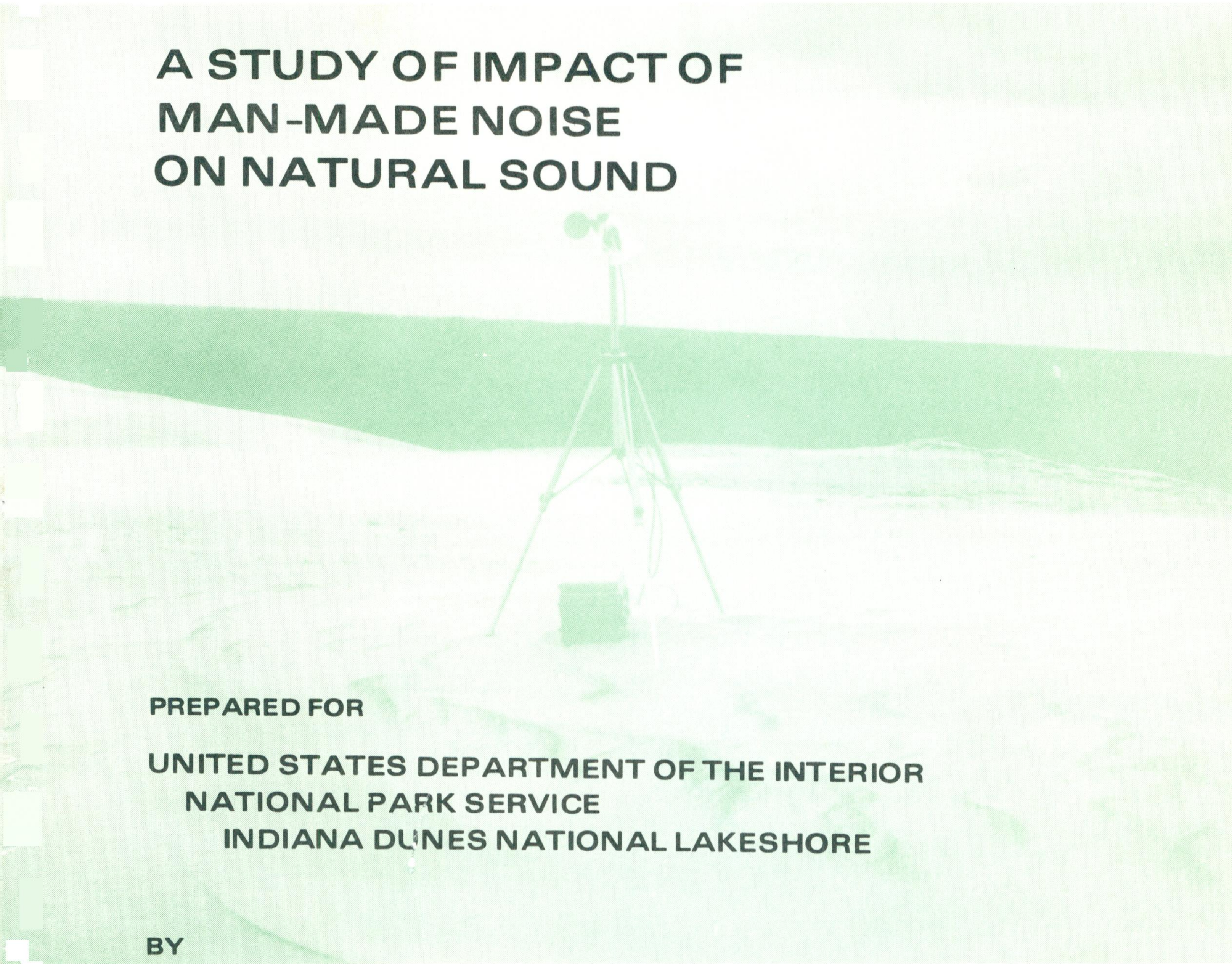

A STUDY OF IMPACT OF MAN-MADE NOISE ON NATURAL SOUND

PREPARED FOR

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE
INDIANA DUNES NATIONAL LAKESHORE

BY

IIT RESEARCH INSTITUTE
CHICAGO, ILLINOIS 60616

FINAL REPORT VOLUME 1
CONTRACT CX-6300-7-007

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TEXT BOOK
TYPE DESCRIPTION
OF SOUND

SEC. 1.5.1 Pg 1.119
gives description of various
sections of park

Engineering Division
IIT Research Institute
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FINAL REPORT

VOLUME I

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January 1980

Prepared by:
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for
U.S. Department of the Interior
National Park Service
Indiana Dunes National Lakeshore

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1. INTRODUCTION AND BASICS OF ACOUSTICS

1.1 Summary of Program Background

The United States, acting by and through the National Park Service, Indiana Dunes National Lakeshore (IDNL), received proposals for a 1-year study of noise intensity at IDNL from April to July of 1977. The area to be surveyed comprised some 4000 acres added or scheduled to be added to IDNL since 1975 and the 8000 acres of the original IDNL. IIT Research Institute (IITRI) was chosen to perform the analysis based upon past experience in noise analysis and proximity to the IDNL area. The purpose of the project was to conduct baseline observations of noise in the expansion areas of IDNL. The investigation was to provide basic resource data for park planning and management, including identification of areas where noise is a problem.

The contracted study was to be completed within 1 year. The actual duration comprised over 2 years due to inclement weather and discoveries about acoustical variances in the area, which quite unique, required numerous reanalyses to confirm the scientific authenticity of the derived conclusions.

A study of noise at IDNL was conducted as part of an ecosystem analysis in 1975 by Reshkin and Feldman (Ref. 1). The present program obtained comparable information for areas that were added to IDNL since the original study, or were proposed for addition.

The study as conducted by IITRI achieved the following:

- Determination of the L_{DN}* intensities for all major areas of IDNL and presentation of the data with accompanying graphs including topographic overlays. This presentation would effectively allow Park planners and managers to understand what the man-made noise and natural sound situation is at IDNL.

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*A U.S. EPA acoustic descriptor which provides a one-number designation for a particular sound climate based upon both daytime and nighttime acoustic energy.

- Through a sampling technique utilizing continuous 24-hour monitoring and oriented to computer analysis, IITRI provided the levels of noise exceeded for 1%, 10%, 50%, 90% and 99% of the time on both an hourly as well as on a 24-hour cumulative basis. This concept is elaborated in subsequent chapters of the report.
- Walkaround sampling surveys were performed by IITRI to analyze man-made noise impact propagation of various traffic and industrial sources into natural sound oriented areas. Tape recordings of Lakeshore acoustical levels were achieved through a process of microsampling of survey areas in a manner allowing a frequency spectral content analysis to be made.

The walkaround sampling identified the sources of noise in each key area chosen over the sampling period, and distinguished between man-made noise and natural sounds. The octave band tape recorded microsamplings made at other continuous monitoring noise sites also identified and distinguished between the frequency/energy characteristics of natural sounds and man-made noise. Full descriptions of each of these techniques is included in Appendix B as well as Section 1.4 of the report.

The Reshkin and Feldman ecosystem study (Ref. 1) of the IDNL described noise levels in certain areas of the original 8000 acres but did so on the basis of A-, B-, and C-weighted levels* only. Frequency/energy content characteristics were not analyzed and so the exact impact of man-made noise on natural sound in the areas previously studied is really unknown in regard to the previous analysis. The overall A-weighted intensities found by Reshkin and Feldman are utilizable as reference to the A-weighted statistical descriptors given in the results section of the report. Comparison to the previous noise levels found by the past program will be found in Section 3, Conclusions.

*A discussion of the weighting scales is included in Section 1.3 of the report.

In Section 1.2 a study guide on the basics of acoustics is presented which is intended for use by Park personnel for training or general information only. This material has been edited from various sources listed in the references section of the report. As such, reproduction of this material for anything other than Park Service use should not take place without prior authorization of said reference authors or publications.

1.2 Basics of Sound

1.2.1 Objective and Subjective Evaluation of Sound

In this discussion of sound, it is intended to move quickly into the use of acoustical terms and to become acquainted with some of the elementary acoustical procedures without necessarily knowing or comprehending all the mathematical saliences of acoustics.

Sound is defined by the United States of America Standards Institute (USASI) (formerly the American Standards Association) as an oscillation in pressure, stress, particle displacement, particle velocity, etc., in a medium with internal forces (e.g., elasticity, viscosity) or the superposition of such propagated oscillations, or as an auditory sensation evoked by the oscillations described above. Thus, objectively speaking, sound is a form of wave motion due to pressure alternation of particle displacement in an elastic medium.

Subjectively speaking, sound is a sensory experience in the brain. It is a moot point, for example, whether a sound is produced when a giant tree crashes to the ground in an uninhabited forest. The word "sound" will be used to denote a physical disturbance, an alteration or pulsation of pressure, capable of being detected by a normal ear. (In accordance with this definition, the falling tree does generate sound.) In general such a disturbance reaches the ears by traveling through air. In any case, a medium possessing inertia and elasticity is needed to propagate it. Sound waves do not travel through a vacuum. The auditory sensation produced by sound waves will thus be called sound sensation. The crashing tree produced a sound sensation only when an ear hears it.

Sound may be objectively classified as ordered or disordered. In an ordered sound the instantaneous pressure follows a regular pattern. Furthermore, a frequency analysis of such sound will show a definite overtone structure; that is, the sound can generally be resolved into a fundamental frequency and a series of overtones, the latter having frequencies that often are integral multiples of the fundamental frequency. Overtones possessing this simple relationship of frequencies are called harmonics. On the other hand, the peaks of acoustic power in disordered sound (for example, the background noise in a large auditorium) occur more or less at random. In such sound, practically all audible frequencies, from the lowest to the highest, are present. The periodic qualities of ordered sound are lacking.

Sounds are frequently subjectively classified into three types: speech, music, and noise. However, this classification is not always clear-cut. It is sometimes questionable, for example, whether a sound should be classified as music or noise. In general, noise may be defined as unwanted sound. Thus, if one is listening to a concert in an auditorium, a conversation in the next row may be regarded as noise. On the other hand, if one is trying to converse on the telephone while "Led Zepplin" is holding forth in a living room, this music, as far as the person on the telephone is concerned, very definitely falls under the classification of noise.

1.2.2 Definitions Regarding Sound

1.2.2.1 Frequency

The number of complete to-and-fro vibrations that the source, and hence the particles in the medium, makes in 1 second is called the frequency of vibration. A string that undergoes 256 complete oscillations in 1 second (middle C) produces a vibration of the same frequency in the surrounding air and in the eardrum of an observer in sound field. This assumes that the source and the observers are at rest with respect to the medium. Frequency is a physical phenomenon; it can be measured by instruments, and it is closely related to, but not the same as pitch--a psychological phenomenon. Frequency is usually designated by a number followed by cycles per second (cps)*.

1.2.2.2 Decibels

Selecting a practical scale for sound measurement involves two problems. The first is caused by the tremendous range of sound power or pressures that encountered, i.e., from 0.0002 microbar at the threshold of hearing under ideal conditions to 10,000 to 200,000 microbars for sounds associated with jet or rocket propulsion systems. The second problem arises from the nonlinear manner in which the ear responds. The ear tends to respond logarithmically to the intensity of an acoustical stimulus.

Both of these problems can be solved by the use of the decibel. Just as meters are used to measure distance and degrees are used to measure temperature, decibels are used to measure sound intensity. As in electrical engineering, decibels are used to express in logarithmic terms the ratio of two powers; i.e., if there are two electrical or acoustical powers P_1 and P_2, the ratio of those powers expressed in decibels would be

$$10 \log P_2/P_1.$$

*With the recent trend to recognize the early men in science, many new names for old units are being adopted. The traditional unit for frequency in the United States had been cycles per second (cps). The new international unit for frequency, recently adopted by the United States standards groups is Hertz (Hz). Throughout the remainder of this report the unit Hz is used.

If the power P_1 were some accepted standard reference power, such as a watt or some other basic unit of power, the decibels could be standardized to that reference value. Since by definition the decibel is a dimensionless unit used to express the logarithm of the ratio of a measured quantity to a referenced quantity, it is commonly used to describe levels of acoustic power, intensity, and pressure.

Most sound-measuring instruments are designed to respond to sound pressure changes and are calibrated to read in terms of the logarithm of the ratio of the root-mean-square sound pressure. The instruments provide a measurement of sound pressure level in decibels; the level emphasizes the fact that this is a measurement in relation to a given reference pressure. In air a reference pressure of 0.0002 microbars (= 0.00002 pascal) has been selected as a standard reference point. Some typical logarithmic variations of sound pressure as measured by such an instrument appear below. Notice that the instruments reading in decibels (dB), correspond to the above-mentioned ear response to acoustical stimulus.

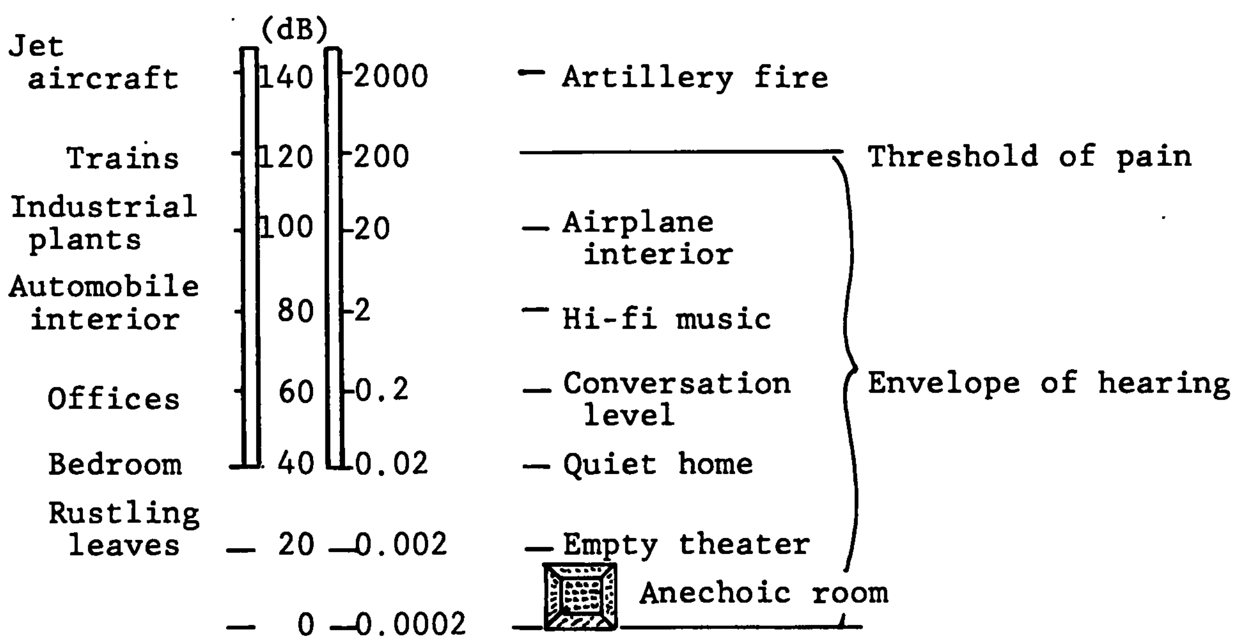


Figure 1.1 LOGARITHMIC VARIATIONS

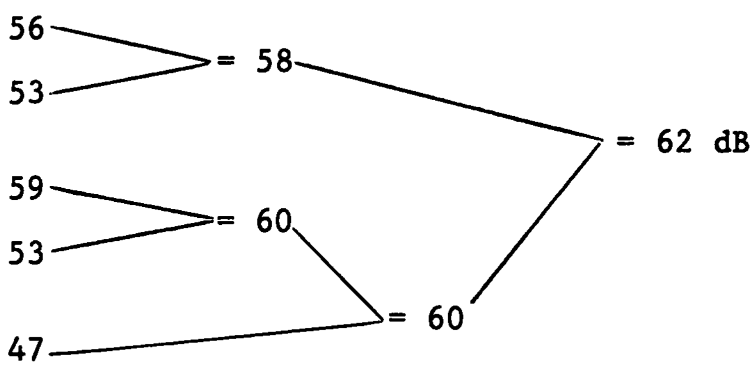
1.2.2.3 Addition of Decibels

Decibels do not add like the aforementioned meters and degrees, which are linear quantities. Thus an increase of 20 dB from 60 to 80 dB represents a tenfold increase in the sound pressure. As a result of this, since decibels are logarithmic values, it is not proper to add them by normal algebraic addition. For example, 63 dB plus 63 dB does not equal 126 dB but only 66 dB.

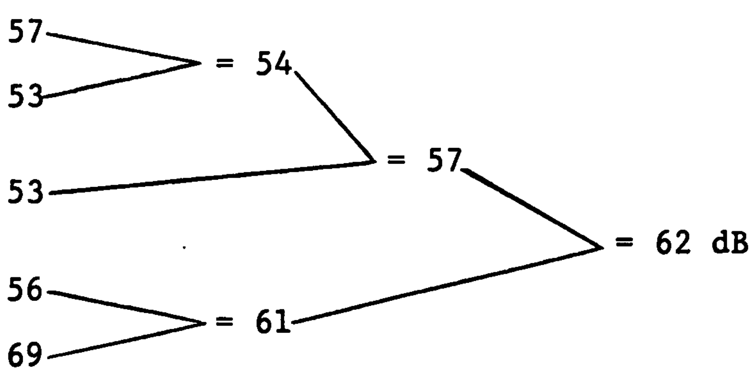
A very simple, but adequate schedule for adding decibels is as follows:

When two decibel values differ by:	Add the following amount to the higher value:
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 - 8 dB	1 dB
9 dB or more	0 dB

As an illustration, add the following five noise levels:



Or, suppose the same numbers are arranged in a different order, as in:



1.2.3 Qualities of Sound

Two of the various characteristics that distinguish one sound from another are loudness and pitch. Loudness is a measure of the quantity of sound that reaches the listener's ear. Pitch is a measure of the quality of a pure tone. Some sounds are pure tones and others a combination of several tones, but many sounds are neither. Instead, they can be described as broadband sounds. Even without distinctive tones the sounds may have a characteristic quality that identifies the source to the average listener.

1.2.3.1 Loudness

In elementary treatments of acoustics it is often stated that the subjective characteristic of a sound which is commonly known as its loudness is determined by its intensity. When properly interpreted, this statement is strictly correct, but it is somewhat misleading, for it may appear to imply that loudness and intensity are synonymous. An inspection of the figure below shows immediately that this is not true.

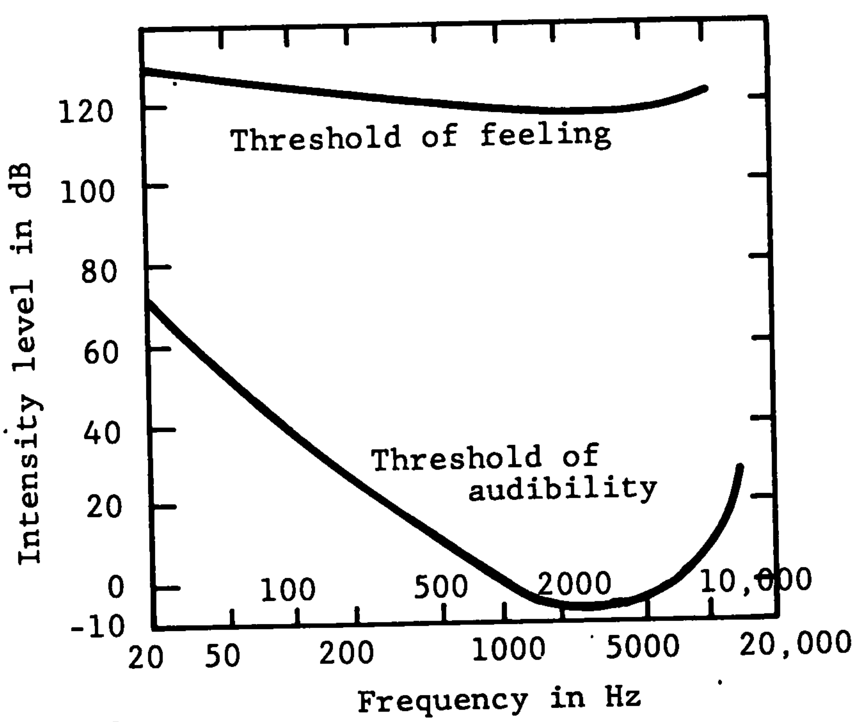


Figure 1.2 THRESHOLDS OF THE EAR
(0 dB = 0.00002 pascals)

For example, a pure tone having an intensity level of 20 dB and a frequency of 1000 Hz is plainly audible, whereas one having the same intensity but a frequency of 100 Hz is well below the threshold of audibility and cannot be heard at all. The loudness of such a tone is therefore a function not only of its intensity but also of its frequency.

