} noise level at 50 feet

SEL_{ref} = reference noise level for stationary noise source represented in sound exposure level (SEL) at 50 feet

N_A = number of automobiles per hour

3.1.4 Ground-Borne Vibration (Construction and Operations)

Ground-borne vibration impacts were evaluated by identifying potential vibration sources, measuring the distance between vibration sources and surrounding structure locations, and making a significance determination based on the significance thresholds described below.

3.2 PROJECT CHARACTERISTICS AND PROJECT DESIGN

3.1.2 Project Characteristics

The Culver Studios Innovation Plan proposes to modernize and expand the existing Central Area, encompassing the portion of the Studio Campus south of the Mansion and proposed Relocated Bungalow Area just south of the Mansion. Proposed improvements include the construction of six new Digital Media buildings which would house a flexible mix of creative space, production space, and digital media stages, and would replace six existing buildings housing offices and support services (Buildings L, O, X, Y, Z, and the Commissary) and four existing buildings housing sound stages, which would be demolished. The Project would also include: (1) the development of a new subterranean Central Parking Structure, and would replace the existing Van Buren Parking Structure with a new below- at- and above-grade Van Buren Parking Structure; (2) the decentralization of central plant (e.g., utility) facilities; (3) the accommodation of production vehicle staging and parking, service vehicle operation, deliveries, and trash activities, below grade where they currently occur above-grade; and (4) circulation and Studio gate improvements intended to improve overall vehicle queuing and backups on Ince Boulevard.

Applicable regulations with which the Project must comply include the following:

- Project construction activities occur between the hours of 8:00 AM and 8:00 PM Monday through Friday; 9:00 AM and 7:00 PM Saturdays; and 10:00 AM and 7:00 PM Sundays.

3.2.2 Project Design Features

In addition to these compliance measures, the Project incorporates—and the analysis assumes implementation of—the following PDF to minimize noise and vibration impacts:

PDF-NOISE-1: Prior to issuance of a building permit, notice of the Project construction schedule shall be provided to all abutting property owners and occupants. Evidence of such notification shall be provided to the Building Division. The notice shall identify the commencement date and proposed timing for all construction phases (demolition, grading, excavation/shoring, foundation, rough frame, plumbing, roofing, mechanical and electrical, and exterior finish).

PDF-NOISE-2:Any foundation piles shall be drilled and cast not driven.

PDF-NOISE-3: All parking structure levels in the new parking garage shall be treated with a broom finish or some other treatment that results in a no-skid surface.

PDF-NOISE-4: A concrete wall shall be placed along level 1 of the new Van Buren parking structure that extend from the ground up to the underside of the Level 2 slab and the concrete wall shall be free from gaps or penetrations.

PDF-NOISE-5: The pre-cast concrete panels at the north and south side of the parking structure shall weigh at least 4 lbs per square foot, form a continuous façade with no gaps between precast concrete panels.

PDF-NOISE-6: All parking structure exhaust or ventilation systems shall be designed, through the use of quiet fans and duct silencers or similar methods, to not exceed 55 dBA L_{eq} from 7:00 AM to 10:00 PM and 50 dBA L_{eq} from 10:00 PM to 7:00 AM at the neighboring property lines including the west property line per sound level limits of the Culver City Noise Element.

PDF-NOISE-7: During all phases of construction, a "Construction Rules Sign" that includes contact names and telephone numbers of the Applicant, Property Owner, construction contractor(s), and the City, shall be posted on the Property in a location that is visible to the public. These names and telephone numbers shall also be made available to adjacent property owners and occupants to the satisfaction of the Planning Manager and Building Official.

PDF-NOISE-8: All staging and storage of construction equipment and materials, including the construction dumpster, shall be on-site only. The Property Owner must obtain written permission from adjacent property owners for any construction staging occurring on adjacent property.

PDF-NOISE-9: The following noise standards from Policy 2.A of the City's General Plan Noise Element shall be complied with at all times:

A. No construction equipment shall be operated without an exhaust muffler, and all such equipment shall have mufflers and sound control devices (i.e., intake silencers and noise shrouds) that are no less effective than those provided on the original equipment;

B. All construction equipment shall be properly maintained to minimize noise emissions;

C. If any construction vehicles are serviced at a location onsite, the vehicle(s) shall be setback from any street and other property lines so as to maintain the greatest distance from the public right-of-way and from Noise Sensitive Receptors;

D. Noise impacts from stationary sources (i.e., mechanical equipment, ventilators, and air conditioning units) shall be minimized by proper selection of equipment and the installation of acoustical shielding as approved by the Planning Manager and the Building

E. The Project shall not allow any delivery truck idling in the loading area. Signs shall be posted prohibiting idling.

PDF-NOISE-10: Shoots, production support film screenings, concerts, outdoor teaming space, housing of amenities, and passive recreational uses in any proposed balconies, courtyards, patios, walkways, and decks on proposed buildings, shall not occur where open to the nearby residences. **[Note: Project Architect should confirm whether this proposed PDF is feasible.]**

3.3 CONSTRUCTION NOISE IMPACTS

Threshold NOISE-1: The Project would have a potentially significant impact on noise if it would result in the exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies.

Impact Statement NOISE-1: Construction activities would increase noise levels at off-site noise-sensitive receptors in excess of the applicable thresholds. However, with implementation of the identified construction mitigation measures and project design features, noise levels would be less than significant. Operation of the Project would not increase noise levels at off-site noise-sensitive receptors in the Project Area in excess of the applicable thresholds. Thus, operational noise impacts would be less than significant and operational mitigation measures would not be required.

3.3.1 Construction Noise

On-Site Construction Noise

Construction of the Project would require the use of heavy equipment during the various construction phases at the Project Site. During each stage of development, there would be a different mix of equipment. As such, construction activity noise levels at and near the Project Site would fluctuate depending on the particular type, number, and duration of use of the various pieces of construction equipment.

Individual pieces of construction equipment anticipated during Project construction could produce maximum noise levels of 74 dBA to 89 dBA L_{max} at a reference distance of 50 feet from the noise source, as shown in **Table 6**. These maximum noise levels would occur when equipment is operating at full power. The estimated usage factor for the equipment is also shown in Table 6. The usage factors are based on FHWA's RCNM User's Guide.[13]

[13] *Federal Highway Administration, Roadway Construction Noise Model User's Guide, P. 3, 2006.*

TABLE 6
CONSTRUCTION EQUIPMENT NOISE LEVELS

Construction Equipment	Estimated Usage Factor, %	Noise Level at 50 Feet (dBA, Lmax)
Air Compressors	50	78
Bore/Drill Rig	20	79
Bulldozer	40	82
Crane	40	81
Dozer	40	82
Excavator	40	81
Forklift	10	75
Grader	40	85
Jackhammers	20	89
Man lift/Scissor Lift	20	75
Other Equipment	50	85
Pumps	50	81
Roller	25	80
Sweeper/Scrubbers	10	82
Tractor/Loader/Backhoe	25	80
Welders	40	74

SOURCE: FHWA, 2006

During Project construction, the nearest and most affected off-site noise sensitive receptors that would be exposed to increased noise levels would be the existing residential uses located in proximity to the Project Site as well as noise sensitive park uses. Specifically, the nearest off-site noise sensitive receptors include the following:

- R1: Single-family residential uses located along Ince Boulevard.
- R2: Residential uses located along Lucerne Avenue.
- R3: Single-family residential uses located along Van Buren Place.
- R4: Single-family residential uses and Linwood E. Howe Elementary School located along Van Buren Place.

Over the course of a construction day, the highest noise levels would be generated when multiple pieces of construction equipment are being operated concurrently. As discussed previously, the Project's estimated construction noise levels were calculated for a scenario in which all construction equipment was assumed to be operating simultaneously and located at the construction area nearest to the affected receptors to present a conservative impact analysis. The estimated noise levels at the off-site sensitive receptors were calculated using the FHWA's RCNM, and were based on a maximum concurrent operation of up to 82 pieces of hand tools and equipment (i.e., pneumatic hand tools/air compressors, cranes, tractor/loader/backhoe, forklift, generator sets, welders, etc.), which is considered a worst-case evaluation because the Project would typically use less overall equipment on a daily basis, and as such would generate lower noise levels. In addition, the noise levels were estimated including the assumption that there would be some construction phase overlap between excavation and foundations and building shell, Van Buren garage construction, and landscaping. **Table 7**, *Estimate of Construction Noise levels (L_{eq}) at Existing Off-Site Sensitive Receptor Locations*, shows the estimated construction noise levels that would occur at the nearest off-site sensitive uses during a peak day of construction activity at the Project Site.

TABLE 7
ESTIMATE OF CONSTRUCTION NOISE LEVELS (L_{EQ}) AT EXISTING OFF-SITE SENSITIVE RECEIVER LOCATIONS

Off-site Sensitive Land Uses	Location	Nearest Distance from Construction Activity to Noise Receptor (ft.)	Estimated Maximum Construction Noise Levels (dBA L_{eq})	Ambient Noise Levels	Exceed Ambient Noise Levels?
R1	North of the Project Site along Ince Boulevard	50	89	66	Yes
R2	East of the Project Site along Lucerne Avenue	75	85	67	Yes
R3	Southeast of the Project Site along Van Buren Place	40	90	57	Yes
R4	South of the Project Site along Van Buren Boulevard; near elementary school	50	89	56	Yes

SOURCE: ESA PCR, 2017.

As shown in Table 7, construction noise levels are estimated to reach a maximum of 90 dBA at the nearest sensitive receptor (namely R3). Construction activities would temporarily increase the existing ambient noise in close proximity of the construction site. Construction activities would be required to comply with the City's allowable hours as described above and would be temporary in nature. Therefore, construction activities would comply with the City's noise standard.

Policy 2.A of the Noise Element requires noise reduction techniques to ensure that the noise impacts associated with construction activities would be minimized to the maximum extent feasible. Implementation of Project design features PDF-NOISE-1 through -5, -8 and -9 would help reduce Project noise impacts during construction. However, construction noise impacts would be considered potentially significant without implementation of additional noise reduction techniques consistent with Policy 2.A.

Off-Site Construction Noise

Delivery and haul truck trips would occur throughout the construction period. Trucks traveling to and from the Project Site would be required to travel along the haul route approved by the City of Culver City for the Project. An estimated maximum of approximately 209 haul truck trips would occur per day. Haul truck traffic would take the most direct route to the appropriate freeway ramp. Haul trucks would enter and exit the Project Site from the Ince Boulevard gates along the eastern part of the property. The trucks would continue onto Washington Boulevard to Robertson Boulevard and then onto the Interstate 10 Freeway.

The Project's truck trips would generate noise levels of approximately 64.2 dBA, L_{eq} at 25 feet distance from the center line of roadways along the route. As shown in Table 4.9-2, the existing noise levels along the haul route are 64.6 dBA, L_{eq} along Ince Street and 68.9 dBA, along Washington Boulevard. Construction traffic noise levels generated by truck trips would increase traffic noise levels along Ince Street by 2.8 dBA and along Washington Boulevard by 1.3 dBA.

As discussed above in Section 1.3, a 3 dBA change in ambient noise levels is considered to be a barely perceivable difference. Therefore, the noise levels generated by truck trips would not substantially increase the existing noise levels in the surrounding environment. Construction truck trips would be required to comply with the City's allowable hours as described above and would be temporary in nature. Therefore, construction activities would comply with the City's noise standard and impacts would be less than significant.

3.4 PROJECT-RELATED OPERATIONAL NOISE IMPACTS

3.4.1 Operational Traffic Noise Compared to Existing Traffic Baseline Conditions

Existing roadway noise levels were calculated along various arterial segments adjacent to the Project Site. Roadway noise attributable to Project development was calculated using the traffic noise model previously described and was compared to baseline noise levels that would occur under the "No Project" condition.

Project impacts are shown in **Table 8**, *Off-Site Traffic Noise Impacts-Existing With Project Conditions*. As indicated, the maximum increase in Project-related traffic noise levels over existing traffic noise levels would be 1.5 dBA CNEL, which would occur along Ince Boulevard, Between Culver Studio Gate 2 and Culver Studio Gate 3 adjacent to commercial uses. This increase in sound level would be below the 5 dBA increase threshold, and the increase in sound level would be lower at the remaining roadway segments analyzed. The Project-related noise increases would be less than significant, and no mitigation measures would be required.

TABLE 8
OFF-SITE TRAFFIC NOISE IMPACTS – EXISTING WITH PROJECT CONDITIONS

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL)				
		Existing (A)	Existing with Project (B)	Project Increment (B-A)	Threshold	Exceed Threshold?
Culver Boulevard						
Between Venice Boulevard and Ince Boulevard	Commercial	65.4	65.7	0.3	5	No
Between Ince Boulevard and Main Street	Commercial	69.4	69.5	0.1	5	No
Between Main Street and Cardiff Avenue	Commercial	68.9	69.1	0.2	5	No
Between Cardiff Avenue and Washington Boulevard	Commercial	69.0	69.2	0.2	5	No
Between Washington Boulevard and Lafayette Place	Commercial	66.2	66.5	0.3	5	No
Between Lafayette Place and Duquesne Avenue	Commercial	67.0	67.3	0.3	5	No
Between Duquesne Avenue and Madison Avenue	Residential/ Commercial	67.9	68.1	0.2	5	No
Between Madison Avenue and Overland Ave	Residential/ Commercial	69.2	69.3	0.1	5	No
Ince Boulevard						
Between Washington Boulevard and Culver Studio Gate 2	Commercial	64.6	65.2	0.6	5	No
Between Culver Studio Gate 2 and Culver Studio Gate 3	Commercial	59.4	60.9	1.5	5	No
Between Culver Studio Gate 3 and Lucerne Avenue	Residential/ Commercial	59.1	59.1	0.0	5	No

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL) Existing (A)	Existing with Project (B)	Project Increment (B-A)	Threshold	Exceed Threshold?
Lucerne Avenue						
Between Higuera Street and Ince Boulevard	Residential	61.5	61.5	0.0	5	No
Between Ince Boulevard and Duquesne Avenue	Residential	62.4	62.4	0.0	5	No
Venice Boulevard						
Between La Cienega Avenue and Cattaraugus Avenue	Lodging/Commercial	67.9	68.0	0.1	5	No
Between Cattaraugus Avenue and National Boulevard	Residential/Commercial	67.8	67.9	0.1	5	No
Between National Boulevard and Robertson Boulevard	Commercial	69.0	69.1	0.1	5	No
Between Robertson Boulevard and Culver Boulevard	Commercial	70.2	70.2	0.0	5	No
Between Culver Boulevard and Main Street/Bagley Avenue	Commercial	69.1	69.1	0.0	5	No
Between Main Street/Bagley Avenue and Hughes Avenue	Residential/Commercial	68.4	68.4	0.0	5	No
Between Hughes Avenue and Clarington Avenue	Residential/Commercial	68.5	68.5	0.0	5	No
Between Clarington Avenue and Motor Avenue	Commercial	68.5	68.6	0.1	5	No
Between Motor Avenue and Overland Avenue	Residential/Commercial	68.9	68.9	0.0	5	No
Washington Boulevard						
Between La Cienega Boulevard and National Boulevard	Commercial	68.7	68.9	0.2	5	No
Between National Boulevard and Higuera Street	Commercial	68.8	68.9	0.1	5	No
Between Higuera Street and Ince Boulevard	Commercial	68.9	69.3	0.4	5	No
Between Ince Boulevard and Culver Boulevard	Lodging/Commercial	68.1	68.3	0.2	5	No
Between Culver Boulevard and Duquesne Avenue	Commercial	67.6	67.7	0.1	5	No
Between Duquesne Avenue and Clarington Avenue	Residential/Commercial	67.6	67.7	0.1	5	No
Between Clarington Avenue and Motor Avenue	Religious/Commercial	69.6	69.7	0.1	5	No
Between Motor Avenue and Overland Avenue	Commercial	69.3	69.3	0.0	5	No
Higuera Street						
Between Washington Boulevard and Lucerne Avenue	Residential/Commercial	66.6	66.6	0.0	5	No
Between Lucerne Avenue and Jefferson Boulevard	Residential/Commercial	66.1	66.1	0.0	5	No
Duquesne Avenue						
Between Jefferson Boulevard and Lucerne Avenue	Residential/Commercial	68.7	68.9	0.2	5	No

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL) Existing (A)	Existing with Project (B)	Project Increment (B-A)	Threshold	Exceed Threshold?
Between Lucerne Avenue and Culver Boulevard	Residential/Commercial	66.8	67.0	0.2	5	No
National Boulevard						
Between Robertson Boulevard and I-10 EB On-Ramp	Commercial	69.5	69.5	0.0	5	No
Between I-10 EB On-Ramp and Venice Boulevard	Commercial	68.4	68.4	0.0	5	No
Between Venice Boulevard and Washington Boulevard	Commercial	67.3	67.3	0.0	5	No
Between Washington Boulevard and Hayden Avenue	Residential/Commercial	69.0	69.1	0.1	5	No
Between Hayden Avenue and Jefferson Boulevard	Residential/Park/Commercial	66.7	66.8	0.1	5	No

SOURCE: ESA PCR, 2017.

3.4.2 Operational Traffic Noise Compared to Future (2021) Traffic Conditions

Future roadway noise levels were also calculated along various arterial segments adjacent to the Project as compared to 2021 baseline traffic noise levels that would occur with implementation of the Project. Project impacts are shown in **Table 9**, *Off-Site Traffic Noise Impacts – Future (2021) With Project Conditions*. As indicated, the maximum increase in Project-related traffic noise levels over existing traffic noise levels would be 1.5 dBA CNEL, which would occur along Ince Boulevard, Between Culver Studio Gate 2 and Culver Studio Gate 3 adjacent to commercial uses. This increase in sound level would be below the 5 dBA increase threshold, and the increase in sound level would be lower at the remaining roadway segments analyzed. The Project-related noise increases would be less than significant, and no mitigation measures would be required.

TABLE 9
OFF-SITE TRAFFIC NOISE IMPACTS – FUTURE (2021) WITH PROJECT CONDITIONS

		Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL)				
Roadway Segment	**Existing Land Uses Located Along Roadway Segment**	**Future (A)**	**Future with Project (B)**	**Project Increment (B-A)**	**Threshold**	**Exceed Threshold?**
Culver Boulevard						
Between Venice Boulevard and Ince Boulevard	Commercial	66.1	66.2	0.3	5	No
Between Ince Boulevard and Main Street	Commercial	69.9	70.1	0.1	5	No
Between Main Street and Cardiff Avenue	Commercial	69.4	69.6	0.2	5	No
Between Cardiff Avenue and Washington Boulevard	Commercial	69.5	69.7	0.2	5	No
Between Washington Boulevard and Lafayette Place	Commercial	66.8	67.0	0.3	5	No
Between Lafayette Place and Duquesne Avenue	Commercial	67.5	67.7	0.3	5	No
Between Duquesne Avenue and Madison Avenue	Residential/ Commercial	68.3	68.5	0.2	5	No
Between Madison Avenue and Overland Ave	Residential/ Commercial	69.7	69.8	0.1	5	No
Ince Boulevard						
Between Washington Boulevard and Culver Studio Gate 2	Commercial	65.1	65.6	0.6	5	No
Between Culver Studio Gate 2 and Culver Studio Gate 3	Commercial	59.6	61.0	1.5	5	No
Between Culver Studio Gate 3 and Lucerne Avenue	Residential/ Commercial	59.3	59.4	0.0	5	No
Lucerne Avenue						
Between Higuera Street and Ince Boulevard	Residential	61.8	61.8	0.0	5	No
Between Ince Boulevard and Duquesne Avenue	Residential	62.7	62.7	0.0	5	No
Venice Boulevard						
Between La Cienega Avenue and Cattaraugus Avenue	Lodging/Commercial	68.7	68.7	0.1	5	No
Between Cattaraugus Avenue and National Boulevard	Residential/Commercial	68.6	68.6	0.1	5	No
Between National Boulevard and Robertson Boulevard	Commercial	69.8	69.9	0.1	5	No
Between Robertson Boulevard and Culver Boulevard	Commercial	71.0	71.1	0.0	5	No
Between Culver Boulevard and Main Street/Bagley Avenue	Commercial	70.0	70.0	0.0	5	No
Between Main Street/Bagley Avenue and Hughes Avenue	Residential/Commercial	69.2	69.3	0.0	5	No
Between Hughes Avenue and Clarington Avenue	Residential/Commercial	69.4	69.4	0.0	5	No
Between Clarington Avenue and Motor Avenue	Commercial	69.3	69.3	0.1	5	No
Between Motor Avenue and Overland Avenue	Residential/Commercial	69.7	69.7	0.0	5	No

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL) Future (A)	Future with Project (B)	Project Increment (B-A)	Threshold	Exceed Threshold?
Washington Boulevard						
Between La Cienega Boulevard and National Boulevard	Commercial	69.6	68.6	0.2	5	No
Between National Boulevard and Higuera Street	Commercial	69.8	69.9	0.1	5	No
Between Higuera Street and Ince Boulevard	Commercial	69.4	69.7	0.4	5	No
Between Ince Boulevard and Culver Boulevard	Lodging/Commercial	68.6	68.7	0.2	5	No
Between Culver Boulevard and Duquesne Avenue	Commercial	68.0	68.1	0.1	5	No
Between Duquesne Avenue and Clarington Avenue	Residential/Commercial	68.1	68.2	0.1	5	No
Between Clarington Avenue and Motor Avenue	Religious/Commercial	70.0	70.1	0.1	5	No
Between Motor Avenue and Overland Avenue	Commercial	69.7	69.7	0.0	5	No
Higuera Street						
Between Washington Boulevard and Lucerne Avenue	Residential/Commercial	66.9	66.9	0.0	5	No
Between Lucerne Avenue and Jefferson Boulevard	Residential/Commercial	66.5	66.5	0.0	5	No
Duquesne Avenue						
Between Jefferson Boulevard and Lucerne Avenue	Residential/Commercial	69.2	69.2	0.2	5	No
Between Lucerne Avenue and Culver Boulevard	Residential/Commercial	67.2	67.4	0.2	5	No
National Boulevard						
Between Robertson Boulevard and I-10 EB On-Ramp	Commercial	70.2	70.2	0.0	5	No
Between I-10 EB On-Ramp and Venice Boulevard	Commercial	69.4	69.5	0.0	5	No
Between Venice Boulevard and Washington Boulevard	Commercial	68.5	68.6	0.0	5	No
Between Washington Boulevard and Hayden Avenue	Residential/Commercial	69.8	69.8	0.1	5	No
Between Hayden Avenue and Jefferson Boulevard	Residential/Park/Commercial	66.7	66.8	0.1	5	No

SOURCE: ESA PCR, 2017.

3.5 ON-SITE OPERATIONAL NOISE IMPACTS

3.5.1 Operational Fixed Mechanical Equipment

The operation of mechanical equipment such as air conditioning equipment may generate audible noise levels. However, mechanical equipment would be shielded from nearby noise sensitive uses to attenuate noise and avoid conflicts with adjacent uses. In addition, the Project's mechanical equipment would need to comply with the City's Exterior Noise Standards shown in Table 5, which establish maximum permitted noise levels from mechanical equipment. Project compliance with the City's noise standards would ensure that operational noise impacts are minimal.

3.5.2 Parking Structure Noise

Two new parking structures are proposed as part of the Innovation Plan, the below-grade Central Parking Structure, and the Van Buren Parking Structure. The proposed below-grade Central Parking Structure would be located south of the Mansion and existing Rear Lawn Parking Structure, within the existing Central Area of the Studio Campus.

The Van Buren Parking Structure would be constructed on the western edge of the Studio Campus on the site of an existing above-grade parking structure, existing surface parking, and the Bungalow Area containing Buildings S, T, U, and V. The Van Buren Parking Structure would include two below-grade, one at-grade, and five above-grade levels. It would be constructed with a solid concrete wall free of gaps or penetrations surrounding the at-grade level, to reduce off-site noise impacts from operations as prescribed in PDF-NOISE-4 and -5. An articulated screen would run the length of its Van Buren Place façade and provide visual interest, screening from potential noise sources.

For the purpose of providing a conservative, quantitative estimate of the noise levels that would be generated from vehicles entering and exiting the Project's parking structure, the methodology recommended by FTA for the general assessment of stationary transit noise sources is used discussed in the Methodology Section.

Based on the Project's traffic study prepared by Fehr & Peers[14] and provided in Appendix J of this Draft EIR, the Project is forecasted to generate 5,834 total daily vehicle trips with an anticipated 616 trips and 592 trips during the A.M. and P.M. peak hours, respectively. Using the FTA's reference noise level of 92 dBA SEL[15] at 50 feet from the noise source for a parking lot, it was determined that the Project's highest peak hour vehicle trips, which would be 616 trips during the A.M. peak hour, would generate noise levels of approximately 54 dBA, L_{eq} at 50 feet from the Project's access gates. The nearest noise sensitive use to any one of the two entrances would be approximately 75 feet. Based on this distance, the vehicle related noise levels would be approximately 51 dBA L_{eq} along Ince Boulevard (R1). All other noise sensitive uses would have lower parking related noise levels. This also conservatively assumes the peak hour traffic would all occur at one entrance. The noise level would not increase the ambient noise levels of 66 dBA L_{eq} at the noise sensitive uses (R1) along Ince Boulevard by 5 dBA (combining noise levels of 51 dBA and 61 dBA would result in 61.4 dBA, which would be a change of 0.4 dBA over existing). As such, impacts would be less than significant, no mitigation measures would be required.

Car alarm and horn noise within parking structures would generate noise levels with the potential to adversely impact adjacent land uses during Project operations. However, the parking structures would be constructed with a solid concrete wall free of gaps or penetrations surrounding the at-grade level, to reduce off-site noise impacts from

[14] *Fehr & Peers, Culver Studios Modified Comprehensive Plan Update #7, May, 2017.*

[15] *FTA, Transit Noise and Vibration Impact Assessment. May 2006.*

operations. PDF-NOISE-6 is also prescribed to reduce off-site noise impacts from exhaust or ventilation systems operations. Therefore, car alarm, horn noise, and exhaust or ventilation system would not increase ambient noise levels at nearby residences. As such, impacts would be less than significant.

3.5.3 Operational Loading Dock Area Noise

Loading bays/cores would be provided beneath each building, with numerous truck maneuvering areas between those bays to allow passing, turnaround, and egress.

Loading dock activities such as truck movements/idling and loading/unloading operations generate noise levels that have the potential to adversely impact adjacent land uses during long-term Project operations. However, since the proposed loading areas would be enclosed within the subterranean parking structures and shielded from surrounding off-site sensitive uses there would be no perceptible increases in noise from loading dock areas at off-site sensitive receptor locations. As such, impacts would be less than significant.

3.5.4 Operational Special Events and Outdoor Programming Noise

The Front Lawn is currently used for a variety of special events including filming, screenings and concerts, weddings, picnics, and “pop-up” events, educational events, and community events. Following implementation of the Project, the Front Lawn would continue to support these and similar uses and events. If activities are ultimately proposed, including those in association with Parcel B and Town Plaza, that would include use of the Front Lawn or otherwise change the nature of existing uses and events in a manner that could result in significant noise or other environmental impacts, such activities/uses would be addressed through the City special permit process, including the need for any mitigation measures to address noise. Therefore, activities on the Front Lawn would be consistent with the existing ambient noise levels, or would be addressed through the City special permit process, and accordingly impacts would be less than significant at the nearby noise sensitive uses.

The Central Courtyard would be used for a range of activities and special events, including but not limited to shoots, production support film screenings, concerts, outdoor teaming space, housing of amenities, and passive recreational uses. Other on-site areas that could be used for outdoor programming and special events include balconies, courtyards, patios, walkways, and decks on proposed buildings. Proposed buildings are located north and south of the Central Courtyard area and other on-site areas and block the line-of-sight to nearby residences. **[Note: Project Architect should confirm.]** Furthermore, PDF-NOISE-10 is proposed which would prohibit outdoor special event and recreational activities where adjacent to off-site residential uses. Therefore, the Central Courtyard and related noise and other outdoor activity noise would not increase ambient noise levels at nearby residence by 5 dBA threshold, and impacts would be less than significant.

3.5.5 Composite Noise Level Impacts from Project Operations

An evaluation of the combined noise levels from the Project’s various operational noise sources (i.e., composite noise level) was conducted to conservatively ascertain the potential maximum Project-related noise level increase that may occur at the nearest noise-sensitive receptors. Noise sources associated with the Project include the incremental increase in traffic noise, on-site mechanical equipment, parking structure, and loading area activities noise.

The maximum composite noise impacts would generally occur close to the Project Site. Since with the exception of the Project’s incremental contribution to roadway traffic noise, Project noise sources would be located on the Project Site. As shown in Table 4.9-8 and Table 4.9-9, the Project would result in a maximum increase in traffic noise of 1.5

dBA CNEL, which would occur along Ince Boulevard, Between Culver Studio Gate 2 and Culver Studio Gate 3 adjacent to commercial uses.

As discussed previously, mechanical equipment would be shielded from nearby noise sensitive uses to attenuate noise and avoid conflicts with adjacent uses. Therefore, mechanical related noise is expected to be a minimum of 10 dBA below the ambient noise levels, which would have a contribution of approximately 0.4 dBA or less to the composite noise level.[16] Noise from vehicle activity at the Studio gates would generate a noise level of 51 dBA along Ince Boulevard (R1), which would have a contribution of approximately 0.1 dBA. Loading dock would be located in the subterranean parking structures and would not increase ambient noise levels at nearby sensitive receptor locations. Operational special events and outdoor programming related noise would increase ambient noise levels up to 1 dBA. Overall, relative to the existing noise environment, the Project is estimated to increase the ambient noise level by approximately 3.0 dBA (1.5+0.4+0.1+1 dBA) at the nearest noise-sensitive receptors along Ince Boulevard (R1), which is less than the significance threshold of a 5 dBA increase. Composite noise level increases at all other receptor locations are expected to be less than significant as well, given their distance from the Project Site and the presence of intervening structures. As such, the composite noise level impact on the nearest sensitive receptors due to the Project's future operations would be less than significant, and no mitigation would be required.

3.6 GROUND-BORNE VIBRATION IMPACTS

Threshold NOISE-2: The Project would have a potentially significant impact on noise if it would result in the exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels.

Impact Statement NOISE-2: Operational activities would not exceed the vibration significance thresholds. Thus, operational vibration impacts would be less than significant. However, construction activities would result in sporadic, temporary vibration effects adjacent to the Project area, which would exceed the vibration significance thresholds. Impacts due to vibration from on-site construction activity would be potentially significant.

3.6.1 Construction Vibration

Construction activities at the Project Site have the potential to generate low levels of groundborne vibration as the operation of heavy equipment (i.e., backhoe, dozer, excavators, grader, loader, scraper, and haul trucks, etc.) generates vibrations that propagate though the ground and diminish in intensity with distance from the source. No high-impact activities, such as pile driving or blasting, would be used during Project construction. The nearest off-site sensitive buildings to the Project Site are residential buildings approximately from 5 feet to 50 feet from the Project Site including low-density multi-family residential uses to the east, single- and low-density multi-family residential uses on Van Buren Place abut the Studio Campus, and multi-family residential uses abut the Studio Campus and primarily front on Lucerne Avenue. In addition, the Linwood E. Howe Elementary School buildings are located approximately 75 feet from the Project Site. Groundborne vibrations from construction activities very rarely reach the levels that can damage structures, but they may be perceived in buildings very close to a construction site.

The PPV vibration velocities for several types of construction equipment that can generate perceptible vibration levels are identified in **Table 10,** *Vibration Source Levels for Construction Equipment*. Based on the information presented in Table 10, vibration velocities could range from 0.003 to 0.089 in/sec PPV at 25 feet from the source of activity.

[16] *Caltrans, Technical Noise Supplement (TeNS), Section 2.1.3.5, September, 2013.*

TABLE 10
VIBRATION SOURCE LEVELS FOR CONSTRUCTION EQUIPMENT

Equipment	Approximate PPV (in/sec)					Approximate RMS (VdB)				
	25 Feet	50 Feet	60 Feet	75 Feet	100 Feet	25 Feet	50 Feet	60 Feet	75 Feet	100 Feet
Large Bulldozer	0.089	0.031	0.024	0.017	0.011	87	78	76	73	69
Hoe Ram	0.089	0.031	0.024	0.017	0.011	87	78	76	73	69
Caisson Drilling	0.089	0.031	0.024	0.017	0.011	87	78	76	73	69
Loaded Trucks	0.076	0.027	0.020	0.015	0.010	86	77	75	72	68
Jackhammer	0.035	0.012	0.009	0.007	0.004	79	70	68	65	61
Small Bulldozer	0.003	0.001	0.0008	0.0006	0.0004	58	49	47	44	40

SOURCE: FTA 2006; ESA PCR, 2017.

At a distance of 5 feet from the nearest residential buildings, the maximum vibration level would be up to approximately 0.523 in/sec PPV for a large bulldozer and would be reduce to 0.19 in/sec PPV at 15 feet from a large bulldozer, which would be below the significance threshold of 0.2 in/sec PPV. The Linwood E. Howe Elementary School buildings would be exposed to vibration velocities up to 0.017 in/sec PPV from construction activities. All other structures are located farther away and vibration velocities would be substantially lower at these more distant structures. Therefore, residential buildings located within 15 feet from the Project Site would experience potentially significant vibration impacts from the Project construction. Mitigation measures are therefore prescribed to reduce construction vibration impacts to these vibration sensitive receptors, as presented in Subsection 4, Mitigation Measures, below.

On-site historic buildings such as the Mansion, Bungalows, Building D, E, H, I, and Stage 11/12/14 and 15/16) are located from 15 feet to 70 feet from operation of construction equipment. Historic buildings located within 20 feet from a large dozer would be exposed to vibration levels up to 0.124 in/sec PPV, which would exceed the significance threshold of 0.12 in/sec PPV. Therefore, historic buildings located within 20 feet from operation of heavy construction equipment would experience potentially significant vibration impacts from the Project construction. Mitigation measures are therefore prescribed to reduce construction vibration impacts to these vibration sensitive receptors, as presented in subsection 4, Mitigation Measures.

With respect to human annoyance, the nearest residential uses located within 45 feet from the Project Site would be exposed to vibration levels exceeding 80 VdB. Under the FTA's vibration annoyance potential criteria (refer to Table 4.9-4), vibration levels exceeding 80 VdB would be considered distinctly perceptible for residential uses. The Linwood E. Howe Elementary School buildings would be exposed to vibration velocities up to 73 VdB, which would be below the significance threshold of 83 VdB for schools. Therefore, residential buildings located within 45 feet of the Project Site would experience potentially significant vibration impacts from Project construction. Mitigation measures are therefore prescribed to reduce construction vibration impacts to this sensitive vibration receptor, as presented in subsection 4, Mitigation Measures, below.

3.6.2 Operational Vibration

The Project's operations would include typical commercial-grade stationary mechanical and electrical equipment, such as air handling units, condenser units, and exhaust fans, which would produce vibration. In addition, the primary sources of transient vibration would be passenger vehicle circulation within the proposed parking area. However, vibration isolators and mount would be installed to reduce vibration velocities from typical commercial-grade station machinery. Therefore, ground-borne vibration generated by each of the above-mentioned activities would generate approximately up to 50 VdB adjacent to the Project Site.[17] The potential vibration levels from all Project operational sources at the closest existing and future sensitive receptor locations would be less than the significance threshold of 80 VdB for perceptibility. As such, vibration impacts associated with operation of the Project would be below the significance threshold and impacts would be less than significant.

Threshold NOISE-3: The Project would have a potentially significant impact on noise if it would result in a substantial permanent increase in ambient noise levels in the vicinity of the Project above levels existing without the Project.

Impact Statement NOISE-3: Operational activities would not substantially increase the ambient noise levels in the vicinity of the Project. Thus, impacts would be less than significant.

As discussed in detail under Threshold NOISE-1, overall, relative to the existing noise environment, the Project is estimated to increase the ambient noise level by approximately 2.0 dBA at the nearest noise-sensitive receptor, which is less than the significance threshold of a 5 dBA increase. Composite noise level increases at all other receptor locations are expected to be less than significant as well, given their distance from the Project Site and the presence of intervening structures. As such, the composite noise level impact on the nearest sensitive receptors due to the Project's future operations would be less than significant, and no mitigation would be required.

Threshold NOISE-4: A significant impact would occur if Project would result in a substantial temporary or periodic increase in ambient noise levels in the Project vicinity above levels existing without the Project.

Impact Statement NOISE-4: Construction activities would increase noise levels at off-site noise-sensitive receptors in the Project Area in excess of ambient noise levels. Impacts due to noise from on-site construction activity would be potentially significant at off-site sensitive use locations. However, with implementation of the identified construction mitigation measure, noise levels would be reduced to below the threshold. Thus, construction noise impacts would be less than significant with implementation of mitigation.

As discussed in Threshold NOISE-1, construction noise levels are estimated to reach 85 dBA to 90 dBA at the nearby sensitive receptors. This would substantially increase ambient noise levels at those locations. As such, the Project would have a potentially significant construction noise impact on sensitive receptors in the vicinity of the Project. Mitigation measures are prescribed to reduce construction noise impacts as presented below in Section 4, Mitigation Measures.

Construction traffic noise levels generated by truck trips would increase traffic noise levels along Ince Street by 2.8 dBA and along Washington Boulevard by 1.3 dBA. The noise level increases by truck trips would be below substantial increase of a 5 dBA. Therefore, off-site construction traffic noise impacts would be less than significant.

[17] *FTA, Transit Noise and Vibration Impact Assessment, Section 7.2.1, May. 2006.*

3.7 CUMULATIVE IMPACTS

The geographic context for the analysis of cumulative noise impacts depends on the impact being analyzed. Noise is by definition a localized phenomenon, and significantly reduces in magnitude as the distance from the source increases. As such, only cumulative Projects and growth due to occur in the immediate Project area within 500 feet would be likely to contribute to cumulative noise impacts. However, the cumulative impacts on roadway noise would be affected by traffic from all cumulative Projects throughout a larger vicinity.