Although our hearing mechanism is not well adapted to making quantitative measurements of the relative loudness of different sounds, there is fair agreement between observers as to when two pure tones of different frequency appear to be equally loud. It is therefore possible to plot contour curves of equal loudness, such as those shown in the following figure.

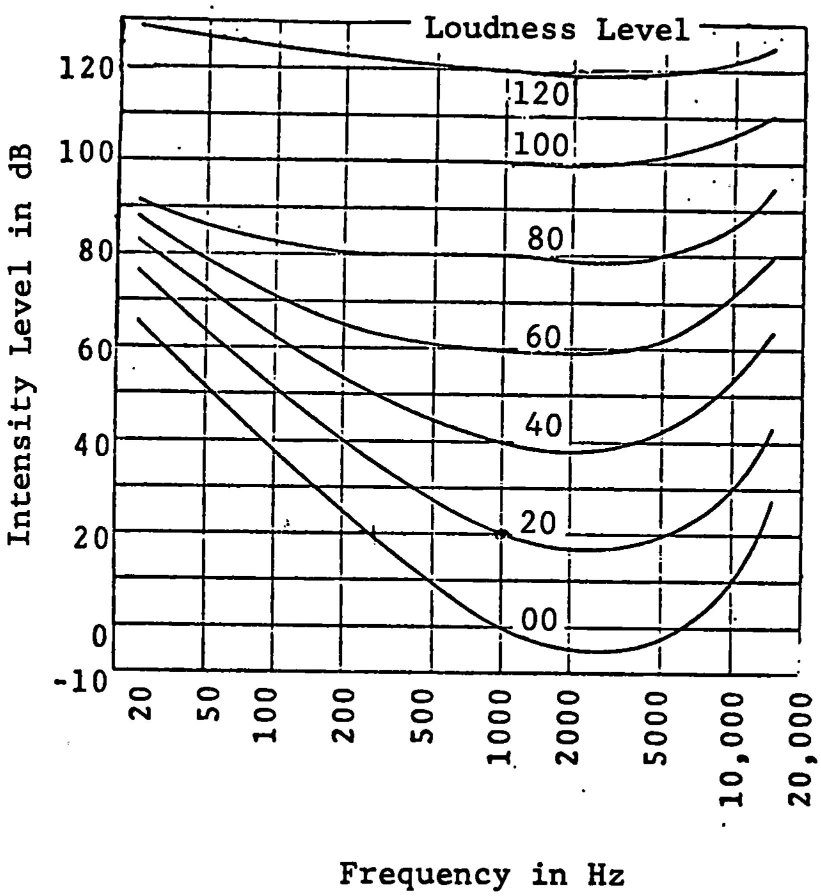


Figure 1.3 EQUAL LOUDNESS LEVEL CONTOURS
($0dB = 10^{-16}$ Watt/cm^2)

The data for these curves are obtained by alternately sounding a reference tone of 1000 Hz and a second tone of some other frequency. The intensity level of the second tone is then adjusted to the value that makes the two tones appear equally loud. The unit of loudness level is the phon, the loudness level (in phons) of any sound being taken as numerically equal to the intensity level in decibels of a pure 1000-cycle tone that is judged by the average observer to be equally loud. For example, a pure tone having a frequency of 100 Hz and an intensity level of about 50 dB sounds as loud as a pure 1000-cycle tone whose intensity level is 20 dB, and hence the loudness level of this 100-cycle tone is be definition 20 phons. It should be noted that the reference intensity level used in defining the phon is that of the previous figure, i.e., zero decibels correstponds to a 1000-cycle intensity of 10^{-16} watt/cm^2.

1.2.3.2 Pitch

The second subjective characteristic of a sound is its pitch. Pitch, like loudness, is a complex characteristic and is not dependent on any single physical quantity, the pitch of a musical sound being determined primarily by its frequency but being also a function of its intensity and waveform. For example, if a pure tone having a sinusoidal waveform and a frequency of about 100 or 200 Hz is first sounded at a moderate and then at a high loudness level, nearly all observers will agree that the louder sound has a lower pitch, in spite of the fact that its frequency remains unchanged. Experiments of this type show that the most pronounced decrease in pitch with increasing loudness occurs for tones of low frequency and that when the loudness of such a tone is increased from a level of 10 to one of 100 phons it may be necessary to increase the frequency by as much as 10 percent in order to maintain the pitch at a constant value. There has been some disagreement as to the exact frequency at which this change in pitch with loudness is most apparent, one set of experiments having indicated a frequency of about 100 and another 200 Hz, but both groups of observers are in agreement that it occurs at a low frequency and that it is most apparent for pure sinusoidal tones. For frequencies between about 1000 and 5000 Hz, i.e., over the range for which the ear is most sensitive, the pitch of a pure tone is relatively independent of its intensity; at still higher frequencies an increase in loudness produces an increase, rather than a decrease, in pitch.

It should be emphasized that the appreciable changes in pitch with loudness that have just been discussed are characteristic only of pure tones. For ordinary musical tones, such as those produced by violins, clarinets, trumpets, etc., the changes in pitch are much smaller, usually not more than one-fifth as great. This is to be expected, since Fourier's theorem shows that the complex acoustic waves produced by these instruments may be resolved into a fundamental frequency and a series of harmonics, some of which have amplitudes that are quiet large, and may even exceed that of the fundamental. Consequently, even if the fundamental lies in the frequency range where a pure tone shows a large decrease in pitch, the harmonics will have frequencies for which the pitch changes very little, or increases with increasing loudness, so that the ear judges the entire series of components as remaining at essentially the same pitch.

Several different approaches have been employed in an attempt to establish a relationship between our subjective sense of pitch and the physical property of frequency. One method is to present alternately to an observer two pure tones of the same loudness level, usually 40 or 60 phons, and to require the observer to adjust the frequency of one of the tones until its pitch appears to be exactly half that of the other. The experiment is then repeated for a series of frequencies covering the entire audible range. As is to be expected, the agreement between different observers is by no means exact, but the average results show clearly that pitch and frequency are not proportional. For example, the frequency that is judged to be half as great as one of 200 Hz is about 120 Hz, but the frequency that sounds half as high as

5000 Hz is less than 2000 Hz. It should be clearly understood that in making tests of this type the two frequencies are presented alternately, and not at the same time. If a pair of tones that are judged to have a pitch ratio of 2:1 are sounded simultaneously, the result is in general very discordant so that if the tones had originally been presented together the observer would have instinctively adjusted the lower frequency to exactly half that of the upper, i.e., to an octave below, and would thus have avoided the discord.

1.2.4 Sound Pressure and Sound Power

In acoustics, the term "level" is used whenever a decibel quantity is expressed relative to a reference value. Particular levels of interest in measuring sound are sound power levels and sound pressure levels. These two quantities though relatable to one another, are often confused and interchanged frequently, in conversations concerning sound. The following discussion will hopefully shed some light on a rather confusing subject in sound measurement.

1.2.4.1 Sound Power Level

The quantity sound power level expresses, in decibels relative to the reference power of 10^{-12} watt, the total amount of sound power radiated by a sound source, regardless of the space into which the source is placed. Sound power radiates away from the sound source in all directions in the form of spherical waves. These waves will continue to travel until they are absorbed by the air, or reflected by some object. The acoustic power passing through a unit surface area decreases as the distance from the source increases. This acoustical power is related to the sound pressure in the same manner that electrical power is related to volts. Ohm's law says that:

$$E \text{ (volts)} = I \text{ (current)} \times R \text{ (resistance)}$$

and

$$\text{Watts} = E \times I = E^2/R$$

Similarly in acoustics, acoustical power (W) over a small unit area(s) is expressed as:

$$W_s = (Prms)^2/\rho c$$

where P is sound pressure and ρc is the resistance to sound propagation by the transmitting medium. Thus, the total acoustical power of a source is the integral of $(Prms)^2/\rho c$ measured over an imaginary sphere surrounding the sound source. The question then arises, why fool with sound power if one already has a sound pressure. The answer once again lies in our electrical analogy. Voltage will not harm one, unless there is an appreciable current to go with it. In other words, it is a matter of how much power it presents. A similar situation exists in sound. Sound pressure states the pressure at a given distance, in a given direction from a sound source. It tells nothing about the acoustical power generated by such a source. Power output, however, provides information about the sound source and such information is required by engineers in designing rooms which may contain such sources so as to isolate surrounding or adjacent areas from the affects of their power output. That is why sound power ratings are used by manufacturers of furnaces, air conditioners, and electrical motors for office buildings and apartments, and by manufacturers of shipboard machinery in the Navy.

The sound power level is actually defined as:

$$L_W = 10 \log_{10} \frac{W}{W_0}$$

where

W = the sound power of a source in watts, and
W_0 = the reference sound power which we have defined as 10^{-12} watts.

Note this level is independent of any reflective surface or room condition in which the sound source exists. The sound pressure level, on the other hand, is dependent upon the environment in which a sound source radiates. As suggested above, if the power level of a sound source is known and if the acoustic character-istics of a space are known, it will then be possible to estimate or calculate the sound pressure level in that space. Ultimately it is the sound pressure level that usually must be determined because it is on that basis that people judge an acoustic environment.

1.2.4.2 Sound Pressure Level

The quantity sound pressure level (SPL) is defined as 20 times the logarithm to the base 10 of the ratio of the pressure of the sound to the reference sound pressure . Unless otherwise specified, the effective root-mean-square (rms) pressure is to be understood. Mathematically this looks like:

$$SPL = 20 \log_{10} \frac{P}{Po} dB$$

where

P = measured rms sound pressure

Po = reference pressure = 0.0002 μbar = 0.00002 pascal

The sound pressure level is the measure of the sound power radiated by a source through a given area in space. As a result, the sound pressure is dependent upon numerous extraneous factors in the environment which will affect the sound power waves emanating from the source. Table 1.1 has been prepared as an example to show a typical sound source and an environment, and relating the sound pressure to the overall sound pressure level.

1.2.4.3 Analogy Between Light and Sound

Sound pressure and sound power can be illustrated simply with an analogy between light and sound. Suppose first that a room is illuminated with a bare 15-watt electric lamp. Even in a room with white painted walls and ceiling, this normally would be considered as a weak light source. If the room had only dark, unreflecting surfaces, the general room illumination would be very poor. Now a bare 150-watt lamp would give good general illumination if the walls are white, or light-colored, or highly reflecting (and depending, of course, on the size of the room and the distance to the lamp). However, the same 150-watt lamp might not give adequate room illumination if the walls and ceiling were black, or dark-colored or nonreflective. Thus, it is reasonably obvious that the intensity of the general room illumination depends not only on the power rating of the lamp, but also the light-reflecting (or absorbing) properties of the room surfaces, on the size of the room, and on the distance to the light source.

TABLE 1.1

SOUND PRESSURE AND DECIBEL VALUES FOR SOME TYPICAL SOUNDS

Sound Pressure (microbars)	Overall Sound Pressure Level (dB re 0.0002 microbar)	Example
0.0002	0	Threshold of hearing
0.00063	10	Anechoic room
0.002	20	Studio for sound pictures
0.0063	30	Soft whisper (5 ft)
0.02	40	Quiet office Audiometric testing booth
0.063	50	Average Residence Large Office
0.2	60	Conversational speech (3 ft)
0.63	70	Freight train (100 ft)
1.0	74	Average automobile (30 ft)
2.0	80	Very noisy restaurant Average factory
6.3	90	Subway Printing press plant
20.0	100	Looms in textile mill Electric furnace area
63.0	110	Woodworking Casting shakeout area
200.0	120	Hydraulic press 50 hp siren (100 ft)
2000.0	140	Jet plane
200,000.0	180	Rocket launching pad

NOTE: The doubling of any sound pressure corresponds to an increase of 6 dB in the sound pressure level. A change of sound pressure by a factor of 10 corresponds to a change in sound pressure level of 20 dB.

Further, if the lamp had a lampshade or if it were recessed in a flush-mounted ceiling receptacle, the light would be brighter in some directions than in others.

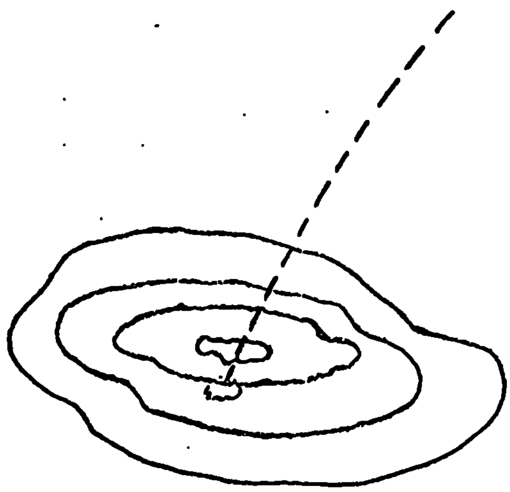
All the same factors apply to sound in a room. Sound pressure level is somewhat analogous to room illumination; sound power level is somewhat analogous to the power rating of the lamp. A weak sound power source would produce low sound power levels while a stronger sound source would produce higher sound power levels. A constant sound source that would produce on sound pressure level in a hard-walled bare room would produce a lower sound pressure level in the same room surfaced with a large amount of soft, fluffy acoustic absorption material.

The sound source would produce a higher sound pressure level a few inches away than it would several feet away. It might radiate higher sound pressure levels from one side than from another side. It would produce different sound pressure levels in a large room than it would in a small room. Thus, the sound pressure level in the room depends not only on the sound source (actually its sound power), but also on the sound absorption properties of the room surfaces, on the size of the room, the distance to the sound source, and also the directional characteristics of the sound source. In effect, the sound pressure levels heard by a person in the room are determined both by the sound power radiated by the source and by the acoustic characteristics of the room. All of this is merely leading up to the fact that (1) there is need for a way of rating a sound source that is independent of the environmental surroundings, and (2) there is need for a way of describing the acoustic characteristics of a room that is independent of the sound source. Then, with these two independently determined bits of information, any known definable room or space and the sound field or sound pressure level about the room can be determined, remembering that it is the sound pressure level to which people respond in their living, working, and recreational environments. Just as the 150-watt lamp may produce relatively poor to good illumination in a given room, so also will a sound source produce relatively low or high sound pressure levels in a given room. The acoustic properties of a room will affect the sound pressure level as generated by indoor sound sources, and may also affect the amount of sound pressure level generated by outdoor sound sources as well.

1.2.5 How Sound Travels

1.2.5.1 Wave Motion

If a stone is dropped into a quiet pool of water, a disturbance is created where the rock enters the liquid. However, the disturbance is not confined to that place alone but spreads out so that it eventually reaches all parts of the pool.



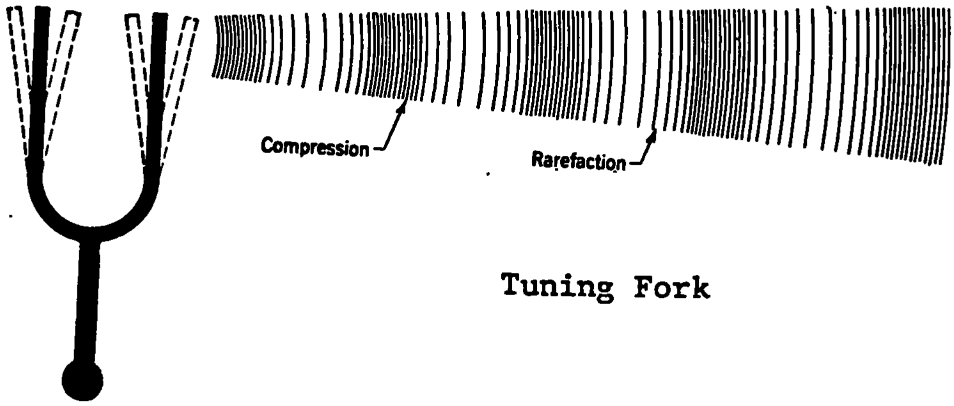
Rock in Pond

When the stone enters the water, it sets into motion the particles of water with which it comes in contact. These particles set into motion neighboring particles. They in turn produce similar motion in others and so on until the disturbance reaches particles at the edge of the pool. In all this disturbance no particle moves far from its initial position. Only the disturbance moves through the water. This behavior is characteristic of all wave motions. The particles move over short paths about their initial positions and as a result a wave moves through the medium. A wave is a disturbance that moves through a medium. The medium as a whole does not progress in the direction of the wave (Ref. 3).

1.2.5.2 Propagation of Sound

Sound has its origin in vibrating bodies. A plucked violin string or a struck tuning fork can uaually be seen to vibrate. In the sounding board of a piano and the paper cone of a loudspeaker, as in most other sound sources, the amplitude of vibration is too small to be observed visually but often the vibration can be felt with the finger tips.

Consider the tuning fork vibrating in air.



Tuning Fork

As it moves in an outward direction it pushes a "layer" of air along with it; this layer of air is compressed, and its density and temperature are correspondingly increased. Since the pressure in this layer is higher than that in the undisturbed surrounding atmosphere, the particles (that is, the molecules) in it tend to move in the outward direction and transmit their motion to the next layer, and this layer then transmits its motion to the next, and so on. As the vibrating body moves inward, the layer of air adjacent to it is rarefied. This layer of rarefaction follows the layer of compression in the outward direction, and at the same speed; the succession of outwardly traveling layers of compression and rarefaction is called wave motion. The speed of propagation is determined by the compressibility and density of the medium -- the less the compressibility of the medium and the less its density, the faster will the wave motion be propagated.

As an example of the compression and rarefaction effect, the following figure shows a piston at one end of a long tube filled with a compressible fluid. Their vertical lines represent certain layers of molecules which are equally spaced when the medium, such as a fluid, is at rest. In this discussion the random thermal motion of the molecules is ignored. If the piston is pushed forward, the layers of fluid in front of it are compressed. These layers will in turn compress layers farther along the tube, and a compressional pulse travels down the tube. If then the piston is quickly withdrawn, the layers of fluid in front of it expand and a pulse of rarefaction travels down the tube from layer to layer. These pulses are similar to transverse pulses traveling along a string, except that the particles of the medium are displaced along the direction of propagation (longitudinal) instead of at right angles to this direction (transverse).

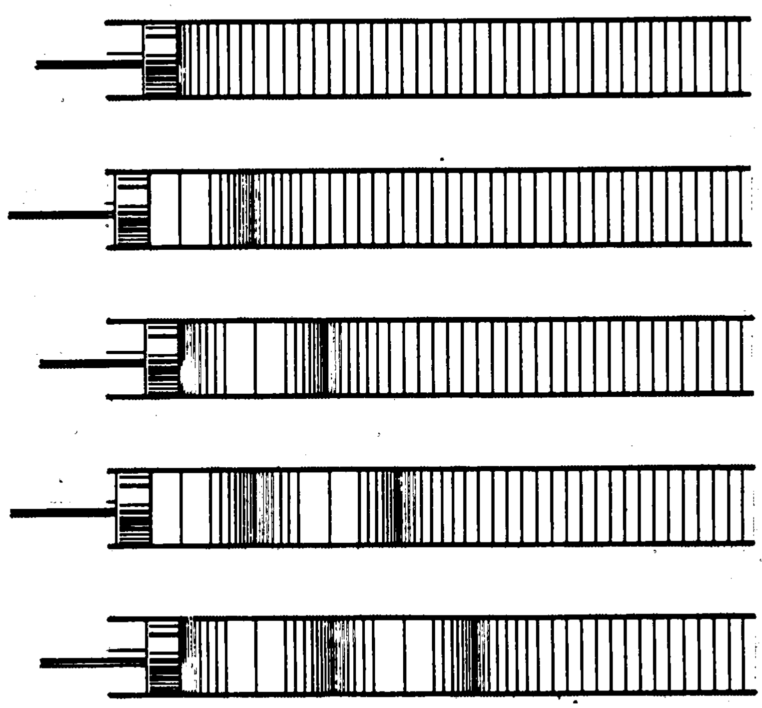


Figure 1.4 SOUND WAVES BEING GENERATED IN A TUBE BY AN OSCILLATING PISTON SHOWING COMPRESSIONS AND RAREFACTIONS (Ref. 2 p 423)

If the piston oscillates back and forth, a continuous train of compressions and rarefactions will travel along the tube. Such velocity of these compressions and rarefactions create the frequency of sounds as the human ear detects them.

1.2.5.3 Audible, Ultrasonic, and Infrasonic Waves

Sound waves can be propagated in solids, liquids, and gases. The material particles transmitting such a wave oscillate in the direction of propagation of the wave itself. Actually, there is a large range of frequencies within which longitudinal mechanical waves can be generated. Sound waves are confined to the frequency range which can stimulate the human ear and brain to the sensation of hearing. This frequency range spreads from about 20 Hz to about 20,000 Hz and is called audible range. A longitudinal mechanical wave whose frequency is below the audible range is called an infrasonic wave, and one whose frequency is above the audible range is called an ultrasonic wave.

Infrasonic waves of interest are usually generated by large sources, earthquake waves being an example. The high frequencies associated with ultrasonic waves may be produced by elastic vibrations of a quartz crystal induced by resonance with an applied alternating electric field (piezoelectric effect). It is possible to produce ultrasonic frequencies as high as 6×10^8 Hz in this way; the corresponding wave-length in air is about 5×10^{-5} cm.

Audible waves originate in vibrating strings (violin, human vocal cords), vibrating air columns (organ, clarinet), and vibrating plates and membranes (drum, loudspeaker, xylophone). These vibrating elements alternately compress the surrounding air on a forward movement and rarefy the air on a backward movement. The air transmits these disturbances outward from the source as a wave. Upon entering the ear, these waves produce the sensation of sound. Waveforms which are approximately periodic or consist of a small number of approximately periodic components give rise to a pleasant sensation, as for example musical sounds. Sound whose waveform is very irregular is heard as noise. Noise can be represented as a superposition of periodic waves, but the number of components is very large.

1.2.5.4 Generation and Velocity of Sound

The generation of sound is probably most easiy described by using a vibrating object as the source. While the vibrating object is moving in one direction, there is a buildup of pressure as the air molecules are pushed together, which continues until the object reverses direction. This region of higher pressure is a pressure wave which moves out in all directions from the object. As the object moves in the opposite direction, the air molecules move further apart and a region of reduced pressure is created. This region of reduced pressure is forced out from the vibrating object by the next pressure wave. As the vibration continues, waves of increased and decreased pressures are set up. One complete vibration of the object corresponds to one complete cycle of pressure change. The number of object vibrations or pressure cycles per unit time defines the frequency of the sound wave.

The speed of a sound wave in air does not vary appreciably with frequency in the audible range. Furthermore, the speed does not change with intensity except for very intense waves. For a powerful source of sound such as an air-raid siren, the speed of the sound within a few inches from the source increases slightly with increasing intensity.

The speed with which sound waves travel is a function of the elasticity of the air is equal to a constant times the static pressure of the air, i.e., atmospheric pressure. The constant is equal to the ratio of the specific heat of air at constant pressure to the specific heat at constant volume, which at the temperatures normally encountered would be equal to 1.4. Thus, the speed of sound (c) can be computed from the equation:

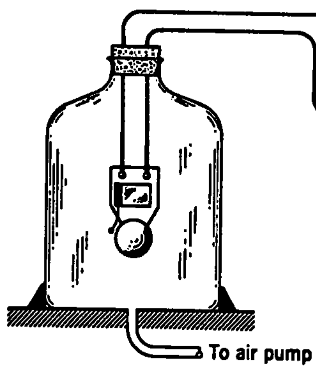
$$c = \sqrt{\frac{1.4\ P_o}{\rho_o}}$$

where

P_o = atmospheric pressure

ρ_o = the density of the air

Since a sound wave involves compression and expansion of some material, sound can be transmitted only through a material medium having mass and elasticity. No sound can be transmitted through a vacuum. This fact can be demonstrated experimentally by mounting an electrical bell under a bell jar and pumping the air out while the bell is ringing. As the air is removed, the sound becomes fainter and fainter until it finally ceases, but it again becomes audible if the air is allowed to reenter the jar.



Bell Jar (Ref. 3, p 256)

Sound waves will travel through any elastic material. All are familiar with sounds transmitted through the windows, walls, and floors of a building. Submarines are detected by the under-water sound waves produced by their propellers. The sound of an approaching train may be heard by waves carried through the rails as well as by those transmitted through the air. In all materials the alternate compressions and rarefactions are transmitted in the same manner as they are in air.

Airborne sound refers to rapid pressure variations; that is, alternate increases and decreases in normal atmospheric pressure produced by a vibrating object or turbulence within the air.

Sound travels much faster in liquids and solids than it does in air. Thus the speed in water is about 1500 m/sec; in hardwood it is about 3900 m/sec along the fibers and only 1000 ft/sec across them: and in stone it is about 12,000 ft/sec.

TABLE 1.2

TYPICAL VALUES FOR THE SPEED OF SOUND

Medium	Temperature (°C)	Speed (meters/sec)	(ft/sec)
Carbon Dioxide	0	258.0	846
Air	0	331.3	1,087
Hydrogen	0	1,286	4,220
Oxygen	0	317.2	1,041
Water	15	1,450	4,760
Lead	20	1,230	4,030
Aluminum	20	5,100	16,700
Copper	20	3,560	11,700
Iron	20	5,130	16,800
Extreme Values			
Granite		6,000	19,700
Vulcanized Rubber	0	54	177

(Ref. 2 p 426)

1.2.6 Climatic Effects on Sound *

Having discussed the basics of acoustics, we may now turn our attention to aspects of sound propagation which relate directly to how changes in meteorological conditions may affect man-made noise impact on natural sounds in the IDNL. It should be remembered that sand dune type environments because of their very nature, provide terrain characteristics which make sound propagation, especially man-made noise a potentially difficult and certainly varying impactor on a natural acoustic climate.

*A good portion of material covered in this section is discussed more rigorously in the article "Sound Propagation and Annoyance Under Forest Conditions," included in Appendix C of the report.

It is well known that every type of wave motion, including sound, loses part of its energy as it is propagated through a medium such as air. The attenuation of sound is due to viscosity, heat conduction, radiation, scattering, and molecular absorption. The attenuation of sound waves having pressures ordinarily associated with speech, music, or noise depends principally on the frequency of the sound wave, relative humidity, wind factor temperature, and other environmental variables.

The wind and temperature variations in the atmosphere may greatly modify the distribution of energy about a sound source by bending the sound rays from their usual rectilinear paths. These affects on the propagation of sound in the atmosphere, as well as the absorptive properties of the air itself and the influence of sound-absorptive surfaces in the sound field, are discussed.

1.2.6.1 Effect of Wind on Sound Propagation

The speed of sound in still air, at a given temperature, is constant, and equal to about 339 m/sec. If the air is in motion, or if the temperature changes, the sound speed will be altered. The speed of sound in the direction of the wind is equal to the speed of the wind plus the speed of sound in still air.

Suppose that the wind is blowing past a source of sound.

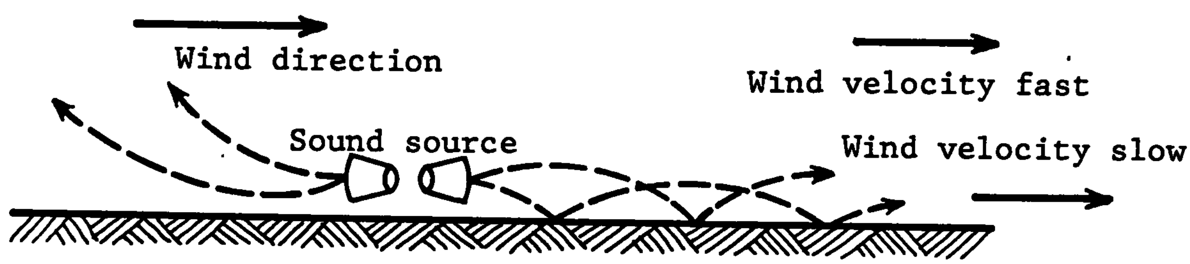


Figure 1.5 EFFECT OF WIND DIRECTION ON PROPAGATION OF SOUND WAVES (Ref. 4)

Then, since the speed of the wind is generally slowest at the surface of the earth and increases at higher elevations above the surface, the normal to the wave front of the sound that travels with the wind is bent more and more toward the earth, whereas the normal to the wave front of the sound that travels against the wind is bent more and more away from the earth.

Consequently, the upper portions of the sound waves that travel with the wind are deflected downward and they contribute to the flow of sound energy near the earth's surface, thus intensifying the sound near the earth and facilitating the propagation of sound to great distances in the direction of the wind. On the other hand, the upper portions of waves that travel against the wind are relatively retarded so that these waves are deflected upward from the level plane, thus making impossible the propagation of sound to great distances in the direction against the wind. The wind has a marked effect upon the distribution of sound; the pressure of the sound wave in the direction of the wind, at a given distance over a level plane, amounts to several times the pressure at the same distance but in the direction against the wind.

1.2.6.2 Effect of Temperature on Sound Propagation

Temperature does have a significant effect on the speed, increasing it about .33 m/sec per degree Celsius rise in temperature. The dependence of the speed of sound on temperature is one of the prime causes of the bending of sound rays in the atmosphere.

The speed of the upper portion of sound waves may be increased or decreased with respect to the lower portion as a result of temperature differences in the atmosphere. Suppose that the temperature of the air decreases with the altitude above the earth's surface, as it most commonly does. Then the upper portions of sound waves originating at a sound source will be retarded in relation to the lower portions, and consequently the wave front will be bent upward.

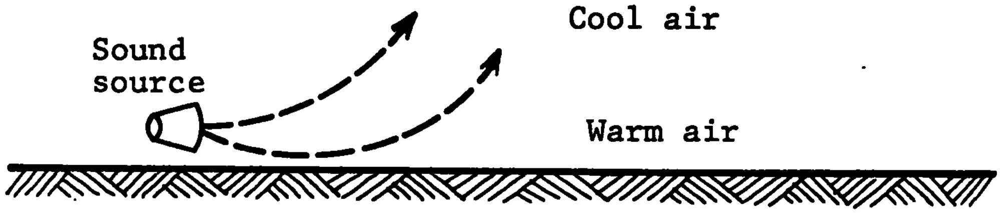


Figure 1.6 EFFECT OF TEMPERATURE GRADIENT ON PROPAGATION OF SOUND WAVES--DECREASING TEMPERATURE WITH INCREASING ALTITUDE (Ref. 4)

Suppose that the air temperature increases with the altitude, as it frequently does over land surfaces just after sunset or whenever meteorological conditions give rise to an "inverted temperature gradient." Then the upper waves travel faster than the lower ones, and consequently the wave front will be bent downward.

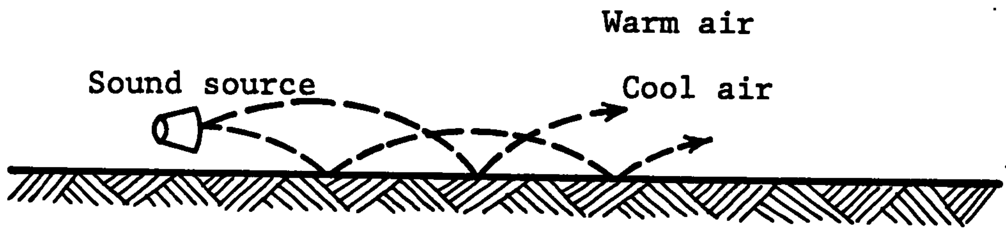


Figure 1.7 EFFECT OF TEMPERATURE GRADIENT ON PROPAGATION OF SOUND WAVES--INCREASING TEMPERATURE WITH INCREASING ALTITUDE (Ref. 4)

Under certain conditions of increasing temperature with altitude, an appreciable portion of the sound originating at a point source will be totally reflected by the upper and warmer layers of air. When these circumstances prevail there will be repeated reflections between the earth and the upper layers of air. Therefore, the pressure of the sound waves decreases only as the inverse square root of the distance instead of as the inverse of the distance, the usual decrease for a spherical wave in free space. These conditions often are approximated in the air over a frozen lake when it is possible on a quiet day to hear and understand ordinary conversation at a distance of a half mile or even more.

Closely associated with the absorption and scattering of sound in the atmosphere is the phenomenon of "fluctuations." The slow but sometimes large fluctuations in the loudness of the sound coming from a distant airplane is a familiar observation. A study of the micrometeorological properties of the atmosphere reveals great turbulence, especially near the surface of ground which has been heated by the sun. Temperature changes of 3 C^{o} or more, occurring several times a second, are not uncommon; the wind is everchanging; convection currents keep the air in a state of agitation. The motion in the air of smoke particles or of small bits of paper reveals the turbulent nature of the atmosphere. Sounds of long wavelength are not greatly influenced by the micrometeorological properties of the atmosphere, but sounds of short wavelength are subject to violent fluctuations.

1.2.6.3 Effect of Clouds or Fog on Sound Propagation

When a sound wave strikes a cloud or a fog bank, most of the sound energy usually is refracted (with a very small change of direction) into the cloud or fog, and only a small portion of the sound energy is reflected. If, however, the sound wave strikes the cloud or fog bank at nearly grazing incidence, the sound wave may be totally reflected, in which case the direction of propagation of the sound wave may be appreciably altered.

The actual affect of fog on sound propagation is usually attributable to other secondary meteorological effects. Fog is usually present on days of little wind motion, thus the air is still. The gradients of wind and temperature tend to be small and thus sound has a tendency to propagate further on foggy days. There is also the factor that background noise is usually lower in foggy weather due to slowness or absence of traffic and/or other outdoor activities. More concise laboratory and field experiments will be needed to study the actual affect of fog on sound in the outdoor environment.

1.2.6.4 Meteorological Examples of Sound Propagation Variances

An example of these phenomena in IDNL areas includes both wind and temperature gradient effects. Highway noise will impact certain natural land areas more on a day in which the wind is blowing from the south to southwest, and temperature conditions give rise to adiabatic heating of the atmosphere above cooler dune and valley areas (temperature inversion). The highway noise waves will be bent downward and deflected into valley areas such as Inland Marsh, Bailly Unit areas, Dune Acres, etc. Conversely, at night, or during certain summer daytime conditions, the ground will remain warm and cooler air above will cause upward diffraction of highway noise waves and thus produce shadow regions in which very quiet natural acoustic conditions will prevail. This apparently occurs very naturally in State Park and Mount Baldy areas, due no doubt to the sandy terrain holding the heat of the day and causing the near ground atmosphere to remain warmer than the upper air.

Wintertime and summertime conditions produce reflectivity effects from clouds, fog, and snow conditions which may cause highway noise, fog horn propagation from the Michigan City Coast Guard Station, stack hum from the power plants, or marshalling yard noise from the Michigan City plant to impact different IDNL areas at different times. The phenomena of noise propagation fluctuation can take place due to just such conditions. Figure 1.8 presents an acoustic picture of such fluctuation. These data were recorded at the Blue Heron Rookery unit during wintertime conditions, with snow cover between the survey site and the interstate highway to the north. The wind was a calm to slight northerly breeze. The slow movement of low level clouds and reflection between ground and sand, coupled with the variances in temperature in the air aloft produced the 8 to 10 dB fluctuations in man-made noise impact as shown in the figure.

As an example of seasonal variation in man-made noise and natural sound, Figures 1.9 and 1.10 present the frequency/energy characteristic change in relative ambient sound climate for a secluded area of the IDNL. The dotted red lines are man-made noise, and the solid black lines are natural sound or background (residual) acoustic energy for the area. The natural sounds significantly mask the man-made noise in summer, but the wintertime repeat shows how the fluctuating distant highway noise (upper curve) will dominate the total sound climate for the area. Note that even though the man-made noise A-weighted level for summertime conditions is only 3 dB less than the wintertime repeat levels, the high natural sound level in summer more than masks any man-made noise in the area.

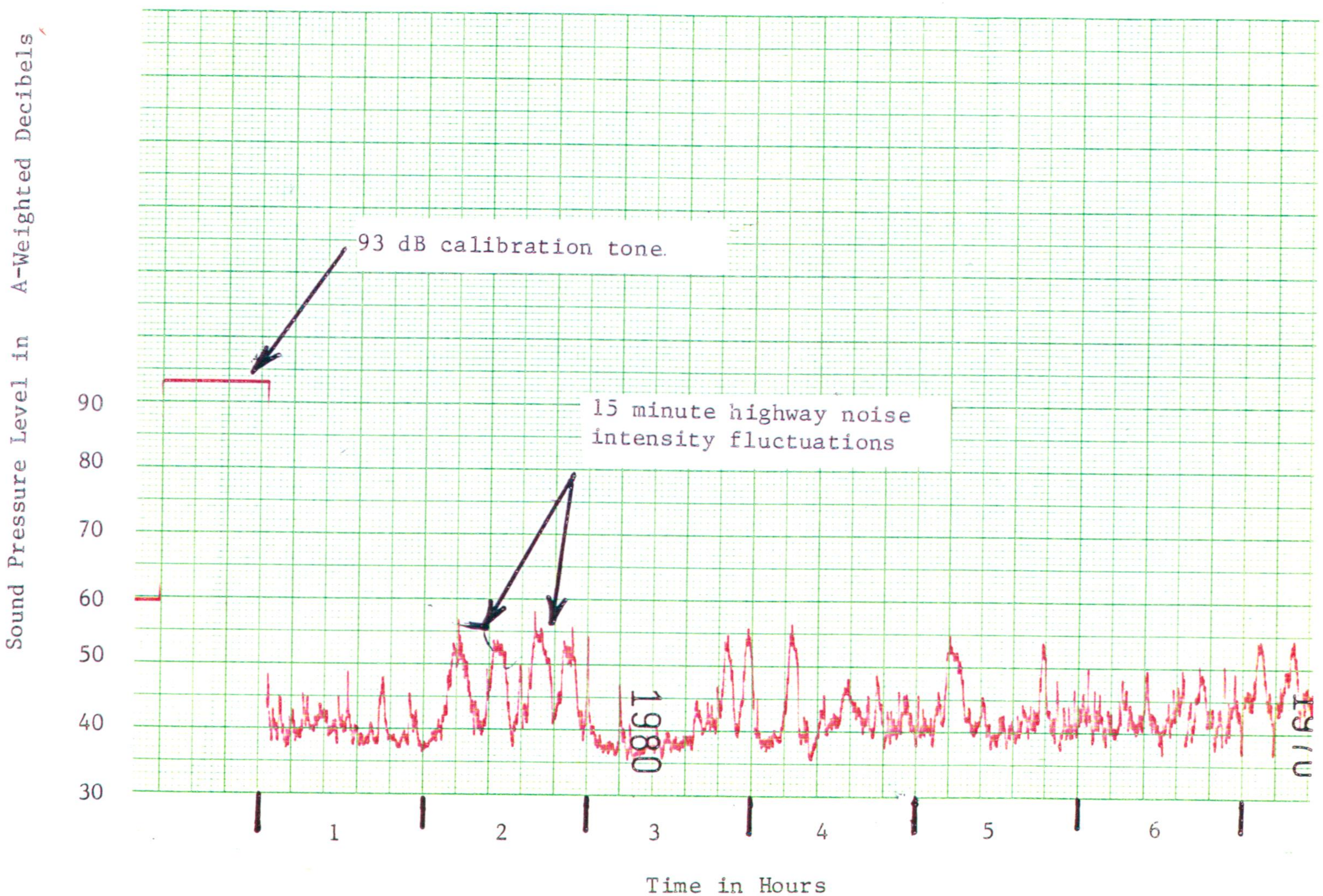


Figure 1.8 - First 6 hours of a 24-hour graphic readout for the Blue Heron Rookery survey.