As discussed in Chapter 3.0, General Description of Environmental Setting, Subsection 3.B, Related Projects, of this Draft EIR, there are 56 related Projects identified in the vicinity of the Project. The three closest related Projects, situated approximately 180 feet to 500 feet from the Project Site, are Related Project No. 22, Office and Apartment, 9355 Culver Boulevard, Related Project No. 24, Office, Restaurant, and Retail, 9300 Culver Boulevard, and Related Project No. 54, Apartment, 4227 Ince Boulevard. All other related Projects are a minimum of 1,000 feet away from the Project Site. The potential for noise impacts to occur are specific to the location of each Related Project as well as cumulative traffic on the surrounding roadway network.

3.7.1 Construction

As stated above, of the Project's 56 Related Projects, three are located within the immediate vicinity of the Project Site. By contrast, at the Project Site construction traffic from all Related Projects would contribute to noise levels on major thoroughfares throughout the area, although the Related Projects are located in different areas and to some extent would have varied haul routes and traffic patterns associated with their construction.

Because the timing of the construction activities for all cumulative Projects cannot be defined and are beyond the control of the City and the Applicant, a quantitative analysis that assumes multiple, concurrent construction Projects would be speculative. The cumulative noise levels would be intermittent, temporary and would cease at the end of the respective construction periods. It is not likely that maximum construction noise impacts from the cumulative Projects would occur simultaneously, as sound levels vary from day to day depending on the construction activity performed that day and its location on the development site.

Sensitive receptors R1 and R3 are located away from the related Projects and existing building are located between the sensitive receptors located at R1 and R3 and the related Projects. The existing buildings would block construction noise from the related Projects at locations R1 and R3. Therefore, cumulative construction noise impacts would not occur on the sensitive receptor location R1 and R3 with implementation of the prescribed mitigation measures and Project design features.

The nearest Project which may be under construction concurrently with the Project that has potential for cumulative impacts to sensitive receptors at location R2 would be Related Project No. 54, located 180 feet to the east of the Project Site and within 50 feet from the receptor locations (R2) along Lucerne Avenue. Construction of this Project could overlap with construction of the Project. The Project would result in a maximum construction noise level of 85 dBA L_{eq} at the off-site receptor locations (R2) along Lucerne Avenue. Policy 2.A of the Noise Element would require the Project to implement noise reduction techniques to ensure that the noise impacts associated with construction activities would be minimized to the maximum extent feasible. Implementation of construction mitigation measures would reduce the Project's impact to less than significant,

If Related Project No. 24 and Related Project No. 54 proceed simultaneously with the Project, the Related Project No. 24 and Related Project No. 54 could contribute to cumulative construction noise impacts on the noise sensitive receptor locations R4.

Noise associated with other cumulative construction Projects would be required to comply with the City's construction noise standards and Noise Element Policy 2.A, similar to this Project, and would be required under CEQA, if necessary, to reduce construction noise levels to the degree reasonably and technically feasible through proposed mitigation measures for each individual Project, including time restrictions for construction activities. Therefore, with implementation of design features and mitigation measures, cumulative construction noise impacts would be less than significant.

3.7.2 Operations

Cumulative noise impacts would occur primarily as a result of increased traffic on local roadways due to operation of the Project and Related Projects, as traffic is the greatest source of operational noise in the Project area. Cumulative traffic-generated noise impacts were assessed based on a comparison of the future cumulative base traffic volumes with the Project to the existing base traffic volumes without the Project. The noise levels associated with existing base traffic volumes without the Project, and cumulative base traffic volumes with the Project are provided in **Table 11**, *Off-Site Traffic Noise Impacts – Future 2021Cumulative Increment*. Table 11 shows the Project's contribution to the cumulative noise levels. The maximum cumulative noise increase from the Project plus cumulative Project traffic would be 1.6 dBA CNEL, CNEL, which would occur along Ince Boulevard, Between Culver Studio Gate 2 and Culver Studio Gate 3 adjacent to commercial uses. This increase in sound level would be below 5 dBA increase, and the increase in sound level would be lower at the remaining roadway segments analyzed. The Project-related noise increases would be less than significant, and no mitigation measures would be required.

TABLE 11
OFF-SITE TRAFFIC NOISE IMPACTS – FUTURE 2021 CUMULATIVE INCREMENT

		Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL)				
Roadway Segment	**Existing Land Uses Located Along Roadway Segment**	**Existing (A)**	**Future with Project (B)**	**Cumulative Increment (B-A)**	**Threshold**	**Exceed Threshold?**
Culver Boulevard						
Between Venice Boulevard and Ince Boulevard	Commercial	65.4	66.2	0.8	5	No
Between Ince Boulevard and Main Street	Commercial	69.4	70.1	0.7	5	No
Between Main Street and Cardiff Avenue	Commercial	68.9	69.6	0.7	5	No
Between Cardiff Avenue and Washington Boulevard	Commercial	69.0	69.7	0.7	5	No
Between Washington Boulevard and Lafayette Place	Commercial	66.2	67.0	0.8	5	No
Between Lafayette Place and Duquesne Avenue	Commercial	67.0	67.7	0.7	5	No
Between Duquesne Avenue and Madison Avenue	Residential/ Commercial	67.9	68.5	0.6	5	No
Between Madison Avenue and Overland Ave	Residential/ Commercial	69.2	69.8	0.6	5	No
Ince Boulevard						
Between Washington Boulevard and Culver Studio Gate 2	Commercial	64.6	65.6	1.0	5	No
Between Culver Studio Gate 2 and Culver Studio Gate 3	Commercial	59.4	61.0	1.6	5	No
Between Culver Studio Gate 3 and Lucerne Avenue	Residential/ Commercial	59.1	59.4	0.3	5	No

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL)				
		Existing (A)	Future with Project (B)	Cumulative Increment (B-A)	Threshold	Exceed Threshold?
Lucerne Avenue						
Between Higuera Street and Ince Boulevard	Residential	61.5	61.8	0.3	5	No
Between Ince Boulevard and Duquesne Avenue	Residential	62.4	62.7	0.3	5	No
Venice Boulevard						
Between La Cienega Avenue and Cattaraugus Avenue	Lodging/Commercial	67.9	68.7	0.8	5	No
Between Cattaraugus Avenue and National Boulevard	Residential/Commercial	67.8	68.6	0.8	5	No
Between National Boulevard and Robertson Boulevard	Commercial	69.0	69.9	0.9	5	No
Between Robertson Boulevard and Culver Boulevard	Commercial	70.2	71.1	0.9	5	No
Between Culver Boulevard and Main Street/Bagley Avenue	Commercial	69.1	70.0	0.9	5	No
Between Main Street/Bagley Avenue and Hughes Avenue	Residential/Commercial	68.4	69.3	0.9	5	No
Between Hughes Avenue and Clarington Avenue	Residential/Commercial	68.5	69.4	0.9	5	No
Between Clarington Avenue and Motor Avenue	Commercial	68.5	69.3	0.8	5	No
Between Motor Avenue and Overland Avenue	Residential/Commercial	68.9	69.7	0.8	5	No
Washington Boulevard						
Between La Cienega Boulevard and National Boulevard	Commercial	68.7	68.6	-0.1	5	No
Between National Boulevard and Higuera Street	Commercial	68.8	69.9	1.1	5	No
Between Higuera Street and Ince Boulevard	Commercial	68.9	69.7	0.8	5	No
Between Ince Boulevard and Culver Boulevard	Lodging/Commercial	68.1	68.7	0.6	5	No
Between Culver Boulevard and Duquesne Avenue	Commercial	67.6	68.1	0.5	5	No
Between Duquesne Avenue and Clarington Avenue	Residential/Commercial	67.6	68.2	0.6	5	No
Between Clarington Avenue and Motor Avenue	Religious/Commercial	69.6	70.1	0.5	5	No
Between Motor Avenue and Overland Avenue	Commercial	69.3	69.7	0.4	5	No
Higuera Street						
Between Washington Boulevard and Lucerne Avenue	Residential/Commercial	66.6	66.9	0.3	5	No
Between Lucerne Avenue and Jefferson Boulevard	Residential/Commercial	66.1	66.5	0.4	5	No

Roadway Segment	Existing Land Uses Located Along Roadway Segment	Calculated Traffic Noise Levels along Adjacent Land Uses (dBA CNEL) Existing (A)	Future with Project (B)	Cumulative Increment (B-A)	Threshold	Exceed Threshold?
Duquesne Avenue						
Between Jefferson Boulevard and Lucerne Avenue	Residential/Commercial	68.7	69.2	0.5	5	No
Between Lucerne Avenue and Culver Boulevard	Residential/Commercial	66.8	67.4	0.6	5	No
National Boulevard						
Between Robertson Boulevard and I-10 EB On-Ramp	Commercial	69.5	70.2	0.7	5	No
Between I-10 EB On-Ramp and Venice Boulevard	Commercial	68.4	69.5	1.1	5	No
Between Venice Boulevard and Washington Boulevard	Commercial	67.3	68.6	1.3	5	No
Between Washington Boulevard and Hayden Avenue	Residential/Commercial	69.0	69.8	0.8	5	No
Between Hayden Avenue and Jefferson Boulevard	Residential/Park/Commercial	66.7	66.8	0.1	5	No

SOURCE: ESA PCR, 2017.

The CCMC-required provisions that limit stationary-source noise from items such as roof-top mechanical equipment would ensure noise levels would be less than significant at the property line for each Related Project. In addition, on-site noise generated by each Related Project would be sufficiently low that it would not result in an additive increase to Project-related noise levels. Further, noise from other stationary sources, including parking structures, open space activity and loading docks would be limited to areas in the immediate vicinity of each Related Project. Although each Related Project could potentially impact an adjacent sensitive use, that potential impact would be localized to that specific area and would not contribute to cumulative noise conditions at or adjacent to the proposed Project Site. As the Project's composite stationary-source impacts would be less than significant, the Project's cumulative stationary-source noise impacts would be less than significant.

3.6.3 Ground-Borne Vibration

Due to the rapid attenuation characteristics of ground-borne vibration and distance from each of the Related Projects to the Project Site, there is no potential for cumulative construction- or operational-period impacts with respect to ground-borne vibration. Therefore, cumulative impacts would be less than significant.

4. MITIGATION MEASURES

4.1 CONSTRUCTION NOISE AND VIBRATION

Construction-related vibration has the potential to result in potential significant vibration impacts on the surrounding area. In addition, the City requires the implementation of construction noise reduction techniques consistent with General Plan Noise Element Policy 2.A. Thus, the following mitigation measures are required to reduce construction-related vibration impacts and to minimize the generation of construction noise:

MM-NOISE-1: The Project shall provide a temporary 20-foot-tall construction fence equipped with noise blankets rated to achieve sound level reductions of at least 20 dBA between the Project Site and the surrounding residences and elementary school. Prior to the commencement of any excavation, the applicant shall install a temporary construction fence with screening around the site. The height, fence and screening materials are subject to approval by the City Engineer or his/her designee. Temporary noise barriers shall be used to block the line-of-sight between the construction equipment and the noise-sensitive receptors during early Project construction phases (up to the start of framing) when the use of heavy equipment is prevalent. Standard construction protective fencing with green screen or pedestrian barricades for protective walkways shall be installed along property lines facing streets or commercial buildings. All temporary barriers, fences, and walls shall have gate access as needed for construction activities, deliveries, and site access by construction personnel.

MM-NOISE-2: Construction and demolition activities shall be scheduled so as to avoid operating several pieces of equipment simultaneously.

MM-NOISE-3: Heavy equipment, such as use of a large bulldozer (greater than 600 horsepower), shall not be used within 45 feet of the neighboring residential structures. If such proximate construction is required, alternative equipment and methods such as small bulldozers (less than 300 horsepower), shall be used to ensure that vibration effects on adjacent residential uses.

MM-NOISE-4: To avoid or minimize potential construction vibration damage to finish materials on historic buildings, the condition of such materials shall be documented by a qualified preservation consultant, prior to initiation of construction. During construction, the contractor shall install and maintain at least two continuously operational automated vibrational monitors on historic buildings. The monitors must be capable of being programmed with two predetermined vibratory velocities levels: a first-level alarm equivalent to a 0.1 inches per second at the face of the building and a regulatory alarm level equivalent to 0.12 inches per second at the face of the buildings. The monitoring system must produce real-time specific alarms (via text message and/or email to on-site personnel) when velocities exceed either of the predetermined levels. In the event of a first-level alarm, feasible steps to reduce vibratory levels shall be undertaken, including but not limited to halting/staggering concurrent activities and utilizing lower-vibratory techniques. In the event of an exceedance of the regulatory level, work in the vicinity shall be halted and the historic buildings visually inspected for damage. Results of the inspection must be logged. In the event damage occurs to historic finish materials due to construction vibration, such materials shall be repaired in consultation with a qualified preservation consultant, and if warranted, in a manner that meets the Secretary of the Interior's Standards.

4.2 OPERATIONAL NOISE AND VIBRATION

As discussed above, the Project would result in less than significant impacts associated with operational noise and vibration. Therefore, no operational noise and vibration mitigation measures would be required.

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5. CONCLUSIONS

Noise and vibration levels associated with the Project have been evaluated to determine the level of impact from construction activities and future operations of the Project.

5.1 CONSTRUCTION

Mitigation Measure MM-NOISE-1 would provide at least 20 dBA noise reduction at the noise sensitive receptor locations R1 through R4. Implementation of MM-NOISE-2, MM-NOISE-3, PDF-NOISE-8, and PDF-NOISE-9 would reduce construction noise at least 10 dBA at the noise sensitive receptor locations R1 through R4. Therefore, with implementation of MM-NOISE-1 through MM-NOISE-3 and PDF-NOISE-8 and PDF-NOISE-9, the maximum construction noise levels of up to 90 dBA would be reduce to 60 dBA (90 – 20 – 10 = 60) at the noise sensitive receptor location R3, which would not substantially increase the ambient noise level of 57 dBA at the noise sensitive receptor location R3. As such, construction noise impacts would be reduced by a level that is technically feasible mitigation measures of MM-NOISE-1 through MM-NOISE-9 pursuant to Policy 2.A of the City General Plan Noise Element and impacts would be less than significant.

With implementation of Mitigation Measure NOISE-3, the use of smaller bulldozers (less than 300 horsepower) would result in vibration levels of 0.15 inch-per second PPV at residential buildings located within 15 feet from the Project Site and of 70 VdB at residential uses within 45 feet from the Project, which would not exceed the 0.2 inch-per second PPV building damage and 80 VdB perception threshold, respectively. As such, construction vibration impacts would be less than significant.

With the implementation of Mitigation Measure MM-NOISE-4, vibration levels in excess of the threshold would transmit an alarm to on-site personnel with authorization to halt work in the vicinity. Furthermore, in the event damage occurs to historic finish materials due to construction vibration, such materials would be repaired in consultation with a qualified preservation consultant in a manner that meets the Secretary of the Interior's Standards. Thus, vibration impacts on the historic buildings would be less than significant. As such, construction vibration impacts would be less than significant.

PDF-NOISE7 would ensure the proper implementation of Mitigation Measures MM-NOISE-1 through MM-NOISE-4 and PDF-NOISE-8 and PDF-NOISE-9. The construction liaison would ensure that Project related construction noise and vibration would not substantially increase the ambient noise levels at the noise sensitive receptor locations R1 through R4.

In addition, with implementation of design features and mitigation measures, cumulative construction noise impacts would be less than significant at the nearby noise sensitive receptor locations.

5.2 OPERATION

As demonstrated above, operation of the Project would not result in any significant noise or vibration impacts to off-site noise sensitive receptors. As such, operational noise and vibration impacts would be less than significant.

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Appendix A
Construction Noise Calculations

Project: Culver Studios

Construction Noise Impact on Sensitive Receptors

Parameters

Construction Hours:	8	Daytime hours (7 am to 7 pm)
	0	Evening hours (7 pm to 10 pm)
	0	Nighttime hours (10 pm to 7 am)
Leq to L10 factor	3	

				Single-Family				
Construction Phase **Equipment Type**	**No. of Equip.**	**Reference Noise Level at 50ft, Lmax**	**Acoustical Usage Factor**	**Distance (ft)**	**Lmax**	**Leq**	**L10**	**Estimated Noise Shielding, dBA**
Demolition					**84**	***83***		
Air Compressor	1	78	50%	75	74	71	74	
Air Compressor	9	78	50%	150	78	75	78	
Tractor/Loader/Backhoe	1	80	25%	75	76	70	73	
Tractor/Loader/Backhoe	11	80	25%	200	78	72	75	
Other Equipment	2	85	50%	75	84	81	84	
Shoring					**80**	***78***		
Drill Rig Truck	2	79	20%	75	78	71	74	
Cranes	2	81	40%	75	80	77	80	
Excavation/Grading/Foundations					**82**	***85***		
Graders	1	85	40%	75	81	77	80	
Excavator	3	81	40%	100	80	76	79	
Roller	2	80	20%	80	79	72	75	
Other Equipment	1	85	50%	200	73	70	73	
Drill Rig Truck	3	79	20%	80	80	73	76	
Tractor/Loader/Backhoe	4	80	25%	75	82	76	79	
Dozer	1	82	40%	75	78	74	77	
Cranes	2	81	40%	75	80	77	80	
Pumps	3	81	50%	80	82	79	82	
Subterranean Parking					**66**	***67***		
Cranes	3	81	40%	500	66	62	65	
Forklift	3	75	10%	500	60	50	53	
Pumps	3	81	50%	500	66	63	66	
Man Lift	5	75	20%	500	62	55	58	
Other Equipment	1	85	50%	500	65	62	65	
Building Shell/Core Buildings/Van Buren Garage/Landscaping					**83**	***85***		
Cranes	3	81	40%	75	82	78	81	
Man Lift	1	75	20%	75	71	64	67	
Man Lift	17	75	20%	150	78	71	74	
Pumps	4	81	50%	75	83	80	83	
Welders	1	74	40%	75	70	66	69	
Welders	39	74	40%	150	80	76	79	
Cranes	1	81	40%	1000	55	51	54	
Tractor/Loader/Backhoe	1	80	25%	1000	54	48	51	
Man Lift	6	75	20%	1000	57	50	53	
Pumps	2	81	50%	1000	58	55	58	
Tractor/Loader/Backhoe	3	80	25%	150	75	69	72	
Dozer	2	82	40%	75	81	78	81	
Excavator	2	81	40%	75	80	77	80	

Source for Ref. Noise Levels: LA CEQA Guides, 2006 & FHWA RCNM, 2005

Appendix B
Construction Traffic Noise

TRAFFIC NOISE ANALYSIS TOOL

Project Name: [Project Name Here]
Project Number: [Project Number Here]
Analysis Scenario: [Scenario Here, i.e., year, alternative]
Source of Traffic Volumes: [Source Here]

Roadway Segment	Ground Type	Distance from Roadway to Receiver (feet)	Speed (mph)			Peak Hour Volume			Peak Hour Noise Level (Leq(h) dBA)
			Auto	MT	HT	Auto	MT	HT	
Culver Studios									
Haul Trucks	Hard	25	40	40	40	0	0	27	64.2

Model Notes:
The calculation is based on the methodology described in FHWA Traffic Noise Model Technical Manual (1998).
The peak hour noise level at 50 feet was validated with the results from FHWA Traffic Noise Model Version 2.5.
Accuracy of the calculation is within ±0.1 dB when comparing to TNM results.
Noise propagation greater than 50 feet is based on the following assumptions:
For hard ground, the propagation rate is 3 dB per doubling the distance.
For soft ground, the propagation rate is 4.5 dB per doubling the distance.
Vehicles are assumed to be on a long straight roadway with cruise speed.
Roadway grade is less than 1.5%.

Appendix C
Off-Site Traffic Noise Calculations

TRAFFIC NOISE ANALYSIS TOOL

Project Name: The Culver Studio Innovation Plan
Project Number: DPHAC03.EP
Analysis Scenario: Existing (2016)
Source of Traffic Volumes: Fehr & Peers

Roadway Segment	Ground Type	Distance from Roadway to Receiver (feet)	Speed (mph)			Peak Hour Volume			Peak Hour Noise Level (Leq(h) dBA)	Noise Level dBA CNEL
			Auto	MT	HT	Auto	MT	HT		
Culver Blvd, Venice Blvd and Ince Blvd	Hard	60	35	35	35	1235	25	13	65.1	65.4
Culver Blvd, Ince Blvd and Main St	Hard	60	35	35	35	3073	63	32	69.1	69.4
Culver Blvd, Main St and Cardiff Ave	Hard	70	35	35	35	3248	67	33	68.6	68.9
Culver Blvd, Cardiff Ave and Washington Blvd	Hard	70	35	35	35	3311	68	34	68.7	69.0
Culver Blvd, Washington Blvd and Lafayette Pl	Hard	70	35	35	35	1724	36	18	65.9	66.2
Culver Blvd, Lafayette Pl and Duquesne Ave	Hard	70	35	35	35	2086	43	22	66.7	67.0
Culver Blvd, Duquesne Ave and Madison Ave	Hard	60	35	35	35	2206	45	23	67.6	67.9
Culver Blvd, Madison Ave and Overland Ave	Hard	50	35	35	35	2450	51	25	68.9	69.2
Ince Blvd, Washington Blvd and Culver Studio Gate 2	Hard	30	25	25	25	1389	28	0	64.3	64.6
Ince Blvd, Culver Studio Gate 2 and Culver Studio Gate 3	Hard	25	25	25	25	345	7	0	59.1	59.4
Ince Blvd, Culver Studio Gate 3 and Lucerne Ave	Hard	25	25	25	25	327	7	0	58.8	59.1
Lucerne Ave, Higuera St and Ince Blvd	Hard	25	25	25	25	565	12	0	61.2	61.5
Lucerne Ave, Ince Blvd and Duquesne Ave	Hard	25	25	25	25	691	14	0	62.1	62.4
Venice Blvd, La Cienega Ave and Cattaraugus Ave	Hard	85	35	35	35	3132	65	32	67.6	67.9
Venice Blvd, Cattaraugus Ave and National Blvd	Hard	85	35	35	35	3054	63	31	67.5	67.8
Venice Blvd, National Blvd and Robertson Blvd	Hard	75	35	35	35	3535	73	36	68.7	69.0
Venice Blvd, Robertson Blvd and Culver Blvd	Hard	65	35	35	35	3990	82	41	69.9	70.2
Venice Blvd, Culver Blvd and Main St/Bagley Ave	Hard	60	35	35	35	2888	60	30	68.8	69.1
Venice Blvd, Main St/Bagley Ave and Hughes Ave	Hard	75	35	35	35	3053	63	31	68.1	68.4
Venice Blvd, Hughes Ave and Clarington Ave	Hard	75	35	35	35	3138	65	32	68.2	68.5
Venice Blvd, Clarington Ave and Motor Ave	Hard	75	35	35	35	3145	65	32	68.2	68.5
Venice Blvd, Motor Ave and Overland Ave	Hard	70	35	35	35	3196	66	33	68.6	68.9
Washinton Blvd, La Cienega Blvd and National Blvd	Hard	50	35	35	35	2204	45	23	68.4	68.7
Washinton Blvd, National Blvd and Higuera St	Hard	50	35	35	35	2228	46	23	68.5	68.8
Washinton Blvd, Higuera St and Ince Blvd	Hard	45	35	35	35	2062	43	21	68.6	68.9
Washinton Blvd, Ince Blvd and Culver Blvd	Hard	50	35	35	35	1916	40	20	67.8	68.1
Washinton Blvd, Culver Blvd and Duquesne Ave	Hard	50	35	35	35	1696	35	17	67.3	67.6
Washinton Blvd, Duquesne Ave and Clarington Ave	Hard	50	35	35	35	1711	35	18	67.3	67.6
Washinton Blvd, Clarington Ave and Motor Ave	Hard	35	35	35	35	1882	39	19	69.3	69.6
Washinton Blvd, Motor Ave and Overland Ave	Hard	50	35	35	35	2503	52	26	69.0	69.3
Higuera St, Washington Blvd and Lucerne Ave	Hard	25	35	35	35	788	16	0	66.3	66.6
Higuera St, Lucerne Ave and Jefferson Blvd	Hard	30	35	35	35	829	17	0	65.8	66.1
Duquesne Ave, Jefferson Blvd and Lucerne Ave	Hard	25	35	35	35	1280	26	0	68.4	68.7
Duquesne Ave, Lucerne Ave and Culver Blvd	Hard	25	35	35	35	824	17	0	66.5	66.8
National Blvd, Robertson Blvd and I-10 EB On-Ramp	Hard	40	35	35	35	2107	43	22	69.2	69.5
National Blvd, I-10 EB On-Ramp and Venice Blvd	Hard	40	35	35	35	1624	33	17	68.1	68.4
National Blvd, Venice Blvd and Washington Blvd	Hard	60	35	35	35	1899	39	20	67.0	67.3
National Blvd, Washington Blvd and Hayden Ave	Hard	60	40	40	40	1963	40	20	68.7	69.0
National Blvd, Hayden Ave and Jefferson Blvd	Hard	75	40	40	40	1459	30	15	66.4	66.7

Model Notes:
The calculation is based on the methodology described in FHWA Traffic Noise Model Technical Manual (1998).
The peak hour noise level at 50 feet was validated with the results from FHWA Traffic Noise Model Version 2.5.
Accuracy of the calculation is within ±0.1 dB when comparing to TNM results.
Noise propagation greater than 50 feet is based on the following assumptions:
- For hard ground, the propagation rate is 3 dB per doubling the distance.
- For soft ground, the propagation rate is 4.5 dB per doubling the distance.

Vehicles are assumed to be on a long straight roadway with cruise speed.
Roadway grade is less than 1.5%.
CNEL levels were obtained based on Figure 2-19, on page 2-58 Caltran's TeNS 2013.

TRAFFIC NOISE ANALYSIS TOOL

Project Name: The Culver Studio Innovation Plan
Project Number: DPHAC03.EP
Analysis Scenario: Existing With Project (2016)
Source of Traffic Volumes: Fehr & Peers

Roadway Segment	Ground Type	Distance from Roadway to Receiver (feet)	Speed (mph)			Peak Hour Volume			Peak Hour Noise Level (Leq(h) dBA)	Noise Level dBA CNEL
			Auto	MT	HT	Auto	MT	HT		
Culver Blvd, Venice Blvd and Ince Blvd	Hard	60	35	35	35	1312	27.06	13.53	65.4	65.7
Culver Blvd, Ince Blvd and Main St	Hard	60	35	35	35	3179.2	65.55	32.775	69.2	69.5
Culver Blvd, Main St and Cardiff Ave	Hard	70	35	35	35	3374.6	69.58	34.79	68.8	69.1
Culver Blvd, Cardiff Ave and Washington Blvd	Hard	70	35	35	35	3463.9	71.42	35.71	68.9	69.2
Culver Blvd, Washington Blvd and Lafayette Pl	Hard	70	35	35	35	1845.4	38.05	19.025	66.2	66.5
Culver Blvd, Lafayette Pl and Duquesne Ave	Hard	70	35	35	35	2207.7	45.52	22.76	67.0	67.3
Culver Blvd, Duquesne Ave and Madison Ave	Hard	60	35	35	35	2276.1	46.93	23.465	67.8	68.1
Culver Blvd, Madison Ave and Overland Ave	Hard	50	35	35	35	2533.6	52.24	26.12	69.0	69.3
Ince Blvd, Washington Blvd and Culver Studio Gate 2	Hard	30	25	25	25	1582.2	32.29	0	64.9	65.2
Ince Blvd, Culver Studio Gate 2 and Culver Studio Gate 3	Hard	25	25	25	25	489.51	9.99	0	60.6	60.9
Ince Blvd, Culver Studio Gate 3 and Lucern Ave	Hard	25	25	25	25	326.83	6.67	0	58.8	59.1
Lucerne Ave, Higuera St and Ince Blvd	Hard	25	25	25	25	564.97	11.53	0	61.2	61.5
Lucerne Ave, Ince Blvd and Duquesne Ave	Hard	25	25	25	25	690.9	14.1	0	62.1	62.4
Venice Blvd, La Cienega Ave and Cattaraugus Ave	Hard	85	35	35	35	3179.7	65.56	32.78	67.7	68.0
Venice Blvd, Cattaraugus Ave and National Blvd	Hard	85	35	35	35	3100.1	63.92	31.96	67.6	67.9
Venice Blvd, National Blvd and Robertson Blvd	Hard	75	35	35	35	3585	73.92	36.96	68.8	69.1
Venice Blvd, Robertson Blvd and Culver Blvd	Hard	65	35	35	35	4068.2	83.88	41.94	69.9	70.2
Venice Blvd, Culver Blvd and Main St/Bagle Ave	Hard	60	35	35	35	2888.2	59.55	29.775	68.8	69.1
Venice Blvd, Main St/Bagle Ave and Hughes Ave	Hard	75	35	35	35	3090.4	63.72	31.86	68.1	68.4
Venice Blvd, Hughes Ave and Clarington Ave	Hard	75	35	35	35	3175.3	65.47	32.735	68.2	68.5
Venice Blvd, Clarington Ave and Motor Ave	Hard	75	35	35	35	3182.1	65.61	32.805	68.3	68.6
Venice Blvd, Motor Ave and Overland Ave	Hard	70	35	35	35	3233	66.66	33.33	68.6	68.9
Washinton Blvd, La Cinega Blvd and National Blvd	Hard	50	35	35	35	2289.7	47.21	23.605	68.6	68.9
Washinton Blvd, National Blvd and Higuera St	Hard	50	35	35	35	2322.2	47.88	23.94	68.6	68.9
Washinton Blvd, Higuera St and Ince Blvd	Hard	45	35	35	35	2248	46.35	23.175	69.0	69.3
Washinton Blvd, Ince Blvd and Culver Blvd	Hard	50	35	35	35	2006.4	41.37	20.685	68.0	68.3
Washinton Blvd, Culver Blvd and Duquesne Ave	Hard	50	35	35	35	1732.4	35.72	17.86	67.4	67.7
Washinton Blvd, Duquesne Ave and Clarington Ave	Hard	50	35	35	35	1743.6	35.95	17.975	67.4	67.7
Washinton Blvd, Clarington Ave and Motor Ave	Hard	35	35	35	35	1914.3	39.47	19.735	69.4	69.7
Washinton Blvd, Motor Ave and Overland Ave	Hard	50	35	35	35	2535.1	52.27	26.135	69.0	69.3
Higuera St, Washington Blvd and Lucerne Ave	Hard	25	35	35	35	787.92	16.08	0	66.3	66.6
Higuera St, Lucerne Ave and Jefferson Blvd	Hard	30	35	35	35	829	16.91	0	65.8	66.1
Duquesne Ave, Jefferson Blvd and Lucerne Ave	Hard	25	35	35	35	1318.1	26.9	0	68.6	68.9
Duquesne Ave, Lucerne Ave and Culver Blvd	Hard	25	35	35	35	861.91	17.59	0	66.7	67.0
National Blvd, Robertson Blvd and I-10 EB On-Ramp	Hard	40	35	35	35	2106.8	43.44	21.72	69.2	69.5
National Blvd, I-10 EB On-Ramp and Venice Blvd	Hard	40	35	35	35	1643.7	33.89	16.945	68.1	68.4
National Blvd, Venice Blvd and Washington Blvd	Hard	60	35	35	35	1914.8	39.48	19.74	67.0	67.3
National Blvd, Washington Blvd and Hayden Ave	Hard	60	40	40	40	1995.3	41.14	20.57	68.8	69.1
National Blvd, Hayden Ave and Jefferson Blvd	Hard	75	40	40	40	1491.4	30.75	15.375	66.5	66.8

Model Notes:
The calculation is based on the methodology described in FHWA Traffic Noise Model Technical Manual (1998).
The peak hour noise level at 50 feet was validated with the results from FHWA Traffic Noise Model Version 2.5.
Accuracy of the calculation is within ±0.1 dB when comparing to TNM results.
Noise propagation greater than 50 feet is based on the following assumptions:
For hard ground, the propagation rate is 3 dB per doubling the distance.
For soft ground, the propagation rate is 4.5 dB per doubling the distance.
Vehicles are assumed to be on a long straight roadway with cruise speed.
Roadway grade is less than 1.5%.
CNEL levels were obtained based on Figure 2-19, on page 2-58 Caltran's TeNS 2013.

TRAFFIC NOISE ANALYSIS TOOL

Project Name: The Culver Studio Innovation Plan
Project Number: DPHAC03.EP
Analysis Scenario: Future Without Project (2021)
Source of Traffic Volumes: Fehr & Peers

Roadway Segment	Ground Type	Distance from Roadway to Receiver (feet)	Speed (mph)			Peak Hour Volume			Peak Hour Noise Level (Leq(h) dBA)	Noise Level dBA CNEL
			Auto	MT	HT	Auto	MT	HT		
Culver Blvd, Venice Blvd and Ince Blvd	Hard	60	35	35	35	1435	29.58	14.79	65.8	66.1
Culver Blvd, Ince Blvd and Main St	Hard	60	35	35	35	3485.7	71.87	35.935	69.6	69.9
Culver Blvd, Main St and Cardiff Ave	Hard	70	35	35	35	3613.7	74.51	37.255	69.1	69.4
Culver Blvd, Cardiff Ave and Washington Blvd	Hard	70	35	35	35	3686	76	38	69.2	69.5
Culver Blvd, Washington Blvd and Lafayette Pl	Hard	70	35	35	35	1961.3	40.44	20.22	66.5	66.8
Culver Blvd, Lafayette Pl and Duquesne Ave	Hard	70	35	35	35	2343	48.31	24.155	67.2	67.5
Culver Blvd, Duquesne Ave and Madison Ave	Hard	60	35	35	35	2422.1	49.94	24.97	68.0	68.3
Culver Blvd, Madison Ave and Overland Ave	Hard	50	35	35	35	2764	56.99	28.495	69.4	69.7
Ince Blvd, Washington Blvd and Culver Studio Gate 2	Hard	30	25	25	25	1536.2	31.35	0	64.8	65.1
Ince Blvd, Culver Studio Gate 2 and Culver Studio Gate 3	Hard	25	25	25	25	363.58	7.42	0	59.3	59.6
Ince Blvd, Culver Studio Gate 3 and Lucern Ave	Hard	25	25	25	25	339.57	6.93	0	59.0	59.3
Lucerne Ave, Higuera St and Ince Blvd	Hard	25	25	25	25	600.74	12.26	0	61.5	61.8
Lucerne Ave, Ince Blvd and Duquesne Ave	Hard	25	25	25	25	735.98	15.02	0	62.4	62.7
Venice Blvd, La Cienega Ave and Cattaraugus Ave	Hard	85	35	35	35	3689.9	76.08	38.04	68.4	68.7
Venice Blvd, Cattaraugus Ave and National Blvd	Hard	85	35	35	35	3605.5	74.34	37.17	68.3	68.6
Venice Blvd, National Blvd and Robertson Blvd	Hard	75	35	35	35	4245	87.53	43.765	69.5	69.8
Venice Blvd, Robertson Blvd and Culver Blvd	Hard	65	35	35	35	4834.5	99.68	49.84	70.7	71.0
Venice Blvd, Culver Blvd and Main St/Bagle Ave	Hard	60	35	35	35	3535.7	72.9	36.45	69.7	70.0
Venice Blvd, Main St/Bagle Ave and Hughes Ave	Hard	75	35	35	35	3733	76.97	38.485	68.9	69.2
Venice Blvd, Hughes Ave and Clarington Ave	Hard	75	35	35	35	3827.1	78.91	39.455	69.1	69.4
Venice Blvd, Clarington Ave and Motor Ave	Hard	75	35	35	35	3736	77.03	38.515	69.0	69.3
Venice Blvd, Motor Ave and Overland Ave	Hard	70	35	35	35	3841.7	79.21	39.605	69.4	69.7
Washinton Blvd, La Cinega Blvd and National Blvd	Hard	50	35	35	35	2680.1	55.26	27.63	69.3	69.6
Washinton Blvd, National Blvd and Higuera St	Hard	50	35	35	35	2813	58	29	69.5	69.8
Washinton Blvd, Higuera St and Ince Blvd	Hard	45	35	35	35	2301.3	47.45	23.725	69.1	69.4
Washinton Blvd, Ince Blvd and Culver Blvd	Hard	50	35	35	35	2125.8	43.83	21.915	68.3	68.6
Washinton Blvd, Culver Blvd and Duquesne Ave	Hard	50	35	35	35	1861.4	38.38	19.19	67.7	68.0
Washinton Blvd, Duquesne Ave and Clarington Ave	Hard	50	35	35	35	1908	39.34	19.67	67.8	68.1
Washinton Blvd, Clarington Ave and Motor Ave	Hard	35	35	35	35	2093.7	43.17	21.585	69.7	70.0
Washinton Blvd, Motor Ave and Overland Ave	Hard	50	35	35	35	2744.6	56.59	28.295	69.4	69.7
Higuera St, Washington Blvd and Lucerne Ave	Hard	25	35	35	35	846.23	17.27	0	66.6	66.9
Higuera St, Lucerne Ave and Jefferson Blvd	Hard	30	35	35	35	908	18.53	0	66.2	66.5
Duquesne Ave, Jefferson Blvd and Lucerne Ave	Hard	25	35	35	35	1405.3	28.68	0	68.9	69.2
Duquesne Ave, Lucerne Ave and Culver Blvd	Hard	25	35	35	35	904.54	18.46	0	66.9	67.2
National Blvd, Robertson Blvd and I-10 EB On-Ramp	Hard	40	35	35	35	2457	50.66	25.33	69.9	70.2
National Blvd, I-10 EB On-Ramp and Venice Blvd	Hard	40	35	35	35	2066.6	42.61	21.305	69.1	69.4
National Blvd, Venice Blvd and Washington Blvd	Hard	60	35	35	35	2535.6	52.28	26.14	68.2	68.5
National Blvd, Washington Blvd and Hayden Ave	Hard	60	40	40	40	2349.3	48.44	24.22	69.5	69.8
National Blvd, Hayden Ave and Jefferson Blvd	Hard	75	40	40	40	1751.8	36.12	18.06	67.2	67.5

Model Notes:
The calculation is based on the methodology described in FHWA Traffic Noise Model Technical Manual (1998).
The peak hour noise level at 50 feet was validated with the results from FHWA Traffic Noise Model Version 2.5.
Accuracy of the calculation is within ±0.1 dB when comparing to TNM results.
Noise propagation greater than 50 feet is based on the following assumptions:
- For hard ground, the propagation rate is 3 dB per doubling the distance.
- For soft ground, the propagation rate is 4.5 dB per doubling the distance.