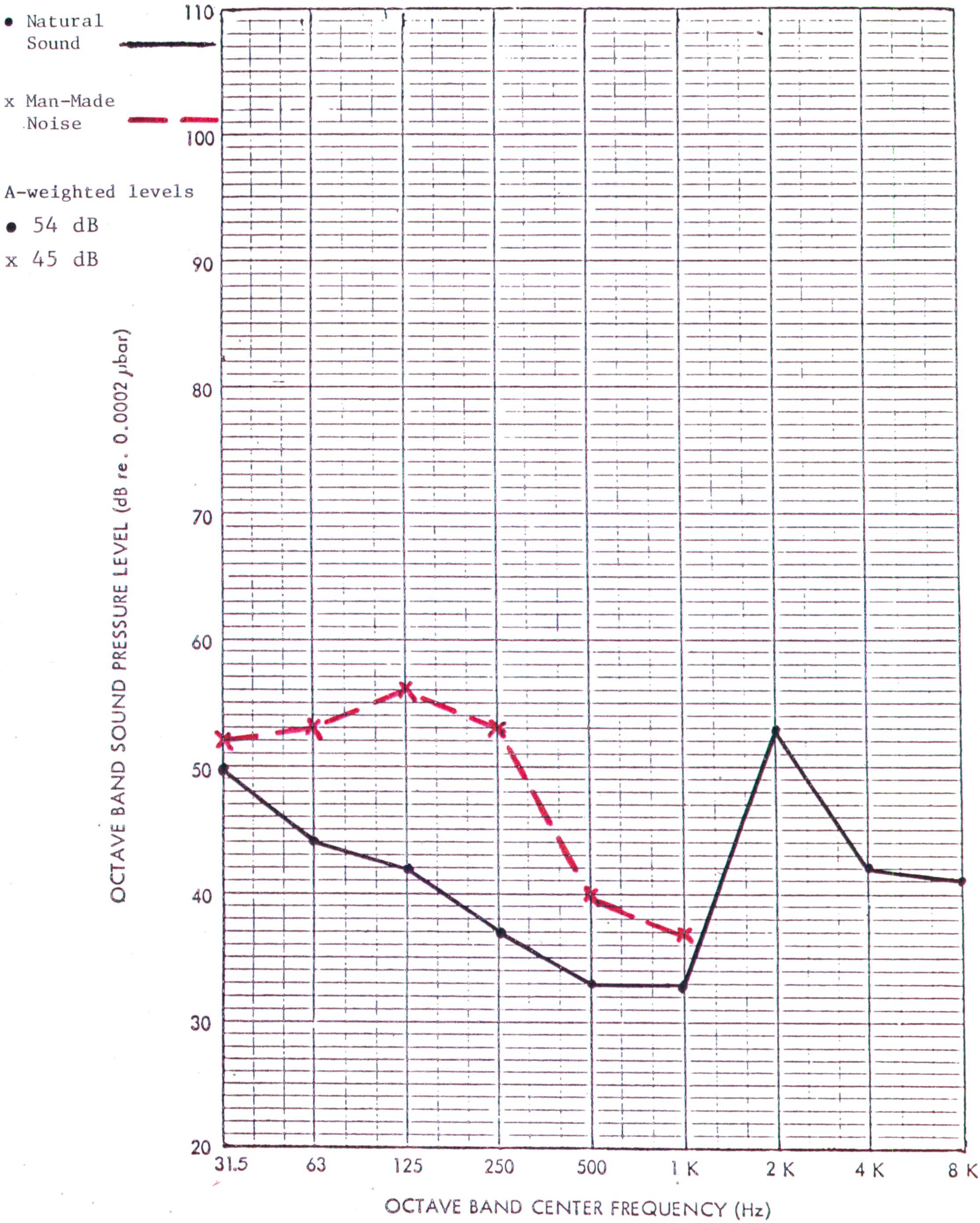


Figure 1.9 SUMMERTIME OCTAVE BAND SOUND PRESSURE LEVELS AT HILL OVERLOOKING EAST LAKE PARK AVENUE, IN MOUNT BALDY AREA 11:10 - 11:15 p.m. 8/8/77

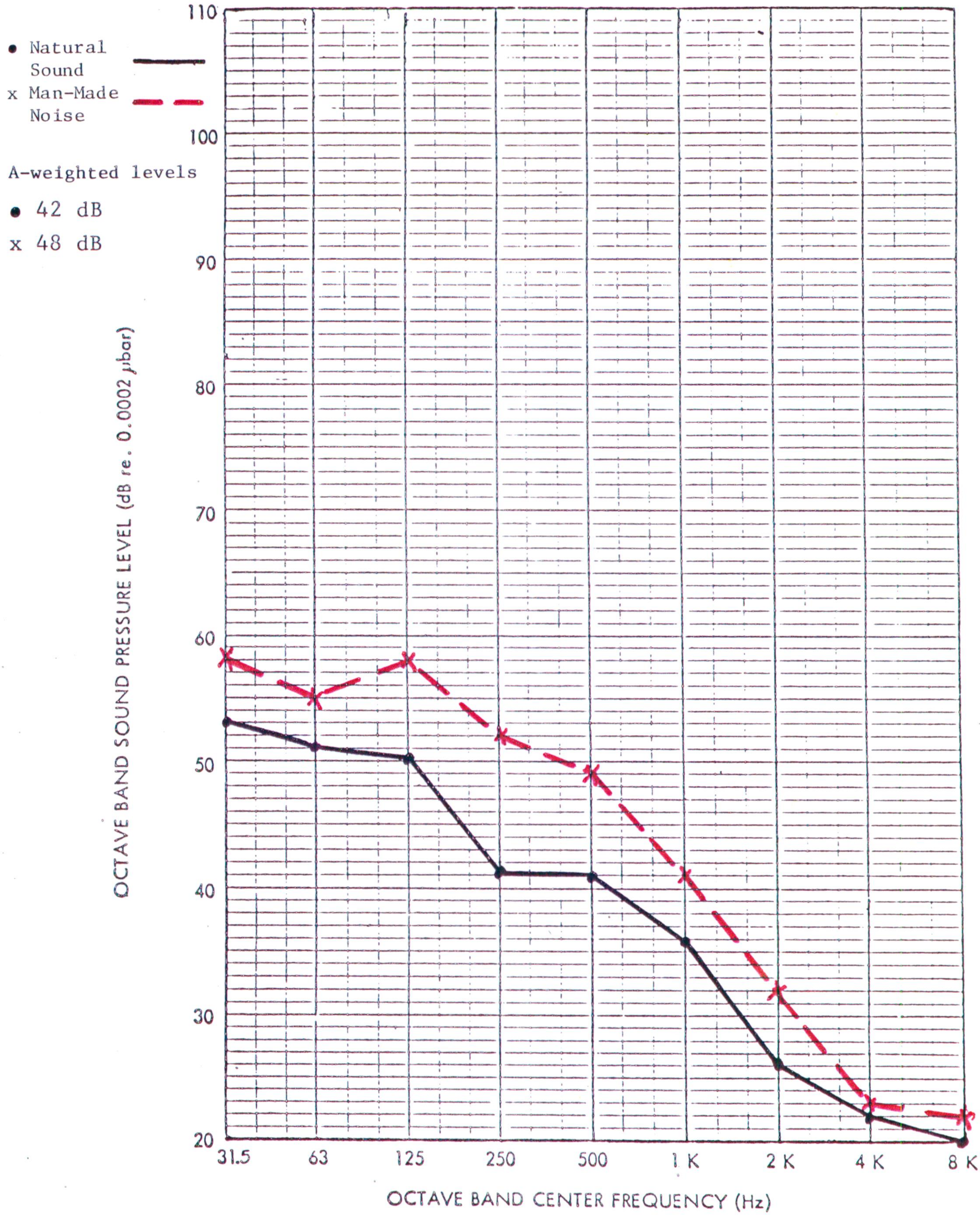


Figure 1.10- WINTERTIME OCTAVE BAND SOUND PRESSURE LEVELS AT HILL OVERLOOKING EAST LAKE PARK AVENUE, IN MOUNT BALDY AREA 11:10 - 11:15 p.m. 8/8/77

1.2.7 Closure

The material included in Section 1.2 contains only a small part of the actual information required to become proficient in dealing with acoustical principles and problems. This section was intended to merely introduce certain concepts and basic knowledge concerning sound and its propagation in the environment. The aspect of sound known as noise is discussed in Section 1.3.

1.3 Man-Made Noise Terminology and Assessment Techniques

The following quote from philosopher-writer Arthur Schopenhauer's article "On Noise," describes in his particular style the disturbing quality of noise as it has at one time or another affected human thinking processes.

"Kant wrote a treatise on The Vital Powers. I should prefer to write a dirge for them. The superabundant display of vitality, which takes the form of knocking, hammering, and tumbling things about, has proved a daily torment to me all my life long. There are people, it is true-nay, a great many people-who smile at such things, because they are not sensitive to noise; but they are just the very people who are also not sensitive to argument, or thought, or poetry, or art, in a word, to any kind of intellectual influence. The reason of it is that the tissue of their brains is of a very rough and coarse quality. On the other hand, noise is a torture to intellectual people. In the biographies of almost all great writers or wherever else their personal utterances are recorded, I find complaints about it; in the case of Kant, for instance, Goethe, Lichtenberg, Jean Paul; and if it should happen that any writer has omitted to express himself on the matter, it is only for want of an opportunity.

This aversion to noise I should explain as follows: If you cut up a large diamond into little bits, it will entirely lose the value it had as a whole; and an army divided up into small bodies of soldiers, loses all its strength. So a great intellect sinks to the level of an ordinary one, as soon as it is interrupted and disturbed, its attention distracted and drawn off from the matter in hand: for its superiority depends upon its power of concentration of bringing all its strength to bear upon one theme, in the same way as a concave mirror collects into one point all the rays of light that strike upon it. Noisy interruption is a hindrance to this concentration. That is why distinguished minds have always shown such an extreme dislike to disturbance in any form, as something that breaks in upon and distracts their thoughts. Above all have they been averse to that violent interruption that comes from noise. Ordinary people are not much put out by anything of the sort. The most sensible and intelligent of all nations in Europe lays down the rule, Never Interrupt! as the eleventh commandment. Noise is the most impertinent of all forms of interruption. It is not only an interruption, but also a disruption of thought. Of course, where there is nothing to interrupt, noise will not be so particularly painful. Occasionally it happens that some slight but constant noise continues to bother and distract me for a time before I become distinctly conscious of it. All I feel is a steady increase in the labor of thinking just as though I were trying to walk with a weight on my foot. At last I find out what it is".

Unfortunately, noise as an environmental health hazard was little discussed or written about until approximately 20 years ago. Within the past 10 years legislative bodies at federal, state, and municipal levels have decided to do something about controlling this pollutant. The purpose of this section is to discuss and evaluate the energy source known as noise, as well as some of the health hazards indigeneous to this form of pollution. The manner in which this particular sound energy affects the health, welfare, and well-being of persons so exposed is described. In Schopenhauer's time noise may have been only a disturbance factor, but in the present environment it has joined a long list of other hazardous pollutants.

Definitions: The following terms apply to noise and noise sources, and the manner in which they affect the working apparatus of the ear. Definitions in this section are in substantial conformity to those appearing in various United States Environmental Protection Agency documents published within the past 6 years and are thus the federally recognized manner of describing such noise variables.

audiometry	measurement of hearing acuity over various ranges of sound, including loudness and pitch or intensity and frequency
auditory	related to or pertaining to the sense of hearing
Broadband Noise	Noise whose energy is distributed over a wide range of frequency
cardiovascular	pertaining to the heart and blood vessels
chronic	long-term continuous or frequently repeated
Cochlea; Chochlear	A spiral shaped cavity in the temporal bone, resembling a snail shell, which forms part of the inner ear and contains the end organ of hearing; pertaining to the cochlea
clinical studies	examination of a health related phenomenon in the human population on the living patients
Continuous Noise	On-going noise, the intensity of which remains at a measurable level (which may vary) without interruption over an indefinite period or a specified period of time--losely, nonimpulsive noise.
cross-sectional studies	in epidemiology, an examination of a comprehensive sampling of the population at a given time
dB(A) scale	the frequency weighting network for averaging sound pressure levels specified for sound level meters conforming to the American National Standard specification for sound level meters, ANSI S1.4 (1971)
endocrine	pertaining to the internally-secreting glands whose products are distributed via the blood rather than through ducts

epidemiological studies	investigation of the incidence, distribution, duration of diseases or pathological conditions such as hearing problems
Frequency	number of times per second that a periodic sound repeats itself--now expressed in Hertz (Hz), formerly in cycles per second (cps)
exposure	the cumulative amount of noise received by an individual integrated over time, i.e., one day
hearing impairment	lessening of auditory acuity at any normally hearable range of sound frequency or intensity
hearing loss	diminuation in (or even total absence of) ability to detect sound waves in normal intensity ranges
hearing threshold level	hearing in the loudness range at the exact level between barely audible sounds and barely inaudible acoustic pressures for the subject individual
Impulse Noise (Impulsive Noise)	noise of short duration (typically, less than 1 sec) especially of high intensity, abrupt onset and rapid decay, and often rapidly changing spectral composition

NOTE: Impulse noise is characteristically associated with such sources as explosions, impacts, the discharge of firearms, the passage of supersonic aircraft (sonic boom) and many industrial processes.

infrasound	sound with frequencies below the audible range, i.e., below 16 Hz
intermittent	occurring at intervals
level	magnitude or amount
L_{DN}	one-number scheme for designating the 24-hour equivalent energy exposure in a particular environment adjusted so that nighttime background is given more weight
L_{eq}	noise level formulated in terms of the equivalent steady noise level which in a stated period of time would contain the same noise energy as the time-varying noise during the same time period
Longitudinal Studies	long-term surveying and monitoring of a given group of the population

Noise Exposure	combination of effective noise level and exposure duration
Noise Induced Permanent Threshold Shift (NIPTS)	permanent threshold shift (PTS) caused by noise damage to the auditory system
ototoxic	poisonous or damaging to the auditory (hearing) organs and/or associated areas of the brain
permanent threshold shift	(PTS) a permanent change in the ability to detect sounds in a given loudness range
physiologic	pertaining to the functions and activities of a living cell tissue or organism
pure tone	a sound wave, the instantaneous sound pressure at which it is a simple function of time, i.e., a single discrete frequency
spectral characteristics	the detailed composition of frequencies and sound pressure levels comprising speech or a noise
speech interference level (SIL)	a calculated quantity providing a guide to the interfering effect of a noise on reception of speech communication. The SIL is the arithmetic average of the octaveband sound-pressure levels of the interfering noise in the most important part of the speech frequency range. The levels in the three octave-frequency bands centered at 500, 1000, and 2000 Hz are commonly averaged to determine the SIL. Numerically, the magnitudes of aircraft sounds in the SIL scale are approximately 18 to 22 dB less than the same sounds in the perceived noise level scale in PNdB, depending on the spectrum of the sound
sound level	the average sound pressure obtained by a sound level meter whose frequency weighting characteristics are specified in a standard. It is measured in decibels
temporary threshold shift	(TTS) a short duration change in the ability to detect sounds in a given loudness range
threshold hearing	auditory sensing of very weak sounds, barely audible to the subject individual
tinnitus	a purely subjective sensation of sound such as ringing, whistling, hissing, buzzing in the ears that is not induced by sound waves

vestibular	pertaining to the inner ear which contains the sensory organs of balance and audition
ultrasound	sound with frequencies above the audible range, i.e., above 20,000 Hz

Sound is usually divided into three major classifications: Speech, music, and noise, with noise being defined simply as unwanted or undesirable sound. More objectively speaking, sounds with either single or combinations of random fluctuations, fundamentals, and disordered overtones or harmonic series structure, can be classified as noise. These fundamentals and overtones may be of steady or nonsteady nature which means simply that the noise is either constant (steady), or shifts levels significantly during the period of observation (nonsteady). The following table gives examples of different types of indoor and outdoor environmental noises or sounds divided into these two major classifications.

Steady	Nonsteady
City background noise	Traffic passby
Rushing river	Ocean surf
Power transformer	Aircraft flyover
Stationary motor vehicle with engine running	Train passby
Air conditioner	Dog barks
Air makeup ventilation equipment	Pistol firing
	Riveting
	Pneumatic hammer
	Pile driver

While discussing human response to noise and its affects on hearing it would be beneficial to discuss and evaluate some of these indoor and outdoor noise sources which are sometimes both an annoyance factor, and an actual environmental hazard. Some noise variables that contribute to human subjective and objective reactions to noise are presented.

1.3.1 <u>Noise Variables and Evaluation Techniques</u>

To represent properly the total noise of a noise source, it is usually desirable or necessary to break the total noise down into its various frequency components; that is, how much of the noise is low frequency, how much high frequency and how much is in the middle frequency range. This is essential for any comprehensive study of noise for three reasons:

- A hearing loss, annoyance, speech interference, sound absorption, etc., all vary with frequency.
- People react differently to low frequency and high frequency noise (for the same sound pressure level, high frequency noise is much more disturbing and is more capable of producing hearing loss than is the case for low frequency noise);
- Engineering solutions to reduce or control noise are different for low frequency and high frequency noise (low frequency noise is more difficult to control, in general).

It is conventional practice in acoustics to determine the frequency distribution of a noise by passing that noise successively through several different filters that separate the noise into eight or nine "octave bands" on a frequency scale. An octave is a frequency interval in which the upper frequency is twice the lower frequency, such as 150 to 300 Hz or 1200 to 2400 Hz. The frequency bands in use in the United States before adoption of the bands listed were as follows: 20-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800 and 4800-10,000 Hz. Most of the literature in acoustics before about 1963 will refer to these "old" frequency bands. The "new" international standard frequencies (sometimes called "preferred frequencies" in current literature) are used in this section. Essentiallly the old and new frequency bands may be considered as being equivalent, with a few exceptions that will not be significant to this material. A set of filters used to separate a complex sound into octave bands is commonly referred to as an "octave band analyzer." When a sound <u>pressure</u> level or a sound <u>power</u> level of noise includes all the audio range of frequency, the resulting value is called the "overall" level. When the level refers to the sound in just one specific octave frequency band, it is called an "octave band level" and the frequency band is either stated or clearly implied.

For some special situations, it may be desirable for a noise spectrum to be studied in finer detail than is possible with octave frequency bands. In such cases one-third octave bands or even narrower filter bands might be used to separate one particular frequency from another one if it is desired to separate the causes of a particular complex noise. In this case the bandwidth and the identifying frequency of the band would always be specified.

The normal frequency range of hearing for most people extends from a low frequency of about 20 Hz up to a high frequency of 10,000 to 15,000 Hz, or even higher for some people. By virtue of United States adoption of a recent international frequency standard in acoustics, most octave-band noise analyzing filters now cover this audio range from 22 Hz to about 11,200 Hz in nine octave frequency bands. These filters are identified by their geometric mean frequencies; hence 1000 Hz is the label given to the octave frequency band of 700-1400 Hz. The nine octave bands of the new international standard are as follows (the numbers are frequently rounded off):

Octave Frequency Range (Hz)	Geometric Mean Frequency of Band (Hz)
22-44	31-1/4 (31.5)
44-88	62-1/2 (63)
88-175	125
175-350	250
350-700	500
700-1400	1000
1400-2800	2000
2800-5600	4000
5600-11,200	8000

The term overall sometimes designated "linear" would thus cover the full frequency coverage of all the octave bands, hence 22-11, 200 Hz, or in some cases, 44-11,200 Hz when the 31.5 Hz band is omitted. The range of human hearing as compared with other animals is illustrated in Figure 1.11.

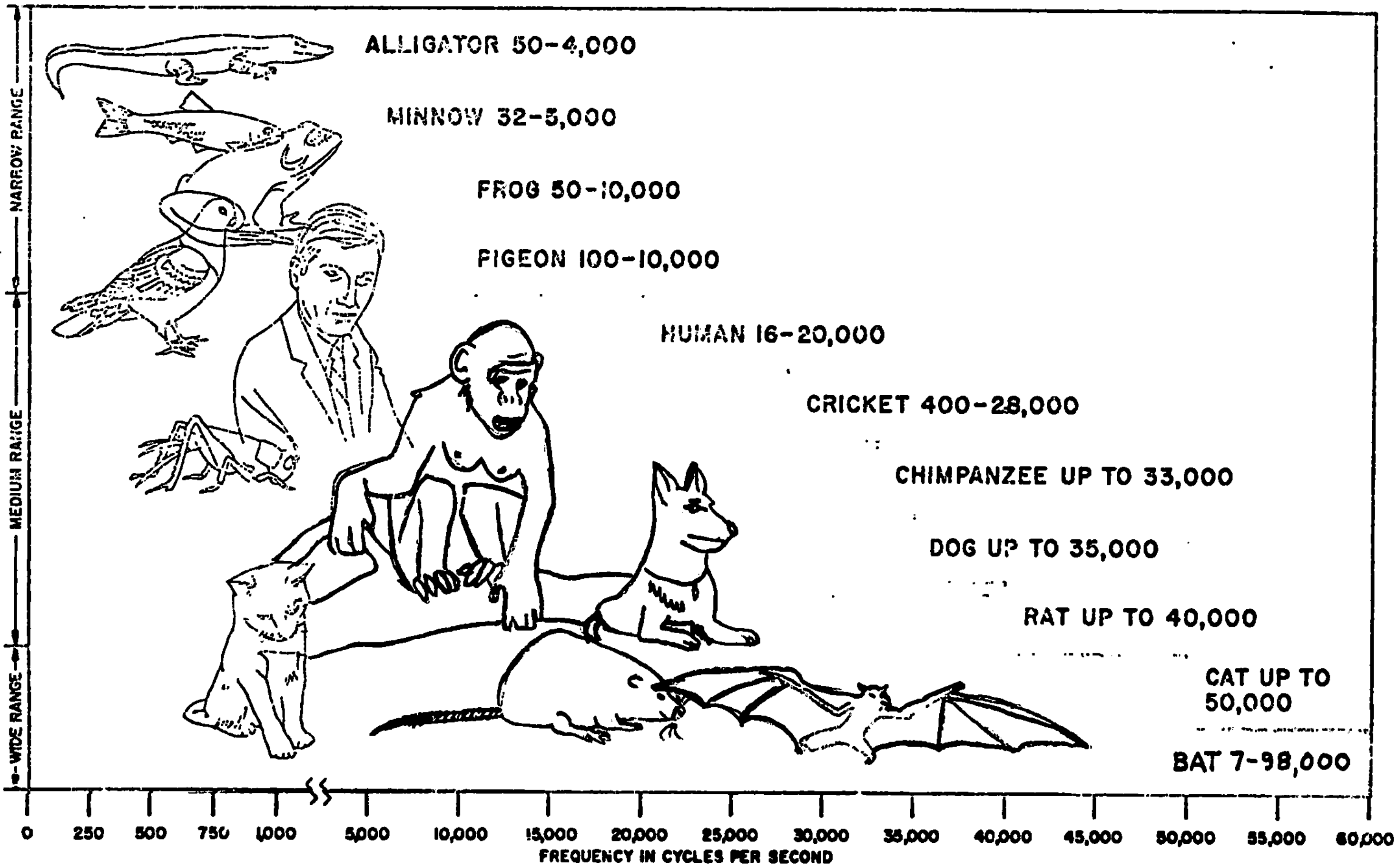


Figure 1.11 RANGES OF HUMAN AND ANIMAL HEARING SENSITIVITY (Ref. 1)

1.3.1.1 Weighting Networks: A-, B-, and C-Scales, Leq, LDN, Decile Descriptors

The measurement methodologies and equipment utilized to analyze the various environments assessed in the Park during the study are described in detail in Section1.4of the report. The author intends to briefly examine the basic acoustic measurement scales, and descriptors so as to explain the reasons for choosing the techniques utilized in the study. The basic unit of measurement as noted previously is the decibel and an instrument known as a sound level meter is utilized for measuring the intensity quality of sound in a particular environment. Sound level meters are usually equipped with "weighting circuits" that tend to represent the frequency characteristics of the average human ear for various sound intensities. Hence, overall readings are sometimes taken with A-scale or B-scale or C-scale settings on the meter. The A-scale setting of a sound level meter filters out as much as 20 to 40 dB of the sound below 100 Hz. This corresponds most closely with the manner in which human,. as well as most animal hearing mechanisms identify acoustic climates. The reason for the attenuation of low frequency is both a function of structural considerations concerning the anatomy of the ear, as well as a subjective result of the vocal interplay of man and nature. Animal warning signals, as well as the human baby cry peak in the region of the A-scale. The B-scale filters out less low frequency energy and has generally fallen into disuse.

The C-scale setting is reasonably "flat" with frequency i.e., it retains essentially all the sound signal over the full overall frequency range. A plot of the frequency response of the electrical system of a sound level meter meeting U.S.A. Standards Institute (USASI), formerly American Standards Association, standards for the A-, B- and C-scale weighting networks is shown as Figure 1.12 For several years the A-scale and B-scale readings were held in disfavor because alone they do not provide complete knowledge of the frequency distribution of the noise, but there is a revival of the use of A-scale readings as a single-number indicator of the relative loudness of a sound as heard by the human ear. It is very important, when reading A-, B- or C-scale sound levels, to positively identify the scale setting used and the values indicated.

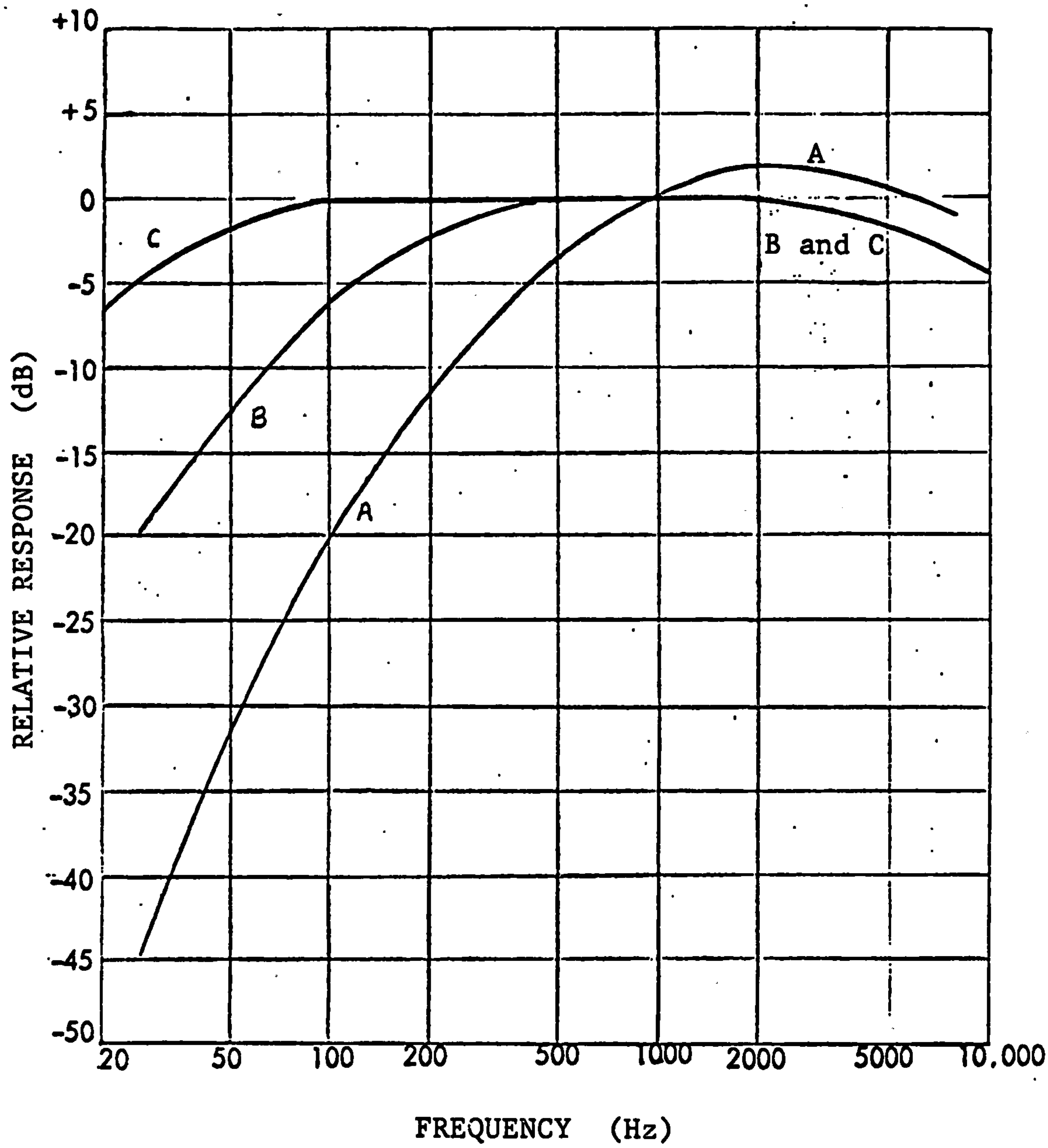


Figure 1.12 PLOT OF FREQUENCY RESPONSE

The resulting values are called "sound levels" and are frequently identified as dB(A), or dB(B) or dB(C) readings. Note that these readings sometimes do not represent true "overall sound pressure levels" because some of the actual signal may have been removed by the weighting filters. For most acoustic applications octave frequency band readings are the most useful. It is always possible to construct A-, B- or C-scale readings from all the octave band readings, but it is only possible to construct the octave band readings from the weighting scale readings if the slope of the octave energy with respect to amplitude is known.

Considering the discussion above, the A-scale, as a single number as well as statistical entity, was chosen for the general analysis descriptor in the study. The overall energy was analyzed for distinct times of the day and night in order to determine the exact nature of a particular man-made noise impact on a natural sound environment. This analysis required the division of the sampled sound climate into frequency and energy components into what are known as 1/3 octave bands of data. This analysis technique was a major means of determining the relative acoustic qualities at Park lands in a manner in which the A-weighted statistical levels might produce more objective evaluations of the the total Park environment.

Three measurement methodologies were employed in gathering these data, two involving the A-weighted statistical descriptor, and one involving the frequency/energy 1/3 octave technique. The two A-weighted techniques employed the sound level meter as an analysis tool, one of which monitored, in stationary fashion, the total sound climate in a Park area for 24 continuous hours, and the other monitored by a human observer walking away from a man-made noise source into dunes and other topologically natural surroundings. The frequency/energy characteristics were simultaneously recorded on a scientific grade tape recorder during the course of obtaining the two A-weighted statistical data gathering exercises. In association with measurement methodologies described in Section 1.4 of this report, it should be noted that the A-weighted decibel descriptor described above is utilized for the statistical analysis discussed in the results section of the report. Two different types of formats are employed: equivalent A-weighted energy level (L_{eq}) and the percentage of exceedance of A-weighted levels known as decile descriptors. Furthermore, the equivalent energy descriptor takes on two forms in the results section: the 15 minute, hourly, and 24-hour L_{eq} and a one-number descriptor employed by the U.S. Environmental Protection Agency for describing various sound climates, known as L_{DN}. L_{eq} and L_{DN} are temporal statistical averages of sound pressure level and as such are expressed mathematically as integral quantities.

The mathematical definition of L_{eq} for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$L_{eq} = 10 \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_o^2} \, dt \right]$$

where p (t) is the time varying sound pressure and p_o is a reference pressure taken as 20 micropascals. Time $t_2 - t_1$ can be any interval and may be designated in the left hand side of the equation as L_{eq} (15 min), L_{eq} (1 hour), L_{eq} (8 hours), L_{eq} (24 hours) etc. As mentioned previously for this study, 15 minute, hourly, and 24-hour L_{eq} were determined.

The day-night equivalent energy level, L_{DN} is a more complicated descriptor which places a 10 dB penalty on sound levels recorded between the hours of 10:00 pm (2200 hours) and 7:00 am (0700 hours). This is to say that data statistically recorded during this temporal period will be automatically increased by 10 dB (a L_{eq} of 55dB(A) becomes 65 dB(A), etc) for purposes of total 24-hour calculation.

Mathematically expressed:

$$L_{DN} = 10 \log_{10} 1/24 \ [15(10^{L_D/10}) + 9(10^{(L_N + 10)/10})]$$

where $L_D = L_{eq}$ (15)for daytime hours (0700-2200)
and $L_N = L_{eq}$ (9) for nighttime hours (2200-0700).

This 10 dB penalty accounts in part for human reaction to the sleep interference aspect of man-made noise.

In relationship to how these acoustical terms affect the study of man-made noise impact on natural sound, it should be noted that most natural sounds are low level and steady, whereas man-made noise (airplane flyover, train passby, truck passby, etc) are intermittent with large rise in sound pressure level in a short duration of time. The L_{eq} and L_{DN} descriptors are very sensitive to such rises and as such reflect the impact of man-made noise in a particular Park area to a great degree.

The other statistical descriptor utilized in the A-weighted evaluation given in the results section is the decile level. These are the levels of noise exceeded for 1% (L_1), 10% (L_{10}), 50% (L_{50}), 90% (L_{90}), and 99% (L_{99}) of a particular temporal period. For the study, decile levels are reported in temporal ranges of 15 minutes, hours, and full 24-hour periods of analysis time. As an acoustical descriptor the A-weighted decile is pertinent for the study insofar as the L_{90} and L_{99} level of sound measured at the various Park areas is usually the sound considered natural (or ambient) oriented. The L_1 and L_{10} level are descriptors of man-made noise impact (except in rare instances of birds chirping into the microphone at close range). The L_{50} level is a medium level useful for interrelating similar sound climate area characteristics.

Thus to summarize, the L_{eq} and L_{DN} descriptors present the time averaged sound pressure level for a particular area over a predetermined analysis period. The L_1, L_{10}, L_{50}, L_{90}, and L_{99} decile A-weighted levels present the amount of sound pressure level exceeded for 1%, 10%, 50%, 90%, and 99% of the time. If we have 100 A-weighted values sampled in a particular time period and 10 of these are above 75 dB(A), the L_{10} level for the sampling period is L_{10} = 75 dB(A); if the highest 90 readings out of the 100 A-weighted values measured are 50 dB(A) or above, then we say that L_{90} = 50 dB(A). Section 1.4 of the report will discuss the measurement methodology utilizing the descriptors discussed above.

1.3.1.2 Addition of Noise Levels

The addition of noise levels follows very closely the methodology heretofore described for adding two sound source levels. Since the addition of noise sources sometimes requires a greater accuracy, the following technique may be used. Suppose that L_1 is the average sound-pressure level of one source of noise, that L_2 is the average level of a second source, and that L_2 is greater than L_1. Let their difference be denoted by D. Then the total noise level in decibels is equal to $L_2 + N$, where N is a number determined from the chart below, which corresponds to the difference D.

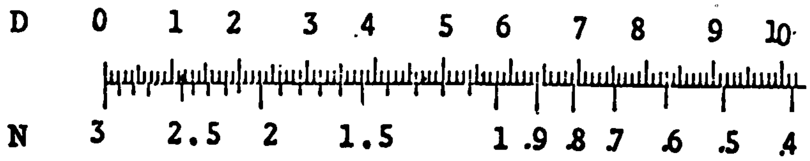


Figure 1.13 CHART FOR COMPUTING THE SOUND LEVEL RESULTING FROM THE ADDITION OF TWO COMBINING NOISES. IF "D" IS THEIR DIFFERENCE IN DECIBELS, "N" IS ADDED TO THE HIGHER LEVEL TO OBTAIN THE TOTAL LEVEL.

Thus, suppose that $L_1 = 50$ db and $L_2 = 60$ db. Here, D = 10 db. From the chart the corresponding value of N is about 0.4. Therefore, the total noise level is 60 + 0.4. Likewise, if $L_1 = 40$ db and $L_2 = 45$ db, N is 1.2, or the total noise level is 46.2 db. For the special case where two noise sources are equal in level, D equals zero, and the total noise level is 3 db higher than the level of either source. As a practical example, suppose that the average background sound level in a theater due to audience noise is 30 db. Now assume that the noise transmitted through the walls of the building from outside has a level of 20 db. Then the total level inside the theater resulting from both sources would be about 30.4 db, and the transmitted noise would probably not be detected by the average person. In general, the addition of noise which raises the total background level by less than 1 db will not be objectionable unless the weaker noise is quite different in character from the louder one.

1.3.2 Types of Noise Sources

1.3.2.1 Outdoor Sources

People tend to compare an intruding noise with the background noise that was present before the new noise came into existence. If the new noise has distinctive sounds that make it readily identifiable or if its noise levels are considerably higher than the background or ambient levels, it will be noticeable to the residents and it might be considered objectionable. On the other hand, if the new noise has a rather unidentifiable, unobtrusive sound and its noise levels blend into the ambient levels, it will hardly be noticed by the neighbors and it probably will not be considered objectionable.

Thus, in trying to estimate the effect of a new noise on the populace, it is necessary to know or to estimate the ambient levels in the absence of the new noise. For example, air-conditioning equipment is planned for continuous day and night operation, and since people are less tolerant of an intruding noise at night, the nighttime ambient noise levels are important to the evaluation of the problem.

Where possible (and especially in the case of sensitive populations), the average minimum nighttime noise levels should be measured several times during several typically quiet nights. Readings should be taken in octave bands at measurement points where there is no nearby major stationary source that would give falsely high values.

If background measurements cannot be made the ambient noise levels can be estimated approximately with the use of the table on the next page in conjunction with that below.

The condition should be determined that most nearly describes the community or residential area or the nearby traffic activity (which frequently set the ambient levels in an otherwise quiet neighborhood) that would exist during the quietest time that the air-conditioning would be in operation. For the condition that is selected, there is an appropriate noise code number that is used to enter into the table. That particular noise code number then gives an estimate of the approximate average minimum background noise levels for that area and traffic condition. This is not an infallible estimate but it will serve in the absence of actual measurements.

TABLE 1.3

OCTAVE BAND SOUND PRESSURE LEVELS OF OUTDOOR BACKGROUND NOISE CODE NUMBERS (see Table 1.4)

	OCTAVE BAND CENTER FREQUENCY IN HZ							
Noise Code	63	125	250	500	1000	2000	4000	8000
1	40	37	32	27	22	18	14	12
2	45	42	37	32	27	23	19	17
3	50	47	42	37	32	28	24	22
4	55	52	47	42	37	33	29	27
5	60	57	52	47	42	38	34	32
6	65	62	57	52	47	43	39	37
7	70	67	62	57	52	48	44	42

It is cautioned that these estimates should be used only as rough approximations of background noise and that local conditions can give rise to a wide range of actual noise levels. It is, nevertheless, realistic to utilize a method such as this to help determine the amount of noise that a new noise can make without becoming noticeably louder than the general background.

1.3.2.2 Indoor Sources

Much of the noise generated in indoor offices results from airflow equipment. When air flows through a ventilating system, obstructions of all types (bends, side branches, changes of duct size, grilles) produce eddy currents or other forms of turbulent flow. Noise containing sounds of all frequencies is generated as a result of this turbulence. Noise arising from such turbulence usually contains relatively more high frequency noise than only air-conditioning motor-fan noise. Sometimes the turbulence will set into vibration parts of the system, particularly the walls of unlined ducts, and give to the resulting noise a definite pitch. There are two types of noise that should be suppressed in a ventilating system--that resulting from solidborne vibration and that which is airborne.

TABLE 1.4

ESTIMATE OF OUTDOOR BACKGROUND NOISE BASED ON GENERAL TYPE OF COMMUNITY AREA AND NEARBY AUTOMOTIVE TRAFFIC ACTIVITY

(Determine the appropriate conditions that seem to best describe the area in question during the time interval that is most critical; i.e., day or night, probably night if for sleeping. Then refer to corresponding noise code the preceding number table for average minimum background noise levels to be used in noise analysis. Use lowest code number where several conditions are found to be reasonably appropriate.)

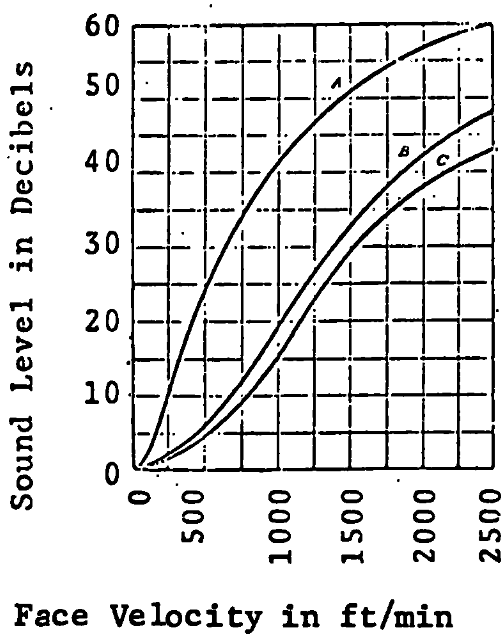
CONDITION	NOISE CODE
1. Nightime, rural; no nearby traffic or concern	1
2. Daytime, rural; no nearby traffic of concern	2
3. Nightime, suburban; no nearby traffic of concern	2
4. Daytime, suburban; no nearby traffic of concern	3
5. Nightime, urban; no nearby traffic of concern	3
6. Daytime, urban; no nearby traffic of concern	4
7. Nightime, business or commercial area	4
8. Daytime, business or commercial area	5
9. Nightime, industrial or manufacturing area	5
10. Daytime, industrial or manufacturing area	6
11. Within 300 ft of intermittent light traffic route	4
12. Within 300 ft of continuous light traffic route	5
13. Within 300 ft of continuous medium-density traffic	6
14. Within 300 ft of continuous heavy-density traffic	7
15. 300 to 1000 ft from intermittent light traffic route	3
16. 300 to 1000 ft from continuous light traffic route	4
17. 300 to 1000 ft from continuous medium-density traffic	5
18. 300 to 1000 ft from continuous heavy-density traffic	6
19. 1000 to 2000 ft from intermittent light traffic	2
20. 1000 to 2000 ft from continuous light traffic	3
21. 1000 to 2000 ft from continuous medium-density traffic	4
22. 1000 to 2000 ft from continuous heavy-density traffic	5
23. 2000 to 4000 ft from intermittent light traffic	1
24. 2000 to 4000 ft from continuous light traffic	2
25. 2000 to 4000 ft from continuous medium-density traffic	3
26. 2000 to 4000 ft from continuous heavy-density traffic	4

The principal sources of solidborne vibrations are the motors and fans. In addition, turbulence in the airstream can cause the duct walls and other parts of the system to rattle. Thus the principal source of airborne noise is the above-mentioned turbulence combined with that which is generated by the structure borne vibration.

From an environmental annoyance standpoint, the noise level at the source of the ventilation equipment (the air makeup equipment room) is often high. This fact may not be important if the equipment is in an out-of-the-way location such as the basement. However, where the equipment noise is likely to be a source of annoyance to occupants adjacent to the equipment room, the motors and fans should be selected with regard to their quietness, acoustical treatment of the equipment room may be desirable, and the wall partitions should provide adequate attenuation of noise.

Solutions now exist for curbing these indoor noise sources. Motors and fans in which noise and vibration are deliberately and effectively suppressed are now manufactured. They are especially desirable, but if their cost is very much higher than others which are less quiet, it is sometimes cheaper to control the noise and vibration by other means. Proper mounting of the motors and fans, so that they will not communicate vibration to the ducts, walls, or floor, is important. There should be no direct contact between the building structure and the foundation of the motors and fans. Isolation of the machinery from the floor is usually accomplished by vibration damping and isolation padding. The blower and exhaust fans should be isolated from the ducts by a flexible sleeve, for example, one fabricated of canvas. It is occasionally helpful to use rubber hose for the piping connections from pumps. The tendency of unlined duct walls to be set into vibration can be reduced by the application of its surface of a material which adds mechanical damping.