Vehicles are assumed to be on a long straight roadway with cruise speed.
Roadway grade is less than 1.5%.
CNEL levels were obtained based on Figure 2-19, on page 2-58 Caltran's TeNS 2013.

TRAFFIC NOISE ANALYSIS TOOL

Project Name: The Culver Studio Innovation Plan
Project Number: DPHAC03.EP
Analysis Scenario: Future With Project (2021)
Source of Traffic Volumes: Fehr & Peers

Roadway Segment	Ground Type	Distance from Roadway to Receiver (feet)	Speed (mph)			Peak Hour Volume			Peak Hour Noise Level (Leq(h) dBA)	Noise Level dBA CNEL
			Auto	MT	HT	Auto	MT	HT		
Culver Blvd, Venice Blvd and Ince Blvd	Hard	60	35	35	35	1486	30.64	15.32	65.9	66.2
Culver Blvd, Ince Blvd and Main St	Hard	60	35	35	35	3632.2	74.89	37.445	69.8	70.1
Culver Blvd, Main St and Cardiff Ave	Hard	70	35	35	35	3767.5	77.68	38.84	69.3	69.6
Culver Blvd, Cardiff Ave and Washington Blvd	Hard	70	35	35	35	3839.3	79.16	39.58	69.4	69.7
Culver Blvd, Washington Blvd and Lafayette Pl	Hard	70	35	35	35	2083.6	42.96	21.48	66.7	67.0
Culver Blvd, Lafayette Pl and Duquesne Ave	Hard	70	35	35	35	2420.6	49.91	24.955	67.4	67.7
Culver Blvd, Duquesne Ave and Madison Ave	Hard	60	35	35	35	2492.4	51.39	25.695	68.2	68.5
Culver Blvd, Madison Ave and Overland Ave	Hard	50	35	35	35	2834.3	58.44	29.22	69.5	69.8
Ince Blvd, Washington Blvd and Culver Studio Gate 2	Hard	30	25	25	25	1729.7	35.3	0	65.3	65.6
Ince Blvd, Culver Studio Gate 2 and Culver Studio Gate 3	Hard	25	25	25	25	507.64	10.36	0	60.7	61.0
Ince Blvd, Culver Studio Gate 3 and Lucern Ave	Hard	25	25	25	25	343.98	7.02	0	59.1	59.4
Lucerne Ave, Higuera St and Ince Blvd	Hard	25	25	25	25	600.74	12.26	0	61.5	61.8
Lucerne Ave, Ince Blvd and Duquesne Ave	Hard	25	25	25	25	735.98	15.02	0	62.4	62.7
Venice Blvd, La Cienega Ave and Cattaraugus Ave	Hard	85	35	35	35	3737.4	77.06	38.53	68.4	68.7
Venice Blvd, Cattaraugus Ave and National Blvd	Hard	85	35	35	35	3652.1	75.3	37.65	68.3	68.6
Venice Blvd, National Blvd and Robertson Blvd	Hard	75	35	35	35	4295	88.56	44.28	69.6	69.9
Venice Blvd, Robertson Blvd and Culver Blvd	Hard	65	35	35	35	4913.1	101.3	50.65	70.8	71.1
Venice Blvd, Culver Blvd and Main St/Bagle Ave	Hard	60	35	35	35	3535.7	72.9	36.45	69.7	70.0
Venice Blvd, Main St/Bagle Ave and Hughes Ave	Hard	75	35	35	35	3770.4	77.74	38.87	69.0	69.3
Venice Blvd, Hughes Ave and Clarington Ave	Hard	75	35	35	35	3864.5	79.68	39.84	69.1	69.4
Venice Blvd, Clarington Ave and Motor Ave	Hard	75	35	35	35	3760.2	77.53	38.765	69.0	69.3
Venice Blvd, Motor Ave and Overland Ave	Hard	70	35	35	35	3878.5	79.97	39.985	69.4	69.7
Washinton Blvd, La Cinega Blvd and National Blvd	Hard	50	35	35	35	2144.7	44.22	22.11	68.3	68.6
Washinton Blvd, National Blvd and Higuera St	Hard	50	35	35	35	2907.1	59.94	29.97	69.6	69.9
Washinton Blvd, Higuera St and Ince Blvd	Hard	45	35	35	35	2487.6	51.29	25.645	69.4	69.7
Washinton Blvd, Ince Blvd and Culver Blvd	Hard	50	35	35	35	2216	45.69	22.845	68.4	68.7
Washinton Blvd, Culver Blvd and Duquesne Ave	Hard	50	35	35	35	1894.9	39.07	19.535	67.8	68.1
Washinton Blvd, Duquesne Ave and Clarington Ave	Hard	50	35	35	35	1940.5	40.01	20.005	67.9	68.2
Washinton Blvd, Clarington Ave and Motor Ave	Hard	35	35	35	35	2126.2	43.84	21.92	69.8	70.1
Washinton Blvd, Motor Ave and Overland Ave	Hard	50	35	35	35	2777.1	57.26	28.63	69.4	69.7
Higuera St, Washington Blvd and Lucerne Ave	Hard	25	35	35	35	846.72	17.28	0	66.6	66.9
Higuera St, Lucerne Ave and Jefferson Blvd	Hard	30	35	35	35	908	18.53	0	66.2	66.5
Duquesne Ave, Jefferson Blvd and Lucerne Ave	Hard	25	35	35	35	1430.3	29.19	0	68.9	69.2
Duquesne Ave, Lucerne Ave and Culver Blvd	Hard	25	35	35	35	942.27	19.23	0	67.1	67.4
National Blvd, Robertson Blvd and I-10 EB On-Ramp	Hard	40	35	35	35	2457	50.66	25.33	69.9	70.2
National Blvd, I-10 EB On-Ramp and Venice Blvd	Hard	40	35	35	35	2086	43.01	21.505	69.2	69.5
National Blvd, Venice Blvd and Washington Blvd	Hard	60	35	35	35	2551.1	52.6	26.3	68.3	68.6
National Blvd, Washington Blvd and Hayden Ave	Hard	60	40	40	40	2381.8	49.11	24.555	69.5	69.8
National Blvd, Hayden Ave and Jefferson Blvd	Hard	75	40	40	40	1784.3	36.79	18.395	67.3	67.6

Model Notes:
The calculation is based on the methodology described in FHWA Traffic Noise Model Technical Manual (1998).
The peak hour noise level at 50 feet was validated with the results from FHWA Traffic Noise Model Version 2.5.
Accuracy of the calculation is within ±0.1 dB when comparing to TNM results.
Noise propagation greater than 50 feet is based on the following assumptions:
For hard ground, the propagation rate is 3 dB per doubling the distance.
For soft ground, the propagation rate is 4.5 dB per doubling the distance.
Vehicles are assumed to be on a long straight roadway with cruise speed.
Roadway grade is less than 1.5%.
CNEL levels were obtained based on Figure 2-19, on page 2-58 Caltran's TeNS 2013.

Appendix D
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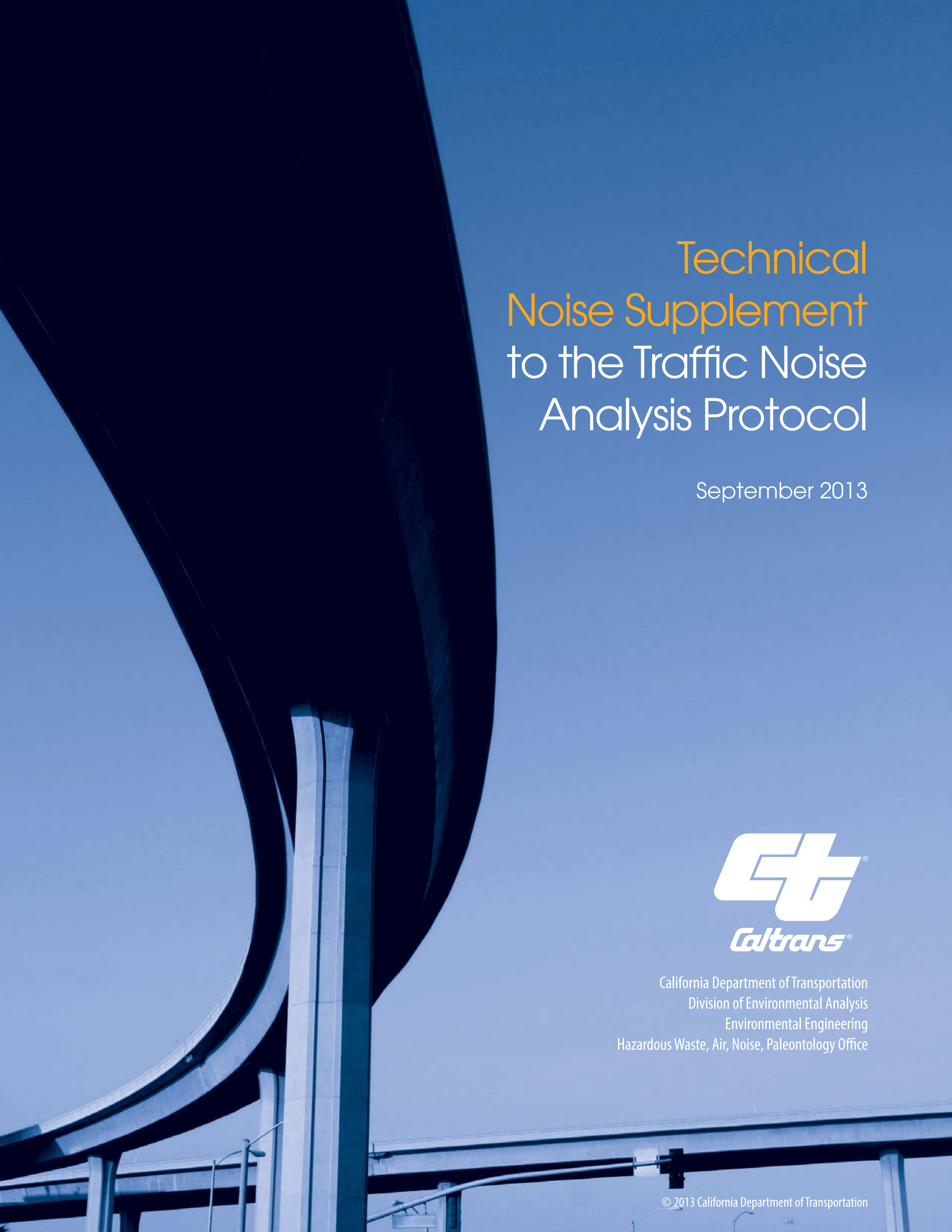

Technical Noise Supplement to the Traffic Noise Analysis Protocol

September 2013

California Department of Transportation
Division of Environmental Analysis
Environmental Engineering
Hazardous Waste, Air, Noise, Paleontology Office

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Sound Pressure Level (dB)	Relative Energy	Relative Pressure	Sound Pressure (μPa)
$10\log_{10}\left(\frac{p_1}{p_0}\right)^2$	$\left(\frac{p_1}{p_0}\right)^2$	$\left(\frac{p_1}{p_0}\right)$	(P_1)
34			10^3 μPa
30	10^3		
20	10^2	10^1	
14			10^2 μPa
10	10^1		
0	**10^0 = 1 = Ref.**	**10^0 = 1 = Ref.**	**$P_1 = P_0 = 20$** μPa

2.1.3.5 Adding, Subtracting, and Averaging Sound Pressure Levels

Because decibels are logarithmic units, SPL cannot be added or subtracted by ordinary arithmetic means. For example, if one automobile produces an SPL of 70 dB when it passes an observer, two cars passing simultaneously would not produce 140 dB; they would combine to produce 73 dB. The following discussion provides additional explanation of this concept. The SPL from any source observed at a given distance from the source may be expressed as $10\log_{10}(P_1/P_0)^2$ (see Equation 2-6). Therefore, the SPL from two equal sources at the same distance would be calculated as follows:

$$SPL = 10\log_{10}\left[(P_1/P_0)^2+(P_1/P_0)^2\right] = 10\log_{10}\left[2(P_1/P_0)^2\right]$$

This can be simplified as $10\log_{10}(2) + 10\log_{10}(P_1/P_0)^2$. Because the logarithm of 2 is 0.301, and 10 times that would be 3.01, the sound of two equal sources is 3 dB more than the sound level of one source. The total SPL of the two automobiles therefore would be 70 + 3 = 73 dB.

Adding and Subtracting Equal Sound Pressure Levels

The previous example of adding the noise levels of two cars may be expanded to any number of sources. The previous section described the relationship between decibels and relative energy. The ratio $(P_1/P_0)^2$ is the relative (acoustic) energy portion of the expression SPL = $10\log_{10}(P_1/P_0)^2$, in this case the relative acoustic energy of one source. This must immediately be qualified with the statement that this is not the acoustic power output of the source. Instead, the expression is the relative acoustic energy per unit area received by the observer. It may be stated that *N* identical automobiles or other noise sources would yield an SPL calculated as follows:

$$SPL_{Total} = SPL_1 + 10\log_{10}(N) \quad \textbf{(2-9)}$$

Where:

SPL_1 = SPL of one source

N = number of identical sources to be added (must be more than 0)

Example

If one noise source produces 63 dB at a given distance, what would be the noise level of 13 of the same source combined at the same distance?

Solution

$SPL_{Total} = 63 + 10\log_{10}(13) = 63 + 11.1 = 74.1$ dB

Equation 2-9 also may be rewritten as follows. This form is useful for subtracting equal SPLs:

$$SPL_1 = SPL_{Total} - 10\log_{10}(N) \quad \textbf{(2-10)}$$

Example

The SPL of six equal sources combined is 68 dB at a given distance. What is the noise level produced by one source?

Solution

$SPL_1 = 68$ dB $- 10\log_{10}(6) = 68 - 7.8 = 60.2$ dB

In these examples, adding equal sources actually constituted multiplying one source by the number of sources. Conversely, subtracting equal sources was performed by dividing the total. For the latter, Equation 2-9 could have been written as $SPL_1 = SPL_{Total} + 10\log_{10}(1/N)$. The logarithm of a fraction yields a negative result, so the answers would have been the same.

These exercises are very useful for estimating traffic noise impacts. For example, if one were to ask what the respective SPL increases would be along a highway if existing traffic were doubled, tripled, or quadrupled (assuming traffic mix, distribution, and speeds would not change), a reasonable prediction could be made using Equation 2-9. In this case, N would be the existing traffic (N = 1); N = 2 would be doubling, N = 3 would be tripling, and N = 4 would be quadrupling the existing traffic. Because $10\log_{10}(N)$ in Equation 2-9 represents the increase in SPL, the above values for N would yield +3, +4.8, and +6 dB, respectively.

Similarly, one might ask what the SPL decrease would be if traffic were reduced by a factor of 2, 3, or 4 (i.e., N = 1/2, N = 1/3, and N = 1/4, respectively). Applying $10\log_{10}(N)$ to these values would yield -3, -5, and -6 dB, respectively.

The same problem also may arise in a different form. For example, the traffic flow on a given facility is 5,000 vehicles per hour, and the SPL is 65 dB at a given location next to the facility. One might ask what the expected SPL would be if future traffic increased to 8,000 vehicles per hour. The solution would be:

$$65 + 10\log_{10}(8{,}000/5{,}000) = 65 + 2 = 67 \text{ dB}.$$

Therefore, *N* may represent an integer, fraction, or ratio. However, *N* always must be more than 0. Taking the logarithm of 0 or a negative value is not possible.

In Equations 2-9 and 2-10, $10\log_{10}(N)$ was the increase from SPL_1 to SPL_{Total} and equals the change in noise levels from an increase or decrease in equal noise sources. Letting the change in SPLs be referred to as ΔSPL, Equations 2-9 and 2-10 can be rewritten as follows:

$$\Delta SPL = 10\log_{10}(N) \qquad \textbf{(2-11)}$$

This equation is useful for calculating the number of equal source increments (N) that must be added or subtracted to change noise levels by ΔSPL. For example, if it is known that an increase in traffic volumes increases SPL by 7 dB, the factor change in traffic (assuming that traffic mix and speeds did not change) can be calculated as follows:

$7 \text{ dB} = 10\log_{10}(N)$

$0.7 \text{ dB} = \log_{10}(N)$

$10^{0.7} = N$

$N = 5.0$

Therefore, the traffic volume increased by a factor of 5.

Adding and Subtracting Unequal Sound Pressure Levels

If noise sources are not equal or equal noise sources are at different distances, $10\log_{10}(N)$ cannot be used. Instead, SPLs must be added or subtracted individually using the SPL and relative energy relationship in Equation 2-8. If the number of SPLs to be added is *N*, and SPL_1, SPL_2, and SPL_n represent the first, second, and *n*th SPL, respectively, the addition is accomplished as follows:

$$SPL_{Total} = 10\log_{10}[10^{SPL_1/10} + 10^{SPL_2/10} + \ldots 10^{SPL_n/10}] \qquad \textbf{(2-12)}$$

The above equation is the general equation for adding SPLs. The equation also may be used for subtraction (simply change "+" to "–"). However, the result between the brackets must always be more than 0. For example, determining the total SPL of 82, 75, 88, 68, and 79 dB would use Equation 2-12 as follows:

$$SPL = 10\log_{10} (10^{68/10} + 10^{75/10} + 10^{79/10} + 10^{82/10} + 10^{88/10}) = 89.6 \text{ dB}$$

Adding Sound Pressure Levels Using a Simple Table

When combining sound levels, a table such as the following may be used as an approximation.

Table 2-3. Decibel Addition

When Two Decibel Values Differ by:	Add This Amount to the Higher Value:	Example:
0 or 1 dB	3 dB	70 + 69 = 73 dB
2 or 3 dB	2 dB	74 + 71 = 76 dB
4 to 9 dB	1 dB	66 + 60 = 67 dB
10 dB or more	0 dB	65 + 55 = 65 dB

This table yields results within about 1 dB of the mathematically exact value and can be memorized easily. The table can also be used to add more than two SPLs. First, the list of values should be sorted, from lowest to highest. Then, starting with the lowest values, the first two should be combined, the result should be added to the third value, and so on until only the answer remains. For example, to determine the sum of the sound levels used in the preceding example using Table 2-3, the first step would be to rank the values from low to high: 68, 75, 79, 82, and 88 dB.

Using Table 2-3, the first two noise levels then should be added. The result then would be added to the next noise level, etc., as follows:

68 + 75 = 76,

76 + 79 = 81,

81 + 82 = 85,

85 + 88 = 90 dB

For comparison, using Equation 2-12, total SPL was 89.6 dB.

Two decibel-addition rules are important. First, when adding a noise level to an approximately equal noise level, the total noise level increases 3 dB.

2.1.3.8 White and Pink Noise

White noise is noise with a special frequency spectrum that has the same amplitude (level) for each frequency interval over the entire audible frequency spectrum. It is often generated in laboratories for calibrating sound level measuring equipment, specifically its frequency response. One might expect that the octave or one-third-octave band spectrum of white noise would be a straight line, but this is not true. Beginning with the lowest audible octave, each subsequent octave spans twice as many frequencies than the previous ones, and therefore contains twice the energy. This corresponds with a 3-dB step increase for each octave band, and 1 dB for each one-third-octave band.

Pink noise, in contrast, is defined as having the same amplitude for each octave band (or one-third-octave band), rather than for each frequency interval. Its octave or one-third-octave band spectrum is truly a straight “level” line over the entire audible spectrum. Therefore, pink noise generators are conveniently used to calibrate octave or one-third-octave band analyzers.

Both white and pink noise sound somewhat like the static heard from a radio that is not tuned to a particular station.

2.1.4 Sound Propagation

From the source to receiver, noise changes both in level and frequency spectrum. The most obvious is the decrease in noise as the distance from the source increases. The manner in which noise reduces with distance depends on the following important factors.

- Geometric spreading from point and line sources.
- Ground absorption.
- Atmospheric effects and refraction.
- Shielding by natural and manmade features, noise barriers, diffraction, and reflection.

2.1.4.1 Geometric Spreading from Point and Line Sources

Sound from a small localized source (approximating a point source) radiates uniformly outward as it travels away from the source in a spherical pattern. The sound level attenuates or drops off at a rate of

6 dBA for each doubling of the distance (6 dBA/DD). This decrease, resulting from the geometric spreading of the energy over an ever-increasing area, is referred to as the inverse square law. Doubling the distance increases each unit area, represented by squares with sides "a" in Figure 2-7, from a^2 to $4a^2$.

Because the same amount of energy passes through both squares, the energy per unit area at 2D is reduced four times from that at distance D. Therefore, for a point source the energy per unit area is inversely proportional to the square of the distance. Taking $10\log_{10}(1/4)$ results in a 6-dBA/DD reduction. This is the point source attenuation rate for geometric spreading.

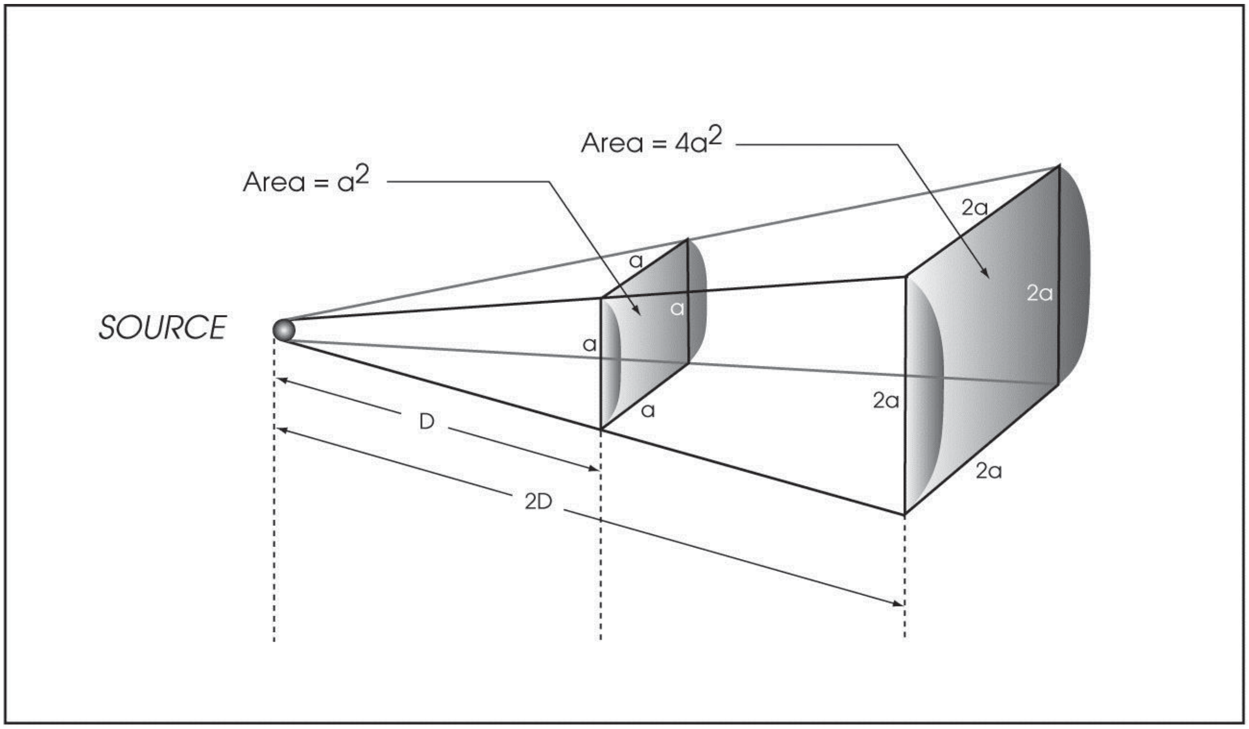

Figure 2-7. Point Source Propagation (Spherical Spreading)

As seen in Figure 2-8, based on the inverse square law the change in noise level between any two distances because of spherical spreading can be found using the following equation:

$$dBA_2 = dBA_1 + 10\log_{10}[(D_1/D_2)]^2 = dBA_1 + 20\log_{10}(D_1/D_2) \qquad \textbf{(2-13)}$$

Where:

dBA_1 = noise level at distance D_1

dBA_2 = noise level at distance D_2

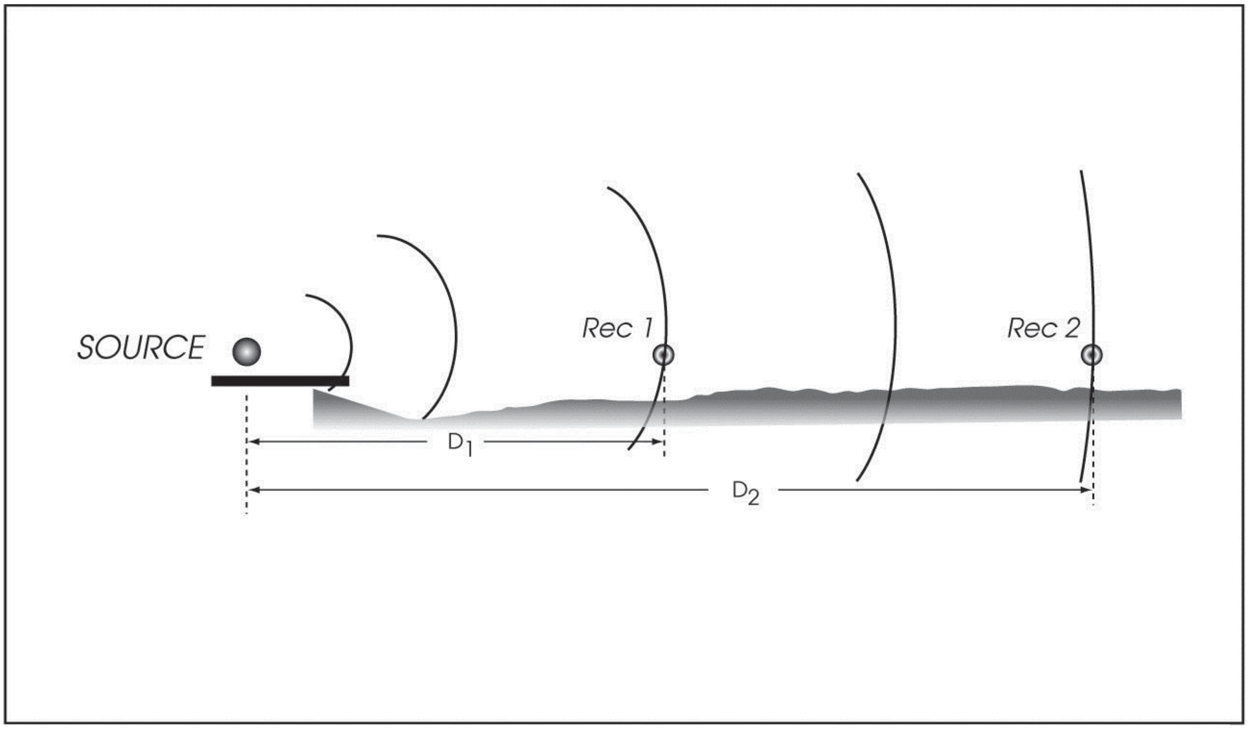

Figure 2-8. Change in Noise Level with Distance from Spherical Spreading

However, highway traffic noise is not a single, stationary point source. The movement of the vehicles makes the source of the sound appear to emanate from a line (line source) rather than a point when viewed over a time interval (Figure 2-9). This results in cylindrical spreading rather than spherical spreading. Because the change in surface area of a cylinder only increases by two times for each doubling of the radius instead of the four times associated with spheres, the change in sound level is 3 dBA/DD. The change in noise levels for a line source at any two different distances from cylindrical spreading is determined using the following equation:

$$dBA_2 = dBA_1 + 10\log_{10}(D_1/D_2) \qquad \textbf{(2-14)}$$

Where:

dBA_1 = noise level at distance D_1 and conventionally the known noise level

dBA_2 = noise level at distance D_2 and conventionally the unknown noise level

Note

The expression $10\log_{10}(D_1/D_2)$ is negative when D_2 is more than D_1 and positive when D_1 is more than D_2. Therefore, the equation automatically accounts for the receiver being farther or closer with respect to the source—$\log_{10}$ of a number less than 1 gives a negative result, $\log_{10}$ of a number more than 1 is positive, and $\log_{10}(1) = 0$.

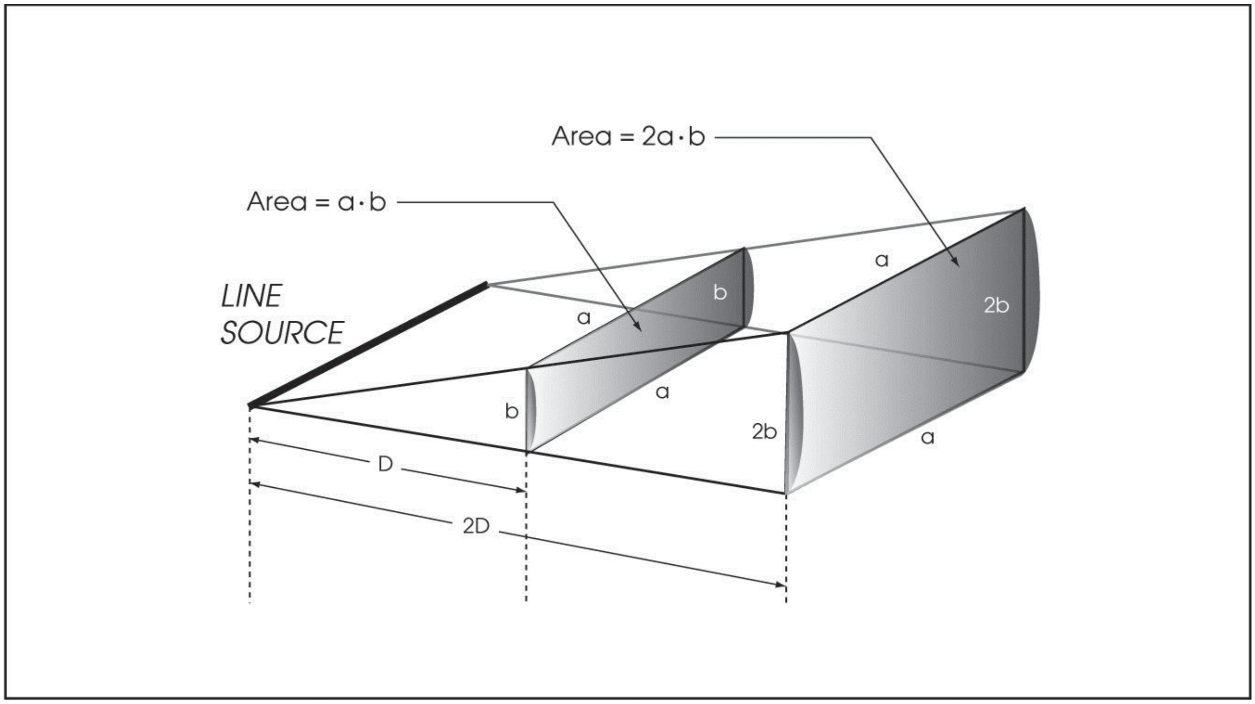

Figure 2-9. Line Source Propagation (Cylindrical Spreading)

2.1.4.2 Ground Absorption

Most often, the noise path between the highway and observer is very close to the ground. Noise attenuation from ground absorption and reflective wave cancellation adds to the attenuation from geometric spreading. Traditionally, this excess attenuation has been expressed in terms of decibels of attenuation per doubling of distance. This approximation is done for simplification only; for distances of less than 200 feet, the prediction results based on this scheme are sufficiently accurate. The sum of the geometric spreading attenuation and excess ground attenuation (if any) is referred to as the attenuation or dropoff rate. For distances of 200 feet or more, the approximation causes excessive inaccuracies in predictions. The amount of excess ground attenuation depends on the height of the noise path and characteristics of the intervening ground or site. In practice, excess ground attenuation may vary from 0 to 8–10 dBA/DD or more. In fact, it varies as the noise path height changes from the source to receiver and with vehicle type because the source heights are different. The complexity of terrain also influences the propagation of sound by potentially increasing the number of ground reflections.

The FHWA TNM is the model that is currently approved by FHWA for use in noise impact studies. The TNM has complex algorithms that directly calculate excess ground attenuation based on ground type and site geometry.

2.1.4.3 Atmospheric Effects and Refraction

Research by Caltrans and others has shown that atmospheric conditions can have a profound effect on noise levels within 200 feet of a highway. Wind has shown to be the most important meteorological factor within approximately 500 feet, while vertical air temperature gradients are more important over longer distances. Other factors such as air temperature, humidity, and turbulence also have significant effects.

Wind

The effects of wind on noise are mostly confined to noise paths close to the ground because of the wind shear phenomenon. Wind shear is caused by the slowing of wind in the vicinity of a ground plane because of surface friction. As the surface roughness of the ground increases, so does the friction between the ground and the air moving over it. As the wind slows with decreasing heights, it creates a sound velocity gradient (because of differential movement of the medium) with respect to the ground. This velocity gradient tends to bend sound waves downward in the same direction of the wind and upward in the opposite direction. The process, called refraction, creates a noise shadow (reduction) upwind of the source and a noise concentration (increase) downwind of the source. Figure 2-10 shows the effects of wind on noise. Wind effects on noise levels along a highway depend very much on wind angle, receiver distance, and site characteristics. A 6-mph cross wind can increase noise levels at 250 feet by about 3 dBA downwind and reduce noise by about the same amount upwind. Present policies and standards ignore the effects of wind on noise levels. Unless wind conditions are specifically identified, noise levels are always assumed to be for zero wind. Noise analyses are also always made for zero-wind conditions.

Wind also has another effect on noise measurements. Wind “rumble” caused by air movement over a microphone of a sound level meter can contaminate noise measurements even if a wind screen is placed over the microphone.

Limited measurements performed by Caltrans in 1987 showed that wind speeds of about 11 mph produce noise levels of about 45 dBA, using a ½-inch microphone with a wind screen. This means that noise measurements below 55 dBA are contaminated by wind speeds of 11 mph or more. A noise level of 55 dBA is about at the low end of the range of noise levels routinely measured near highways for noise analysis. FHWA’s *Measurement of Highway-Related Noise* (1996) recommends that highway noise measurements should not be made at wind speeds above 12 mph. An 11 mph criterion for maximum allowable wind speed for routine highway noise measurements seems reasonable and is therefore recommended. More information concerning wind/microphone contamination is provided in Section 3.

Wind Turbulence

Turbulence also has a scattering effect on noise levels, which is difficult to predict. It appears, however, that turbulence has the greatest effect on noise levels in the vicinity of the source.

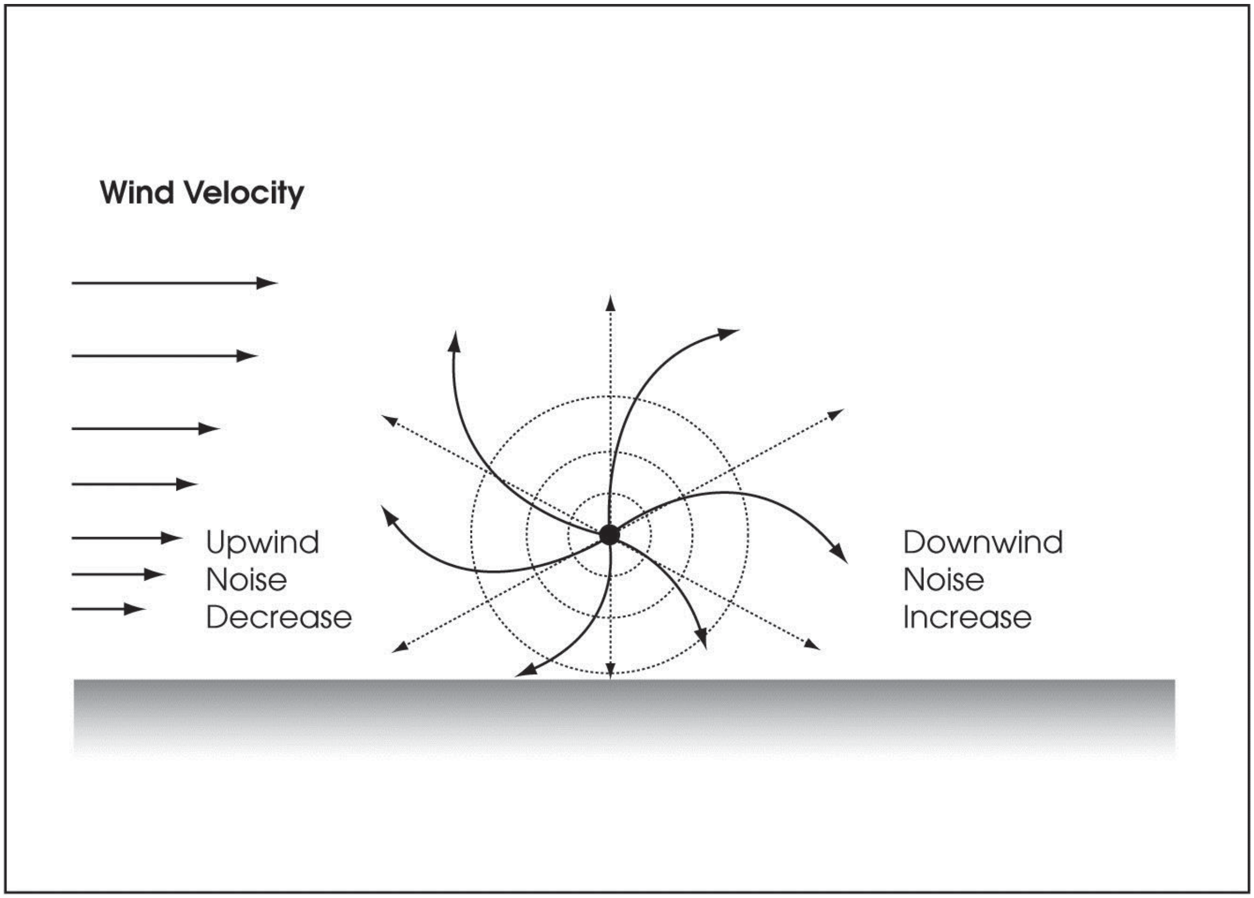

Figure 2-10. Wind Effects on Noise Levels

Temperature Gradients

Figure 2-11 shows the effects of temperature gradients on noise levels. Normally, air temperature decreases with height above the ground. This is called the normal lapse rate, which for dry air is about -5.5ºF per 1,000 feet. Because the speed of sound decreases as air temperature decreases, the resulting temperature gradient creates a sound velocity gradient with height. Slower speeds of sound higher above the ground tend to refract sound waves upward in the same manner as wind shear upwind from the source. The result is a decrease in noise. Under certain stable atmospheric conditions temperature profiles can become inverted (i.e., temperatures increase with height either from the ground up or at some altitude above the ground). This inversion results in speeds of sound that temporarily increase with altitude, causing noise refraction similar to that caused by wind shear downwind from a noise source. Also, once trapped within an elevated inversion layer, noise may be carried over long distances. Both ground and elevated temperature inversions have the effect of propagating noise with less than the usual attenuation rates and therefore increase noise. The effects of vertical temperature gradients are more important over longer distances.