Noise that results from the turbulent flow of air increases with increasing velocity of flow. From this standpoint, it is desirable to have the air velocity low; however, this involves relatively larger ducts and hence greater expense. If a certain level of noise is acceptable in a room, acoustical correctives will permit the ventilation system to have a higher velocity. The increase in noise with airflow velocity is illustrated by the curves of grille noise level shown in Figure 1.14. The measurements were taken at a distance of 6 feet from each of three typical grilles having a face area of 0.5 square foot. These data indicate that grilles that produce a large spread of air by deflectors which offer obstruction to the outward flow produce a somewhat higher noise level than do those having little air resistance. For a grille of a given type, increasing the face area increases the noise level if the air velocity is constant; the increase is approximately 3 dB for each doubling of the face area. For example the noise level for grille B which has an area of 0.5 square foot, is 27 dB for a face velocity of 1250 feet per minute The noise generated by a grille of this type having an area of 1 square foot would be 30 db for the same air velocity of 1250 feet per minute. If the total amount of air flowing past the grille remains the same, the noise level decreases rather rapidly as the size of the grille is increased.



CURVE A IS FOR A GRILLE PROVIDING LITTLE SPREAD.
CURVE B IS FOR A GRILLE OF THE HONEYCOMB TYPE GIVING A SMALL SPREAD.
CURVE C IS FOR A GRILLE PRODUCING A LARGE SPREAD.

Figure 1.14 NOISE LEVEL NEAR GRILLE VS FACE VELOCITY OF AIRSTREAM

1.3.2.3 Traffic and Sundry Noises

In a recent analysis of noise complaints in Boulder, Colorado, traffic noises and barking dogs ranked number one and two in order of annoyance value. The number one traffic culprit was the motorcycle with 83 percent of the people interviewed being annoyed by this source. The barking dog rated 55 percent annoyance with buses, sirens, construction, aircraft and railroads, bringing up the rear. The point here is that extent of annoyance percentages for various traffic and sundry noise sources is chiefly a question of locale. For a small town such as Boulder, Colorado with an overabundance(%) of dogs, cats, and motorcycles, such noise sources would be high on the annoyance list. In larger cities, other stationary noise sources usually rank higher. Table 1.5 presents a breakdown of complaints from a typical major metropolis over a two year period with number of complaints and percentage of total listed separately. Stationary noise sources appear to lead the list of complaints. In large congested cities, many air conditioning units piled one on top of another in bedroom windows of apartment buildings and homes often cause sleeping problems during summer months and thus it would be expected that such sources might lead the field of noise complaints. The second highest complaint generated was factory noise, which in a large city can be a major nuisance when industrial zones abutt residential districts. In both instances, the value of strict district boundary noise limits is highly revealed.

1.3.3 Noise and Communication

Noise has been defined by the USASI as any undesired sound. This may be a pure tone, a combination of pure tones, or a broadband of sound that is undesired at a particular location, in a given circumstance at a particular time. At times one type of sound may be pleasing; at other times it may be annoying or harmful. A stereo set playing a record on the first floor of a house may have a pleasant psychological effect on some persons. For someone trying to sleep in an upstairs bedroom, it may be psychologically disturbing. Loudness of a sound is a psychological judgement which the listener makes of a sound above his threshold for hearing.

TABLE 1.5

COMPLAINT SUMMARY & BREAKDOWN

	1971 to 1972		1972 to 1973	
Air Conditioners	462	10.9%	190	10.9%
Factories	360	8.56%	113	6.5%
Scavengers	333	7.9%	142	8.1%
Construction	303	7.28%	151	8.7%
Trucks	288	6.9%	125	7.2%
Cars	264	6.35%	80	4.61%
Motorcycles	246	5.8%	82	4.73%
Musical inst.	230	5.7%	109	6.2%
Loud speakers	182	4.33%	95	5.4%
Exhaust Fans	186	4.42%	97	5.6%
Hornblowing	136	3.30%	77	4.4%
Railroads	125	5.3%	60	3.4%
Vibrations	115	2.7%	55	3.1%
Ice cream trucks	93	2.21%	13	3.1%
Gas stations	66	1.57%	34	1.96%
Church bells	60	1.42%	25	1.4%
Reefer trucks	43	1.02%	8	.46%
Whistles	37	.88%	11	.63%
Animals	33	.57%		
Buses	30	.713%	23	1.32%
Burglar Alarms	16	.38%	7	.404%
Lawn Equipment	15	.356%	2	.11%
Car wash	14	.33%	9	.51%
Airplanes	12	.28%	4	.230%
Buses	12	.28%	3	.173%
Dust collectors	5	.118%	3	.173%
Miscellaneous	616	14.8%	214	12.3%

Not all sounds are noise; many convey information, which is useful or essential to life. The sound of a machine, for example, conveys information to the operator. It lets him know whether it is running normally. But, to an adjacent operator tending another machine, the sound coming from his co-worker's machine would be considered noise. In the development of the mechanization of industry such machines of greater power and higher speed, often with correspondingly augmented noise output, replaced smaller ones. The growth of mechanization has thus been accompanied by an increase in noise. Although commendable efforts are being made to reduce the noise of machines and appliances, there has been no marked reversal in the upward trend in city and industrial noise. On the other hand, the public is becoming increasingly conscious of the ill effects of noise. Even quite feeble noises interfere with the hearing of speech and music; moderately loud noises produce auditory fatigue; and very loud noises, if long endured, induce permanent losses of hearing.

Although the influence of noise on the working efficiency and general health of human beings is generally recognized as harmful, those who have scientifically investigated these effects are not in complete agreement about their nature and extent. There is evidence from one carefully conducted investigation that both the working efficiency and the total output of weavers increased when they wore ear plugs which reduced the noise level from 96 to 81 db. The detrimental effects of the noise were observed to be greatest at the beginning and near the end of work periods, possibly indicating that persons go through a process of adaptation to noise, endure it without noticeable effects for a time, but finally suffer from its incessant attack. The bulk of other evidence indicates that the reduction of noise and reverberation results in increases in output of labor and in human well-being that more than offset the cost of the acoustical treatment. Although it is difficult to measure fatigue, most observers agree that excessive noise exacts a heavy toll in frayed nerves and physical exhaustion.

1.3.3.1 Speech Power and Noise Interference

The average person is surprised at the exceedingly minute amount of energy contained in speech. Approximately 15,000,000 lecturers speaking at the same time generate acoustical energy at a rate of only 1 horsepower. When the speech power of a single speaker is diffused in a large auditorium, the sound pressure in the room is reduced to extraordinarily small values. Under such circumstances, it is easy to understand why it is difficult to hear well in a large room, and why very feeble sources of extraneous noise may produce serious interference with the speech. For example, the noise of the distant ventilating fan or motor, the shuffling of feet on the floor, the jarring of a nearby door, or the whispering or coughing of inconsiderate "spectators" may be sufficient to mask many of the speech sounds and especially the feeble consonants, which reach a listener in a large auditorium.

An extensive investigation of the conversational speech power output of individuals of two groups, six men and five women, was conducted by Dunn and White. This study indicates that the average male person produces a long-time-interval average sound-pressure level of about 64 db at a distance of 1 meter, directly in front of him, when he talks in a normal conversational voice; the average for women, as shown by this study, is about 61 db at a distance of 1 meter.

The above data are for conversational speech in a quiet location in the absence of reflecting surfaces. Noise, the size of the room in which a person is speaking, his distance from the auditor, the acoustical conditions of the room, and other factors affect the power output of his speech, and especially the sound-pressure distribution throughout the room. If a noisy condition prevails, the voice must be raised in order to override the noise. Thus in general an increase in power output versus distance from a listener is required.

1.3.3.1.1 Voice Sounds

Voice sounds are formed by passage of air through the vocal cords, lips, and teeth. As the airstream passes through the vocal cords, they are set in vibration. The cavities of the nose and throat impress resonant characteristics on these vibrations to produce speech sounds. All the vowel sounds and some of the consonant sounds are produced in this manner. Other sounds called unvoiced sounds, for example, f, s, th, sh, t, and k are produced by passage of air over the teeth and tongue without use of the vocal cords. Voiced consonants, such as b, d, g, j, v, and z, are combinations of the two processes.

The various vowel sounds are made by changing the shape of the resonant chamber so that different frequencies are enhanced. Each of the vowel sounds has certain characteristic frequency groups as shown in the frequency chart and table.

CHARACTERISTICS FREQUENCIES OF VOWEL SOUNDS

Vowel sound	Low frequency	High frequency
a (tape)......	550	2100
a (father)....	825	1200
e (eat).......	375	2400
e (ten).......	550	1900
i (tip).......	450	2200
o (tone)......	500	850
u (pool)......	400	800

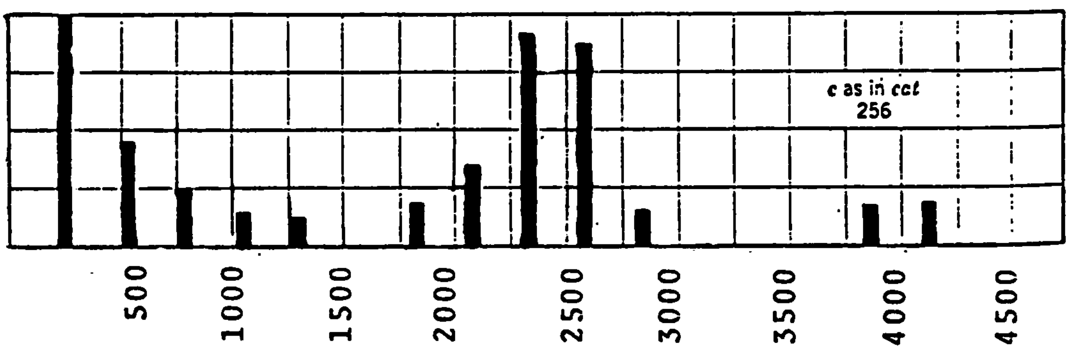


Figure 1.15 FREQUENCY CHART FOR A VOWEL SOUND (Ref. 2, p. 270)

The values given are average values and there is considerable variation for different individuals and for a single individual at different times. If one of these speech sounds is passed through a sound filter that absorbs frequencies in the neighborhood of one of the characteristic frequencies, the vowel sound is no longer recognizable.

Articulated speech consists of a flow of various combinations of these consonants and vowels. The nature of the articulation of the separate syllables and words in speech, and the rapidity with which the separate syllables follow one another, have a great bearing upon how well the speech is heard. If the separate syllables are inaccurately formed, and if they follow each other in rapid succession, they may not be heard distinctly.

1.3.3.2 Noise and Speech Interference

The most demonstrable effect of noise on man is that it interferes with his ability to use voice communication. A noise that is not intense enough to cause hearing damage may still disrupt speech communication as well as the hearing of other desired sounds.

The arithmetic average of the readings in decibels for the three octave bands, centered on 500, 1,000 and 2,000 Hz, contained in a wideband noise has empirically been shown to provide an indication of the ability of that noise to affect the intelligibility of voice communication. The average of these three octave band decibel values is called the speech-interference-level (SIL). The graph on the next page gives a relationship between this speech interference as a function of background noise. In noises whose spectra yield an SIL greater than 85 dB, personnel would have to speak in a very loud voice and use a selected and possibly prearranged vocabulary to be understood over a distance of 1 foot. A SIL between 65 and 75 dB would barely permit reliable communication over 2 feet with a raised voice. This span of communications would be extended to 4 feet by using a loud voice and to 8 feet by shouting. In noise having an SIL between 55 and 65 dB, a normal voice level would be effective over a distance of 3 feet, a raised voice over a distance of 6 feet, and a very loud voice over a distance of 12 feet. A SIL of 55 dB or less would be permissible in large business or secretarial office areas. A SIL of 45 dB or less would be desirable for private offices or conference rooms.

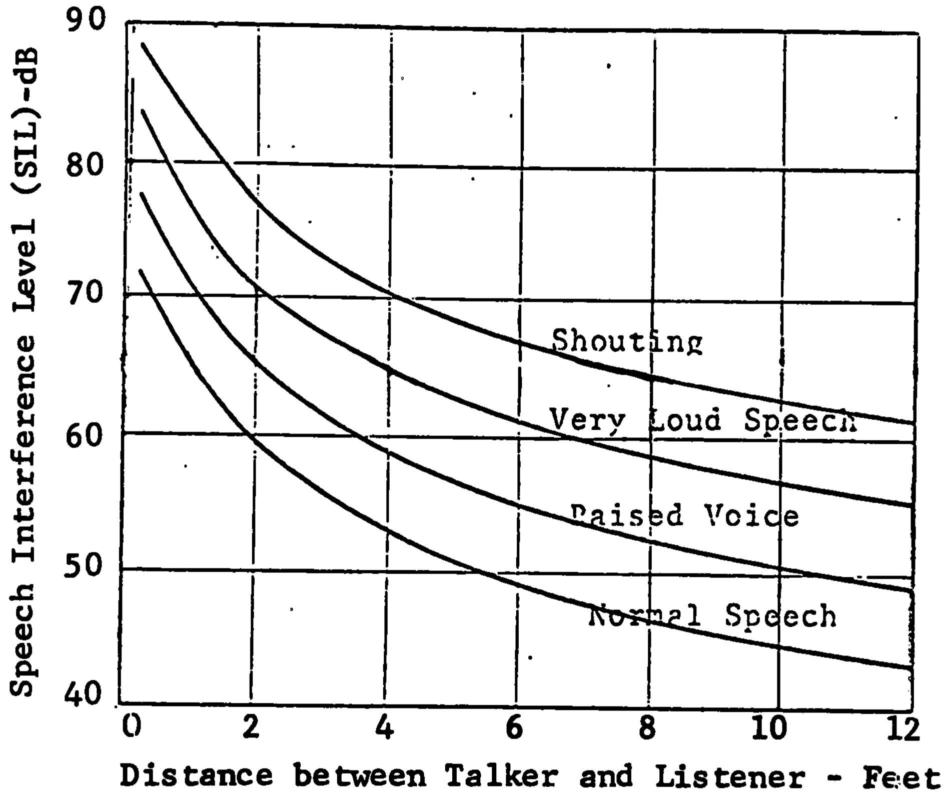


Figure 1.16 VOICE LEVEL AND DISTANCE CONDITIONS NEEDED TO ENSURE SATISFACTORY SPEECH INTELLIGIBILITY

Another format for determining SIL is through use of table postulated by L. Beranek in 1947. As it appears on the next page, the table gives the average SIL of noise that will just barely permit reliable speech communication for a range of voice levels and distances. The data are based on tests performed out-of-doors where there are no reflecting surfaces to help reinforce the speech sounds, but the values can be used as approximations for indoor conditions as well.

As a simple example of the use of this table if the noise levels in a mechanical equipment room average 62 dB in the 500, 1000 and 2000 Hz bands, barely reliable speech conversations could be carried on in that room by shouting at a 16 foot distance, by using a loud voice level at a distance of 8 feet, by using a raised voice at a distance of 4 feet or by using a normal voice level at a distance of 2 feet.

	Voice level (average male)			
Distance, ft	Normal	Raised	Very loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

As can be noticed, the graph from the preceding page is generated by data such as this and it is suggested to the reader that he make up his own set of SIL levels and thus determine various distances and background noise levels which yield effective speech communication.

1.3.3.3 Noise and Annoyance

1.3.3.3.1 Aircraft Flyover

Perhaps the most widespread reaction to noise is that it is annoying. Whether annoyance types of noise conditions constitute a hazard to health is not known. It has been stated that residents of communities surrounding airports develop hypertension, ulcers, undue anxiety and nervous disorders as a result of the aircraft flyover noise exposure. These effects, however, have rarely been verified. In fact, studies of communities impacted by aircraft noise show complaints to be motivated by factors that do not bear directly on the health status of the exposed population, e.g., interruption in voice conversation (telephone use), TV reception, and personal grievances against the airport management. Such studies, however, have not included a survey of the health of the residents in the impacted area and so do not rule out the possibility that physiological or mental type disorders may stem from such noise conditions.

In any event, judgments of noise-annoyance are complicated by many nonacoustical considerations. Some of these considerations are cited with examples to illustrate each of them.

1. Factor: The sound has unpleasant associations.

   Example: The annoyance caused by the intrusion of aircraft noise into communities around airports is based, in part, upon the residents being fearful of the planes crashing into their homes.

2. Factor: The sound is inappropriate to the activity at hand.

   Example: Music tolerated during waking hours may be annoying during the hours of sleep.

3. Factor: The sound is unnecessary.

   Example: People may complain of the noise made by the neighbor's pets, but not by the delivery trucks in the same neighborhood.

4. Factor: The sound has an advantage associated with it.

   Example: The comforts derived from air conditioning outweighs the noise of such units. Similarly, the economic value of nearby plants to a community may balance out the noise produced by the plants; annoyance due to military aircraft noise may be offset by the assurance against surprise attack by an enemy.

5. Factor: Individual tolerance to noise.

   Example: Some individuals complain about all kinds of noise as well as other types of nuisances.

As for the stimulus itself, there appear to be some basic characteristics of sound which can be considered as more annoying than others. These characteristics are:

1. Loudness - the more intense and consequently louder sounds are more annoying.
2. Pitch - a high pitch sound, i.e., one containing high frequencies is more annoying than a low pitch sound of equal loudness.
3. Intermittency and irregularity - a sound that occurs randomly in time and/or is varying in intensity or frequency is judged more annoying than one which is continuous and unchanging.
4. Localization - a sound which originates from several sources or locations is less preferred than one which originates from a single source.

At the present time, extensive interest is being directed toward identifying which measure or measures of noise best correlates with annoyance reaction. A new measure called perceived noisiness in decibels (PN_{dB}) has been found to agree well with subjective rating of the acceptability of aircraft flyover noises. This measure takes into account the octave band intensity levels of the noise in question and adjusts them in terms of data showing equal annoyance judgments for different bands of noise. Some noise criteria for airport operations are specified in terms of PNdB. John F. Kennedy Airport (formerly Idlewild), for example, has a noise ceiling of 112 PN_{dB} for all aircraft operations as measured under the flight path of outgoing or incoming aircraft at 7 meters from the end of the runway.

Besides PNdB computations, still other procedures have been proposed to convert the physical measurements of a noise into numerical expressions of annoyance level: Specifically, conversions to loudness measures in sones or phons as developed by Stevens or by Zwicker's technique are quite popular for noise annoyance quantification. The assumption in using loudness formulations for rating noise-annoyance is that loudness is the chief determinant in annoyance judgments. Also A-scale sound-level values read directly off a conventional sound pressure-level meter have been frequently used to provide numerical expressions of noise-annoyance conditions.

Inherent to the A-scale readings as well as the conversion procedures noted are weighing schemes which reflect, in various ways, established relationship between the physical dimensions of sound (primarily frequency and intensity) and associated auditory reactions, both psychological and physiological.

It must be emphasized again that the procedures noted above can give only limited prediction of community noise nuisance because they consider only the physical characteristics of the noise stimulus itself. Other factors -- social, personal, economic -- must also be taken into account in making such predictions. Several models now exist which consider the physical characteristics of the noise together with known social and psychological factors in estimating the complaint potential of a noise to a community or neighborhood.

1.3.3.3.2 Noise Criteria

The degree of disturbance or annoyance of an intruding unwanted noise depends essentially on three things: (1) the amount and nature of the intruding noise, (2) the amount of background noise already present before the intruding noise occurred and (3) the nature of the working or living activity of the people occupying the area in which the noise is heard. People trying to sleep in their quiet suburban homes would not tolerate very much intruding noise; while office workers in a busy mid-city office could have greater amounts of noise without even noticing it; and factory workers in a continuously noisy manufacturing space might not even here a noisy nearby equipment installation.

It is common practice in noise engineering to rate various environments by "noise criteria" and to describe these criteria by fairly specific noise level values. Detailed discussions of noise criteria can be found in other literature, and only a brief useful summary of that material is introduced here. In the interest of brevity, many important details and qualifications are omitted.

From earlier studies of many types of noise environments that people have found either acceptable or unacceptable for various indoor working or living activities, a family of Noise Criterion Curves (NC curves) has been evolved. Figure 1.17 on page 1.65 represents these curves. Each curve represents a reasonably acceptable balance of low frequency to high frequency noises for particular situations. These curves are also keyed-in to the speech communication conditions permitted by the noise. Thus, the lower NC curves prescribe noise levels that are quiet enough for resting and sleeping or for excellent listening conditions, while the upper NC curves describe rather noisy work areas where even speech communication becomes difficult and restricted. The curves within this total range may be used to set desired noise level goals for almost all typical indoor functional areas where some acoustic need must be served. For convenience in using NC curves, octave band sound pressure levels are usually given in conjunction with them.

In Table 1.6, a number of typical indoor living, working, and listening spaces are grouped together into categories and each category is assigned a representative range of noise criterion values. Low category numbers indicate areas in which relatively low noise levels are desired; higher category numbers indicate areas in which relatively higher noise levels are permissible. Any occupied or habitable area not specifically named in Table 1.6 can be added under any appropriate category number as long as the acoustic requirements of the new area are reasonably similar to those of the areas already named under that category.

In general, the lower limit of each range should be used for the more critical spaces or the more sensitive or critical occupants of an area, while the upper limit of each range may be used for the less critical spaces or occupants of an area. An exception to this generalization may occur when it is clearly known that the background noise of an area is so quiet and the walls between adjoining rooms have such low transmission loss that speech sounds or other clearly identifiable sounds that may intrude from one

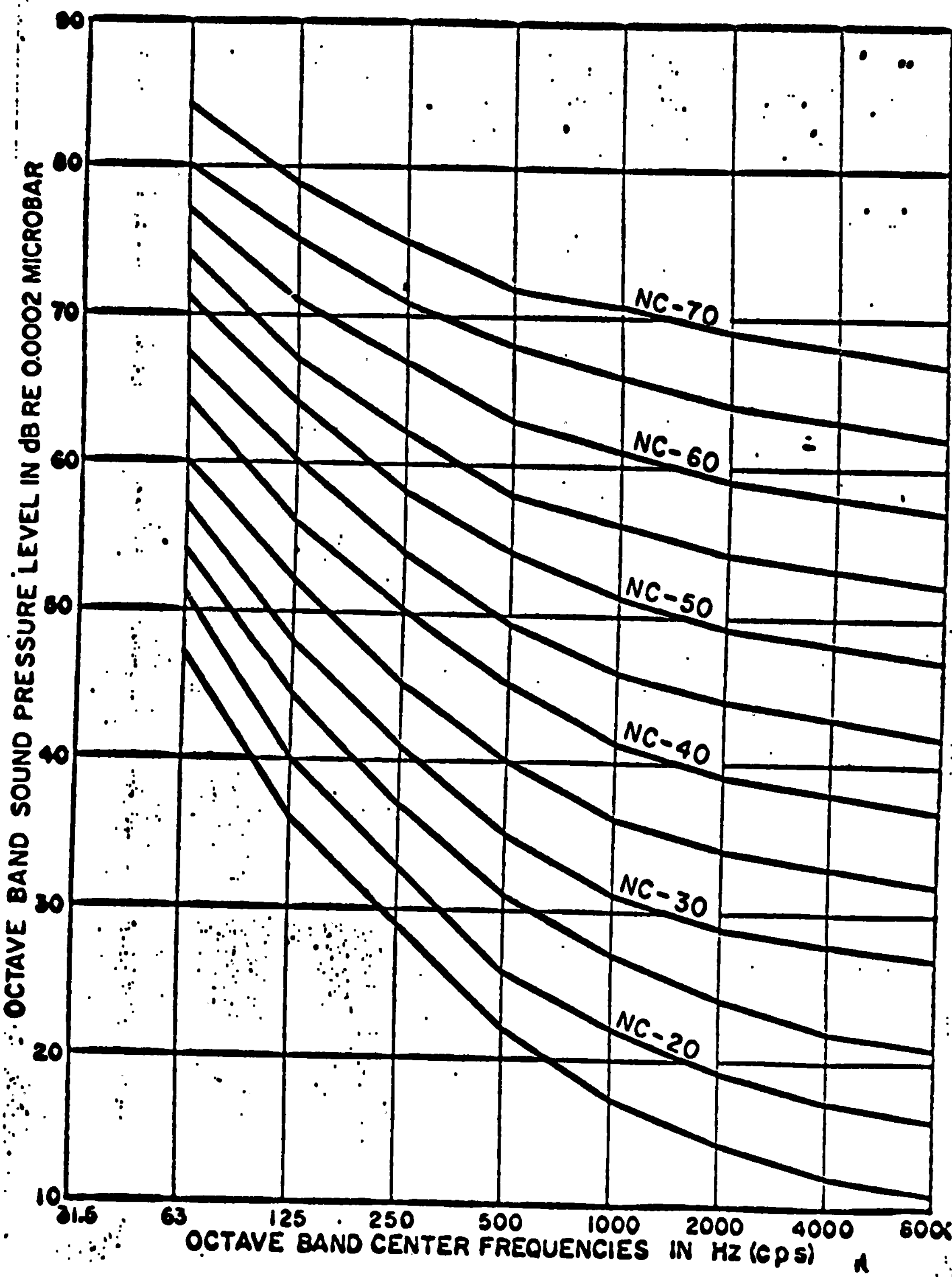


Figure 1.17 NOISE CRITERIA CURVES FOR INDOOR SUBJECTIVE REACTION TO NOISE

TABLE 1.6

CATEGORY CLASSIFICATION AND SUGGESTED NOISE CRITERION RANGE FOR BACKGROUND NOISE AS HEARD IN VARIOUS INDOOR FUNCTIONAL ACTIVITY AREAS

Category	Area (and Acoustic Requirements)	Noise Criterion
1	Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing)	NC-20 to NC-30
2	Auditoriums, theaters, large meeting rooms, large conference rooms, churches chapels, etc. (for very good listening conditions)	NC-20 to NC-30
3	Private offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions)	NC-30 to NC-35
4	Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for fair listening conditions)	NC-35 to NC-40
5	Lobbies, laboratory work spaces, drafting and engineering rooms, maintenance shops such as for electrical equipment etc. (for moderately fair listening conditions)	NC-40 to NC-50
6	Kitchens, laundries, shops, garages, machinery spaces, power plant control rooms, etc. (for minimum acceptable speech communication, no risk of hearing damage)	NC-45 to NC-65

It is noted here that much of the known data on criteria do not extend down to the very low frequency band of 31 Hz. Some of the noise source data, however, include 31 Hz levels. For most ordinary noise problems, there will be no serious concern for the 31 Hz band so it can be ignored for most calculations. If it is known that a serious problem involves decision-making at 31 Hz, acoustical assistance should be obtained.

office to another would not be disturbing to occupants of either area. In this type of situation, masking noise may also have to be introduced into the rooms in order to reduce some of the intelligibility of the intruding sounds so that the higher range of noise criterion values may actually be useful. When properly controlled as to spectrum shape and sound level, ventilation system noise (the gentle hissing of diffusers, under-window induction units, dampers or air valves) sometimes provides some of this masking noise. In more critical cases, where spectrum and level must be held under close control, electronic noise sources may be used.

A special note of concern is given for Category 1 and 2 areas as they appear in Table 1.6. For a very quiet community area or for a quiet building with no internal ventilation system noise, the NC-20 noise criterion should be applied for indoor conditions. For a noisy city environment outdoors or for a building with a ventilation system known to fall in the NC-30 noise range, an NC-30 noise criterion can be applied to rooms other than bedrooms or auditoriums. For bedrooms or auditoriums or for situations that do not clearly fall at the NC-20 lower limit or NC-30 upper limit, NC-25 indoor noise criterion levels should be applied.

1.3.3.3.3 <u>Vibration Criteria</u>

Relationships between vertical sinusoidal vibration levels and subjective response based upon various studies have been derived over the past 40 years. The surveys have in general consisted of placing a reasonable sampling of individuals on vibrating platforms. The vibration of the platform is reduced to a point whereby the majority of individuals tested report no perceptible vibration. The intensity of vibrations is then increased until perceptible vibration is felt, and finally up to a point where the platform shakings are considered annoying by the majority of those tested.

Two major studies have been undertaken to report such vibrations. The first was made by Reiher & Meister in the early thirties, and the most recent study was made by Dieckman in 1958. Figures 1.18 and

1.19 on pages 1.69 and 1.70 show the acceleration levels relative to 1 g of force at frequencies from 3.2 Hz to 250 Hz that resulted from these two studies. Figure 1.19 also relates the Reiher and Meister study to the NC curves described previously. The original studies based their data on displacement and thus in order to obtain the intensity levels given here, a double derivative was taken for each frequency and each amplitude characteristic. As will be noted, acceleration levels in the higher frequency bands become less annoying than low frequency vibrational energy whereby levels as much as 43 dB below 1 g are annoying in the 3.2 to 4.0 Hz one-third octave. As will also be noted, the Dieckman study seems to indicate a lower threshold of vibration sensitivity than did the earlier Reiher & Meister survey. Whether this was due to the type of sampling subjects tested, or perhaps changes in scientific analysis techniques, only future surveys will be able to deduce.

A discussion of hearing and the affects of noise thereon is prepared for the concluding part of this final report. At this point it would be best to bear in mind that vibration can also be a hazard to health and welfare and should be considered as such.

1.3.4 Mechanism of Hearing

Major interest in this section will be given to the structure and function of the ear as related to the hearing process. The brain mechanisms underlying the hearing process will be largely ignored since noise-induced hearing loss seems to be primarily a peripheral as opposed to a central-type of disorder.

1.3.4.1 Ear Anatomy and Physiology

Anatomically, the ear can be divided into three subdivisions called the external, middle and inner ears. The external and middle ear functions are principly to collect and transmit sound stimuli to the inner ear where the sensory receptors for sound sensation are located. The pinna of the external ear funnels sound inward through the external ear canal to the tympanic membrane or eardrum. The incoming sound waves strike the eardrum and set it into vibration. Behind the eardrum is the middle ear, an air-filled cavity

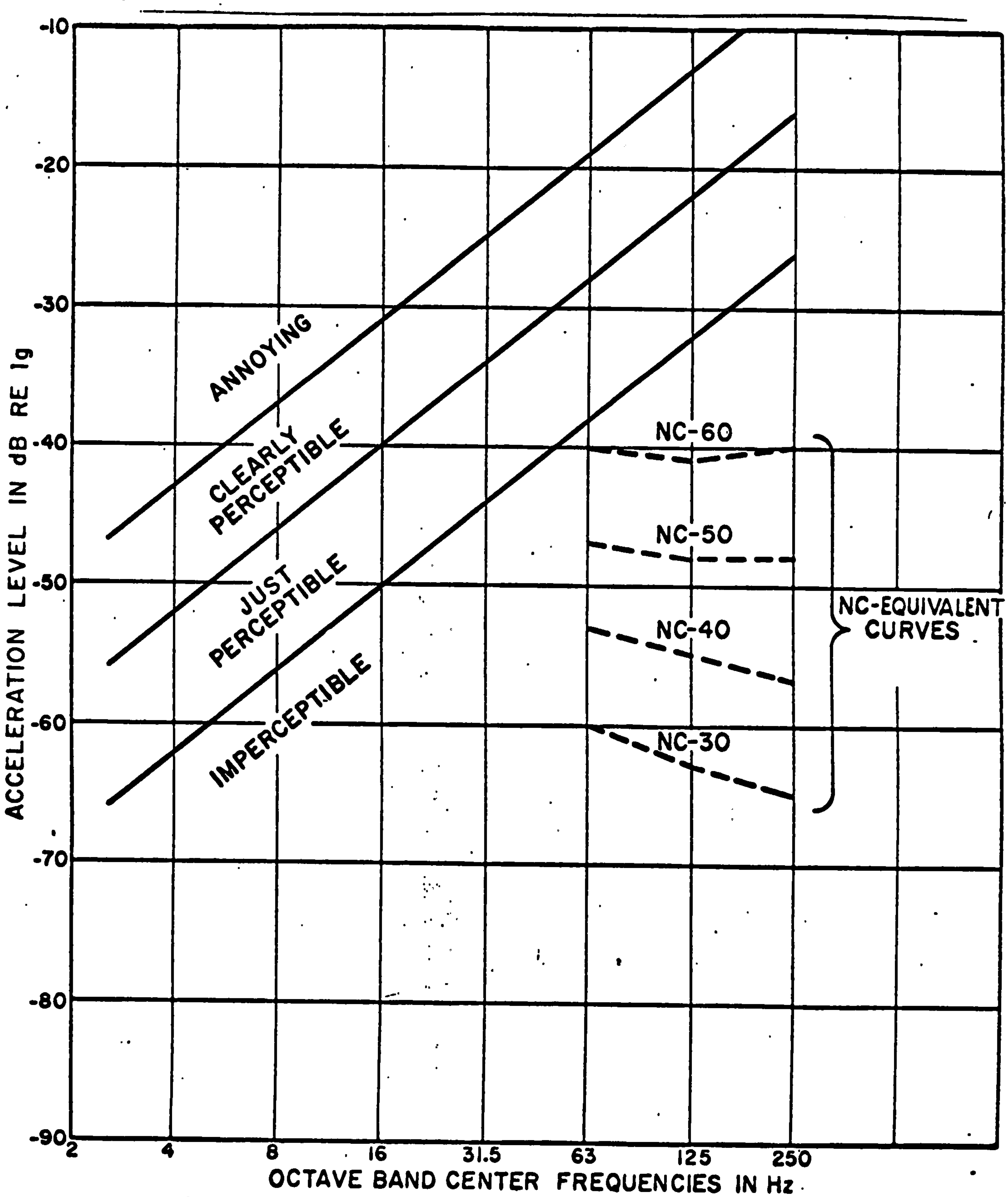


Figure 1.18 RELATIONSHIPS BETWEEN VERTICAL SINUSOIDAL VIBRATION LEVELS AND SUBJECTIVE RESPONSE BASED ON REIHER AND MEISTER DATA

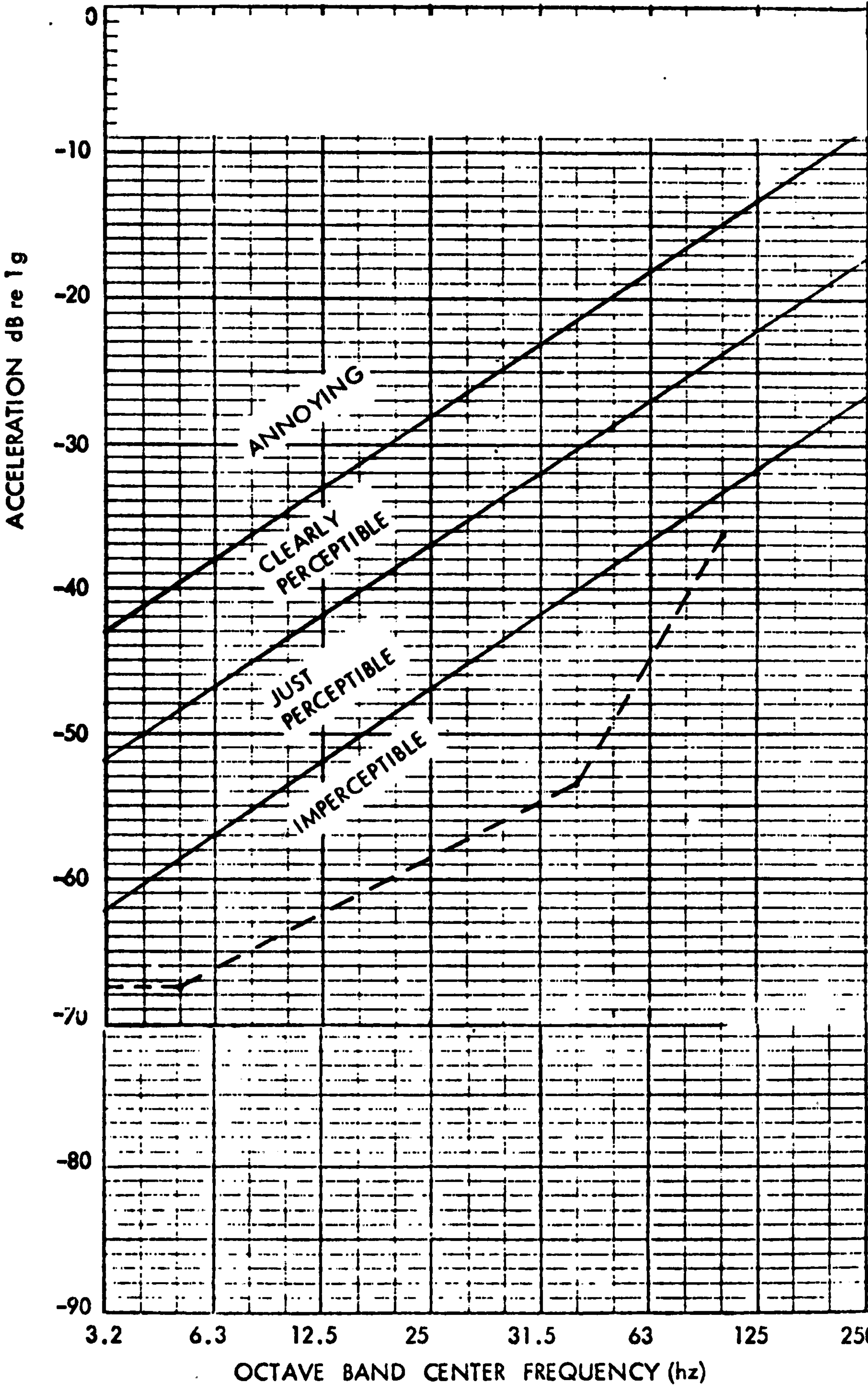


Figure 1.19 COMPARISON OF REIHER AND MEISTER AND DIECKMAN STUDIES ON SUBJECTIVE EVALUATIONS OF VIBRATION

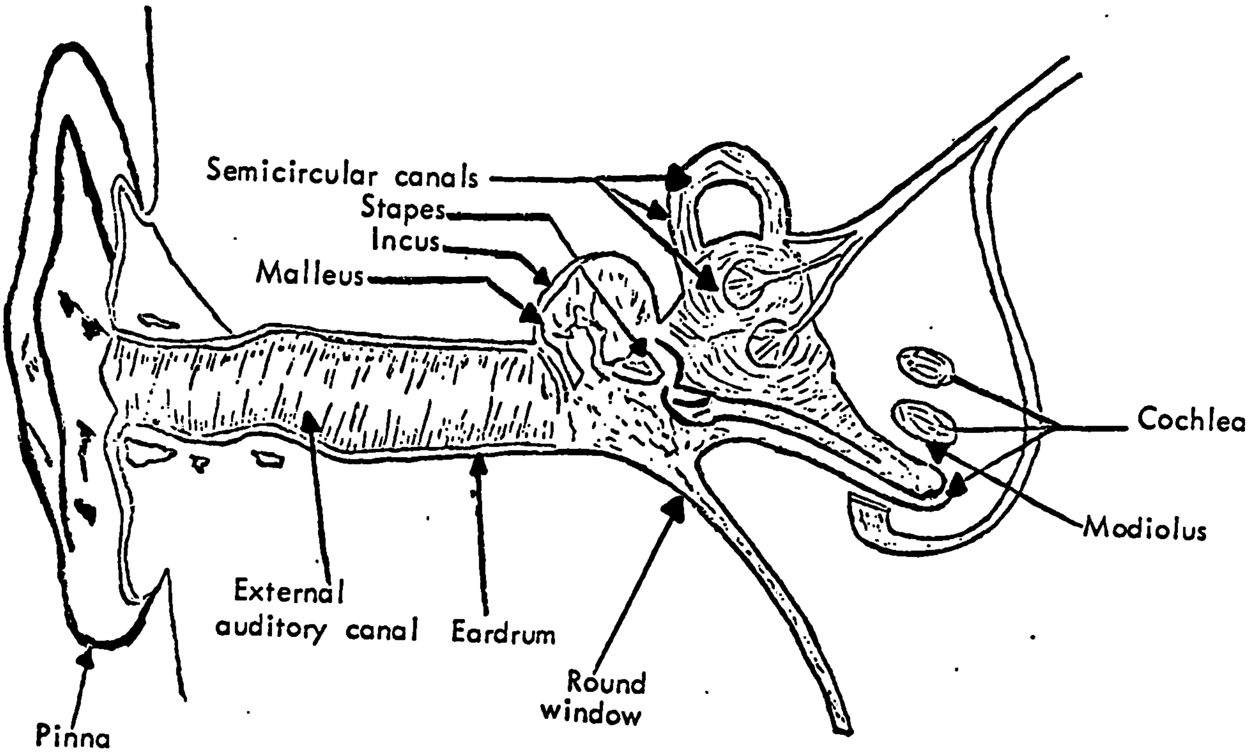


Figure 1.20 HUMAN EAR SHOWING THREE SUBDIVISIONS IN CROSS SECTION

containing three small bones or ossicles referred to as the malleus, incus and stapes. The handle of the malleus is attached to the eardrum and articulates with the incus, which, in turn, is joined to the stapes. The footplate of the stapes fits snugly in the oval window which is one of the two covered openings between the middle and inner ears. The other opening lies just below the oval window and is called the round window. Functionally, the three ossicles form a chain which carry the sound-produced vibrations of the eardrum through the middle ear to the inner ear.