Temperature and Humidity

Molecular absorption in air also reduces noise levels with distance. Although this process only accounts for about 1 dBA per 1,000 feet under average conditions of traffic noise in California, the process can cause significant longer-range effects. Air temperature and humidity affect molecular absorption differently depending on the frequency spectrum and can vary significantly over long distances in a complex manner.

Rain

Wet pavement results in an increase in tire noise and corresponding increase in frequencies of noise at the source. Wet pavement may increase vehicle noise emission levels relative to dry conditions in the range of 0 to 15 dBA (Sandberg and Ejsmont 2002). Because the propagation of noise is frequency-dependent, rain may also affect distance attenuation rates. However, traffic generally slows down during rain, decreasing noise levels and lowering frequencies. When wet, pavement types interact differently with tires than when they are dry. These factors make it very difficult to predict noise levels during rain. Therefore, no noise measurements or predictions should be made under rainy conditions. Noise abatement criteria (NAC) and standards in the FHWA noise regulation (23 CFR 772) are based on completely dry pavement.

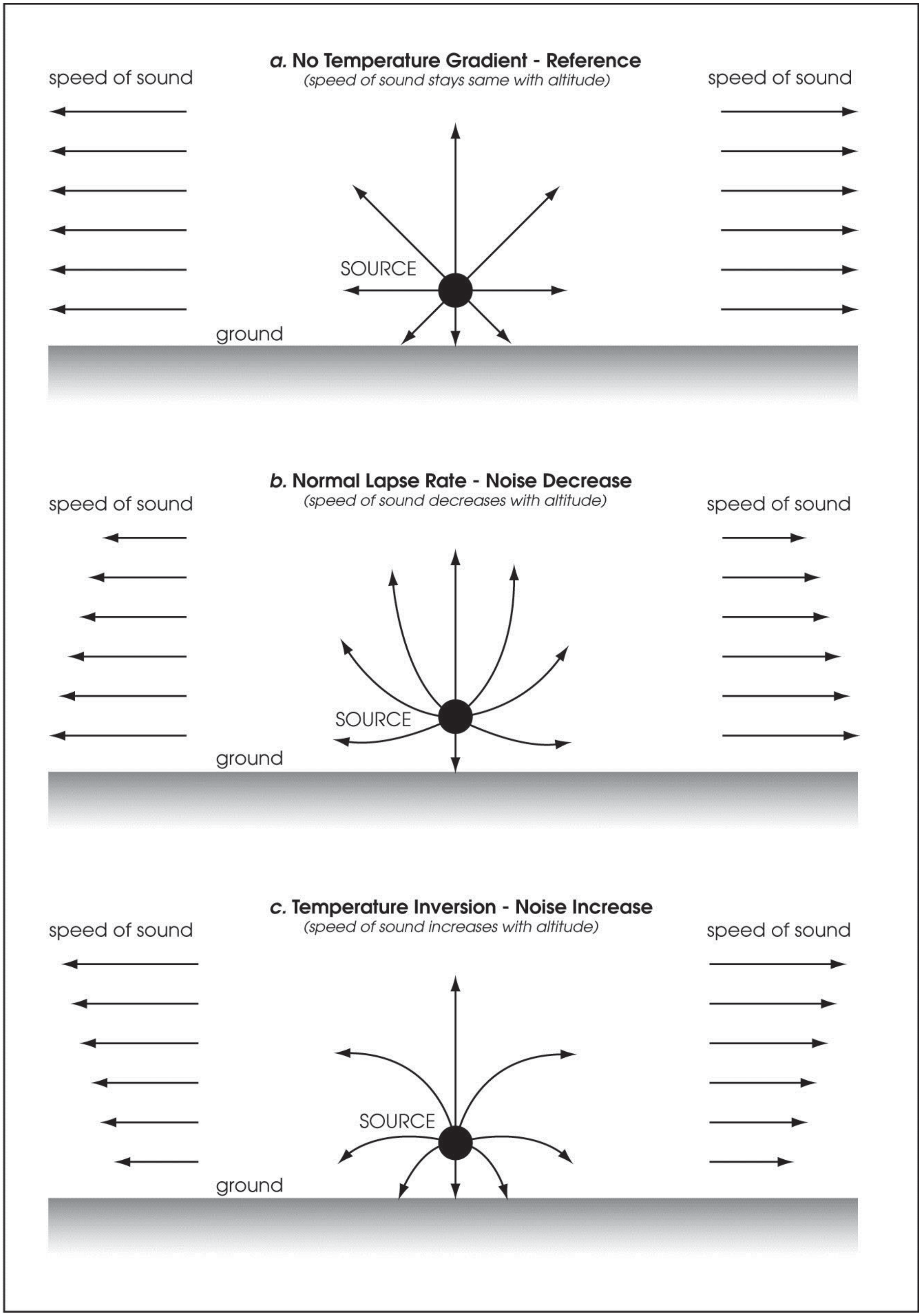

Figure 2-11. Effects of Temperature Gradients on Noise

than the background or ambient, it usually becomes objectionable. One example is an aircraft flying over a residential area.

- **Nature of Work or Living Activity Exposed to Noise Source:** Highway traffic noise might not be disturbing to workers in a factory or office, but it might be annoying or objectionable to people sleeping at home or studying in a library. An automobile horn at 2:00 a.m. is more disturbing than the same noise in traffic at 5:00 p.m.

2.2.1.1 Human Response to Changes in Noise Levels

Under controlled conditions in an acoustics laboratory, the trained healthy human ear is able to discern changes in sound levels of 1 dBA when exposed to steady single-frequency (pure tone) signals in the mid-frequency range. Outside such controlled conditions, the trained ear can detect changes of 2 dBA in normal environmental noise. It is generally accepted that the average healthy ear, however, can barely perceive a noise level change of 3 dBA. If changes to the character (i.e., frequency content) of a sound occur, level changes less than 3 dBA may be noticeable. Individuals who are exposed to continuous traffic noise may also be able to notice small changes in noise levels (i.e., less than 3 dBA).

Earlier, the concept of A-weighting and the reasons for describing noise in terms of dBA were discussed. The human response curve of frequencies in the audible range is simply not linear (i.e., humans do not hear all frequencies equally well).

It appears that the human perception of loudness is also not linear, either in terms of decibels or in terms of acoustical energy. As discussed, there is a mathematical relationship between decibels and relative energy. For example, if one source produces a noise level of 70 dBA, two of the same sources produce 73 dBA, three will produce about 75 dBA, and 10 will produce 80 dBA.

Human perception is complicated by the fact that it has no simple correlation with acoustical energy. Two noise sources do not sound twice as loud as one noise source. Based on studies conducted over the years some approximate relationships between changes in acoustical energy and corresponding human reaction have been charted. Table 2-10 shows the relationship between changes in acoustical energy, dBA, and human perception. The table shows the relationship between changes in dBA (ΔdBA), relative energy with respect to a reference of a ΔdBA of 0 (no change), and average human perception. The factor change in relative energy relates to the change in acoustic energy.

Table 2-10. Relationship between Noise Level Change, Factor Change in Relative Energy, and Perceived Change

Noise Level Change, (dBA)	Change in Relative Energy ($10^{\pm\Delta dBA/10}$)	Perceived Change	
		Perceived Change in Percentage ($[2^{\pm\Delta dBA/10}-1] * 100\%$)	Descriptive Change in Perception
+40	10,000		16 times as loud
+30	1,000		Eight times as loud
+20	100	+300%	Four times as loud
+15	31.6	+183%	
+10	10	+100%	Two times as loud
+9	7.9	+87%	
+8	6.3	+74%	
+7	5.0	+62%	
+6	4.0	+52%	
+5	3.16	+41%	Readily perceptible increase
+4	2.5	+32%	
+3	2.0	+23%	Barely perceptible increase
0	1	0%	Reference (no change)
-3	0.5	-19%	Barely perceptible reduction
-4	0.4	-24%	
-5	0.316	-29%	Readily perceptible reduction
-6	0.25	-34%	
-7	0.20	-38%	
-8	0.16	-43%	
-9	0.13	-46%	
-10	0.10	-50%	One-half as loud
-15	0.0316	-65%	
-20	0.01	-75%	One-quarter as loud
-30	0.001		One-eighth as loud
-40	0.0001		One-sixteenth as loud

Section 2.1.3.3 discusses that the rms value of the sound pressure ratio squared (P_1/P_2) is proportional to the energy content of sound waves (acoustic energy). Human perception is displayed in two columns: percentage and descriptive. The percentage of perceived change is based on the mathematical approximation that the factor change of human perception relates to ΔdBA as follows:

$$\text{Factor Change in Perceived Noise Levels} = 2^{\pm\Delta dBA/10} \qquad \textbf{(2-18)}$$

Contract No. 43A0049
Task Order No. 18

Transportation- and Construction-Induced Vibration Guidance Manual

California Department of Transportation
Environmental Program
Environmental Engineering
Noise, Vibration, and Hazardous Waste Management Office

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CHAPTER 6. VIBRATION CRITERIA

Over the years, numerous vibration criteria and standards have been suggested by researchers, organizations, and governmental agencies. There are no Caltrans or Federal Highway Administration standards for vibration, and it is not the purpose of this manual to set standards. Rather, the following discussion provides a summary of vibration criteria that have been reported by various researchers, organizations, and governmental agencies. The information is used in this chapter to develop a synthesis of these criteria that can be used to evaluate the potential for damage and annoyance from vibration-generating activities. In addition to the criteria discussed in this chapter, additional criteria that apply specifically to blasting are provided in Chapter 11.

A. People

Numerous studies have been conducted to characterize the human response to vibration. Table 4 summarizes the results of an early study (Reiher 1931) on human response to steady-state (continuous) vibration. Human response to vibration generated by blasting is discussed in Chapter 8.

Table 4. Human Response to Steady State Vibration

PPV (in/sec)	Human Response
3.6 (at 2 Hz)–0.4 (at 20 Hz)	Very disturbing
0.7 (at 2 Hz)–0.17 (at 20 Hz)	Disturbing
0.10	Strongly perceptible
0.035	Distinctly perceptible
0.012	Slightly perceptible

Table 5 summarizes the results of another study (Whiffen 1971) that relates human response to vibration from traffic (continuous vibration).

Table 5. Human Response to Continuous Vibration from Traffic

PPV (in/sec)	Human Response
0.4–0.6	Unpleasant
0.2	Annoying
0.1	Begins to annoy
0.08	Readily perceptible
0.006–0.019	Threshold of perception

Table 6 summarizes the results of another study (Wiss 1974) that relates human response to transient vibration.

B. Structures

The effects of vibration on structures has also been the subject of extensive research. Much of this work originated in the mining industry, where vibration from blasting is a critical issue. The following is a discussion of damage thresholds that have been developed over the years. Mining industry standards relating to structure damage thresholds are presented in Chapter 7.

A study by Chae (1978) classifies buildings in one of four categories based on age and condition. Table 9 summarizes maximum blast vibration amplitudes based on building type. (The study recommends that the categories be lowered by one if the structure is subject to repeated blasting.)

Table 9. Chae Building Vibration Criteria

Class	PPV (Single Blast) (in/sec)	PPV (Repeated Blast) (in/sec)
Structures of substantial construction	4	2
Relatively new residential structures in sound condition	2	1
Relatively old residential structures in poor condition	1	0.5
Relatively old residential structures in very poor condition	0.5	—

The Swiss Association of Standardization has developed a series of vibration damage criteria that differentiates between single-event sources (blasting) and continuous sources (machines and traffic) (Wiss 1981). The criteria are also differentiated by frequency. Assuming that the frequency range of interest for construction and traffic sources is 10–30 Hz, Table 10 shows criteria for 10–30 Hz.

Table 10. Swiss Association of Standardization Vibration Damage Criteria

Building Class	Continuous Source PPV (in/sec)	Single-Event Source PPV (in/sec)
Class I: buildings in steel or reinforced concrete, such as factories, retaining walls, bridges, steel towers, open channels, underground chambers and tunnels with and without concrete alignment	0.5	1.2
Class II: buildings with foundation walls and floors in concrete, walls in concrete or masonry, stone masonry retaining walls, underground chambers and tunnels with masonry alignments, conduits in loose material	0.3	0.7
Class III: buildings as mentioned above but with wooden ceilings and walls in masonry	0.2	0.5
Class IV: construction very sensitive to vibration; objects of historic interest	0.12	0.3

Konan (1985) reviewed numerous vibration criteria relating to historic and sensitive buildings, and developed a recommended set of vibration criteria for transient (single-event) and steady-state (continuous) sources. Konan recommended that criteria for continuous vibration be about half the amplitude of criteria for transient sources. Table 11 summarizes the recommended criteria.

U.S. Department
of Transportation

**Federal Highway
Administration**

FHWA
Roadway Construction Noise Model
User's Guide

FHWA-HEP-05-054
DOT-VNTSC-FHWA-05-01

Final Report
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Table 1. CA/T equipment noise emissions and acoustical usage factors database.

CA/T Noise Emission Reference Levels and Usage Factors					
filename: EQUIPLST.xls					
revised: 7/26/05	Impact	Acoustical Use Factor	Spec 721.560 Lmax @ 50ft	Actual Measured Lmax @ 50ft	No. of Actual Data Samples
Equipment Description	Device ?	(%)	(dBA, slow)	(dBA, slow)	(Count)
				(samples averaged)	
All Other Equipment > 5 HP	No	50	85	-- N/A --	0
Auger Drill Rig	No	20	85	84	36
Backhoe	No	40	80	78	372
Bar Bender	No	20	80	-- N/A --	0
Blasting	Yes	-- N/A --	94	-- N/A --	0
Boring Jack Power Unit	No	50	80	83	1
Chain Saw	No	20	85	84	46
Clam Shovel (dropping)	Yes	20	93	87	4
Compactor (ground)	No	20	80	83	57
Compressor (air)	No	40	80	78	18
Concrete Batch Plant	No	15	83	-- N/A --	0
Concrete Mixer Truck	No	40	85	79	40
Concrete Pump Truck	No	20	82	81	30
Concrete Saw	No	20	90	90	55
Crane	No	16	85	81	405
Dozer	No	40	85	82	55
Drill Rig Truck	No	20	84	79	22
Drum Mixer	No	50	80	80	1
Dump Truck	No	40	84	76	31
Excavator	No	40	85	81	170
Flat Bed Truck	No	40	84	74	4
Front End Loader	No	40	80	79	96
Generator	No	50	82	81	19
Generator (<25KVA, VMS signs)	No	50	70	73	74
Gradall	No	40	85	83	70
Grader	No	40	85	-- N/A --	0
Grapple (on backhoe)	No	40	85	87	1
Horizontal Boring Hydr. Jack	No	25	80	82	6
Hydra Break Ram	Yes	10	90	-- N/A --	0
Impact Pile Driver	Yes	20	95	101	11
Jackhammer	Yes	20	85	89	133
Man Lift	No	20	85	75	23
Mounted Impact Hammer (hoe ram)	Yes	20	90	90	212
Pavement Scarafier	No	20	85	90	2
Paver	No	50	85	77	9
Pickup Truck	No	40	55	75	1
Pneumatic Tools	No	50	85	85	90
Pumps	No	50	77	81	17
Refrigerator Unit	No	100	82	73	3
Rivit Buster/chipping gun	Yes	20	85	79	19
Rock Drill	No	20	85	81	3
Roller	No	20	85	80	16
Sand Blasting (Single Nozzle)	No	20	85	96	9
Scraper	No	40	85	84	12
Shears (on backhoe)	No	40	85	96	5
Slurry Plant	No	100	78	78	1
Slurry Trenching Machine	No	50	82	80	75
Soil Mix Drill Rig	No	50	80	-- N/A --	0
Tractor	No	40	84	-- N/A --	0
Vacuum Excavator (Vac-truck)	No	40	85	85	149
Vacuum Street Sweeper	No	10	80	82	19
Ventilation Fan	No	100	85	79	13
Vibrating Hopper	No	50	85	87	1
Vibratory Concrete Mixer	No	20	80	80	1
Vibratory Pile Driver	No	20	95	101	44
Warning Horn	No	5	85	83	12
Welder / Torch	No	40	73	74	5

TRANSIT NOISE AND VIBRATION IMPACT ASSESSMENT

FTA-VA-90-1003-06 **May 2006**

Office of Planning and Environment
Federal Transit Administration

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on the vibration signal in Figure 7-2. The rms amplitude is always less than the PPV* and is always positive.

The PPV and rms velocity are normally described in inches per second in the USA and meters per second in the rest of the world. Although it is not universally accepted, decibel notation is in common use for vibration.

Decibel notation acts to compress the range of numbers required to describe vibration. The bottom graph in Figure 7-2 shows the rms curve of the top graph expressed in decibels. Vibration velocity level in decibels is defined as:

$$L_v = 20 \times \log_{10}\left(\frac{v}{v_{ref}}\right)$$

where "L_v" is the velocity level in decibels, "v" is the rms velocity amplitude, and "v_{ref}" is the reference velocity amplitude. A reference must always be specified whenever a quantity is expressed in terms of decibels. The accepted reference quantities for vibration velocity are $1\text{x}10^{-6}$ inches/second in the USA and either $1\text{x}10^{-8}$ meters/second or $5\text{x}10^{-8}$ meters/second in the rest of the world. Because of the variations in the reference quantities, it is important to be clear about what reference quantity is being used whenever velocity levels are specified. ***All** vibration levels in this manual are referenced to $1\text{x}10^{-6}$ in./sec.* Although not a universally accepted notation, the abbreviation "VdB" is used in this document for vibration decibels to reduce the potential for confusion with sound decibels.

7.1.3 Ground-Borne Noise

As discussed above, the rumbling sound caused by the vibration of room surfaces is called ground-borne noise. The annoyance potential of ground-borne noise is usually characterized with the A-weighted sound level. Although the A-weighted level is almost the only metric used to characterize community noise, there are potential problems when characterizing low-frequency noise using A-weighting. This is because of the non-linearity of human hearing which causes sounds dominated by low-frequency components to seem louder than broadband sounds that have the same A-weighted level. The result is that ground-borne noise with a level of 40 dBA sounds louder than 40 dBA broadband noise. This is accounted for by setting the limits for ground-borne noise lower than would be the case for broadband noise.

---

*The ratio of PPV to maximum rms amplitude is defined as the **crest factor** for the signal. The crest factor is always greater than 1.71, although a crest factor of 8 or more is not unusual for impulsive signals. For ground-borne vibration from trains, the crest factor is usually 4 to 5.

Although the perceptibility threshold is about 65 VdB, human response to vibration is not usually significant unless the vibration exceeds 70 VdB. Rapid transit or light rail systems typically generate vibration levels of 70 VdB or more near their tracks. On the other hand, buses and trucks rarely create vibration that exceeds 70 VdB unless there are bumps in the road. Because of the heavy locomotives on diesel commuter rail systems, the vibration levels average about 5 to 10 decibels higher than rail transit vehicles. If there is unusually rough road or track, wheel flats, geologic conditions that promote efficient propagation of vibration, or vehicles with very stiff suspension systems, the vibration levels from any source can be 10 decibels higher than typical. Hence, at 50 feet, the upper range for rapid transit vibration is around 80 VdB and the high range for commuter rail vibration is 85 VdB. If the vibration level in a residence reaches 85 VdB, most people will be strongly annoyed by the vibration.

The relationship between ground-borne vibration and ground-borne noise depends on the frequency content of the vibration and the acoustical absorption of the receiving room. The more acoustical absorption in the room, the lower will be the noise level. For a room with average acoustical absorption, the unweighted sound pressure level is approximately equal to the average vibration velocity level of the room surfaces.[*] Hence, the A-weighted level of ground-borne noise can be estimated by applying A-weighting to the vibration velocity spectrum. Since the A-weighting at 31.5 Hz is -39.4 dB, if the vibration spectrum peaks at 30 Hz, the A-weighted sound level will be approximately 40 decibels lower than the velocity level. Correspondingly, if the vibration spectrum peaks at 60 Hz, the A-weighted sound level will be about 25 decibels lower than the velocity level.

7.2.2 Quantifying Human Response to Ground-Borne Vibration and Noise

One of the major problems in developing suitable criteria for ground-borne vibration is that there has been relatively little research into human response to vibration, in particular, human annoyance with building vibration. The American National Standards Institute (ANSI) developed criteria for evaluation of human exposure to vibration in buildings in 1983[(1)] and the International Organization for Standardization (ISO) adopted similar criteria in 1989[(2)] and revised them in 2003 [(3)]. The 2003 version of ISO 2361-2 acknowledges that “human response to vibration in buildings is very complex.” It further indicates that the degree of annoyance can not always be explained by the magnitude of the vibration alone. In some cases the complaints are associated with measured vibration that is lower than the perception threshold. Other phenomena such as ground-borne noise, rattling, visual effects such as movement of hanging objects, and time of day (e.g., late at night) all play some role in the response of individuals. To understand and evaluate human response, which is often measured by complaints, all of these related effects need to be considered. The available data documenting real world experience with these phenomena is still relatively sparse. Experience with U.S. rapid transit projects represents a good foundation for developing suitable limits for residential exposure to ground-borne vibration and noise from transit operations.

---

[*]The sound level approximately equals the average vibration velocity level *only* when the velocity level is referenced to 1 micro-inch/second. When velocity level is expressed using the international standard of 1×10^{-8} m/sec, the sound level is approximately 8 decibels lower than the average velocity level.

Figure 7-4 illustrates the relationship between the vibration velocity level measured in 22 homes and the general response of the occupants to the vibration. The data shown were assembled from measurements performed for several transit systems along with subjective ratings by the researchers and residents. These data were previously published in the "State-of-the-Art Review of Ground-borne Noise and Vibration."[4] Both the occupants and the people who performed the measurements agreed that floor vibration in the "Distinctly Perceptible" category was unacceptable for a residence. The data in Figure 7-4 indicate that residential vibration exceeding 75 VdB is unacceptable for a repetitive vibration source such as rapid transit trains that pass every 5 to 15 minutes. Also shown in Figure 7-4 is a curve showing the percent of people annoyed by vibration from high-speed trains in Japan.[5] The scale for the percent annoyed is on the right-hand axis of the graph. The results of the Japanese study confirm the conclusion that at a vibration velocity level of 75 to 80 VdB, many people will find the vibration annoying.

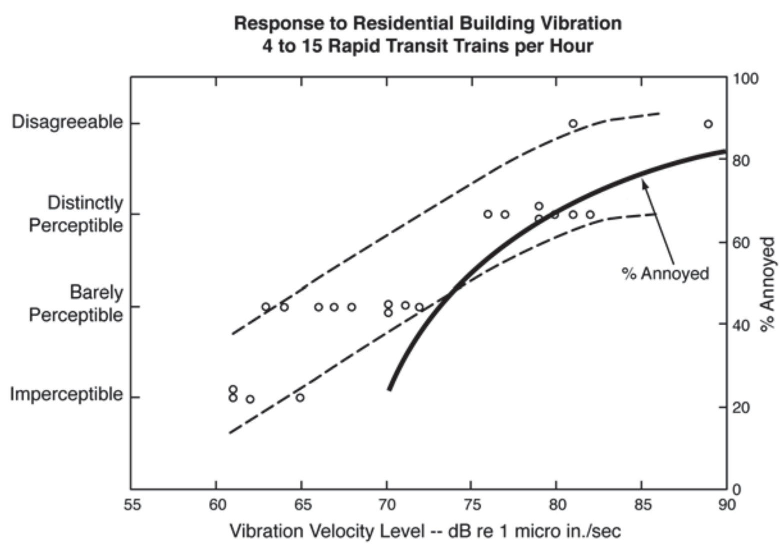

Figure 7-4. Response to Transit-induced Residential Vibration

Table 7-1 describes the human response to different levels of ground-borne noise and vibration. The first column is the vibration velocity level, and the next two columns are for the corresponding noise level assuming that the vibration spectrum peaks at 30 Hz or 60 Hz. As discussed above, the A-weighted noise level will be approximately 40 dB less than the vibration velocity level if the spectrum peak is around 30 Hz, and 25 dB lower if the spectrum peak is around 60 Hz. Table 7-1 illustrates that achieving either the acceptable vibration or acceptable noise levels does not guarantee that the other will be acceptable. For example, the noise caused by vibrating structural components may be very annoying even though the vibration cannot be felt. Alternatively, a low-frequency vibration could be annoying while the ground-borne noise level it generates is acceptable.

Table 7-1. Human Response to Different Levels of Ground-Borne Noise and Vibration

Vib. Velocity Level	Noise Level		Human Response
	Low Freq1	Mid Freq2	
65 VdB	25 dBA	40 dBA	Approximate threshold of perception for many humans. Low-frequency sound usually inaudible, mid-frequency sound excessive for quiet sleeping areas.
75 VdB	35 dBA	50 dBA	Approximate dividing line between barely perceptible and distinctly perceptible. Many people find transit vibration at this level annoying. Low-frequency noise acceptable for sleeping areas, mid-frequency noise annoying in most quiet occupied areas.
85 VdB	45 dBA	60 dBA	Vibration acceptable only if there are an infrequent number of events per day. Low-frequency noise annoying for sleeping areas, mid-frequency noise annoying even for infrequent events with institutional land uses such as schools and churches.

Notes:
1. Approximate noise level when vibration spectrum peak is near 30 Hz.
2. Approximate noise level when vibration spectrum peak is near 60 Hz.

7.3 GROUND-BORNE VIBRATION FOR DIFFERENT TRANSIT MODES

This section provides a brief discussion of typical problems with ground-borne vibration and noise for different modes of transit.

- **Steel-Wheel Urban Rail Transit:** This category includes both heavy rail transit and light rail transit. Heavy rail is generally defined as electrified rapid transit trains with dedicated guideway, and light rail as electrified transit trains that do not require dedicated guideway. The ground-borne vibration characteristics of heavy and light rail vehicles are very similar since they have similar suspension systems and axle loads. Most of the studies of ground-borne vibration in this country have focused on urban rail transit. Problems with ground-borne vibration and noise are common when there is less than 50 feet between a subway structure and building foundations. Whether the problem will be perceptible vibration or audible noise is strongly dependent on local geology and the structural details of the building. Complaints about ground-borne vibration from surface track are more common than complaints about ground-borne noise. A significant percentage of complaints about both ground-borne vibration and noise can be attributed to the proximity of special trackwork, rough or corrugated track, or wheel flats.

A Detailed Vibration Analysis consists of three parts:

1. **Survey Existing Vibration.** Although knowledge of the existing levels of ground-borne vibration is not usually required for the assessment of vibration impact, there are times when a survey of the existing vibration is valuable. Examples include documenting existing background vibration at sensitive buildings, measuring the vibration levels created by sources such as existing rail lines, and, in some cases, characterizing the general background vibration in the project corridor. Characterizing the existing vibration is discussed in Section 11.1.
2. **Predict Future Vibration and Vibration Impact.** All of the available tools should be applied in a Detailed Analysis to develop the best possible estimates of the potential for vibration impact. Section 11.2 discusses an approach to projecting ground-borne vibration that involves performing tests to characterize vibration propagation at sites where significant impact is probable. Section 11.3 describes the vibration propagation test procedure and Section 11.4 discusses the assessment of vibration impact.
3. **Develop Mitigation Measures.** Controlling the impact from ground-borne vibration requires developing cost-effective measures to reduce the vibration levels. The Detailed Analysis helps to select practical vibration control measures that will be effective at the dominant vibration frequencies and compatible with the given transit structure and track support system. Vibration mitigation measures are discussed in Section 11.5.

The discussion in this chapter generally assumes that detailed vibration analysis applies to a steel-wheel/ rail system. The procedures could be adapted to bus systems. However, this is rarely necessary because vibration problems are very infrequent with rubber-tired transit.

11.1 CHARACTERIZING EXISTING VIBRATION CONDITIONS

Environmental vibration is rarely of sufficient magnitude to be perceptible or cause audible ground-borne noise unless there is a specific vibration source close by, such as a rail line. In most cases, feelable vibration inside a building is caused by equipment or activities within the building itself, such as heating and ventilation systems, footsteps or doors closing. Because the existing environmental vibration is usually below human perception, a limited vibration survey is sufficient even for a Detailed Analysis. This contrasts with analysis of noise impact where documenting the existing ambient noise level is required to assess the impact.

Examples of situations where measurements of the ambient vibration are valuable include:

- **Determining existing vibration at sensitive buildings:** Serious vibration impact may occur when there are vibration-sensitive manufacturing, research, or laboratory activities within the screening distances. Careful documentation of the pre-existing vibration provides valuable information on the real sensitivity of the activity to external vibration and gives a reference condition under which vibration is not a problem.

- **Using existing vibration sources to characterize propagation:** Existing vibration sources such as freight trains, industrial processes, quarrying operations, or normal traffic sometimes can be used to characterize vibration propagation. Carefully designed and performed measurements may eliminate the need for more complex propagation tests.
- **Documenting existing levels of general background:** Some measurements of the existing levels of background vibration can be useful simply to document that, as expected, the vibration is below the normal threshold of human perception. Existing vibration in urban and suburban areas is usually due to traffic. If a measurement site has existing vibration approaching the range of human perception (e.g., the maximum vibration velocity levels are greater than about 65 VdB), then this site should be carefully evaluated for the possibility of efficient vibration propagation. Areas with efficient vibration propagation could have vibration problems when the project is built.
- **Documenting vibration from existing rail lines:** Measurements to document the levels of vibration created by existing rail lines can be important in evaluating the impact of the new vibration source and determining vibration propagation characteristics in the area. As discussed in Chapter 8, if vibration from an existing rail line will be higher than that from the proposed transit trains, there may not be impact even though the normal impact criterion would be exceeded.

Although ground-borne vibration is almost exclusively a problem inside buildings, measurements of existing ambient vibration generally should be performed outdoors. Two important reasons for this are: (1) equipment inside the building may cause more vibration than exterior sources, and (2) the building structure and the resonances of the building can have strong, but difficult to predict, effects on the vibration. However, there are some cases where measurements of indoor vibration are important. Documenting the vibration levels inside a vibration-sensitive building can be particularly important since equipment and activities inside the building sometimes cause vibration greater than that due to external sources such as street traffic or aircraft overflights. Floor vibration measurements are taken near the center of a floor span where the vibration amplitudes are the highest.

The goal of most ambient vibration tests is to characterize the root mean square (rms) vertical vibration velocity level at the ground surface. In almost all cases it is sufficient to measure only vertical vibration and ignore the transverse components of the vibration. Although transverse components can transmit significant vibration energy into a building, the vertical component usually has greater amplitudes than transverse vibration. Moreover, vertical vibration is usually transmitted more efficiently into building foundations than transverse vibration.

The manner in which a transducer is mounted can affect the measured levels of ground-borne vibration. However, at the frequencies usually of concern for ground-borne vibration (less than about 200 Hz), straightforward methods of mounting transducers on the ground surface or on pavement are adequate for vertical vibration measurements. Quick-drying epoxy or beeswax is often used to mount transducers to smooth paved surfaces or to metal stakes driven into the ground. Rough concrete or rock surfaces require special mountings. One approach is to use a liberal base of epoxy to attach small aluminum blocks to the surface and then mount the transducers on the aluminum blocks.

Selecting sites for an ambient vibration survey requires good common sense. Sites selected to characterize a transit corridor should be distributed along the entire project and should be representative of the types of vibration environments found in the corridor. This would commonly include:

- measurements in quiet residential areas removed from major traffic arterials to characterize low-ambient vibrations;
- measurements along major traffic arterials and highways or freeways to characterize high-vibration areas;
- measurements in any area with vibration-sensitive activities; and
- measurements at any significant existing source of vibration such as railroad lines.

The transducers should be located near the building setback line for background vibration measurements. Ambient measurements along railroad lines ideally will include: multiple sites; several distances from the rail line at each site; and 4 to 10 train passbys for each test. Because of the irregular schedule for freight trains and the low number of operations each day, it is often impractical to perform tests at more than two or three sites along the rail line or to measure more than two or three passbys at each site. Rail type and condition strongly affect the vibration levels. Consequently, it is important to inspect the track at each measurement site to locate any switches, bad rail joints, corrugations, or other factors that could be responsible for higher than normal vibration levels.

The appropriate methods of characterizing ambient vibration are dependent on the type of information required for the analysis. Following are some examples:

- **Ambient Vibration:** Ambient vibration is usually characterized with a continuous 10- to 30-minute measurement of vibration. The L_{eq} of the vibration velocity level over the measurement period gives an indication of the average vibration energy. L_{eq} is equivalent to a long averaging time rms level. Specific events can be characterized by the maximum rms level (L_{max}) of the event or by performing a statistical analysis of rms levels over the measurement period. An rms averaging time of 1 second should be used for statistical analysis of the vibration level.
- **Specific Events:** Specific events such as train passbys should be characterized by the rms level during the time that the train passes by. If the locomotives have vibration levels more than 5 dB higher than the passenger or freight cars, a separate rms level for the locomotives should be obtained. The locomotives can usually be characterized by the L_{max} during the train passby. The rms averaging time or time constant should be 1 second when determining L_{max}. Sometimes it is adequate to use L_{max} to characterize the train passby, which is simpler to obtain than the rms averaged over the entire train passby.
- **Spectral Analysis:** When the vibration data will be used to characterize vibration propagation or for other special analysis, a spectral analysis of the vibration is required. An example would be if

12.2.2 Vibration Source Levels from Construction Equipment

Ground-borne vibration related to human annoyance is generally related to root mean square (rms) velocity levels expressed in VdB. However, a major concern with regard to construction vibration is building damage. Consequently, construction vibration is generally assessed in terms of peak particle velocity (PPV), as defined in Chapter 7.1.2. The relationship of PPV to rms velocity is expressed in terms of the "crest factor," defined as the ratio of the PPV amplitude to the rms amplitude. Peak particle velocity is typically a factor of 1.7 to 6 times greater than rms vibration velocity.

Various types of construction equipment have been measured under a wide variety of construction activities with an average of source levels reported in terms of velocity as shown in Table 12-2. In this table, a crest factor of 4 (representing a PPV-rms difference of 12 VdB) has been used to calculate the approximate rms vibration velocity levels from the PPV values. Although the table gives one level for each piece of equipment, it should be noted that there is a considerable variation in reported ground vibration levels from construction activities. The data provide a reasonable estimate for a wide range of soil conditions.

Table 12-2. Vibration Source Levels for Construction Equipment (From measured data.[7,8,9,10])

Equipment		PPV at 25 ft (in/sec)	Approximate L_v† at 25 ft
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (sonic)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory Roller		0.210	94
Hoe Ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

† RMS velocity in decibels (VdB) re 1 micro-inch/second

NOISE EFFECTS HANDBOOK

A Desk Reference to Health and Welfare Effects of Noise

By Office of the Scientific Assistant
Office of Noise Abatement and Control
U.S. Environmental Protection Agency

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NOISE EFFECTS HANDBOOK

A DESK REFERENCE TO HEALTH & WELFARE EFFECTS OF NOISE

TOPICAL OVERVIEW (SEE ALSO INDEX, SECTION 12)

1. **The National Noise Problem**
2. **Hearing Loss:** normal auditory function, hearing loss criteria, presbycusis, hearing conservation, hearing impairment formulas
3. **Nonauditory Physiological Response:** stress, arousal response, cardiovascular effects, effects on the fetus
4. **Communication Interference:** factors that affect speech interference, masking, measurement of masking and speech interference, levels and criteria, special populations, overcoming speech interference
5. **Performance Interference:** detriments of interference; qualities of noise and their relationship to performance interference; noise-sensitive tasks; effects on children; positive effects; and injury rates
6. **Sleep Disturbance:** falling asleep, awakening, arousal and sub-awakening effects; criteria; noise and non-noise factors; other considerations
7. **Subjective Response:** (individual, psychological responses) : special populations, coping behavior, antisocial behavior, decrease of helping behavior
8. **Community Response:** criteria, activity interference, predictors of community annoyance, relation to population density, urban survey findings
9. **Health and Welfare Analysis:** how it is carried out in regulatory development; fractional impact; level-weighted population
10. **Summary of Human Effects of Noise from Various Outdoor Noise Levels**
11. **References**
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THE NATIONAL NOISE PROBLEM

Since 1973, the Department of Housing and Urban Development (HUD) (39)* has conducted an Annual Housing Survey for the Census Bureau in which noise has been consistently ranked as a leading cause of neighborhood dissatisfaction. In fact, nearly one-half of the respondents each year have felt that noise was a major neighborhood problem (see Figure 1-1). In the 1975 survey, street noise was mentioned more often than all other unwanted neighborhood conditions. This survey has also shown that aircraft and traffic noise are leading factors in making people want to move from their neighborhoods. Approximately one-third of all the respondents who wished to move because of undesirable neighborhood conditions, did so because of noise. (39)

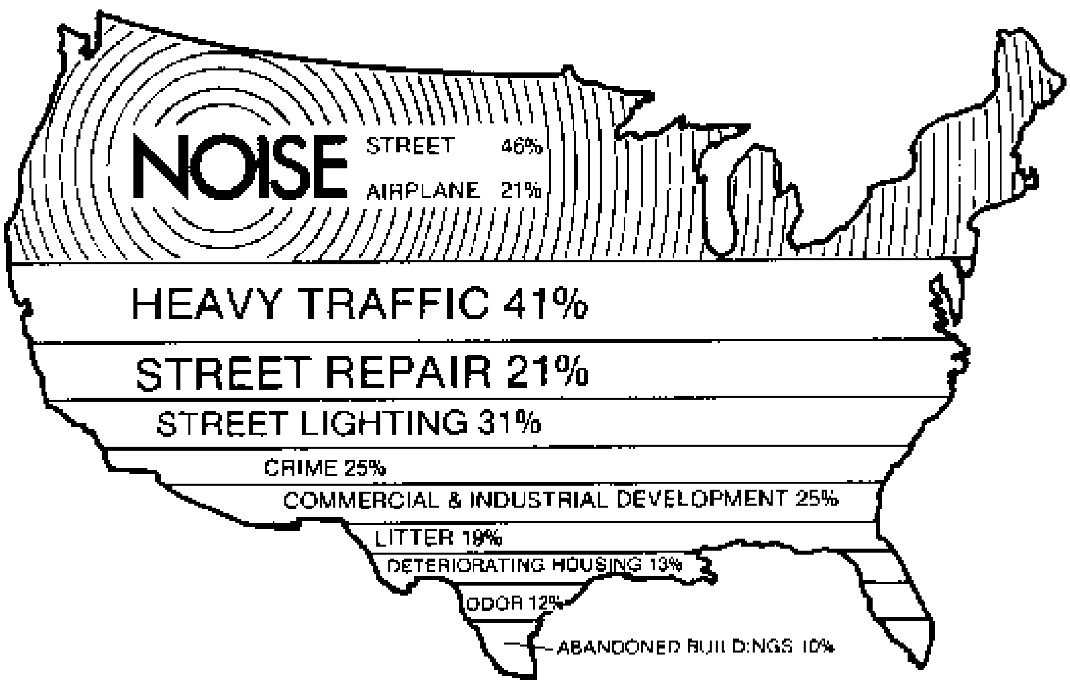

Figure 1-1. Undesirable neighborhood conditions for homeowners and renters: United States Comparative Ranking, 1975.
Source: Ref. 4, pp. 8-12.

Both a poll conducted by the Gallup Organization in November 1978 for the National League of Cities and a Harris Survey for the ABC network in January 1979 on attitudes toward environmental issues indicated that the public views noise as a growing problem warranting more governmental attention and action.

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*References are listed in Section 11, e.g.: (Ref. 39).

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How many people are estimated to live in residential areas with noise levels above recommended limits?

According to the Levels Document, the day-night sound level of residential areas should not exceed 55 dB to protect against activity interference and annoyance (5). It is estimated that well over 100 million people, nearly half the U.S. population, live in areas where the noise exceeds this level (see Figure 1-2), Twelve million people are estimated to live in areas where the outdoor Ldn exceeds 70 dB, and they are likely to experience severe annoyance and possible hearing loss.

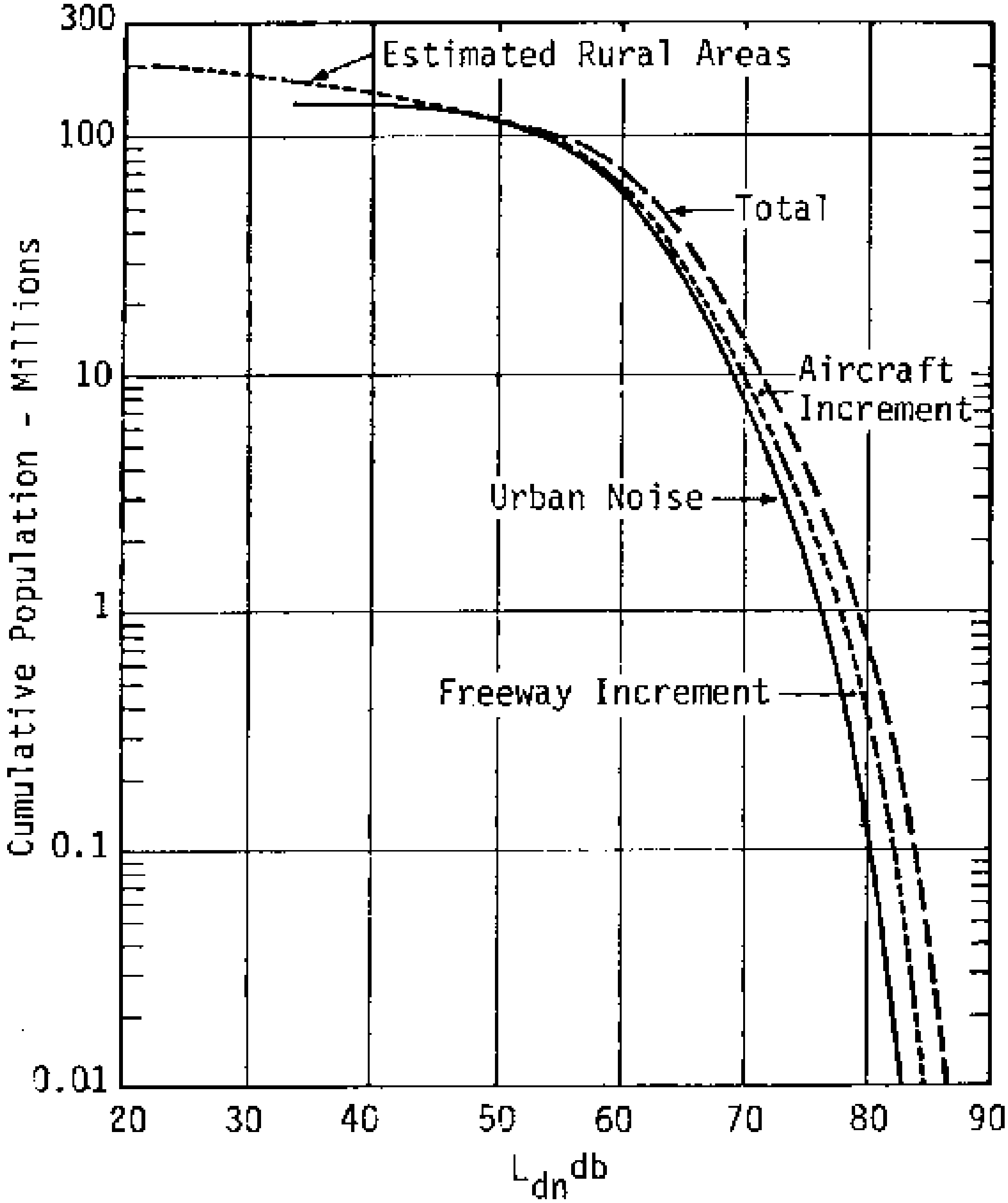

Figure 1-2 Residential noise environment of the national population as a function of exterior day-night average sound level.
Source: Ref 5

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What is the relationship between indoor and outdoor levels?

Indoor levels are often comparable to or higher than levels measured outside (5). However, many outdoor noises still annoy people in their homes more than indoor noises do, and people sometimes turn on indoor sources to mask the noise coming from outside (6).

What is the most pervasive environmental noise source and how many people are exposed to it?

As shown in Table 1-1, urban traffic is by far the most pervasive outdoor residential noise source, although aircraft noise is a significant source as well. Over 96 million persons are estimated to be exposed, in and around their homes, to undesirably high traffic noise levels exceeding $L_{dn} > 55$ dB. Figures contained in Table 1-1 for each source represent the number of people exposed at or above a given level (L_{dn}) for the source in question and do not take into consideration that an individual may be simultaneously exposed to more than one source culminating in a higher total exposure.

	Number of People in Millions for Each Noise Category			
L_{dn} (dB)	Urban Traffic	Aircraft	Rail	Industrial
80	0.1	0.1	--	--
75	1.1	0.3	--	--
70	5.7	1.3	0.8	--
65	19.3	4.7	2.5	0.3
60	46.6	11.5	3.5	1.9
55	96.8	24.3	6.0	6.9

Table 1-1. Summary of the number of people exposed to various levels of L_{dn} or higher from noise sources in the community.
Source: Ref. 7

What are typical noise exposures for people throughout the day for various U.S. life styles?

This information is not precisely known. A study by Schori seems to show an average exposure of L_{eq} (24) = 75 dB. However, his sample is not necessarily typical (8).

How many workers and non-workers are exposed to noise levels which may be damaging to their hearing?

An estimated 15 million American workers are exposed to an $L_{eq}(8)$ of 75 dB or above which may be hazardous to their hearing. Because of tie overlap between persons in occupational and non-occupational noise exposure situations, there is an estimated total of 20 to 25 million persons who may possibly incur hearing losses based on an L_{eq} (8) of 75 dB or above (7).

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What might be considered the typical daily noise exposure pattern?

Figure 1-3 hypothetically depicts an example of what might be considered a typical daily noise exposure of a homemaker, students, and workers.

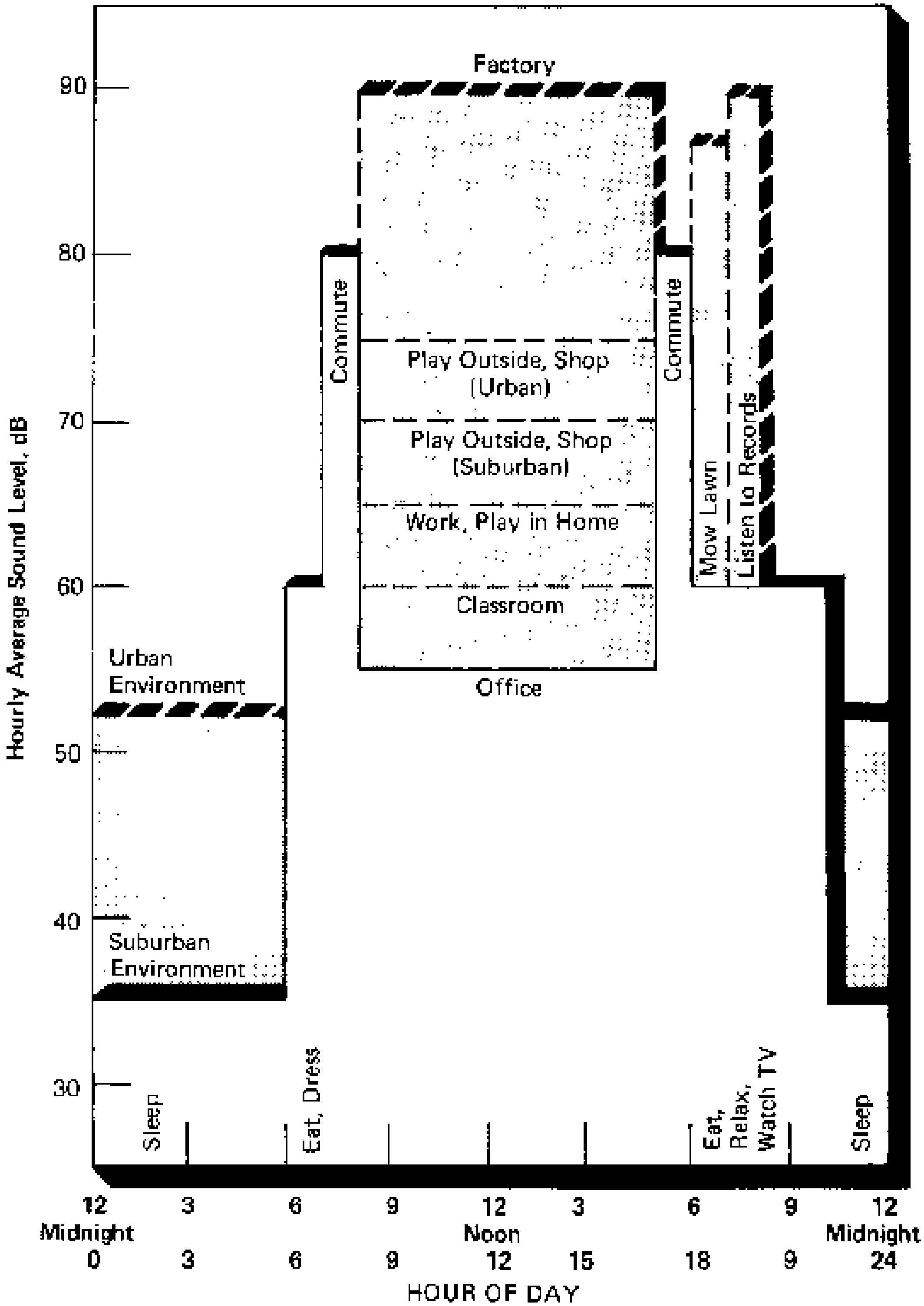

Figure 1-3 Hypothesized life style noise exposure patterns.

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HEARING LOSS

NORMAL HEARING

How does the human ear work?

The Figure 2-1 shows a schematic diagram of how the human ear functions.

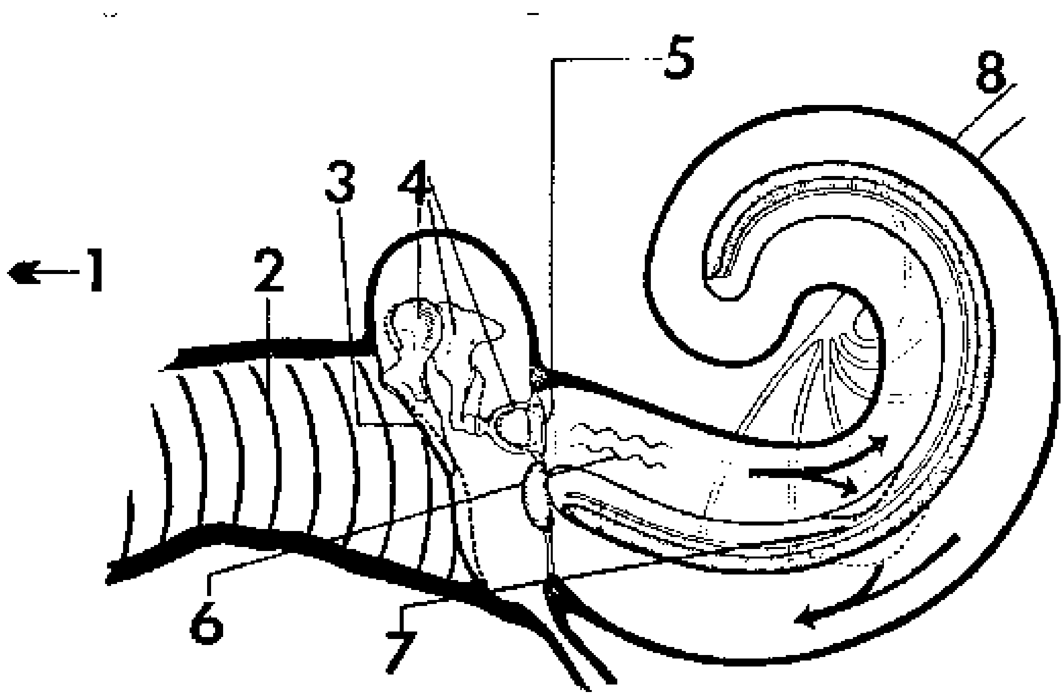

Figure 2-1. A schematic diagram of how the human ear functions.

The outer ear consists of the auricle or pinna [1 not shown] and the auditory canal [2]. The pinna of the human ear is a residual structure although it may aid in the localization of sound entering the ear. The sound wave entering the ear is enhanced by resonant characteristics of the auditory canal (12).* Sound waves travel up the auditory canal [2] and set up vibrations in the eardrum or tympanic membrane [3].

Behind the tympanic membrane is a cavity called the middle ear. The middle ear functions as an impedance matcher.* Specifically, sound pressure from waves traveling through the air (low impedance) is amplified about 21 times so that it may efficiently travel into the high impedance fluid medium in the inner ear. This is accomplished by the leverage action of the three middle ear bones: the malleus, incus, and stapes [4]. The footplate of the stapes, in turn, moves in and out of the oval window [5].

The movement of the oval window sets up motions in the fluid [6] that fill the inner ear or cochlea. Movement of this fluid causes the hairs that are immersed in fluid to move [7]. The movement of these hairs stimulates the cells attached to them to send impulses along the fibers of the auditory nerve [8] to the brain. The brain translates these impulses into the sensation of sound. (12)

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* References are listed in Section 11, e.g.: (Ref. 12).

* Impedance is comprised of frictional resistance, mass, and stiffness, and thus acts in opposition to the incoming sound wave.

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What is considered to be normal hearing?

The ability to hear means being capable of detecting sounds within the frequency range of 16-20,000 Hz. The threshold of audibility or the point at which sounds are barely detectable is shown in Figure 2-2. In clinical hearing assessment, normal hearing falls within a range of 0 to 25 dB of the threshold of audibility. (12)

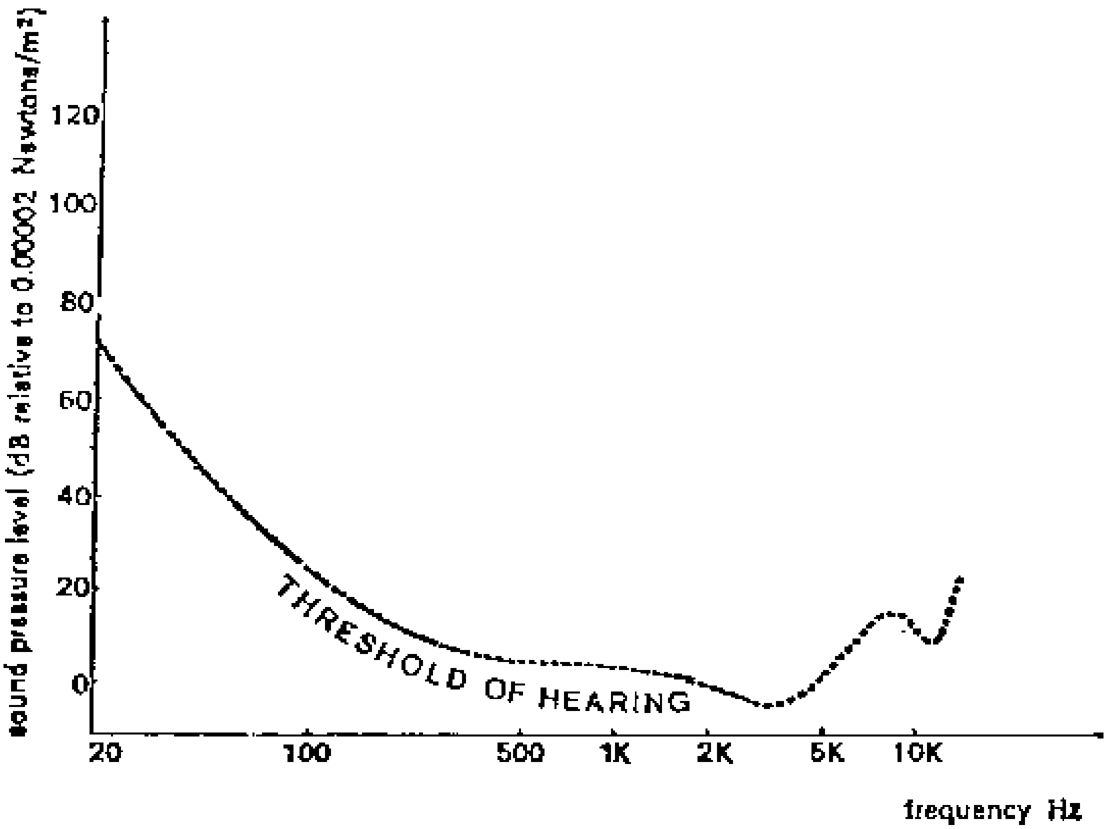

Figure 2-2. Average threshold of hearing.
Source: Ref. 13, p. 12.

At what level is the threshold of pain?

The threshold of pain is located at the upper boundary of audibility and in normal hearers is in the region of 135 dB for all frequencies. (13)

Are there differences in normal adult hearing based on sex?

Starting in the early teenage years, and particularly in the age range of 25 to 65, women in industrial countries have better hearing than do men. However, the rate of hearing loss in men over 50 declines while that of women of the same age increases. Above 75 years of age the difference in hearing between the sexes tends to become insignificant. These differences most likely exist because noise exposure is primarily greater for men due to the occupational noise they usually encounter in their early and middle years. (14)

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Are there differences in normal adult hearing based on age?

The threshold of hearing rises (hearing becomes less sensitive) with age. This effect involves primarily, and is most marked at, the higher frequencies above 3000 Hz (14). Studies of large population samples have shown that this loss begins at around age 20 and increases with each decade (13). Refer to Figure 2-7 which shows curves representing changes in the average threshold of hearing with age for males and females. (Also see section on Presbycusis.)

Are there differences in normal adult hearing based on race?

There is no inherent difference in hearing levels between the races that make up the population of the U.S. Human ears are essentially the same around the world. Any demographic differences that have appeared in some studies may be attributable to differing environmental noise exposures. (15)

How is hearing measured?

Hearing is commonly measured by the use of a pure-tone audiometer. Test tones are produced by the audiometer at known intensities and are presented to the subject's ears through earphones. This is known as air conduction testing. Each ear is tested separately and commonly at the following test frequencies: 250, 500, 1000, 2000, 4000, and 8000 Hz. At each test frequency, the hearing threshold for that test tone is identified as the lowest level of tone to which the subject responds correctly at least 50 percent of the time (13). Hearing level is reported as the difference between the sound pressure level (SPL) of the measured hearing threshold for the subject and the SPL for a "normal" or "average" subject as defined in Figure 2-2 on page 2-3. The results are plotted on an audiogram. The sample audiogram shown in Figure 2-3 reflects hearing level ranging from 45 dB at 250 Hz to 25-35 dB at 8000 Hz. Each ear is represented separately (O = right, X = left). The modified brackets indicate bone conduction thresholds; (< = right, > = left).

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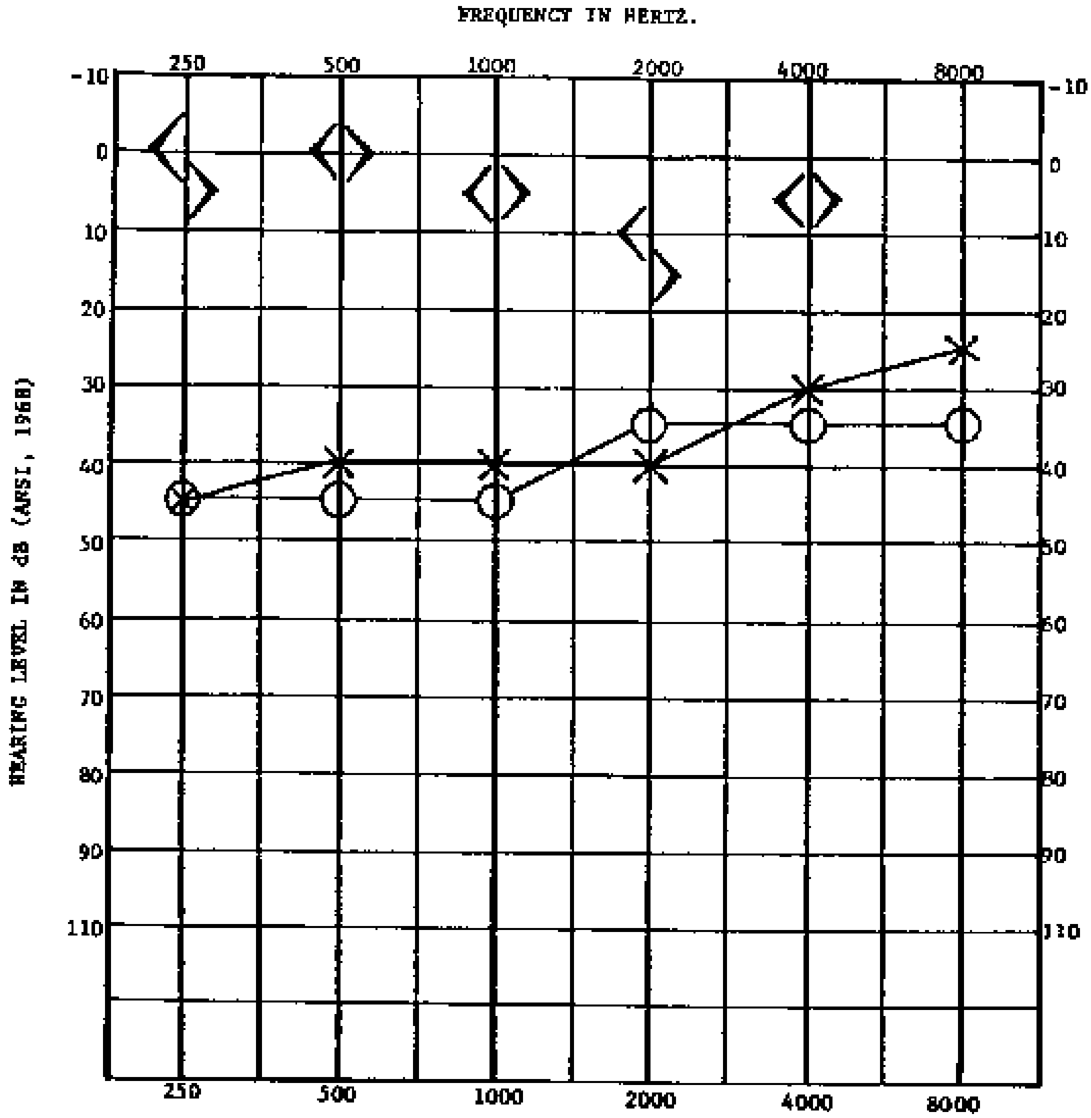

Figure 2-3 Sample Audiogram
Source: Ref. 13

HEARING LOSS

What different types of hearing loss are there?

There are two major types of hearing loss: conductive and sensori-neural. A conductive loss is usually associated with the outer or middle ear. This kind of loss is usually caused by a perforation or infection in the middle ear or an inflammation of the middle ear bones. This loss blocks transmission of sound to the cochlea or inner ear. Conductive losses are correctable by surgery.

A sensori-neural loss results from damage to the cochlea or neural structures of the ear. Birth defects, noise, ototoxic drugs, fever, or trauma may cause this type of loss. Sensori-neural losses are not medically correctable. In addition, sensori-neural hearing loss can be classified in several ways: noise-induced, presbycusis, sociocusis, or due to birth defects, congenital problems, disease, injury, or drugs.

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How is the type of hearing loss determined?

If air conduction testing indicates that a hearing loss exists, it is necessary to determine whether it is of the conductive or sensori-neural type through bone conduction testing. To do this a bone-conduction vibrator is attached to the mastoid process of the skull just behind the ear. Test tones are presented at differing intensities just as with tones presented through earphones. Again each ear is tested separately. Often a masking tone has to be applied to the untested ear to ensure that responses are heard only by the test ear. If the hearing threshold determined by bone conduction testing is essentially normal, the hearing loss indicated by air conduction is of the conductive type. If the threshold for bone conduction is consistent with that determined by air conduction, the hearing loss is of the sensori-neural type. A mixed loss exists if there is a sensori-neural loss with a superimposed conductive loss. (16)

Can conductive losses be caused by noise?

Yes. Rupture of the ear drum and disturbance of the middle ear bones can result from a very high amplitude impulse or blast. This is often called traumatic hearing loss. The maximum conductive loss is usually around 50 to 60 dB, (12)

What are some common causes of sensori-neural hearing loss in newborn babies?

Most babies born with hearing impairments have sensori-neural hearing losses. These can be either congenital (genetically inherited from the parents) or due to damage to the embryo in utero. Certain diseases such as rubella (German measles) or influenza that the mother contracts during pregnancy can result in a sensori-neural hearing loss as a birth defect in the child. (13)

What diseases can lead to sensori-neural hearing loss?

Diseases such as measles, mumps, scarlet fever, diphtheria, whooping cough, influenza, and certain other viral infections can lead to sensori-neural hearing loss. The processes of these diseases can have a toxic effect on the sensitive nerve endings in the cochlea. Infections of the cerebrospinal fluid such as meningitis can also cause damage to the cochlea. Tumorous growths near the auditory nerve can cause sensori-neural hearing loss due to pressure on the nerve. (13)

Can drugs lead to sensori-neural hearing loss?

High doses of ototoxic drugs such as quinine, dihydro-streptomycin, neomycin, and kanamycin can have toxic effects on the cochlea and cause subsequent sensori-neural hearing loss. (13) The use of these drugs is now restricted.

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What is the extent of hearing loss among the U.S. population?

Based on the audiometric results in 1960-62 Public Health Survey, it is estimated that approximately 19 million Americans or 13 percent of the U.S. population have hearing losses that can be described as handicapping. Criteria recommended by the National Institute of Occupational Safety and Health (NIOSH) (25 dB HL averaged at 1000, 2000, and 3000 Hz) as the beginning point of handicap was used to derive these estimates. The population suffering such losses increases with age and the number of people significantly accelerates after age 40.

Information gathered by EPA and the National Association of the Deaf shows that 13,362,842 Americans of all ages have some type of hearing impairment, from mild to severe. One-half of these people are age 65 or older.

There are 6,548,842 Americans of all ages with significant bilateral damage. There are 1,767,046 Americans of all ages that are deaf. Of these, 410,522 are prevocational (prior to age 19) and 201,626 are prelingual (prior to age 3). The prelingual figure essentially represents those who were born deaf. Three out of every 100 school children have some type of hearing impairment and 30 out of every 1000 Americans age 65 or older have a hearing loss. In 1971 the U.S. Public Health Service conducted a survey which found that hearing impairment is the most frequently reported health problem in the country, with seven out of every 100 people reporting a hearing problem. (19)

NOISE INDUCED HEARING LOSS

What is Noise-Induced Permanent Threshold Shift (NIPTS)?

NIPTS is a permanent shift in the hearing threshold (a lowering of the sensitivity) of the ears due to exposure to noise. It is a sensori-neural type of hearing loss, and is not reversible (14). NIPTS can result from either a single exposure to high intensity impulsive noise such as blasts or explosions, or to longer exposures to lower, but still damaging noise levels. Typically, hearing loss due to noise exposure occurs first at the higher frequencies, particularly around the 4000 Hz level (3000-6000 Hz) (13/54). Figure 2-4 shows an example of NIPTS relative to exposure levels of 87-102 dB. (17)

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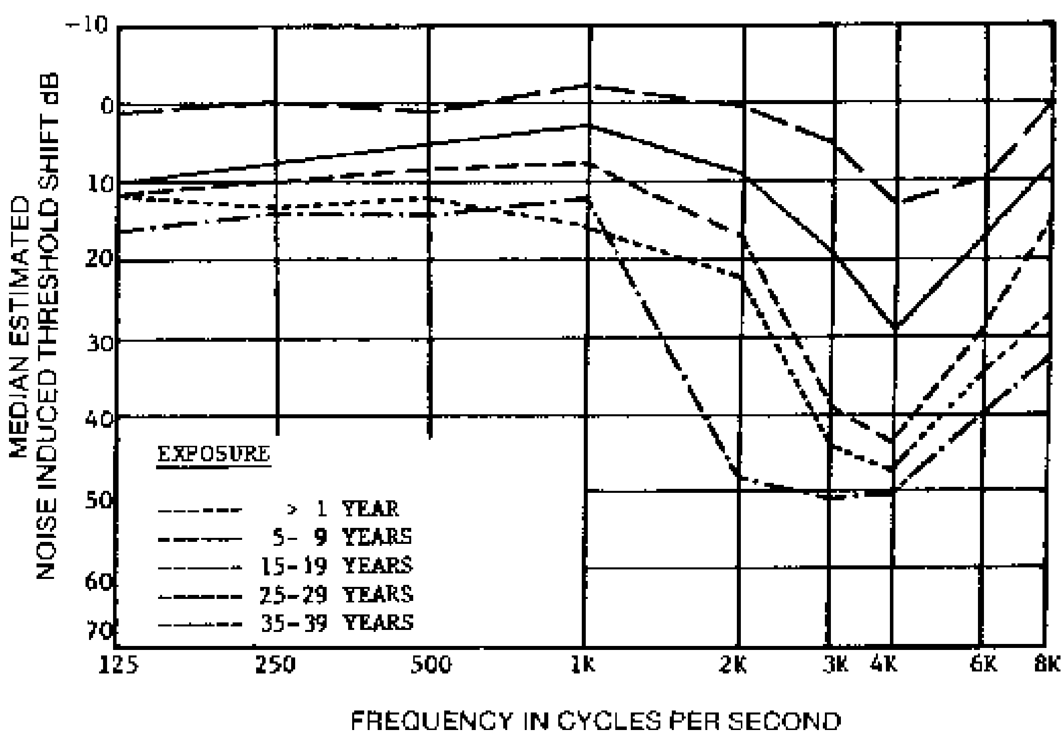

Figure 2-4

What type of relationship exists between hearing loss and the level and duration of noise exposure?

In general, the magnitude of noise-induced hearing loss depends upon the noise levels to which the ear has been habitually exposed, the length of time for which it has been exposed to those levels, and the susceptibility of the individual. Short-term (time in minutes) to high intensity noise, or long-term exposure to noise of lesser intensity, may cause temporary or permanent hearing loss. With an adequate time before the next noise exposure, the ear will generally recover to a previous pre-exposure threshold. Repeated noise exposures without adequate time for recovery between exposures can lead to a Noise-Induced Permanent Threshold Shift (NIPTS). (See References 18 and 20 for a general discussion.)

What factors can increase a person's susceptibility to noise-induced hearing loss?

A significant factor that is known to increase the likelihood of noise-induced hearing loss is continued exposure to hazardous noise. Defects or diseases of the ear are hypothesized to cause a predisposition to noise-induced hearing loss. (14) Some evidence exists that persons are especially susceptible to suffering hearing damage from noise when they are going through physiological changes or are enduring physical stress such as rapid growth or illness. (20)

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Does noise act synergistically with drugs on hearing? Are there other kinds of synergistic effects?

There is some evidence in the literature which suggests that ototoxic drugs such as kanamycin, and a class of antibiotics known as aminoglycosides may cause more severe damage to the ear when treatment with these drugs occurs concurrent with noise exposure. (21) However, only little research has been done in this area, and the data are limited to animals.

Continuous noise may also interact with impulse noise and body vibrations to exacerbate hearing loss, although the magnitude of this effect is not exactly known.

What factors protect the ear against noise-induced hearing loss?

There are several factors which can mitigate the risk of noise-induced hearing loss. The acoustic reflex (tightening of the ossicular chain due to contraction of the muscles in the middle ear in response to high level sound) protects hearing from noise exposure to a very limited degree. The use of hearing protection such as earplugs or earmuffs reduces the risk of hearing damage from noise. Avoidance of noisy areas, limiting exposure to short periods of time, or ensuring intermittent rather than continuous exposure will mitigate the risk of hearing loss from noise. Increased public awareness of the dangers of hearing damage from noise can lead to the use of ear protectors and the avoidance of dangerous noise exposure. (14)

What effect does sex have on the susceptibility to noise-induced hearing loss?

Based on the results of existing research, it is not possible to conclude whether the sex of the noise-exposed person increases or decreases the risk of noise-induced hearing loss.

What is the physiological basis for noise-induced hearing loss?

The following mechanisms are considered to play a role in causing damage to the sensory cells of the inner ear:

- Destruction of cochlear tissue because of the physical force of the sound pressure,
- Cardiovascular factors resulting from diminished blood supply to the cochlea during noise exposure,
- Alteration of fluid transport across Reissner's membrane during noise exposure,
- Alteration of biochemical processes during noise exposure. (49)

The hair cells normally convert the mechanical energy of sound vibrations into neuro-electrical signals that are transmitted to the brain. As the intensity of the noise or the time for which the ear is exposed is increased, a greater proportion of the hair cells are damaged or destroyed. Figure 2-5 schematically shows the progressive destruction of the hair cells due to excessive noise exposure.

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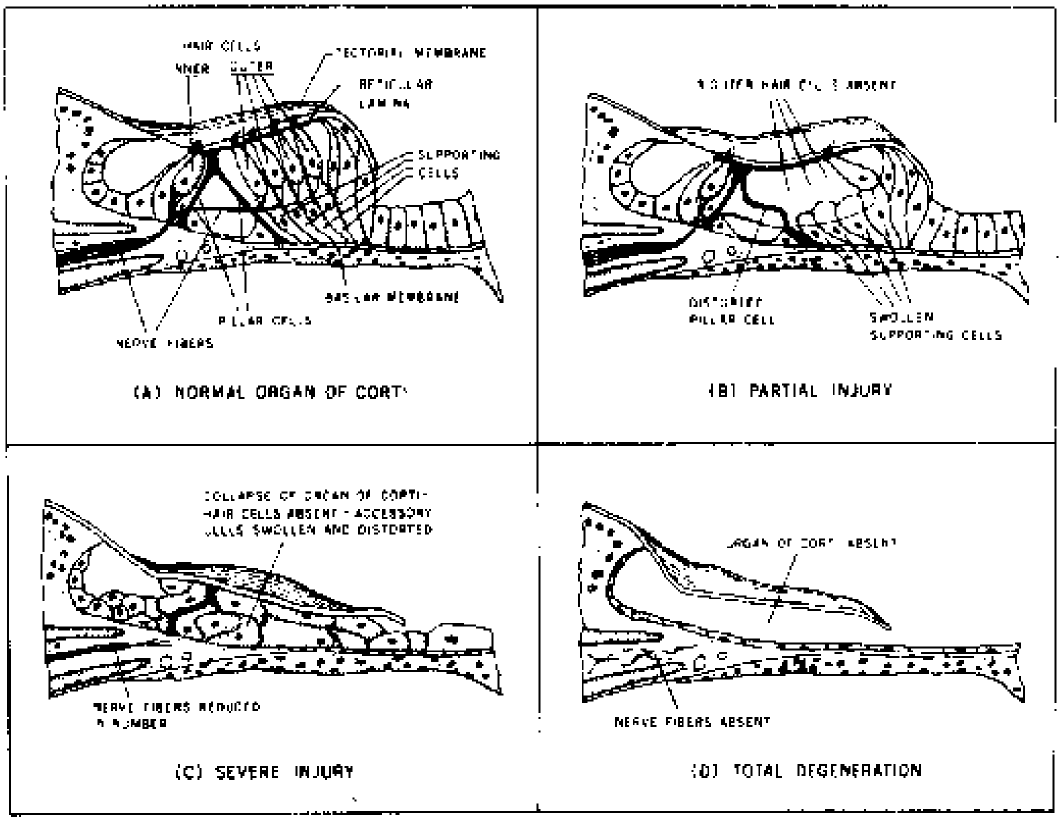

Figure 2-5 Drawings of the organ of corti illustrate the normal state, panel A, and the increasing degrees of noise-induced permanent injury, panels B, C, and D.

How does the "Equal Temporary Effect" Hypothesis predict NIPTS on the basis of NITTS?

This theory states that Noise-Induced Permanent Threshold Shift due to long-term steady-state noise exposure is predicted by the average Noise-Induced Temporary Threshold Shift produced by the same daily noise in a healthy young ear. The hypothesis is based on the convention that noise intense enough to cause NIPTS in the long run is intense enough to cause NITTS in the normal ear, and that noise that does not produce NITTS will not produce NIPTS. (14) The hypothesis states that a NITTS measured two minutes after cessation of an eight-hour noise exposure closely approximates the NIPTS incurred after a 10 to 20 year exposure to the same level. (20)

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What is the "Equal Energy" hypothesis?

The "Equal Energy" hypothesis is another way to attempt to predict NIPTS. The hypothesis states that equal amounts of sound energy will cause equal amounts of NIPTS regardless of the distribution of the energy across time (18). This means that the hazard to hearing is determined by the total energy (product of sound level and duration) that enters the ear on a daily, basis. The "Equal Energy" rule allows a 3 dB increase in sound pressure level for each halving of the duration of continuous daily steady-state noise exposure. (14)

In determining permissible exposures for the workplace to prevent NIPTS, OSHA adopted a 5 dB per doubling rule to account for various breaks in noise levels which occur during the day. (25)

EPA has identified an L_{eq} (24) of 70 dB as the maximum 24-hour exposure necessary to protect hearing. If exposure time is reduced to 8 hours, a maximum L_{eq} (8) of 75 dB, a 5 dB increase, has been identified as a protective level for hearing. (S)

IMPULSE NOISE

What is impulse noise and what are its effects on hearing?

This is noise characterized by a short duration, abrupt onset and decay and high intensity. Impulse noise describes the kinds of sound made by explosions, drop forge impacts, and the discharge of firearms. Exposure to impulse noise may result in temporary and permanent shifts in the threshold of hearing. (22)

What are the criteria for impulsive noise inside and away from the workplace?

OSHA regulations define impulse or impact noise as "sound with a rise time of not more than 35 milliseconds to peak intensity and a duration of not more than 500 milliseconds. " The regulations specify that employees shall not be exposed to impulse or impact noise which exceeds 140 dB peak pressure level. (25)

The Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Academy of Sciences has also recommended damage risk criteria for impulse noise. The CHABA impulse curve is based on peak soundpressure level and the duration of the impulses. Figure 2-6 shows the criteria currently in use, assuming an exposure of 100 impulses per day. The A-duration is the time that the impulse is initially within 20 dB of the peak level. The B-duration measures the total time that the sound is within 20 dB of the peak level. The B-duration also accounts for any reflections or reverberation that may be present, and thus allows less exposure under these conditions. A correction factor for daily exposures other than 100 impulses is provided. (74)

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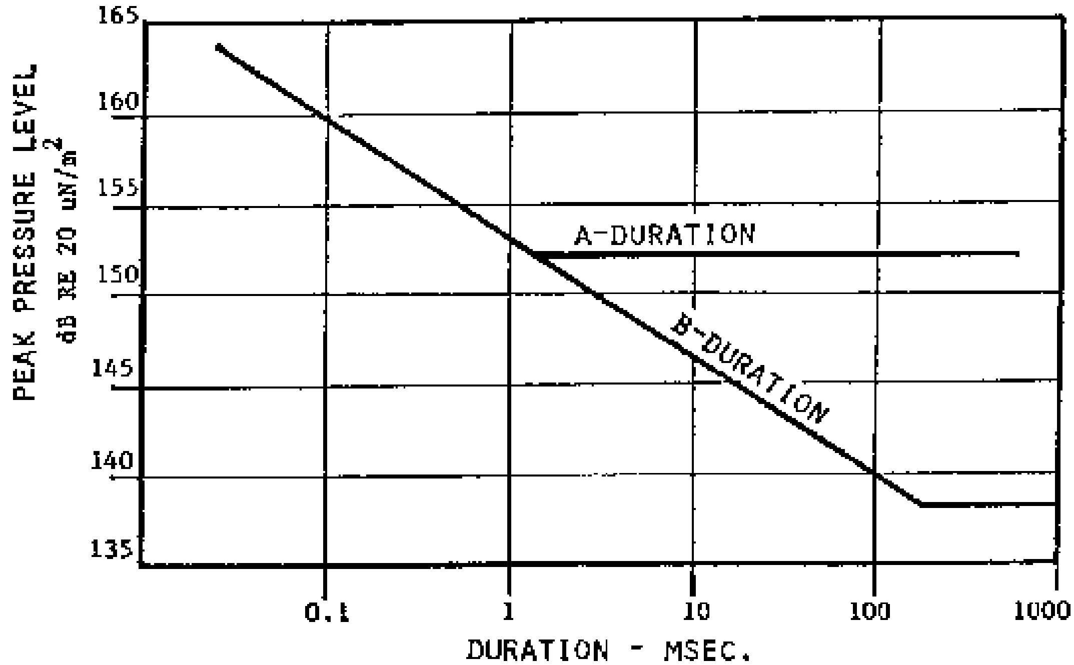

Figure 2-6 Basic limits for impulse noise exposure assuming 100 impulses per day and other conditions as stated in the text.
Source: Ref. 74.

PRESBYCUSIS-SOCIOCUSIS

What is presbycusis?

Presbycusis is a hearing loss associated with increasing age. It is most marked at higher frequencies, especially those above 3000 Hz. The causes of presbycusis are believed to be deterioration of the central nervous system and changes in the auditory system. (12)

What is sociocusis?

Sociocusis is noise-induced permanent threshold shift (loss of hearing sensitivity) attributed to environmental noise (hearing loss from non-occupational noise exposure). (27) It is difficult to separate sociocusis from hearing loss due to aging (presbycusis) or to occupational noise exposure. Exposures to high levels of environmental noise may accelerate loss normally due to aging. (18)

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What is the progression of presbycusis with age?

The threshold of hearing rises naturally (hearing becomes less sensitive) with increasing age. This effect involves primarily the frequencies above 3000 Hz. (14) Figure 2-7 presents data that depict the progression of presbycusis with age and the degree of loss. As age increases, losses at high frequencies become greater and hearing loss progresses farther down the scale to lower frequencies.

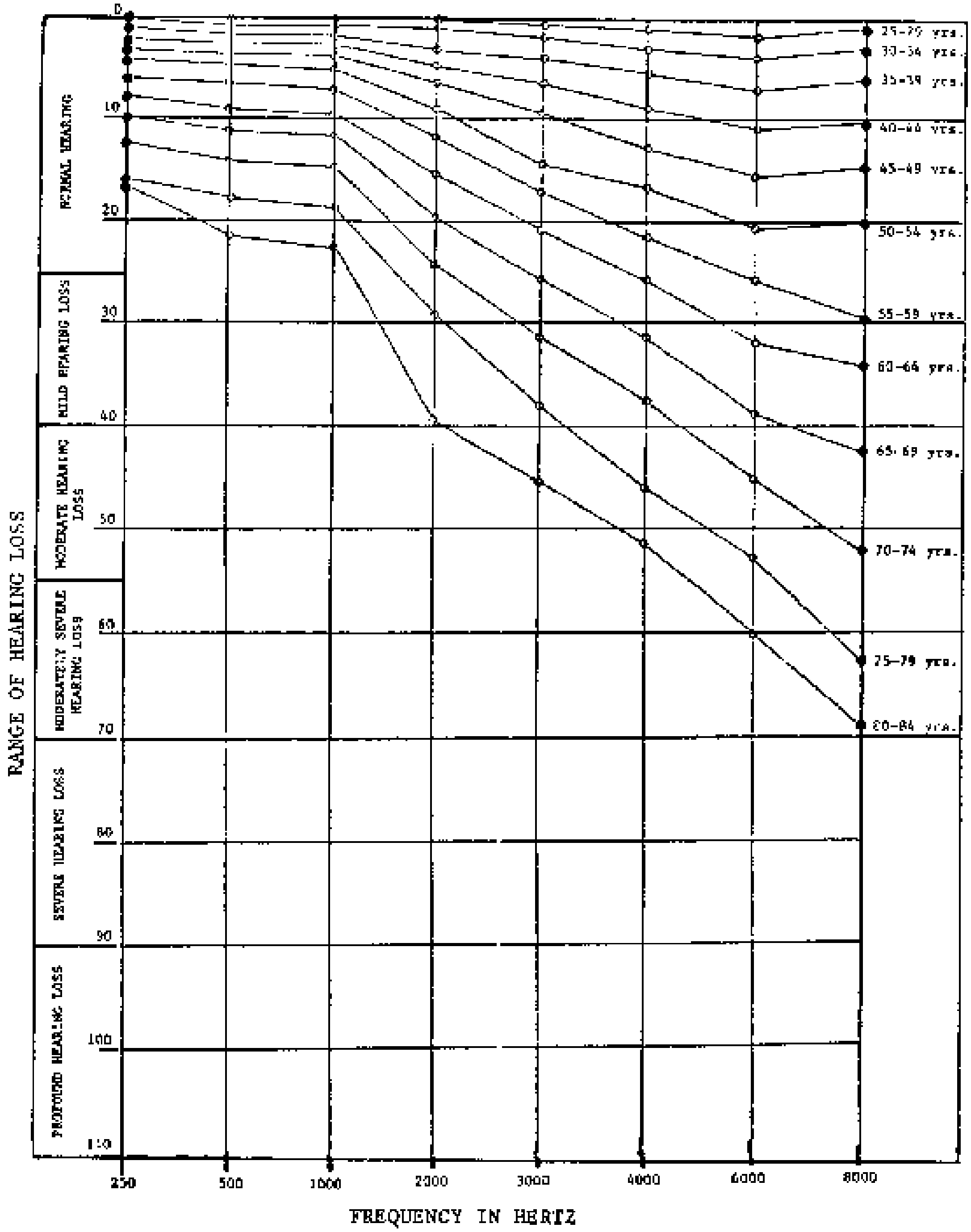

Figure 2-7 Average hearing loss from aging for men and women (without the effects of occupational noise)
Source: Ref. 26

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Due to our complex, noisy environment it is difficult, if not impossible, to separate hearing loss due to aging from noise-induced hearing loss, both from occupational and environmental noise. Few people live their whole lives in quiet surroundings. Almost everyone suffers some exposure to damaging noise either at home, at work, at leisure, or during transportation between these activities.

The data found in Figure 2-7 are not meant to be taken as an exact prediction of the magnitude of hearing loss at each age. Different researchers have found differing values. The figure is presented to represent an average amount of hearing loss that can be expected. However, it is possible that some of the hearing loss described in the graph is due to exposure to environmental noise and not to presbycusis. Some researchers contend that presbycusis consists mainly of hearing loss due to lifetime exposure to the aggregate of noise found in the environment. Another view states that environmental noise only accelerates the losses at high frequencies that would have occurred anyway through aging. (27)

What evidence exists that sociocusis (hearing loss caused by environmental noise) occurs?

Rosen conducted a study of the primitive Mabaans of the African Sudan. Their environment was almost free of noise with a typical background level of 40 dB (A-weighted). Among the Mabaans, the hearing abilities of men in their seventies and eighties is equal to that of healthy children at age ten. (28)

These findings suggest that the Mabaans show little if any hearing loss due to aging (presbycusis). The implication of these findings is that much of the hearing loss observed with age in industrial countries could really be due to environmental noise exposure (sociocusis) rather than aging (presbycusis). Rosen's findings may be attributable to diet or other causative factors, and influenced by difficulties in determination of age.

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Is rock music considered to be a hearing hazard?

Studies have confirmed that overall sound levels of loud rock and roll, either at concerts or from domestic stereos, frequently exceed current hearing damage risk criteria. These noise levels can produce large amounts of noise-induced temporary threshold shifts (NITTS) in both the musicians and the listeners. Sound levels in the area of the band vary from 105-115 dB and in the dance area from 100 to 110 dB (A-weighted levels), which are within hazardous levels according to damage risk criteria established by EPA, OSHA, and NIOSH. (29) Attendance at a rock concert as a fan, or playing and practicing in a rock band, can impair hearing. (30) Figure 2-8 shows before and after audiograms of musicians and dancers at a loud rock concert. (27) NITTS from exposure to the loud music is clearly visible. Generally, however, the incidence of hearing loss is not as large as would be predicted. (29)

One factor that can lessen the effects of rock music on hearing is its intermittency. Rock music is characterized by on-times of approximately three to five minutes alternating with off-times of approximately one minute. (27) Another factor is the prominence of low frequency sounds which are not as damaging as high frequency sounds.

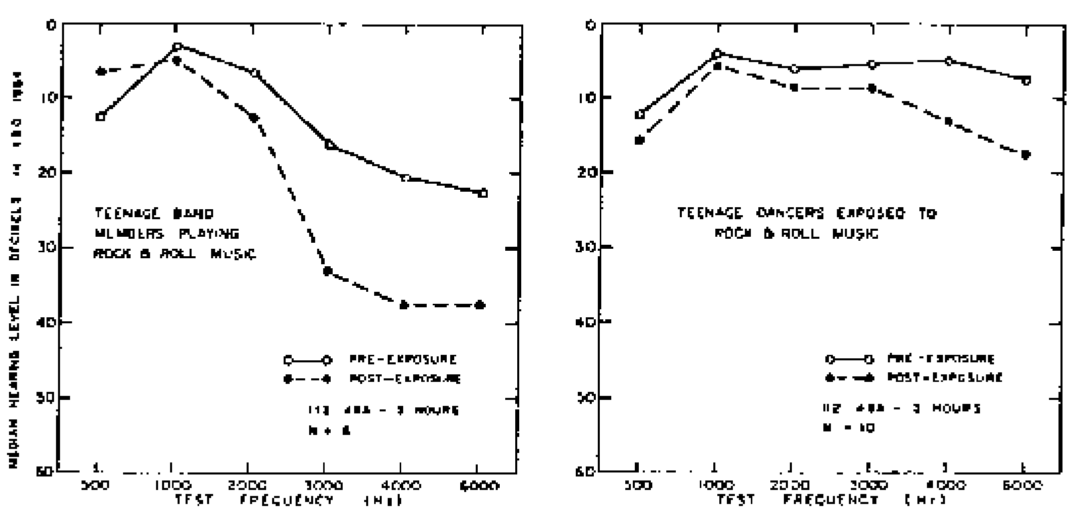

Figure 2-8 Hearing levels of teen-age rock-and-roll musicians and dancers measured just before and between five to eleven minutes after a three-hour "rock session" with average sound levels of 112dB, A-weighted. Data are from PHS sample observation.
Source: Ref. 27

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THE CONSEQUENCES OF HEARING LOSS

How is the ability to discriminate and understand speech affected by noise-induced hearing loss?

Often, the first awareness of hearing loss comes with missing occasional words in general conversation and having difficulty understanding speech on the telephone. Many sufferers of noise-induced hearing loss say that speech is frequently garbled and distorted. Typical noise-induced hearing loss is in the high frequency range and persons with this type of hearing loss can have normal or almost-normal hearing up to 1000 Hz. They exhibit little difficulty in hearing voices at normal intensities but they can have trouble understanding them especially with noise in the background. This is because consonants are characterized by high frequencies and weak intensities and vowels by low frequencies. A person with a noise-induced hearing loss can miss hearing consonants like s, f, and p that give information and meaning to speech and language. It is often difficult for people with this type of loss to understand speech in lectures, meetings, parties, theaters; or on TV, radio, or the telephone.

What is recruitment?

Recruitment is a rapid increase in the perception of loudness at levels above hearing thresholds. It is often characteristic of a sensori-neural hearing loss (13/48) and it may cause discomfort and pain. Once a sound is intense enough for the subject to perceive it, an additional increase in intensity causes a disproportionate increase in the sensation of loudness. For example, a person with a 40 dB hearing loss would just barely detect a sound of 40 dB above the normal threshold of hearing. However, he would hear a sound of 50 dB above the normal threshold with a loudness that was greater than that with which a normal hearing person would hear a sound of 10 dB above the threshold of hearing. (13)

What is tinnitus and how many people incur it?

Tinnitus is buzzing, high-pitched ringing, or roaring in the head that is a common complaint of persons with hearing loss, particularly those losses associated with noise. Tinnitus is often the first recognizable indicator of hearing damage. It can be in one or both ears, although there may not necessarily be a hearing loss present. (13)

According to the National Health Examination Survey (1960) 32 percent of the population or 48 million Americans have experienced some form of Tinnitus, at one time or another.

What other effects can hearing loss have?

Hearing loss can lead to reduced employability of the sufferer. It is especially damaging if children suffer hearing loss during their developmental and educational years. (32) Hearing loss can also be a safety hazard and can contribute to accidents because warning signals or calls for help can be missed by a person with a hearing loss. (33)

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What are the social consequences of hearing loss?

Many times, friends and associates become less willing to be partners in conversation or other activities with a person who suffers a hearing loss. It becomes difficult for a person with a hearing loss to participate in lectures, meetings, parties, theaters, and other public gatherings; to listen to the TV or radio; or have telephone conversations. A severe sense of isolation can set in as hearing decreases. As hearing loss increases so does the sense of being cut off from the rest of the world. Eventually hearing may decrease to the point that the person no longer feels a part of the living world. Emotional depression can be the result. (12)

HEARING LOSS CRITERIA

What level has been identified as protective of the hearing of the general population in the workplace?

Taking into account that 4000 Hz is the frequency most sensitive to hearing loss and that losses of less than 5 dB are generally not considered noticeable or significant, EPA has identified an 8-hour exposure level not exceeding 75 dB in order to protect 96 percent of the population from greater than a 5 dB NIPTS. (5) This recommendation is based on steady noise levels of 8 hours per day, 5 days per week, over a period of 40 years. (5)

What levels have been identified as protective of the hearing of the general population from significant damage due to environmental noise?

Environmental noise differs from workplace noise in that it is generally intermittent, covers 365 days per year rather than 250 work days, and covers 24 hours per day rather than 8 hours. Taking these factors into account, EPA has identified an environmental noise level of L_{eq} (24) = 70 dB in order to protect 96 percent of the general population from a hearing loss of greater than 5 dB at 4000 Hz. (5) For details, see Table 2-1.

		Steady (continuous) Noise	Intermittent Noise	With Margin of Safety
L_{eq}, 8 hour	250 day/year 365 day/year	73 71.4	78 76.4	75
L_{eq}, 24 hour	250 day/year 365 day/year	68 66.4	73 71.4	70

Table 2-1. (At-Ear) exposure levels that produce no more than 5 dB noise-induced hearing damage at 4000 Hz over a 40-year period.
Source: Ref. 5

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If the assumptions underlying this identified level were changed, how would that affect the level?

- **"How would the identified level be affected by a change in the percentage of the population protected?**

  Reducing the 96th percentile value to the 50th percentile (i.e., protecting half the population) would increase the protective level value from 70 dB to 77 dB.

- **"Since agreement on the value of the intermittency correction is imperfect, what other values might be used?**

  The estimated intermittency correction used in the Levels Document is 5 dB. The true intermittency correction is probably within the range 0 to 15 dB.

- **"How accurate is the equal energy assumption?**

  The equal energy assumption when applied to the long times (8 hours to 24, or 250 to 365 days) is fairly accurate. It may be subject to error when applied to short exposures of extreme level.

- **"How meaningful are the basic studies of hearing damage risk?**

  The probable errors of estimates in the three basic studies cannot be stated with absolute accuracy. There are a number of problems in extrapolating percentages of the population damaged from relatively high exposure levels to the protective level. Also, there is the problem of determining the amount of hearing damage when the control (non-exposed) population is subject to high levels of non-occupational noise. Thus, the 70 dB protective level is simply the best present estimate, subject to change if better data become available."

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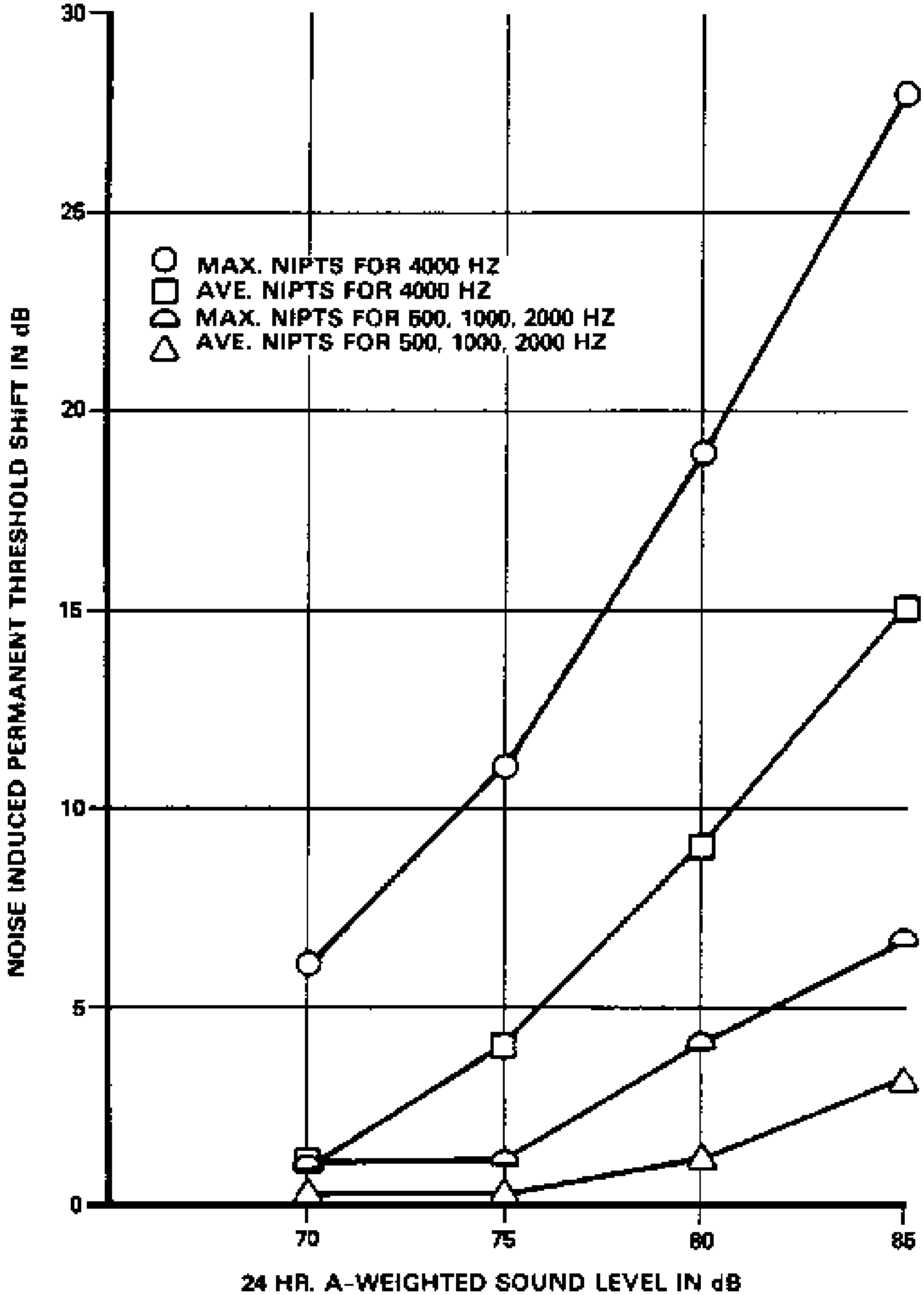

Figure 2.9 Average noise-induced permanent threshold shifts (NIPTS) (beyond presbycusic losses) expected as a function of the continuous A-weighted equivalent sound level

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What criterion has been developed for exposure to steady-state noise?

Figure 2-9 shows curves developed from data used in the EPA Levels Document (5) which depict the maximum and average noise-induced permanent threshold shift expected averaged over a 40-year exposure to a 24-hour continuous A-weighted equivalent sound level. For example, over a 40-year (age 20 to 60) exposure to a continuous A-weighted equivalent sound level of 75 dB, the average noise induced permanent threshold shift (NIPTS) expected is approximately 4 dB at 4000 Hz. This means that at age 20, the individual will have hearing equal to the non-exposed population (0 dB NITPS). At age 60, the individual will have an NIPTS considerably greater than 4 dB. The average expected shift in threshold is 4 dB. This change in hearing is caused by the workplace noise exposure. This is in addition to the expected loss of hearing due to aging which at the age of 60 is approximately an average loss of 24 dB for each frequency in the range of 250-8000 Hz. (26) The maximum values indicated in Figure 2-9 show the worst case expected from the given sound level.

HEARING CONSERVATION

In what ways can noise problems be approached in order to lessen the chances of hearing loss due to exposure to noise?

Attempts to solve a noise problem can be made by attacking any combination of the three basic elements of the problem:

- By modifying the **source** to reduce its noise output
- By altering the **transmission path** to reduce the noise level reaching the listener
- By altering the **receiver's** exposure either through limiting the exposure time or by providing personal protective equipment (11)

In what ways can a source be modified to reduce its noise output?

Noise sources can be quieted by:

- Reducing impact or impulsive forces
- Reducing speed in machines, and flow velocities and pressures in fluid systems
- Balancing rotating parts
- Reducing frictional resistance
- Isolating vibrating elements within the machine
- Reducing noise radiating areas
- Applying vibration damping materials
- Reducing noise leakage from the interior of the machine
- choosing quieter machinery when replacing appliances (11)

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In what ways can the transmission path be altered to reduce the noise level reaching the listener?

Noise transmission paths can be altered by:

- Separating the noise source and receiver as much as possible
- Using sound absorbing materials
- Using sound barriers or deflectors
- Using acoustical linings
- Using mufflers, silencers, or snubbers
- Using vibration isolators and flexible couplers
- Using enclosures (11)

If it is impossible technologically or unfeasible economically to solve a noise problem by modifying the source or altering the transmission path, what other methods can be used to protect the listener from hearing damage?

Limiting the amount of continuous exposure to high noise levels is one approach. This can be accomplished either by conducting noisy operations for only short periods of time or by allowing listeners to be exposed to high levels of noise for only short periods of time. After all other methods have failed to reduce noise to acceptable levels, personal hearing protectors can be used as a last resort where exposure to these high levels is required. (11) Hearing protectors do not solve the noise problem; they only treat the symptoms of the problem.

How is the exposure of workers to high levels of noise regulated by the Federal government?

The Walsh-Healey Public Contracts Act of 1938 as amended in 1969 requires that all companies doing at least $10,000 annual business with the Federal government limit the exposure of their workers to noise at various levels to the durations detailed in the next table. Table 2-2 shows that as the noise exposure level increases by 5 dB, the allowable time of exposure is halved. (25)

These same occupational exposure levels were promulgated covering industries engaged in interstate commerce by the Occupational Safety and Health Administration (OSHA) under the mandate of the Occupational Safety and Health Act of 1970. In November 1981, OSHA adopted a hearing conservation amendment which would require industries with an Leq of 85 dB or greater to implement noise exposure monitoring and hearing conservation programs. (99)

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Duration Per Day (h)	Noise Level dB Slow Response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105

1/2	110
1/4 or less	115 max

Table 2-2. Permissible noise exposures under the Walsh-Healey Public Contracts Act, 1969
Source: Ref. 25

If noise exposure exceeds these limits what additional protective measures do the OSHA regulations require?

If noise exposure exceeds these duration and noise level limits, after economically feasible engineering remedies are exhausted, employees are to wear hearing protectors issued by the employer. (25)

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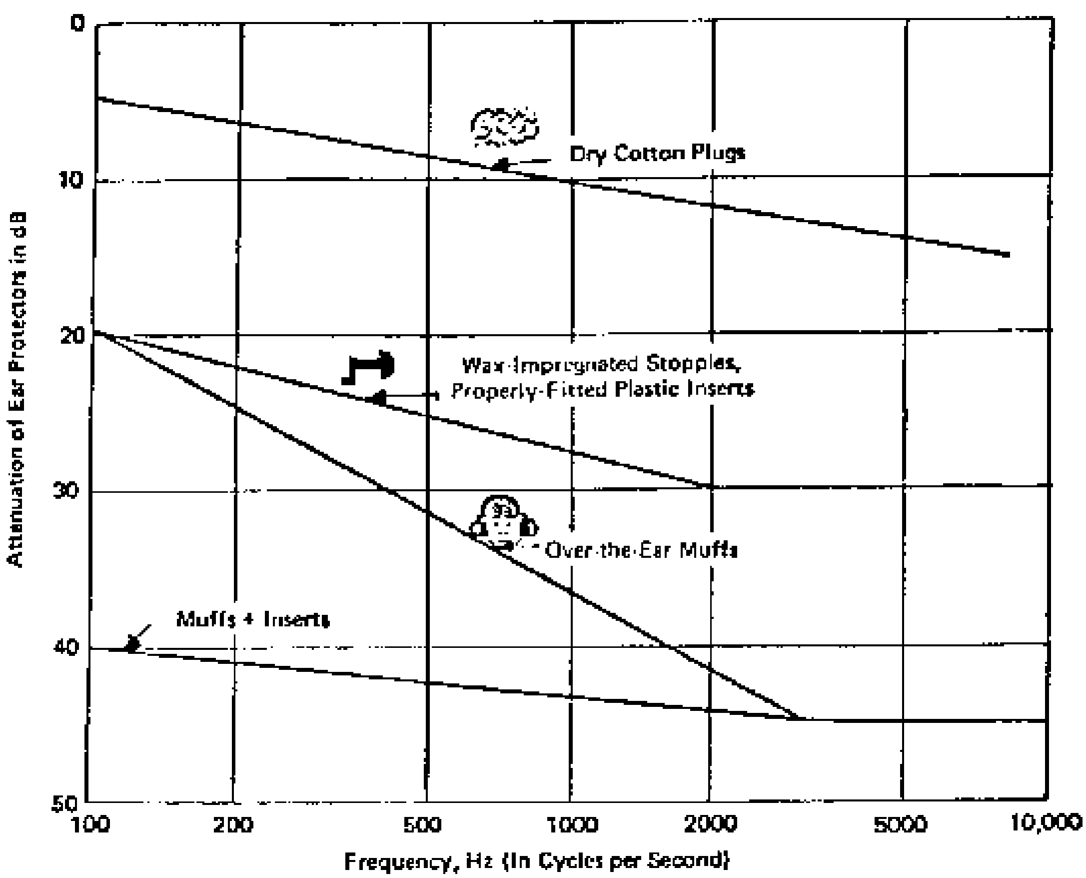

Figure 2-10 Sound attenuation characteristics of various types of ear protectors
Source: Ref. 23

What different types of hearing protectors are available?

Hearing protectors can either be earplugs or muffs. Earplugs can be made of many materials, such as soft flexible plastic, wax, paper, glasswool, cotton, and mixtures of these materials. To be effective they must provide a snug, airtight and comfortable seal. Muff-type protectors cover the entire external ear and generally provide greater protection than do earplugs. (23) Figure 2-10 depicts the sound attenuation characteristics of several representative types of hearing protectors.

What other requirements must be fulfilled under the OSHA Act of 1970?

The Act requires yearly audiograms for all employees whose noise exposure exceeds the OSHA limits. In addition, these employees are to be issued hearing protection devices.

What are baseline and follow-up audiograms and why are they useful?

Baseline or reference audiograms are the results of hearing tests performed on new employees at their time of hire. Follow-up audiograms are periodic tests performed to identify any deterioration in the employee's hearing due to on-the-job noise exposure. Baseline and follow-up audiograms are important because employers are only liable for hearing loss incurred during the time

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that a claimant was employed by them. Baseline audiograms pinpoint the extent of hearing loss prior to starting work and also can serve as a placement mechanism. An effort can be made to place employees with an existing hearing loss in areas that are less damaging to their remaining hearing. Follow-up audiograms point out developing hearing loss problems and determine those susceptible individuals who are at risk. Their exposures should be modified immediately to protect against continued deterioration of hearing. The follow-up periodic audiograms help in pinpointing those individuals needing further testing and in documenting compensation claims. (13)

Why is compensation paid for hearing impairments?

In recent years occupational diseases have become compensable, and loss of hearing has been recognized by the Federal government and most states as an occupational disease. Today, there are some state laws that consider gradual hearing impairment as a series of traumas or accidents, and therefore treat it as a safety rather than a health problem. At the present time nearly all states have provisions for compensating hearing loss but the statutes vary considerably. While a few states compensate fairly liberally, some states require "total" loss of hearing in one or both ears, and others still require proof of disability and lost wages. (34) (For general information and discussion see Reference 38.)

In terms of compensation and criteria, how are disability, impairment, and handicap defined and used?

- Disability: actual or presumed inability to remain employed at full wages
- Impairment: a deviation or a change for the worse in either structure or function, usually outside of the range of normal
- Handicap: the disadvantage imposed by an impairment sufficient to affect one's personal efficiency in the activities of daily living

Clearly, the term handicap is meant to apply to the compensation situation, whereas the term impairment is more appropriate to preventive criteria. (35) The decision of what is an unacceptable amount of impairment continues to be in dispute.

What are the two most often used hearing impairment compensation formulas?

1. **AMA/AAOO Formula (1978)**

This recently revised formula was developed by the American Academy of Ophthalmology and Otolaryngology. The formula averages hearing loss at 500, 1000, 2000, and 3000 Hz (prior to the revision, the 3 KHz test frequency was not used) with a 25 dB low fence below which no hearing impairment is considered to exist. An average hearing impairment of 92 dB is considered total hearing loss with each decibel loss between 25 and 92 dB representing a 1.5 percent impairment rate of growth. (36)

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2. **Compensation Formula for Federal Employees (NIOSH Formula)**

The original AMA (AAOO) formula was used until 1969. It was modified at that time by the Department of Labor to include test frequencies of 1, 2, and 4 KHz with the same high and low fence as before. It was again modified in 1973 to the present form. This later modification was largely based on NIOSH recommendations in its criteria document, "Criteria for a Recommended Standard Occupational Exposure to Noise." (37) NIOSH recommended that hearing impairment should be assessed by the ability to hear and understand speech not only in quiet surroundings, but in everyday conversational settings where significant background noise may be present. The NIOSH formula averages hearing loss at 1000, 2000, and 3000 Hz, also using a 25 dB low fence below which no hearing loss is considered. A 1.5 percent hearing impairment rate of growth occurs for every decibel loss above 25 dB. The inclusion of the 3 KHz test frequency while deleting the 500 Hz makes the formula more sensitive to noise-induced hearing loss since such losses are incurred initially at higher frequencies. In view of this, a number of states have incorporated similar high frequency components in their formulas in recent years.

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NONAUDITORY PHYSIOLOGICAL RESPONSE

EFFECTS - GENERAL

Why is noise considered a health problem?

Noise is generally viewed as being one of a number of general biological stressors. It is felt that excessive exposure to noise might be considered a health risk in that noise may contribute to the development and aggravation of stress related conditions such as high blood pressure, coronary disease, ulcers, colitis, and migraine headaches. (20)*

Growing evidence suggests a link between noise and cardiovascular problems. There is also evidence suggesting that noise may be related to birth defects and low birth-weight babies. (40)

There are also some indications that noise exposure can increase susceptibility to viral infection and toxic substances. (14)

What physiological changes occur in response to noise?

Loud sounds can cause an arousal response in which a series of reactions occur in the body. Adrenalin is released into the bloodstream; heart rate, blood pressure, and respiration tend to increase; gastrointestinal motility is inhibited; peripheral blood vessels constrict; and muscles tense. On the conscious level we are alerted and prepared to take action. Even though noise may have no relationship to danger, the body will respond automatically to noise as a warning signal. (14)

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*References are listed in Section 11, e.g.: (Ref. 20).

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Illustrated in Figure 3-1 are possible clinical manifestations of stress concomitant with noise. Not only might there be harmful consequences to health during the state of alertness, but research also suggests effects may occur when the body is unaware or asleep.

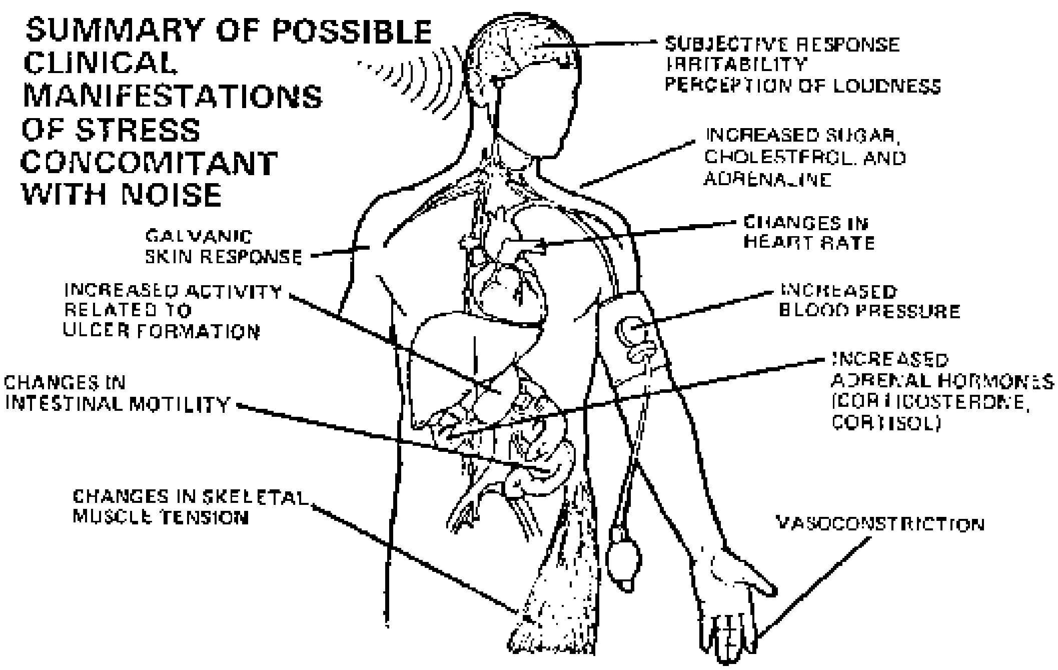

Figure 3-1

How are these physiological responses activated?

Impulses from the brain activate centers of the autonomic nervous system which trigger a series of bodily reactions as part of a general stress response. Systems that may be affected include the glandular, cardiovascular, gastrointestinal, and musculoskelatal systems.

Is short-term exposure to noise considered a health risk?

No. It is generally believed that there is no risk since the body has a chance to recover. A little stress, as many people will attest, may be beneficial. There may be exceptions to the above statement. (41)

Is long-term exposure to noise considered a health risk?

It is possible that repeated or constant exposure to noise can contribute to a deterioration in health. Whether or not environmental or industrial noise by itself can lead to chronic disturbances is hard to determine since there are so many other stresses to which people are exposed. (41) This research is difficult to conduct and little has been done in this area, but research is accumulating which suggests a relationship between long-term noise exposure and stress-related health effects, particularly those related to the cardiovascular system.

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Have criteria been established for the nonauditory effects of noise?

Not at the present time. In the past, EPA stated that noise levels identified to protect against hearing loss should be sufficient to protect against the nonauditory effects of noise. However, growing evidence suggests that this assumption needs to be tested through research. (5) In considering noise as a general stressor, the need to establish quantitative criteria has now become evident, given the growing concern about these effects.

NOISE AND THE BODY'S REACTIONS

Why is the investigation of cardiovascular effects so important?

The extent to which noise may contribute to the prevalence of hypertension and other cardiovascular disorders points to an important public health concern. Heart disease has been the leading cause of death in the United States for the past several decades, accounting for almost 50 percent of the deaths in this country. Hypertension is the most common of all cardiovascular diseases, and it is estimated that from 23 to 60 million Americans, depending on the criteria used for defining hypertension and the age groups included, have hypertension. Hypertension is a factor contributing to the death of at least 250,000 Americans each year. (84) Heart and blood vessel diseases cause a great share of the financial burden of illness, constituting about one-fifth of the total cost of illness in this country.

Is there credible scientific evidence which suggests that noise-induced stress is related to hypertension and cardiovascular disease?

Yes. It has long been known that noise is capable of producing short term systemic stress reactions in animals and humans. The major question concerns the extent to which these reactions, if repeatedly elicited, translate into health problems. More than 40, mostly foreign, retrospective epidemiological studies have been done assessing the cardiovascular effects of occupational noise. (100, 86) A large number of these studies indicate that long-term exposure to high levels of occupational noise is associated with increased rates of high blood pressure and other cardiovascular health problems. Field studies have also been conducted on various other groups - people living near airports, and school children exposed to traffic noise - showing that there may be some risk for these people. (66, 85) In addition, laboratory studies on animals and humans (42) have demonstrated a relationship between noise and high blood pressure. It should be noted that in field studies, while noise may be the major variable between test and control groups, noise cannot be singled out as the only cause of stress effects. Attention has to be paid to the type of work being done, other noxious environmental conditions, and the physical and emotional health of the subjects. (43)

Are there any studies which have focused on health effects associated with community or environmental noise exposures?

Several correlational field studies have examined health outcomes as a function of exposure to varying levels of traffic and aircraft noise. (66) Although these studies must be viewed as exploratory rather than confirma-

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tory, evidence has been obtained for increased rates of hypertension and cardiovascular disease, increased usage of various prescription drugs, increased rates of physician's visits, and increased subjective and self-reported symptoms and complaints. (86, 101) These studies suggest the possibility of adverse health outcomes associated with environmental noise and further underscore the need for additional research.

Is noise of special concern for those persons already suffering from circulatory and heart problems?

Noise may be potentially more dangerous to these people since it can aggravate an existing health problem. There are millions with heart disease, high blood pressure, and emotional illness who may need protection from the additional stress of noise. However, no research exists to document this area of concern.

Are children more susceptible to the physiological stress effects of noise?

The contribution of various environmental factors to the early development of high blood pressure is an important question. With respect to noise, at least two studies exist which suggest that exposure to high noise levels in schools and neighborhoods is associated with elevations in blood pressure. The blood pressure levels of children living in high noise environments were found to be significantly higher than those of children attending schools or residing in quieter areas. (96, 100, 104)

What are some of the findings from the study of blood pressure in laboratory animals exposed to noise?

Research in this area has been sponsored by EPA. Data from an experiment by Dr. Ernest Peterson, using monkeys subjected to 24 hours of recorded noise daily (representing typical daily noises for an industrial worker), indicate that such exposures, repeated daily for months, can cause sustained changes in blood pressure. This suggests that noise may make a long-term contribution to the development of cardiovascular disease. (42)

Have any long-term human experimental or other such controlled studies been conducted?

One long-term laboratory study has been conducted by the Navy. In this study, subjects were exposed to short bursts of noise at moderate levels over a 30-day period. (102) Among the results found in this study were statistically significant elevations in cholesterol and cortisol. Cholesterol is a known risk factor for cardiovascular disease and cortisol is a stress hormone. Two other field studies have been able to obtain high and low noise comparisons on the same subjects in field settings. (103, 86) These studies have reported noise-related elevations in blood pressure and in various stress-related hormones, and have found increases in a variety of health disorders and complaints.

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Is there a relationship between noise-induced hearing loss and high blood pressure?

Studies have been done which have tried to use noise-induced hearing loss as an indirect index of noise exposure. One such study did report higher blood pressure levels among workers with obvious noise-induced hearing loss. However, this study has been criticized on methodological grounds and subsequent studies have yielded mixed results. (43, 105)

With what other stress effects can noise be associated?

Stress can be manifested in any number of ways, including headaches, irritability, insomnia, digestive disorders, and psychological disorders. Workers who are exposed to excessive noise frequently complain that noisejust makes them tired.

Quite a few field studies have been done on workers in Europe, examining the relationship between noise and illness. In these studies, noise has been related to the following:

General morbidity (illness)

Neuropsychological disturbances

- headaches
- fatigue
- insomnia
- irritability
- neuroticism

Cardiovascular system disturbances

- hypertension
- hypotension
- cardiac disease

Digestive disorders

- ulcers
- colitis

Endocrine and biochemical disorders

There is a need for additional laboratory replications of these potentially important findings.

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Do experts agree on the significance of nonauditory physiological effects of noise?

No. While a growing body of evidence, provided and accepted by a growing number of scientists, suggests that noise can be considered a general biological stressor, not all findings and not all scientists agree. Dr. Karl Kryter (98, 20) performed studies in which his subjects demonstrated relatively small physiological changes in response to noise. He feels that the acoustic-vascular response to noise can be explained by, a non-stressful protective auditory, system sympathetic nervous system reflex rather than the general stress response generally assumed to be responsible for what he believes to be transient physiological changes observed after noise exposure. So there are differences in scientific opinion about both the mechanism by which noise affects the body and the degree to which these effects are stressful. Many of these differences may eventually be explained in terms of the distinct ways in which two different individuals may respond to an identical stimulus.

Have increased illness, accidents, and absenteeism been related to noise?

A study was conducted on the medical attendance and accident files of 500 workers situated in noisy plants (95 dB or higher) and 500 workers in quieter plants (80 dB or less) in the southeast U.S. Comparing the records of those workers, it was found that the workers exposed to the higher levels of noise had a significantly greater rate of accidents, diagnosed medical problems, and absenteeism (especially in the boiler manufacturing plant where most of the records were obtained). (86) The study cautions, however, that there may be other conditions besides noise responsible for these differences.

Does noise have any nonauditory synergistic effects with toxic substances?

There are now 13,000 toxins used in industry and business. Noise as a stressor in combination with toxins may pose a serious health hazard for workers. However, no definitive data are available at the present time.

Does noise have an effect on mortality rates?

Some research has been conducted by W. C. Meecham and W. Shaw on the effects of jet noise and mortality rates around Los Angeles Airport. The results showed an effect that is provocative and suggest the need for more in-depth, larger scale research. Considerable caution should be exercised in generalizing from these findings since there were many intervening noise exposure and demographic variables not considered in this ecological-correlation study. Therefore, the effects of noise on mortality are still uncertain. (97, 44)

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Does protecting against hearing loss guarantee that no nonauditory physiological effects will occur?

It is not possible to provide a definitive answer to this question at this time. However, EPA-sponsored primate research has shown that significant and sustained elevations in blood pressure can be produced as a result of exposure to noise levels which do not produce any significant permanent hearing loss in the subjects. (106) These data would suggest that protecting against the auditory effects of noise does not necessarily prevent the nonauditory effects. Human data confirming this conclusion are needed.

Is there a link between annoyance and nonauditory physiological response to noise?

Although it is reasonable to view annoyance as a symptom or sign of noise-induced stress, no direct test of this relationship has been made.

NOISE AND THE UNBORN

Can noise affect the fetus?

Physiologically, there are reasons to suspect that noise may affect the fetus. Studies have shown maternal stress causes constriction of the uterine blood vessels which supply nutrients and oxygen to the developing baby. Stress may then threaten fetal development if it occurs early in pregnancy. The most important period is about 14 to 60 days after conception. During this time, important developments in the central nervous system and vital organs are taking place. (45) However, it is presently not known whether noise affects the fetus in any lasting ways.

As an example of possible outcomes due to fetal noise exposure, a Japanese study showed a statistical tendency toward low birth weights in noisy areas near a major airport compared to surrounding areas (40). Other intervening factors that may have contributed to this finding, such as maternal stress, have not been confirmed.

The U.S. study in Los Angeles found that, in addition to greater incidence of low birth weights, there was also a greater incidence of birth defects such as clefts of the lip or palate, and spinal malformations. These results should be judged cautiously because of many correlational problems with the data.

On the other hand, a similar study on fetal birth weight was conducted by the Center for Disease Control. (85) This study found that there were no effects. (46)

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COMMUNICATION INTERFERENCE

EFFECTS

The indirect effects of speech interference are:

- Disturbance of normal domestic or educational activities
- Creation of an undesirable living environment
- Safety hazards
- A source of extreme annoyance (5)*

Can high background noise levels affect social interaction?

For certain individuals who live in noisy areas, the adoption of a lifestyle that is nearly devoid of communication and social interaction can result. If noise interferes with their communication, they stop talking, change the content of their conversations, talk only when absolutely necessary, or frequently repeat themselves. (31)

How is communication interference important in safety?

Masking of warning signals and directions by other intrusive sounds can be hazardous. For example, an airline pilot's reception of an air traffic control message can be affected by too much background noise. A missed warning in a noisy steel mill can result in an accident, injury, or even death. (47)

Can vigilance be disrupted by noise?

Yes, listening for particular signals can be hindered by high background noise levels. For example, a parent working downstairs might be listening for sounds of a child upstairs awakening from sleep. A noisy environment could interfere with this.

What factors determine the extent to which noise affects speech communication?

- Location (whether indoors or outdoors)
- The attenuation characteristics of the building and internal structures when indoors
- The vocal effort and skill of the talkers and listeners
- The background noise level and spectrum. (5)
- Hearing acuity

Does speech quality have an effect on speech interference?

If the talker is imprecise in his speech (poor articulation), speaks a different dialect than the listener, or speaks softer than most, lower background noise levels are required. (14)

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*References are listed in Section 11, e.g.: (Ref. 5).

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Is the duration of the noise a determinant in speech interference?

Intermittent noises will mask speech in variable degrees. Impulse noise in isolated one-second bursts is unlikely to disrupt much speech communication due to the redundancy of speech. However, as the frequency and duration of the noise bursts increase, so does the masking effect. (14)

Do fluctuating sound levels have any effect on intelligibility?

For a fixed L_{eq}, sufficient to mask some speech, interference with speech is greater for a steady noise than for almost all types of environmental noise whose magnitude varies with time (fluctuating sound levels). (5)

What methods are used to characterize noises in respect to their speech-making abilities?

- The Articulation Index (AI), a complex measure which accounts for the differences in masking capabilities of frequencies in background noise. (91)
- The Speech Interference Level (SIL), an arithmetic average of the octave-band sound pressure levels of noise that affect the major speech frequencies (octave band sound pressure levels are centered at 500, 1000, 2000, and 4000 Hz). (92)
- A-weighted sound level, which reflects the sensitivity pattern of the ear's response to noise and speech. (14)

Why is the A-weighted sound level a good measure of speech interference potential of noise?

A-weighting gives the greatest weight to those components of noise that fall in the frequency range where most speech information resides. It gives less emphasis to noise in the lower frequency (500 Hz or lower) range than does the overall sound pressure level. (5)

How does the Speech Interference Level (SIL) relate to A-weighted sound level?

The difference between the two varies depending on the exact spectrum of each noise. However, by adding 8 dB to L_A values, a good approximation of the SIL can be obtained. (92)

What are the appropriate noise levels to prevent speech interference with oral communication?

For outdoors, Table 4-1 shows distances between speaker and listener for satisfactory outdoor speech at two levels of vocal effort in steady background noise levels. In other words, if the noise levels in Table 4-1 are exceeded, the speaker and listener must either move closer together or expect reduced intelligibility. This is also shown in Figure 4-1.

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	COMMUNICATION DISTANCE (meters)					
VOICE LEVEL	0.5	1	2	3	4	5
Normal Voice (in dB)	72	66	60	56	54	52

Raised Voice (in dB)	78	72	66	62	60	58

Table 4-1. Steady A-weighted sound levels that allow communication with 95 percent sentence intelligibility over various distances outdoors for different voice levels
Source: Ref. 5.

*Assumes normal voice level of 70 dB (67 dBA) or raised voice of 76 dB (73 dBA)

What criteria are used to predict the effect of noise on speech communication?

For indoors, Figure 4-1 shows that an L_{dn} of 50 dB permits virtually 100 percent intelligibility within buildings (5). IA given percentage of sentence intelligibility, such as 95 percent or 100 percent, indicates the proportion of

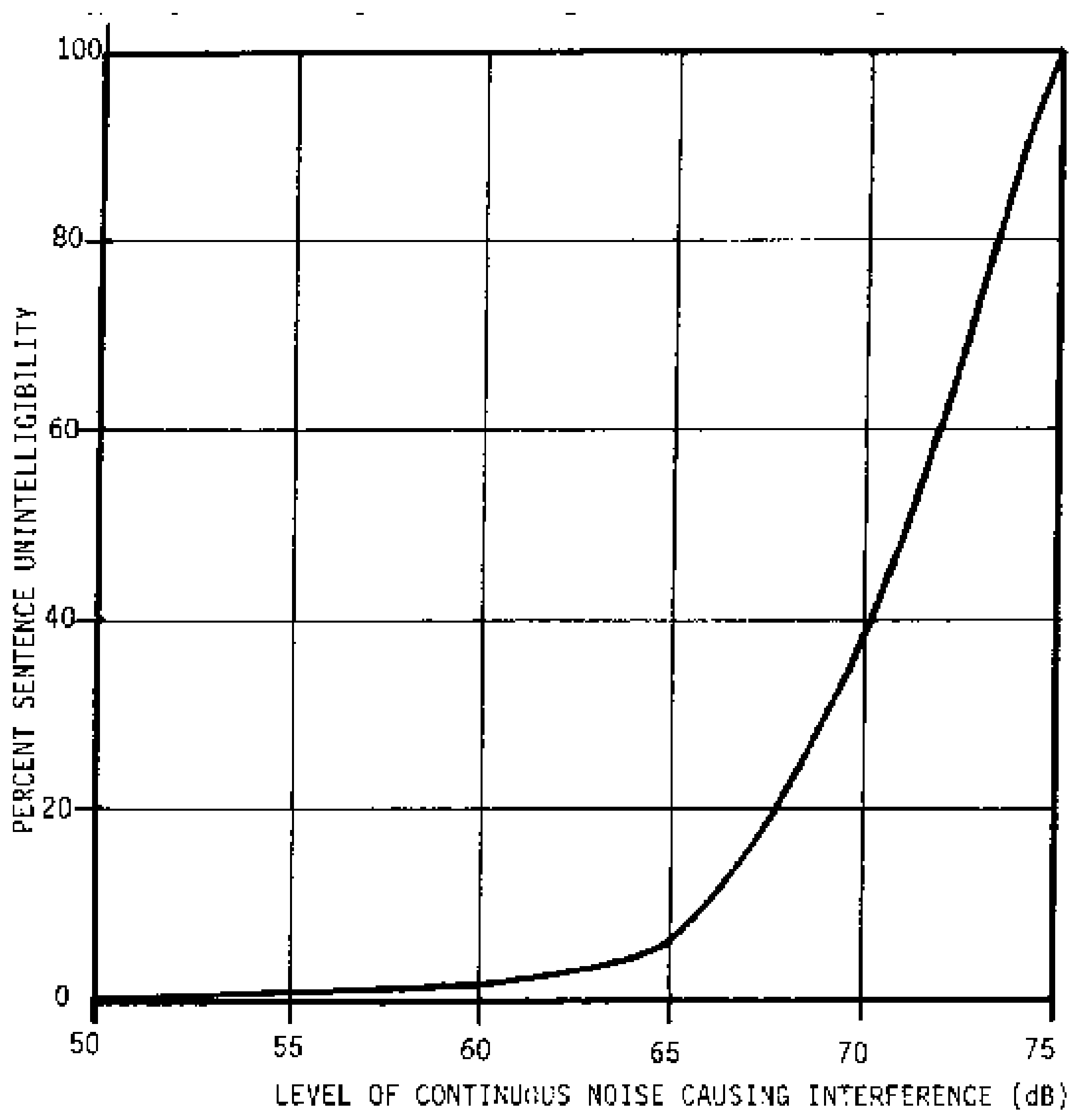

Figure 4-1 Criteria for indoor speech interference (relaxed conversation at greater than 1 meter separation, 45 dB background in the absence of interfering noise)
Source: Ref. 5.

4-3

key words in a group of sentences which are correctly heard by normal-hearing listeners.)

For outdoors, Figure 4-2 shows that an L_{dn} of 50 dB which also indicates nearly 100 percent intelligibility (5).

Figure 4-3 shows appropriate voice levels limited by ambient noise conditions. Along the abscissa are various measures of noise, along the ordinate distance, and the parameters are voice level. At levels above 50 dB people raise their voice level as shown by the "expected" line if communications are not vital or by the "communicating" line if communications are vital. Below and to the left of the "normal" voice line, communications are at an AI level of 0.5, 98 percent sentence intelligibility. At a shout, communications are possible except above and to the right of the "impossible" area line. (50)

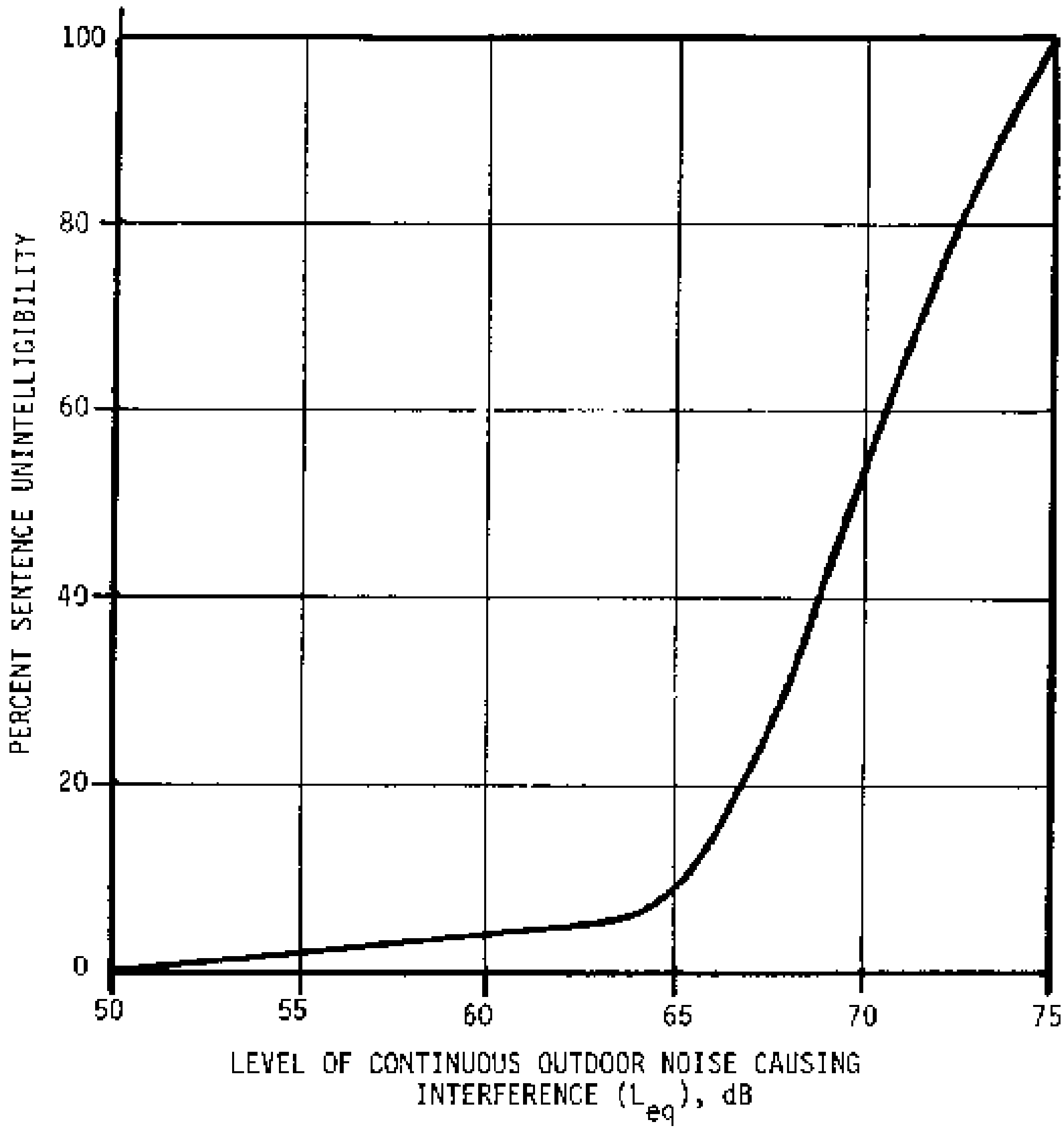

Figure 4-2 Criteria for outdoor speech interference (normal voice at 2 meters)
Source: Ref. 5.

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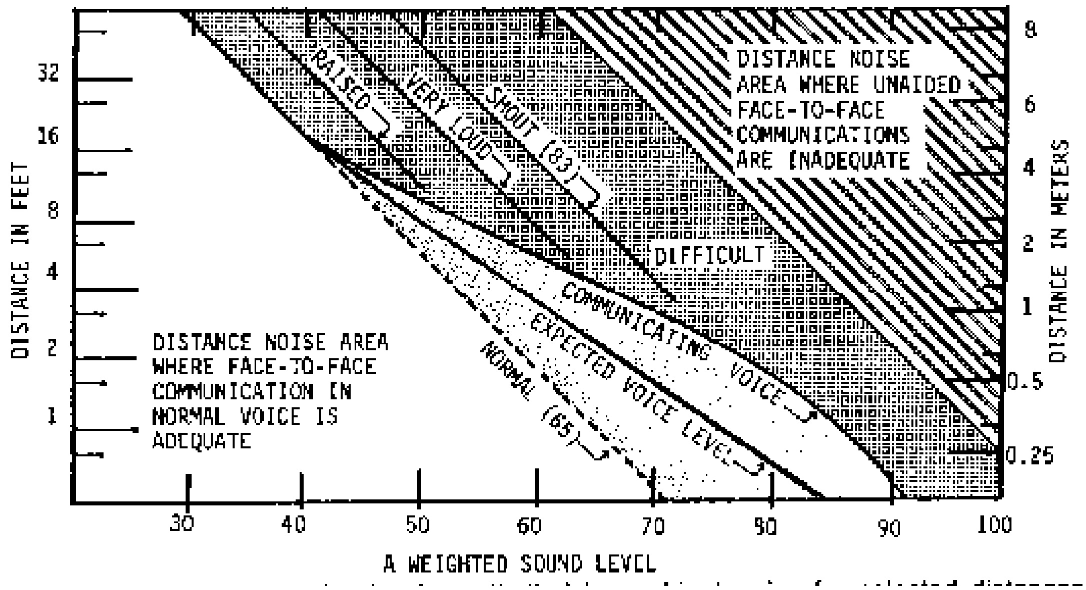

Figure 4-3 Necessary voice levels as limited by ambient noise for selected distances between talker and listener for satisfactory face-to-face communication.
Source: Ref. 50, 28.

NOTE: The figures are based on data from sentences known to listeners." As a result, these levels may not be completely adequate in describing fluctuating noise conditions and would be conservative estimates for situations where communication is unpredictable.

SPECIAL POPULATIONS

Does the age of adults have any effect on the ability to discriminate speech in noise?

The ability to understand partially masked or distorted speech begins to deteriorate around age 30 and declines steadily thereafter. Generally, therefore, the older the listener, the lower the back ground noise must be for normal communication. (14)

Do people with hearing loss have any special problems with regard to speech interference?

People with hearing losses require more favorable speech-to-noise ratios than do persons with normal hearing. (14) This means that the difference between the level of speech and the background noise level must be greater for hearing impaired individuals than for people with normal hearing. This can be achieved either by decreasing the background noise level or increasing the speech level. Increased levels of noise, in relation to the speech signal, tend to aggravate the adverse effects of hearing loss. (48)

What are the effects of noise on children's communication skills?

High levels of noise reduce the number of conversations and their content, quality, and fidelity. Children have a relative lack of knowledge of language that makes them less able to "hear" speech when some of the cues are lost. Repeated exposure to high levels of noise in "critical periods of development" might affect conceptual development and the acquisition of speech, language, and language-related skills like reading and listening. (32)

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Can reading ability be affected by high noise levels?

A study based on the reading scores of children in grades two through five who live in an apartment building showed that the noise in and around the building was detrimental to their reading development. The longer the children had lived in the noisy environment, the lower their reading test scores. (66)

Are these effects only important at home?

Studies have shown that schools located next to expressways or tinder aircraft flight paths also show severe effects on learning. For example in addition to the length of the disruptive aircraft flyovers, in many cases, considerable time is spent refocusing the students' attention on the study material. (32)

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PERFORMANCE INTERFERENCE

DETERMINANTS OF INTERFERENCE

What noise parameters affect work performance?

The question is a complex one and in any particular case, at least four factors should be kept in mind:

- Characteristics of the noise
- Characteristics of the task
- Aspects of performance considered important
- Individual differences

In general, noise is more likely to reduce the accuracy rather than the total quantity of work and it affects complex tasks more than simpler ones. (31)* As the noise level increases, both reaction times and numbers of errors increase. These effects are more pronounced for complex tasks than for simpler tasks. In fact, for some simple tasks, noise may enhance performance.

How does noise exposure interfere with human performance?

Noise often results in a disruption of one's attentional processes. Cues that are irrelevant to task performance are dropped out first. If attention is further restricted, then cues that are relevant to performance of the task are eliminated. (96)

Why does performance sometimes improve during exposure to noise?

Performance improves during exposure to noise when distracting cues are dropped out. Task performance improves when only relevant primary task cues are focused upon. (96)

Noise levels most likely to be detrimental to performance are:

- Continuous noise levels above 90 dB (A-weighted)

- Levels less than 90 dB (A-weighted), if they have predominantly high frequency components, are intermittent, unexpected, or uncontrollable (5)

Does the intermittency or predictability of the noise play a role in performance interference?

Yes, when a noise occurs in a random, intermittent or unpredictable fashion, errors tend to increase, and greater effort is required to maintain concentration. Unpredictable noise may lead to breaks in concentration that are followed by compensating increases in the work rate. Thus, the overall rate of work may not be affected, but the variability of the work rate may be. (51, 53)

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*References are listed in Section 11, e.g.: (Ref. 31).

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Do high-intensity noises have any special effects on performance?

High-intensity noise such as jet engine noise in close proximity is reported to cause nausea, vertigo, uncoordination, fatigue, and mental confusion. These effects are attributed to vestibular stimulation and to reflexes elicited by vibration of the skin, muscles, and joints. Any of these symptoms can give rise to a reduction in performance efficiency. (52)

Does controllability of the noise have an effect on performance?

Noises that are unpredictable or randomly intermittent tend to be associated with greater decrements in performance than in continuous noise. These decrements may in part be explained by the fact that these noises are perceived by the individual as being unpredictable. Recent research (56) suggests that exposure to unpredictable noise may result in performance decrements which occur after the noise has ceased (aftereffects).

Does the frequency spectrum of the noise have any effect on performance?

Yes, in general, high frequency noises (above 2000 Hz) impair performance more than low frequencies of the same sound pressure level. (54)

Does the meaning of the noise affect its ability to interfere with performance?

Yes, the meaning of the noise is an important variable. Relevant and meaningful information is attended to, rather than ignored, thereby detracting from the task at hand.

What types of tasks can be affected by noise?

- Tasks that involve concentration, learning, or analytic processes
- Tasks where an integral part of performance is speaking and/or listening.
- Tasks requiring fine muscular movements
- Simultaneous tasks
- Tasks which require continuous performance
- Tasks including prolonged vigilance and few signals
- performance of any task that involves auditory signals
- Tasks requiring attention to multiple channels (20)

How can noise affect learning or information gathering?

Noise may compete for the limited number of channels available for information input. When the system is already overloaded, the individual must take more time to evaluate the intruding stimulus, or risk making errors. (55)

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Do individuals differ in the extent to which noise may interfere with their performance?

Yes, laboratory studies have shown that some people who have been exposed to noise are not able to perform tasks requiring skills of retention and attention to detail. These decrements in performance are especially found in those who are exposed to uncontrollable or unpredictable noise. (56)

Research has shown that the motivational involvement of the individual influences the extent that noise will have on performance. (57) Other studies have shown that personality variables, primarily the trait of introversion/extroversion, can influence performance under noise. (58; 59; 60)

Can noise have cumulative effects on performance?

It has been hypothesized that exposure to noise can produce an actual change in the state of the individual that is reflected in failure of selective perception. This change produces measurable performance decrements. (14) More errors tend to occur toward the end of performance sessions, which also suggests a cumulative effect by the end of the workday. (61)

Can noise have both positive and negative effects on task performance?

Yes, depending on the complexity of the task, noise may either improve or interfere with performance. Tasks that are mechanical or repetitive, and where average levels of performance are sufficient, will seldom be affected. Moderate levels of noise can produce beneficial arousal levels during monotonous tasks. Tasks requiring moderate effort seem to be unaffected by the noise. Highly complex tasks requiring attendance to a large number of cues, or to many cues in rapid succession, may be affected by noise at all levels of intensity. (62)

Does noise produce any aftereffects on performance?

Yes, research has shown that noise may produce adverse performance on tasks performed after the noise is no longer present. These effects sometimes occur even when performance during noise was not affected. Aftereffects appear more likely to occur when the noise has been unpredictable or uncontrollable. (56)

Is industrial noise considered a problem in performance interference?

Yes, industrial noise may have the most pronounced effects on performance including exhaustion, absentmindedness, mental strain, absenteeism, tenseness, and irritability. All of these factors affect worker efficiency. (63) It is reasonable to suppose that increased absenteeism can come from workers' psychological aversion to returning each day to an unpleasant, noisy working environment. The frequency and severity of industrial injuries could tend to be higher in noisy environments because of masking of warning signals and of increases in momentary gaps or errors in performance. (64)

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What is the estimated cost to society of the workplace effects of noise due to absenteeism, noise-induced industrial injuries, and performance interferences?

- One day per year, worker exposed to greater than 85 dB
- About $250 per worker per day
- With 8 million exposed workers, about $2 billion not including work-men's compensation (64)

Are children susceptible to performance effects of noise?

Although there is relatively little laboratory evidence to substantiate performance degradation, there have been field studies which demonstrate that high noise levels have been correlated with poor performance on reading tests (65) and auditory discrimination problems (66). These effects were found to have little to do with socio-economic class or IQ. The significance of these effects is particularly important for younger children who through lack of verbal experience need lower noise levels in which to perform in order to develop the basic skills which contribute to cognitive and language development.

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SLEEP DISTURBANCE

Sleep disturbance is one of the major causes of annoyance due to noise. If it becomes a chronic problem, sleep disturbance may potentially lead to health disorders. (67)*

EFFECTS OF NOISE

How does noise interfere with sleep?

Noise, of course, can make it difficult to fall asleep. Noise levels can create momentary disturbances of natural sleep patterns by causing shifts from deep to lighter stages. Noise may even cause awakening which the person may or may not be able to recall. (14)

Is the sleeper aware of all of his bodily reactions to noise?

He can be completely unaware of being affected but can have a disruption of total sleep quality nevertheless. Subjects often forget and underestimate the number of times that they awaken during sleep. (88) Loud noises can continue to awaken or arouse the sleeper, but they may become so familiar with the sounds that they return to sleep very rapidly.

What are the indirect effects of sleep disturbance?

A person whose sleep has been disturbed severely may feel lethargic and nervous during his waking hours and may be unable to perform at his usual level of efficiency. (68)

FALLING ASLEEP

What noise levels can delay falling asleep?

At levels of 40 to 50 dB (A-weighted), some subjects have reported difficulty in falling asleep, frequently taking over an hour. The number of subjects having difficulty increases as the sound level increases. (14)

AWAKENING

What noise levels can cause awakening?

Studies have shown that at levels of 70 dB (A-weighted) or above, behavioral awakening* will most likely occur. (14)

Do noises lasting a long period of time awaken more people than shorter noises?

The temporal pattern of exposure (i.e., short or long duration) has a major effect on awakenings due to noise. Short signals have to be much higher in level to awaken as many people as a longer, steady noise. (93, 68)

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* References are listed in Section 11, e.g.: (Ref. 67).

* Behavioral awakening means a specific motor or verbal response (68).

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Are all sounds equally effective in awakening people?

Not all sounds of the same level are equally capable of awakening people. The character of some sounds causes them to awaken more people than other sounds of the same level. (68, 94)

Does the background noise environment in which people are accustomed to sleeping affect the number of nightly awakenings due to noise?

People living in higher background noise neighborhoods tend to awaken less than people living in quieter background noise neighborhoods. (68, 94)

Do people awaken more at some times of the night than at others?

The awakening effects of noise appear to be related to the time of occurrence of exposure during the night. The probability of awakening to noises of the same level is slightly lower within two hours after retiring than when it occurs later in the night. (68, 94)

AROUSAL AND SUB-AWAKENING EFFECTS

What stages of sleep does noise affect?

Laboratory subjects appear to be most sensitive to acoustic stimuli during the more shallow stages of sleep. A person typically goes through a cycle of sleep which becomes progressively deeper, and the stages of this cycle may vary in length of time. These stages are reflected in EEG measurements. Heart rate changes, vasoconstriction, respiration changes, electrodermal activity, and motor responses are all sensitive to noise during sleep. (68)

CRITERIA FOR SLEEP DISTURBANCE

Do criteria for sleep disturbance include shifts in stage of sleep and behavioral awakening?

Examples of criteria pertaining to sleep disturbance are displayed in Figures 6-1 and 6-2. These figures, which were adapted from a summary and analysis of recent experimental sleep data as related to noise exposure (3), show a relationship between frequency of response (disruption or awakening) and the sound level of an intrusive noise. In Figure 6-1, the frequency of sleep disruption (as measured by changes in sleep stage, including behavioral awakening) is plotted as a function of the Sound Exposure Level, a time-integrated measure referenced to a one second duration. Similarly, the frequency of awakening is shown in Figure 6-2. Thus, Figures 6-1 and 6-2 show that the probability of two types of sleep disturbance, within certain statistical limits, may be predicted by physical indices of noise exposure.

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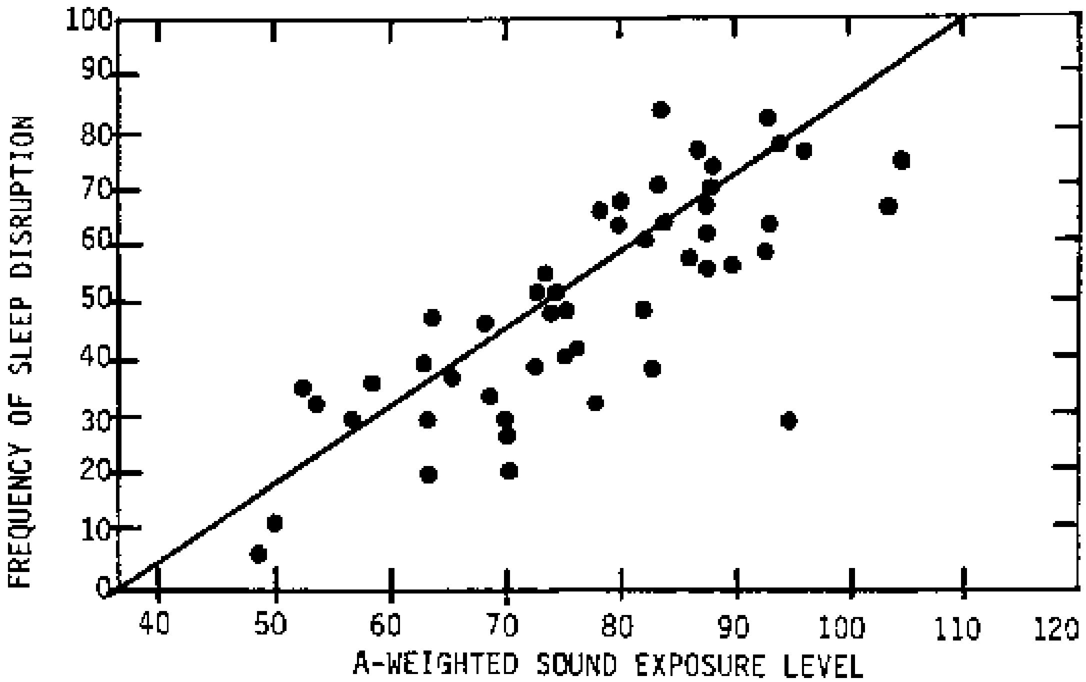

Figure 6-1 Probability of a noise induced sleep stage change.

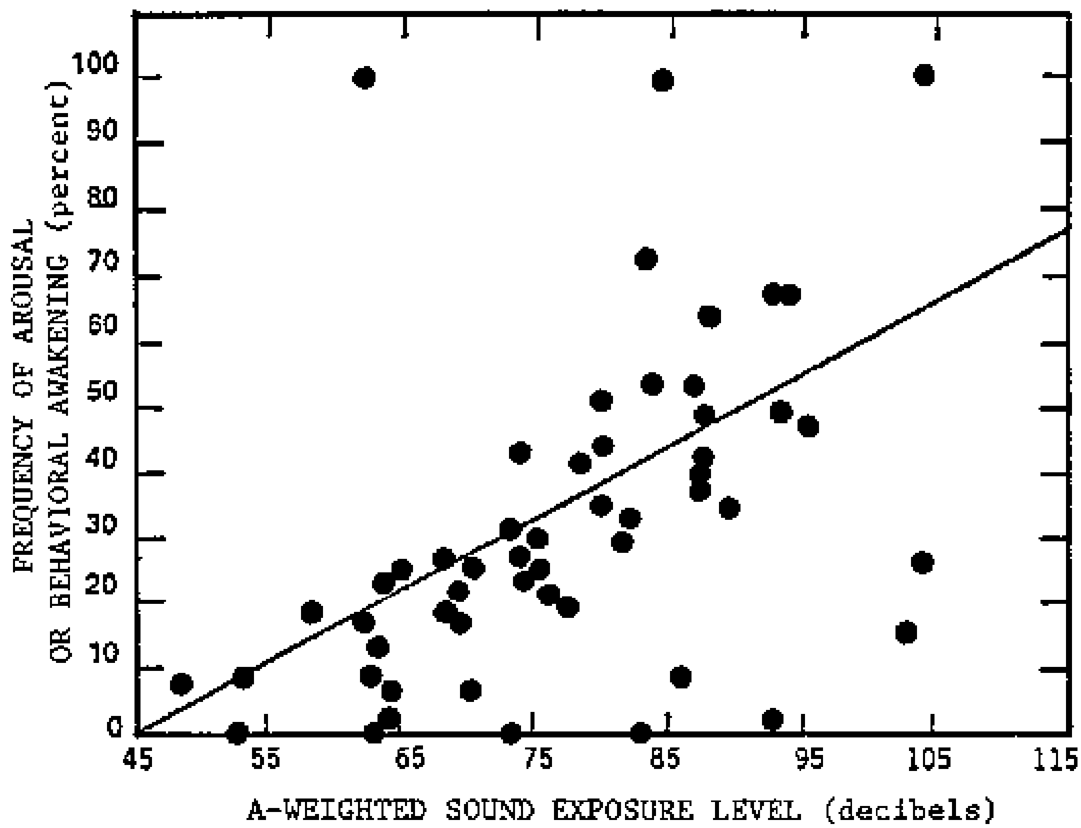

Figure 6-2 Probability of a noise induced awakening.

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How does sleep disturbance vary with noise level?

Generally, the higher the noise level the greater the probability of a response. (68) Thiessen found that there was a 5 percent probability, of subjects being awakened by peak levels of 40 dB (A-weighted level) and a 30 percent probability at 70 dB. If EEC changes are also considered, these probabilities increase to 10 percent at 40 dB and 60 percent at 70 dB. (89)

Do the number of noise peaks have any effect on the ability of the noise to interfere with sleep?

If the number of sound peaks increases, the person will take longer to fall asleep even if the average sound level decreases.(14) However, continuous or very frequent noise through out the night, even as high as 95 dB (A-weighted), appears to cause little change in the average duration of the sleep stages, since such stages are disturbed more by peaks that vary widely from the background ambient level than by high continuous levels alone. (68)

Does the quality of the sound have any effect on the ability of noise to interfere with sleep?

Inherently meaningful sound such as one's name or sound that acquires meaning by instructions or conditioning can awaken a sleeper at lower intensities than those required for meaningless or neutral sounds. Unfamiliar sounds may awaken people at a lower level than familiar ones. (68, 70)

Are the sex and age of the sleeper factors in disturbance of sleep by noise?

Several investigators have reported that middle-aged women may be less sensitive to noise during sleep. (69) In general, though, the older the subject, the more likely he is to respond to noise while sleeping. (68) Young children, on the other hand, appear to be less affected by noise in all stages of sleet). (70)

Does the amount of time asleep affect the response to noise?

Arousal is more likely to occur after longer periods of sleep. (71)

Does sleep deprivation have an effect on the disturbance of sleep by noise?

Sleep after prolonged periods of sleep deprivation consists of increased time in stages Delta and REM. This causes an increase in the thresholds for arousal and stage change. (68) Overall, sleep-deprived individuals require more intense auditory stimuli to awaken than do normally rested persons. (71)

Is sleep disturbance by noise seen as a problem by the population in general?

Survey data show that sleep disturbance is often one of the principal reasons given for noise annoyance. (14)

Can sleep disturbance cause long-term problems?

Sleep is thought to be a restorative process during which organs of the body renew their supply of energy and nutritive elements, Since noise can disrupt the sleep process, it may take its toll on health. (14)

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SUBJECTIVE RESPONSE

Conclusions concerning the factors that determine an individual's subjective, psychological response to noise are difficult to derive since individuals vary so much in their reaction to noise. Clearly, more research is needed to assess this complex topic fully.

MENTAL, PSYCHOLOGICAL EFFECTS

What kind of mental or psychological effects can occur with excessive noise exposure?

Excessive noise exposure can bring about a wide variety of psychological responses or symptoms in the individual. A person may respond with anger, or experience symptoms such as anxiety, irritability, and/or general emotional stress. Noise may negatively affect work performance because of reduced worker morale and motivation. Distraction and poor judgment may result from mental fatigue. (14)*

Is excessive noise exposure related to mental illness?

The answer to this remains unsolved. Studies have shown that residential areas exposed to high noise levels may have a higher incidence of mental illness among their residents; however, the evidence is inconclusive. One study that examined admissions of residents near London's Heathrow Airport to a psychiatric hospital suggests that the prevalence of mental problems was higher in the population nearest the airport (90). On the other hand, a Swiss study looking at the mental health status of residents near three Swiss airports found no significant relationship between minor psychiatric illness and noise exposure,

What physical qualities of noise affect a person's subjective response?

The physical attributes of noise that can affect an individual's subjective response include: apparent loudness or intensity, spectral shape, presence of discrete frequency components, abruptness or impulsiveness, intermittency, duration, and temporal variations. (14)

Besides the physical attributes of the noise itself, what other aspects of the exposure situation affect the individual's response?

Among the factors that affect an individual's response to noise are contextual factors such as: the time of day, the activity interfered with, the ability to control the source, and the information content of the noise. Response may also be affected by personal factors such as previous experience with noise exposure or socio-economic and educational status. (14, 4, 9)

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*References are listed in Section 11, e.g.: (Ref. 14).

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What is the best weighting system to use for analysis of individual subjective, psychological response?

In most cases, the A-weighting scheme can be used to study individual response to noise. Figure 7-1 shows how the A-weighting network on a sound level meter discriminates sounds at different frequencies compared to the B and C-weightings. A recent study has indicated that the D and E weightings generally perform somewhat better than A-weighting. Computational schemes, such as Stevens' Mark VI and Mark VII loudness calculation procedures, Zwicker's loudness calculation procedure, Perceived Noise Level, etc., are typically superior to the frequency weightings. In the long run, however, none of these other weightings or calculation schemes need to displace the simple A-weighting which has the added advantages of ease of use, public acceptance, and reasonable accuracy. (73)

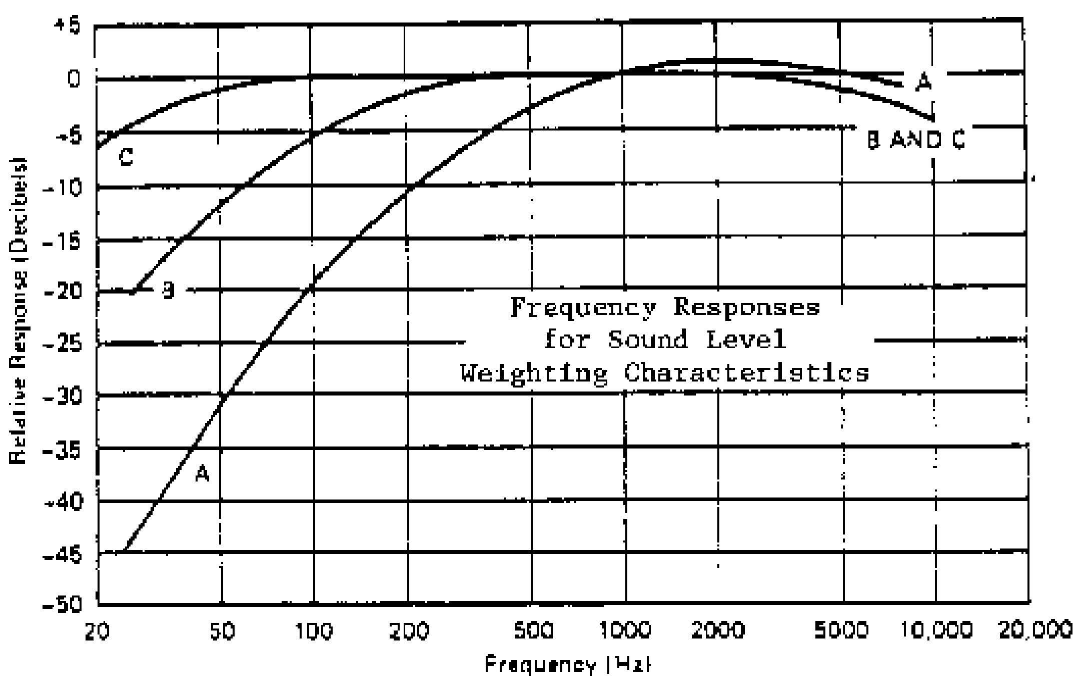

Figure 7-1 Frequency responses for sound level weighting characteristics.

What is meant by the terms "phon" and "sone," and what is their application to subjective response?

Phons and sones are used to measure or rate loudness (the subjective impression of the magnitude of a sound). A phon is the unit of loudness level. It is intended to be equivalent to the decibel level of a 1000 Hz reference tone judged equally loud to the sound being evaluated. Figure 7-2 shows equal loudness contours as a function of frequency which demonstrates the relationship between loudness level (in phons) and intensity (in decibels).

The sone is a linear measure of loudness. The loudness of one sone equals the loudness of a 1000 Hz tone at 40 dB sound pressure level. A sound judged to be twice as loud as a 1000 Hz tone at 40 dB equals 2 sones; half as loud, 2 sone, etc. Generally, an increase of 10 dB is equivalent to a doubling of sone value, and the judged loudness. The Stevens method and Zwicker procedure both calculate sone values of complex wide band sounds.

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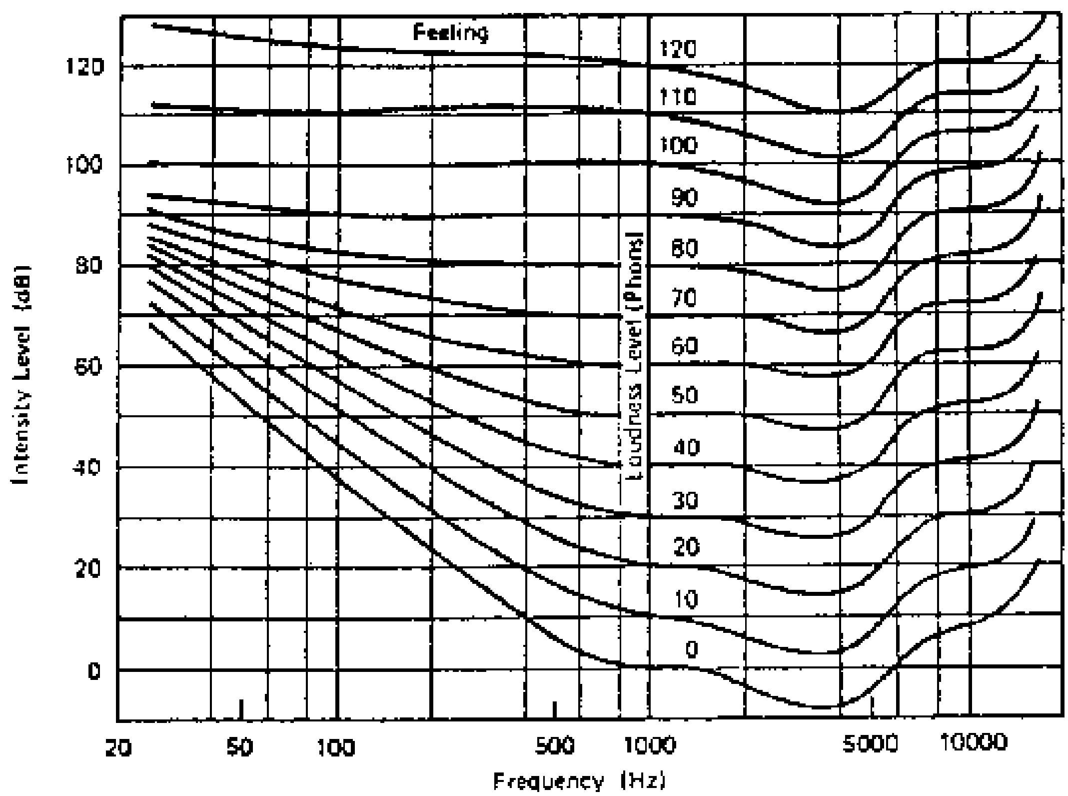

Figure 7.2 Equal Loudness Contours

Are there any particular noises that are more annoying than others?

Sounds of 2 KHz or higher (especially those with discrete frequency components) are generally the most annoying and disruptive, although noises that are abrupt, intermittent, or fluctuate with time can be very annoying as well. (14) In general, the louder the noise the more annoying it is likely to be. (14)

Are there any special populations that are particularly annoyed or bothered by noise?

A number of variables may affect individual susceptibility to noise. These include personality factors, psychological factors, state of health, etc. Special populations that are particularly sensitive have not been identified, however, and research needs to be performed to identify these groups, if any.

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Does personality play a role in individual response to noise?

Social surveys have indicated wide individual variations in response to noise. It appears that personality does play some part in a person's subjective response to noise, although the exact nature of the relationship is too complex to assess readily. Some studies have concluded that those with a fairly., high level of empathy, intelligence, and creativity may be more sensitive to noise than most. (75)

How do individuals alter their behavior in order to cope with noise?

People may either take direct physical actions or make indirect mental adjustments to cope with noise. For example, people may spend less time outdoors, keep their windows closed, take sleeping pills, use earplugs, spend less time talking and socializing, or complain to government officials. On the other hand, they might direct their anger at a noise inward and blame themselves for being bothered by it. They may perhaps deny there is a problem and attempt to stop responding emotionally to it. They may even project their anger at a noise source to a person incidentally associated with it. (76)

Can noise cause an individual to exhibit anti-social behavior?

Noise can cause people to exhibit such anti-social behavior as aggression and violence, though they would not normally do so. certain extreme incidents that have been reported, for example, include a business executive shooting at nearby water-skiers; or a usually quiet, night clerical worker shooting and killing a child playing outside his apartment. Both examples provide anecdotal illustrations of effects on behavior presumably attributed to noise. (14) There also have been lab studies which show that excessive noise may reduce social interaction, social responsibility, and verbal disinhibition, diminish helping behavior, and increase aggressive response. (77, 78, 79)

Can noise lead to reduced social interaction and enjoyment?

Besides the obvious impairment in social interaction associated with noise-induced hearing loss, living in a noisy environment may lead to what could be referred to as a noncommunicative life-style. This is a life-style in which social interaction is avoided and communication is minimized due to noise interference. (31)

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COMMUNITY RESPONSE

This section concerns average community response to noise as determined by community surveys, and other measures of annoyance such as complaints.

How does noise annoy?

Noise by definition is unwanted sound. It is an intrusion on one's sense of privacy. Noise can be an emotional strain and a source of great frustration when the noise is beyond a person's control. Noise may interfere with a broad range of human activities, the overall effect of which is to cause annoyance. Such activities include:

1. Speech communication in conversation and teaching

2. Telephone communication

3. Listening to television and radio broadcasts

4. Listening to music

5. Concentration during mental activities

6. Relaxation

7. Sleep

To what degree does noise cause neighborhood dissatisfaction?

The HUD Annual Housing Survey (1975, 1976) indicates that noise is the most frequently cited undesirable neighborhood condition, surprisingly ranking higher than crime. Noise is often given as the reason for residents wanting to move from their neighborhoods. (4)*

How is community response measured?

Community response to noise is usually studied through social surveys. A number of social surveys have been conducted worldwide to determine the extent of the noise problem as well as to assess the response of people to specific noise sources. These studies attempt to predict, on an aggregate basis, the degree of annoyance or other effects that can be expected by the community at varying noise levels. The average response of the community is used because it is very difficult to predict the response of any given individual.

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*References are listed in Section 11, e.g.: (Ref. 4).

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Are complaints a good indicator of the community noise problem?

Another way of assessing community response is through complaints and legal actions. However, many other economic, political, and social factors influence the filing of complaints. So the quantification of complaints cannot be used as definitive expressions of community response. Figure 8-1 shows the correlation of community complaint reaction to noise after the noise exposure has been adjusted for factors such as time of year (windows open or closed), duration and frequency of intruding noises, presence of pure tones or impulses, etc.

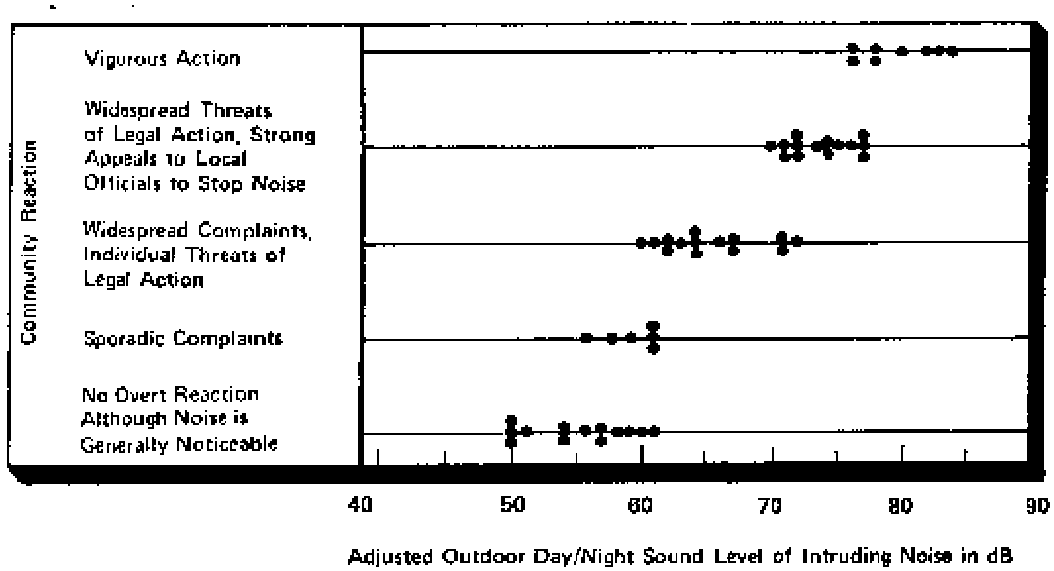

Figure 8-1 Combined data from community case studies adjusted for conditions of exposure
Source: Ref. 5

Why is "percent highly annoyed" used as an index of community annoyance?

The use of the percentage of exposed persons who rate themselves highly annoyed is used because it is the most stable indicator of annoyance. Persons who perceive their noise exposure as an extreme annoyance have little difficulty in sorting their feelings out from other non-acoustic variables which tend to scatter responses on surveys which try to determine the median community response. Because the highly-annoyed individual exhibits a definitive response, a clearer and more meaningful relationship between outdoor noise exposure and annoyance can be seen through this index. (80) By looking at this index, one also has an idea of the magnitude of the annoyance problem by looking at the worst case. Nevertheless, it should be recognized that many more people are annoyed, but to a lesser extent, than would be indicated by the descriptor "highly annoyed."

What, if any, distinction should be made between individual and collective response?

It should be kept in mind that community response to noise is based or statistical averages since it is known that response to noise varies greatly among individuals.

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Based on the Levels Document, what is the relationship between annoyance, complaints, and community reaction as a function of day-night sound levels?

According to the EPA Levels Document, (5) approximately 17 percent of the population will be highly annoyed at an Ldn of 55 dB, and over 40 percent of the population will be highly annoyed if the Ldn exceeds 70 dB, the maximum safe level EPA has identified to protect against a risk of hearing loss. The relationship between noise and annoyance given in the Levels Document is based largely on the results of surveys around airports. These estimates have been criticized because aircraft noise is not present in many urban areas. Complaints occur at a much lower rate than annoyance, and generally do not become evident until the noise levels are rather high. At an L_{dn} of 70 dB, approximately 10 percent can be expected to complain, while 25 to 40 percent of the population will be annoyed. At an Ldn of 55 dB, complaints are expected to be almost non-existent. Vigorous community action can be expected as the Ldn exceeds 70 dB.

What is the latest criteria showing the extent of community annoyance that can be expected from given levels of noise?

Schultz (80) synthesized results from 19 social surveys of annoyance and found a remarkable consistency. The synthesized data yields a somewhat different result from that relationship depicted in the EPA Levels Document. Figure 8-2 from Schultz shows the close clustering of annoyance curves from many transportation sources. Generally, data synthesized from prior social surveys on noise as displayed in Figure 8-2 indicate that very few people (on average three to four percent) will be highly annoyed by noise at or below a level of about L_{dn} = 55 dB. However, about 16 percent of the population will be highly annoyed by noise at about a level of L_{dn} = 65 dB; 25 percent of the population will be highly annoyed at L_{dn} = 70 dB; and 37 percent of the population will be highly annoyed as the noise level reaches L_{dn} = 75 dB. Twenty to 30 percent of the population is apparently imperturable and not bothered even by high noise levels. (81) The Committee on Hearing, Bioacoustics, and Biomechanics has indicated that these data are up-to-date and has included them in its guidelines for environmental impact statements on noise. (81)

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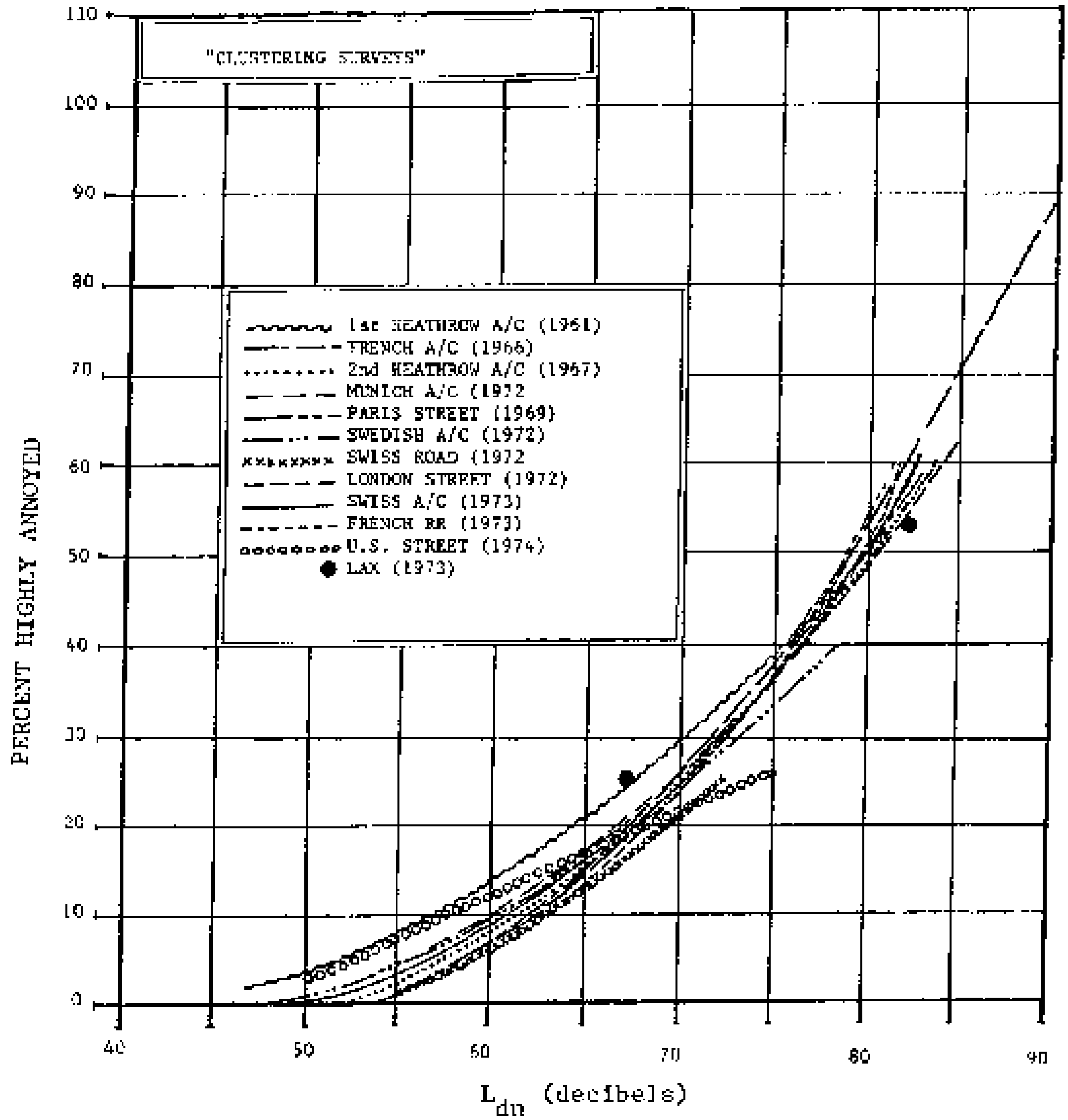

Figure 8-2 Summary of annoyance data from 12 surveys with data showing close agreement.
Source: Ref. 80

Are there other measures which are considered good predictors of community annoyance?

The **Urban Noise Survey** found that activity interference (of speech, sleep, etc.) is a good predictor of annoyance. Speech interference is one of the most widely perceived effects of environmental noise. Another predictor of community annoyance is population density. Higher population density, areas generally have higher noise levels, thus the annoyance is greater. (82)

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What other factors may influence personal reaction to noise?

Social surveys have shown that the following factors may contribute to community noise annoyance:

1. Fear associated with activities of noise sources (such as fear of crashes in the case of aircraft noise)

2. Socioeconomic status and education level
3. The extent to which a community's residents believe that they are being treated fairly
4. Attitude of the community's residents regarding the contribution of activities associated with the noise source to the general well-being
5. The extent to which residents of the community believe that the noise source could be controlled (14)

RESULTS FROM THE URBAN NOISE SURVEY

A total of 2037 people (762 men, 1275 women) were interviewed for this survey. Twenty-four sites were selected to represent areas with different noise levels and population densities. Sites where either aircraft noise or highway noise predominated were excluded.

How does noise exposure relate to general neighborhood satisfaction?

Comparing responses from people in high noise exposure areas (mean L_{dn} = 70 dB) and low noise exposure areas (mean L_{dn} = 54.6 dB), it was found that 34 percent fewer people in the high exposure areas described their neighborhood as an excellent place to live, and 24 percent more people in these areas described their neighborhood as only satisfactory. Seventeen percent more people in the high exposure areas responded that they had been annoyed by noise. (82)

What was the relationship between noise level and annoyance shown by the survey?

Noise Level (L_{dn})	Percentage of Population Annoyed
55	7
60	12
65	17
70	23

(82)

How does population density affect community response to noise?

High population density is usually associated with higher noise levels. It is not surprising then that people in high density areas are more annoyed by noise than people in low density areas. In the Urban Noise Survey, respondents living in high density areas reported 20 percent more listening interferences, nine percent more conversation interferences, and nine percent more sleep disturbances than respondents in low density areas. (82)

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Can socioeconomic status be related to annoyance from noise?

Generally, people in upper income brackets are less likely to be annoyed by noise because they can be more selective in deciding where to live. Since peace and quiet are important selection factors, the wealthy are more likely to reside in quiet neighborhoods and therefore can avoid annoyance from noise.

How does the time of day, season, location (indoors or outdoors) affect community response to noise?

In relatively noisy areas, where the L_{dn} exceeds 60 dB, people consider noise to be more obtrusive in the evening and night hours. People are more annoyed by noise in the summer, presumably because windows are open, and there may be additional noise sources such as air conditioners and lawnmowers. The results of the survey also show that people are more annoyed by noise indoors than outdoors. (82)

What are some of the major conclusions drawn from this survey?

- Exposure to noise typical of many urban (non-aircraft and non-highway) environments produces widespread annoyance, speech interference, and sleep disturbance.
- A strong relationship was demonstrated between exposure level and the proportion of a community highly annoyed by noise.
- The prevalence of speech interference is an especially good predictor of annoyance.
- Population density is an important correlate of noise exposure.
- The number of complaints about noise is a poor predictor of the prevalence of annoyance.
- Demographic factors alone are relatively poor predictors of noise annoyance.
- Freedom from noise exposure is a component of neighborhood satisfaction, and quiet is highly valued.

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HEALTH AND WELFARE ANALYSIS

What methods are used to ascertain noise impact and predict the benefits of implementing noise reduction measures?

A number of current state-of-the-art criteria of noise effects on people may be employed to gauge the impact of noise and the benefits to be gained by reducing noise. Criteria in general use are those representing the amount of annoyance to be expected at different levels of noise, the potential for interference with speech communication, and the probability of disturbed sleep due to noise. This is not to say that other noise effects do not occur. There are indications of the presence of many other effects of noise. However, cause-effect criteria have not been derived for these other effects, and knowledge is generally insufficient for health and welfare analysis purposes. Nevertheless, the criteria for general adverse response (annoyance) may be used as a basis to infer these remaining effects of noise on people. (8, 81)*

What is "Level-Weighted Population" and how is it used?

Level-Weighted Population (LWP) (81) expresses both the extent and the severity of a noise impact. The extent of impact refers to the number of people who are adversely affected, while the severity represents the degree to which each person is affected. LWP provides a simple, single number used to compare benefits of different noise reduction options.

It has been determined that an outdoor L_{dn} value of 55 dB (or an indoor L_{dn} of 45 dB) represents the lower threshold of noise jeopardizing the health and welfare of people. In the range above these levels, noise may be a cause of adverse physiological and psychological effects. These effects often result in annoyance and community action. Noise above L_{dn} 75 dB may, in time, cause hearing loss and the possibility of other severe health effects.

The computation of LWP allows one to combine the number of people jeopardized by noise above an Ldn of 55 dB with the degree of impact at different noise levels. Figure 9-1 is a pictorial representation of the LWP concept. The circle is a noise source which emits noise to a populated area represented by the figures. The various partial amounts of shading represent various degrees of partial impact by the noise. Note that those people closest to the noise source are more severely threatened. The partial impacts are then summed to give the equivalent noise impact. In this example, six people who are adversely affected by the noise (partially shaded) results in a Level-Weighted Population of two (totally shaded).

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*References are listed in Section 11, e.g.: (Ref. 8).

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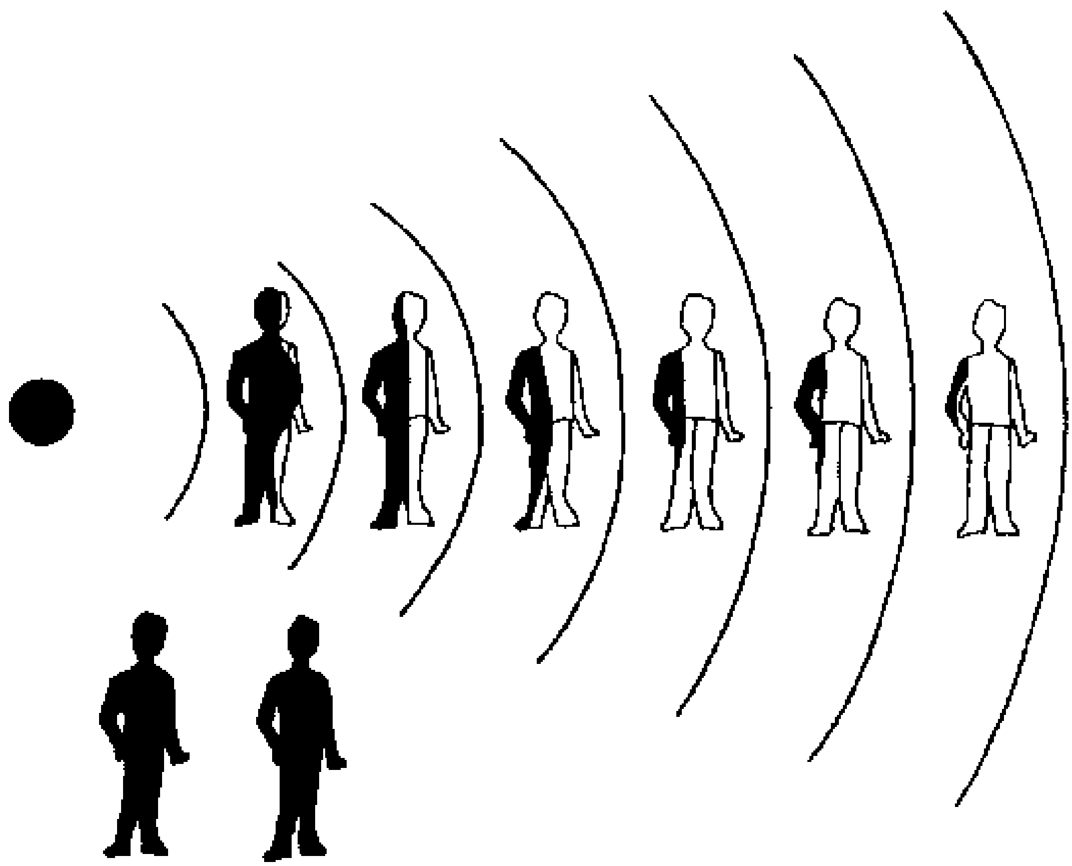

Figure 9-1 Level weighted population: A method to account for the extent and severity of noise impact.

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SUMMARY OF HUMAN EFFECTS FROM VARIOUS OUTDOOR NOISE LEVELS

The following five tables present information on the possible effects on people caused by outdoor-day-night noise levels of 55, 60, 65, 70, and 75 decibels.

Summary of Human Effects for Outdoor Day-Night Sound Level of 55 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur
Risk of nonauditory disease (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with a 5 dB margin of safety
Speech** - Outdoors	Slight disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.35 meter or 99 percent sentence intelligibility (average) at 1.0 meter or 95 percent sentence intelligibility (average) at 3.5 meters
High Annoyance	Depending on attitude and other nonacoustical factors, approximately 4 percent of the population will be highly annoyed.
Overt Community Reaction	None expected; 7 dB below level of significant "complaints and threats of legal action," but at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise considered no more important than various other environmental factors

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* and ** See the notes on page 10-6.

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Summary of Human Effects for Outdoor Day-Night Sound Level of 60 Decibels

Type of Effect	Magnitude of Effect

Hearing Loss	Will not occur
Risk of nonauditory disease (stress)	*
Speech** - Indoors	No disturbance of normal conversation. 100 percent sentence intelligibility (average) with no margin of safety
Speech** - Outdoors	Moderate disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) at 0.2 meter or 99 percent sentence intelligibility (average) at 0.6 meter or 95 percent sentence intelligibility (average) at 2 meters
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 9 percent of the population will be highly annoyed.
Average Community Reaction	Slight to moderate; 2 dB below level of significant "complaints and threats of legal action," but at least 11 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise may be considered an adverse aspect of the community environment.

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* and ** See the notes on page 10-6.

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Summary of Human Effects for Outdoor Day-Night Sound Level of 65 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not occur

Risk of nonauditory disease (stress)	*
Speech** - Indoors	Slight disturbance of normal conversation 99 percent sentence intelligibility (average) with a 4 dB margin of safety
Speech** - Outdoors	Significant disturbance of normal voice or relaxed conversation with 100 per cent sentence intelligibility (average) at 0.1 meter or 99 percent sentence intelligibility (average) at 0.3 meter or 95 percent sentence intelligibility (average) at 1.2 meters
High Annoyance	Depending on attitude and other nonacoustical factors, approximately 15 percent of the population will be highly annoyed.
Average Community Reaction	Significant; 3 dB above level of significant "complaints and threats of legal action," but at least 7 dB below "vigorous action" (attitudes and other nonacoustical factors may modify this effect)
Attitudes Towards Area	Noise is one of the important adverse aspects of the community environment

* and ** See the notes on page 10-6.

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Summary of Human Effects for Outdoor Day-Night Sound Level of 70 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	Will not likely, occur
Risk of nonauditory disease (stress)	*

Speech** - Indoors	Slight disturbance of normal conversation approximately 99 percent sentence intelligibility (average)
Speech** - Outdoors	Significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility (average) possible only at (distances less than .06 meter or 99 percent sentence intelligibility (average) at 0.2 meter or 95 percent sentence intelligibility (average) at 0.6 meter
High Annoyance	Depending on attitude and other nonacoustical factors, approximately 25 percent of the population will he highly, annoyed.
Average Community Reaction	Severe; 8 dB above level of significant "complaints and threats of legal action," but at least 2 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise is one of the most important adverse aspects of the community environment

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* and ** See the notes on page 10-6.

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Summary of Human Effects for Outdoor Day-Night Sound Level of 75 Decibels

Type of Effect	Magnitude of Effect
Hearing Loss	May begin to occur in sensitive individuals, depending on actual noise levels received at-ear.
Risk of nonauditory disease (stress)	*
Speech** - Indoors	Some disturbance of normal conversation. Sentence intelligibility (average) approximately 98 percent

Speech** - Outdoors	Very significant disturbance of normal voice or relaxed conversation with 100 percent sentence intelligibility not possible at any distance or 99 percent sentence intelligibility (average) at 0.1 meter or 95 percent sentence intelligibility (average) at 0.4 meter
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 37 percent of the population will be highly annoyed.
Average Community Reaction	Very severe; 13 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Attitudes Towards Area	Noise is likely to be the most important of all adverse aspects of the community environment

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* and ** See the notes on page 10-6.

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The following notes should be kept in mind when examining the preceding five tables:

* Research implicates noise as a factor producing stress-related health effects such as heart disease, high blood pressure and stroke, ulcers and other digestive disorders. The relationships between noise and these effects have not yet been quantified, however.

** The speech effects data in these tables are drawn from the Levels Document (5), as follows. Indoor effects are based on Table 3, and on Figure D-1, with 15 dB added to the indoor level to obtain the outdoor reading. Outdoor effects come from Figure D-2, using Ld (as determined with Figure A-7). Both Figures D-1 and D-2 are based on steady noise, not on L_{eq}. Table D-3 shows that for fluctuating noise the average percent interference is lower than for steady noise of the same L_{eq}. The values given in this report are the best estimates of the interference.

NOTE: Outdoor speech intelligibility estimates assume 70 dB (67 dBA) level of speech.

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