Also located in the middle ear are the intra-aural ear muscles consisting of the tensor tympani and the stampedius. The tensor tympani is attached to the malleus and, when contracted, places the eardrum under greater tension. The stampedius muscle is fastened to the stapes and upon contraction pulls this bone in a downward and outward direction therein affecting the movement of the stapes footplate in the oval window. The contractile state of these muscles can be produced by the onset of intense sound and, in effect, reduces the amount of sound energy that is conducted by the ossicular chain to the inner ear. This action is considered protective in nature since it minimizes the potentially damaging effects of high intensity sounds on the hearing receptors in the inner ear.

Another middle ear feature is the Eustachian tube, a passageway leading from the middle ear cavity to the back of the nose and throat. The purpose of the tube is to equalize air pressure on both sides of the eardrum. Equalization in pressure is necessary to make the eardrum more capable of responding to and transmitting the sounds impinging upon it.

Just behind the oval and round windows is the inner ear which consists of three sections known as the vestibule, semicircular canals, and cochlea. Of these, the cochlea is the most important for hearing. The human cochlea is essentially a triple canal coiled up spirally around a bony axis, the modiolus, which is channeled to form the pathway for the auditory branch of the VIIIth cranial nerve. The larger turns of the spiral are at the three canals comprising the cochlea and are formed by two partitions. One partition is composed of a ledge of bone, the spiral lamina, which winds around the modiolus like the thread of a screw and the basilar membrane which extends from the projecting tip of the spiral lamina to the outer wall of the cochlea. The second partition is formed by Reissner's membrane which stretches from the upper surface of the spiral lamina to a point on the outer wall of the cochlea, a short distance above the attachment of the basilar membrane. The canal, which lies below the basilar membrane, is called the tympanic canal (scala tympani); the canal enclosed between the basilar membrane and Reissner's membrane is called the cochlear duct (ductus cochlearis), and the canal existing above Reissner's membrane is referred to as the vestibular canal (scala-vestibuli). The vestibular and tympanic canals contain perilymph fluid and communicate with one another through a tiny opening at the apex of the cochlea. The base of the vestibular canal is sealed by the oval window into which the footplate of the stapes is lodged. The lower termination of the tympanic canal is sealed

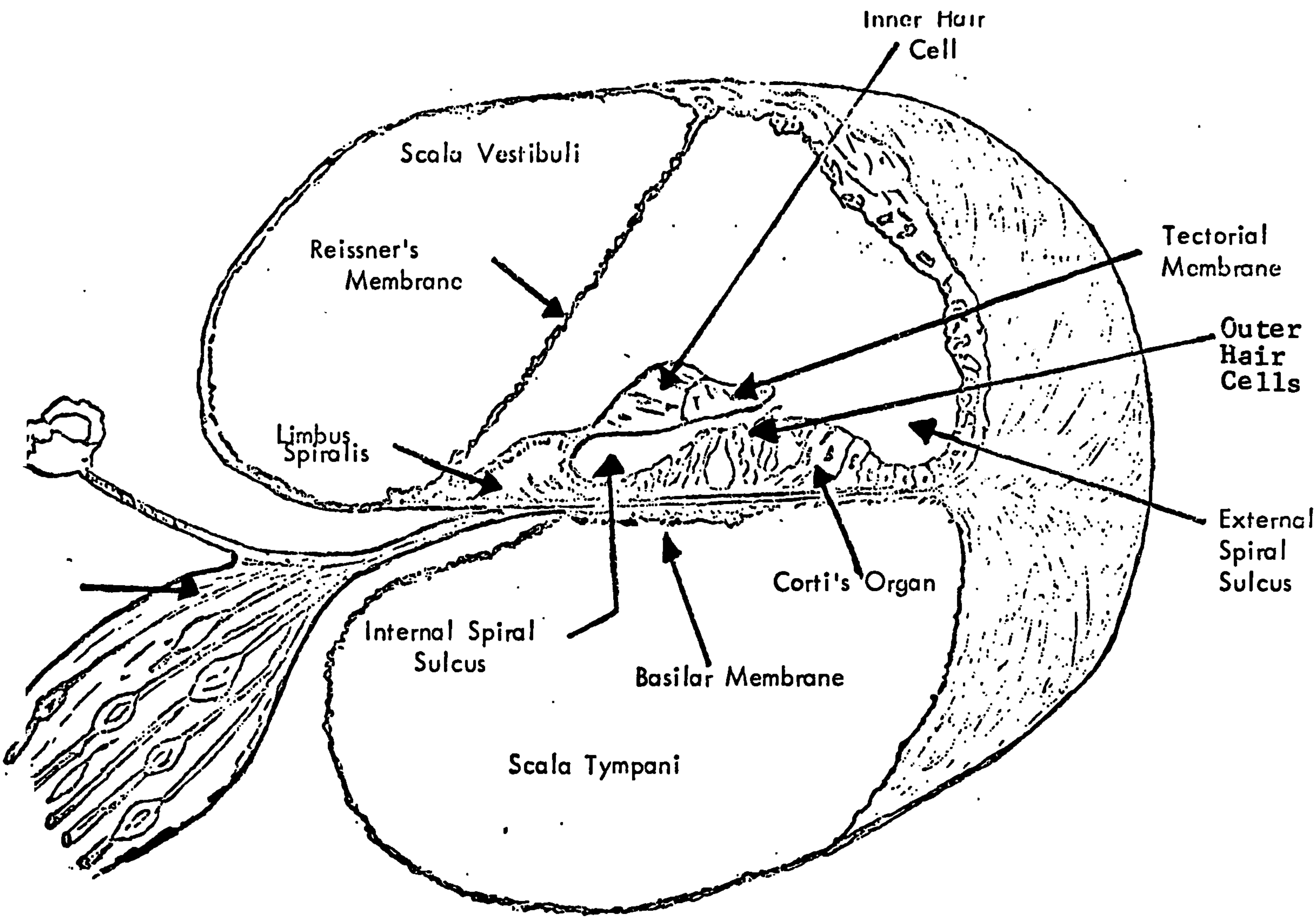


Figure 1.21 ENLARGED CROSS SECTION DRAWING OF THE COCHLEA

by the membrane-covered round window. The cochlear duct contains endolymph fluid and also the tectorial membrane which is attached at one end to the spiral lamina with the other end floating freely in the endolymph just above the basilar membrane.

The basilar membrane is narrowest at the base of the cochlea (i.e., near the oval window) and becomes progressively wider as it extends towards the apex. This is in contradistinction to the dimensions of the total cochlear structure which becomes smaller as the apex is approached. Distributed in four rows (one inner row, three outer rows) along the entire length of the basilar membrane are hair cells which project upward toward the underside of the tectorial membrane. These hair cells are the sensory receptors for hearing which together with supporting cells constitute the Organ of Corti, the auditory sense organ. The hair cells are innervated by nerve fibers which pass through small openings in the spiral lamina and enter the modiolus of the cochlea where their cell bodies are grouped to form the spiral ganglion. Axons from this ganglion collect at the base of the cochlea and pass out from the bottom of the coil as the auditory branch of the VIIIth cranial nerve. These axons end upon nerves in the medulla, which, in turn, pass axons to different and higher nerve centers in the thalamus and cerebellum. Axons from these centers finally lead to the temporal lobe of the cerebral cortex.

Although knowledge is still lacking, cochlear function underlying the hearing process has become clearer in recent years. As a physical system the cochlea has been described as an enclosed column of fluid bounded at one end by the stapes footplate in the round window and at the other end by the membrane covering the round window. Since fluid is incompressible, the vibrations transmitted by the stapes footplate, similar to a plunger action, cause mass movements of fluids in the cochlear canals. In this process every inward movement of the stapes footplate causes the round window to bulge outward, and every stapes outward movement causes the round window to move inward. The fluid movements in the cochlear canals cause structural displacements along the basilar membrane which take the form of a traveling wave whose crest along the membrane depends, upon the frequency of sound stimulation. Generally, the locus of the crest or peak displacement for high frequency sounds is in the basal section of the basilar membrane, the peaks for lower frequencies becoming progressively shifted toward the apex of the basilar membrane.

As a result of the wavelike motions of the basilar membrane, a shearing action develops between the basilar membrane and the tectorial membrane leading to bending face of the basilar membrane.

This hair cell deformation causes electrical and/or chemical changes which are believed to trigger nerve impulses in the nerve fibers associated with the hair cells. The pattern of neural impulses arising within the cochlea provides the basis for auditory sensation and is transmitted to the cerebral cortex for interpretation.

1.3.4.2 Sensitivity of the Ear

A sound wave must have a certain minimum value of pressure in order to be heard by an observer. This value for selected observers, who have good hearing, who are facing the source of plane progressive waves and listening with both ears, is called the minimum audible threshold for a free field. This is shown in the lower curve of the figure below. Frequency is indicated along the horizontal axis; and the pressure level of the plane progressive sound wave that is just barely audible is indicated along the vertical axis. One notes

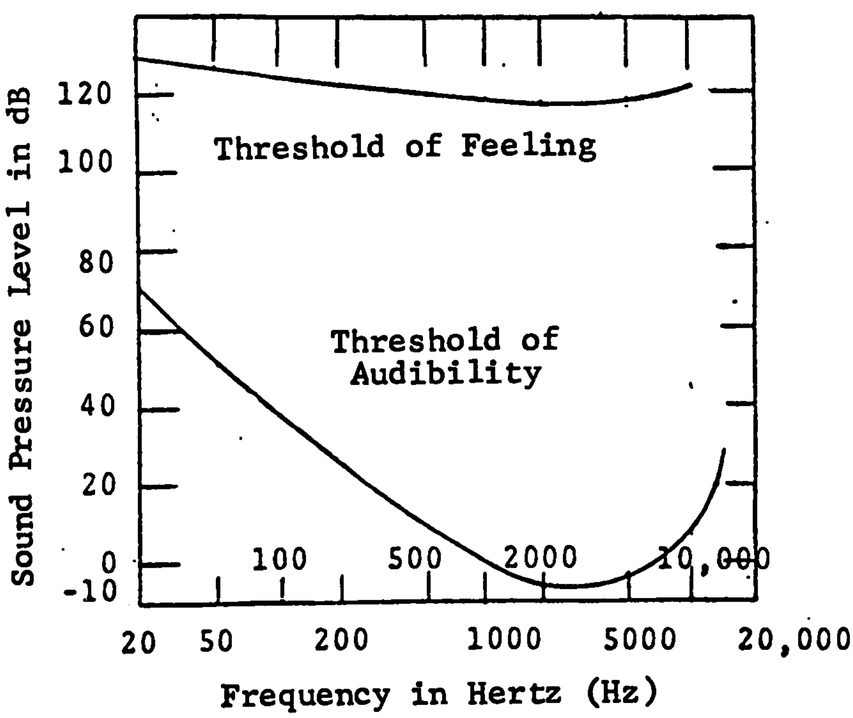


Figure 1.22 CHART SHOWING THE MINIMUM AUDIBLE THRESHOLD VS FREQUENCY, AND THE THRESHOLD OF FEELING (0 dB = 0.00002 pascals)

that the sensitivity of hearing varies enormously for sounds of different frequencies. Fortunately, the ear is most sensitive in the frequency range that is most important for the intelligibility of speech sounds. Since, in the evolution of man, speech and music were developed later than the sense of hearing, it appears that speech and music have developed in such a manner as to be well adapted to the sensitivity characteristics of the ear.

The frequency of maximum sensitivity is in the vicinity of 3000 Hz for normal ears. To some extent this is accounted for by resonance in the auditory canal, but other factors are undoubtedly of greater importance. The threshold curve crosses the 0 dB level at about 1000 Hz and rises in a regular manner with decreasing frequency, the minimum power required to produce an audible sound at 50 Hz being nearly a million times as great as it is at 3000 Hz. Measurements of the threshold curve below about 30 Hz are quite unreliable, as the required intensities become so great that it is difficult to avoid the presence of small percentages of harmonics in the source. Since the pitch-discriminating ability of the ear is relatively poor in this frequency range, the harmonics may be mistaken for the fundamental. Even when the source is known to develop a strictly pure sine wave, nonlinearity in the hearing mechanism itself may give the illusion of hearing a fundamental that is actually inaudible.

An observer in the field of a free plane progressive wave will notice that, as the pressure of the wave is increased, the resulting sound becomes louder and louder until it attains a level at which the sound can be felt (a sort of tingling sensation) as well as heard. This level is called the threshold of feeling. Above this threshold, the observer experiences a mixed sensation of sound, feeling, and pain. The previous figure shows that, unlike the minimum audible threshold, the threshold of feeling varies relatively little with frequency. The minimum audible threshold curve, if extrapolated at both ends, will intersect the threshold of feeling curve at two points which determine the lower and upper frequency limits of audibility; namely, at about 20 Hz for the lower limit and at about 20,000 Hz for the upper limit. These are the average values for young persons with good hearing. The upper frequency limit, along with the sensitivity for the higher frequencies, generally decreases with increasing age.

The ability of the ear to differentiate small changes of sound pressure or frequency is of importance in the hearing of speech and music. Anything that interferes with this function of the ear renders the understandability of speech or music more difficult. It is therefore of interest to inquire about the ear's capability in this respect. The minimum perceptible increment of sound-pressure level of a pure tone varies with both pressure and frequency, but, for levels greater than about 40 db above the threshold of audibility and for frequencies between 200 and 700 Hz, the minimum perceptible increment in pressure level varies from one quarter to three quarters of a decibel. The smallest perceptible change in frequency that the ear can detect is different for different pressure levels and frequencies, but, for pure tones more than 40 db above threshold and for frequencies greater than 500 Hz, it is of the order of 0.3 percent for monaural listening with an earphone.

The sensitivity of the human ear to sounds of low intensity is quite phenomenal. In the range from about 1000 to 5000 Hz, the minimum perceptible sound intensity is less than 10^{-4} micro-micro-watt/cm^2. Calculations show that in this frequency range the changes in pressure due to the thermal agitation of the air molecules are very nearly as great as the minimum audible acoustic pressures, so that any appreciable increase in the sensitivity of our hearing mechanism would also result in our observing a background of thermal noise, a hissing or rushing sound that would interfere with the perception of low-intensity acoustic waves. It is consequently improbable that there are any animals whose hearing is more acute than ours in this frequency range, for they too would be susceptible to the masking produced by thermal noise. On the other hand, it is well known that many animals, such as dogs, are readily capable of perceiving sounds of appreciably higher frequency than can human beings (see Figure 1.11, page 1.41).

1.3.4.3 Equal Loudness

Sounds of equal sound pressure level may not be rated by listeners as being equally loud. Loudness is a subjective quantity that is measured by a human observer. To determine how loud a sound is, a standard sound is chosen and a significant number of people compare the unknown with the standard. The accepted standard is a pure 1,000 Hz tone. The loudness level in phons of a 1,000 Hz tone by definition is the same as the sound pressure level in decibels. The loudness level of any sound in phons is numerically equal to the sound pressure level in dB of an equally loud 1K Hz standard sound. To human ears broadband sounds, like those of jet aircraft, seem much louder than pure tones or narrow band noise having the same sound pressure level.

The loudness of a sound depends not only on the pressure of the sound but also on its frequency spectrum. As we have seen, loudness can be described quantitatively in terms of another subjective characteristic of sound, the so-called loudness level, which is defined in terms of the sound level (which itself is defined in terms of the sound pressure and frequency of a pure tone; see figure below).

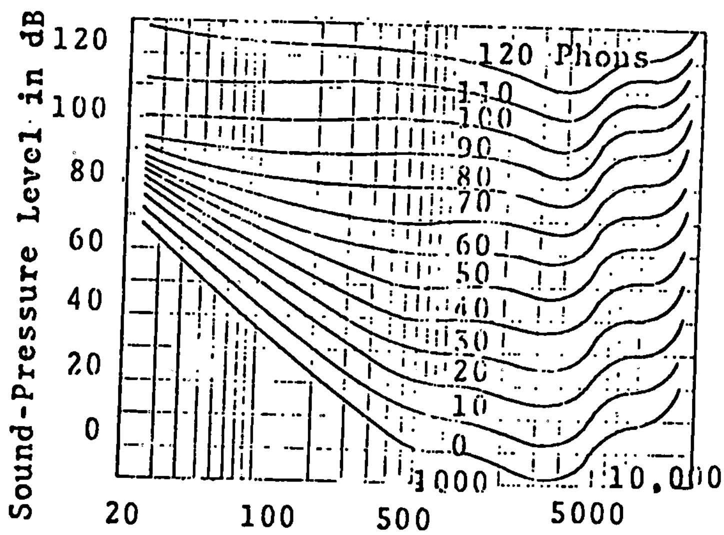


Figure 1.23 . CONTOURS OF EQUAL LOUDNESS

Notice that at low frequencies a given change in sound level produces a much larger change in apparent loudness than does the same change in sound level at higher frequencies. It should be emphasized that the curves in the previous figure are contours of equal loudness for pure tones and may not apply to continuous sound spectra like room noise. This is one of the reasons why sound-level meters do not measure the loudness level of such sounds correctly.

It should be clearly understood that although two sounds having the same loudness level in phons appear to the average observer to be equally loud, this does not imply that the apparent loudness of a sound having a level of 60 phons will seem to be twice as loud as one whose level is 30 phons. The agreement among different observers as to when one sound is just twice as loud as a similar one of lower level is not too satisfactory, but even simple experiments of this type prove conclusively that apparent loudness is not directly proportional to loudness level. More exact determinations made by various indirect methods also show that loudness ratios are not proportional to the increment in loudness level, as might be expected from thelogarithmic nature of the definition of the phon. For example, increasing the loudness level by 10 phons from 10 to 20 phons increases the apparent loudness by a factor of approximately 6, whereas a similar increase from 50 to 60 phons increases the loudness by a factor of only about 2. In a true loudness scale doubling the number of loudness units should double the subjective loudness. Similarly increasing the number of loudness units by a factor of 10 should increase the subjective loudness by the same factor, etc.

1.3.4.4 Effect of Masking Noise on Hearing

Everyone has probably had the experience of being unable to hear some critical lines in a play because noises from the foyer or street often occur just as these lines are spoken. In spite of the apparent correlation, no one has demonstrated the existence of a "masking demon" that knows the play and takes delight in making noise at these most crucial moments. However, one may legitimately conclude that, aside from the annoyance that it causes, noise has the effect of reducing the acuity of hearing; that is, it elevates the threshold of audibility. This shift in threshold of audibility is called masking, and the shift, in decibels, defines the amount of masking. Unless the loudness of speech or music is sufficiently above the level of the surrounding noise, the speech or music cannot be fully recognized or appreciated because of the masking effect of the noise; it is impossible to ignore completely a loud noise and listen only to the wanted sound.

Masking data are generally represented in the form of a curve called a masking spectrum (sometimes called a masking audiogram) which gives the number of decibels at each frequency that the threshold level of a pure tone is shifted when heard by a normal observer in the presence of masking sounds. As an illustration, the masking spectrum due to "average room noise" is given below.

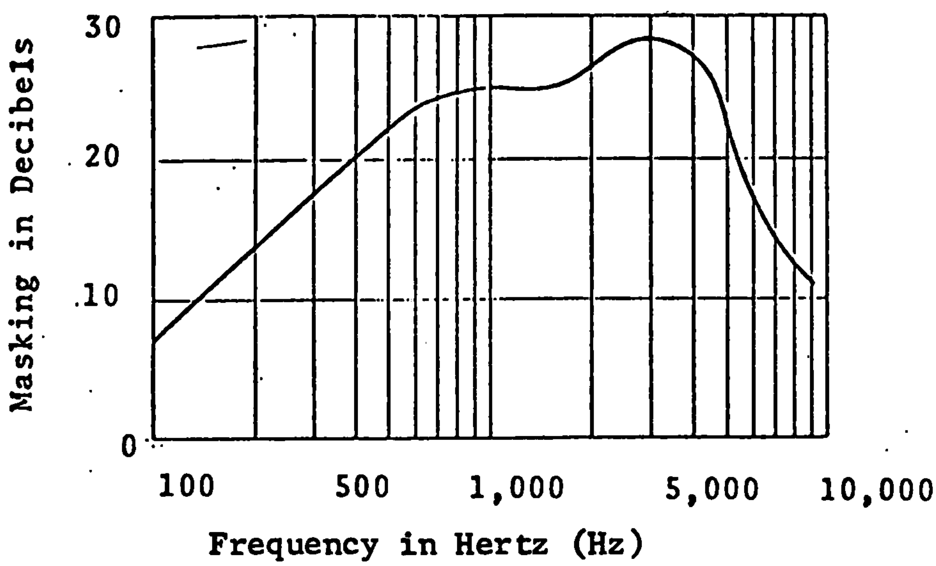


Figure 1.24 MASKING SPECTRUM DUE TO AVERAGE ROOM NOISE HAVING A SOUND LEVEL OF 43 dB.

For instance, a tone of 1000 Hz would have to be raised 25 dB above the minimum audible threshold to be heard in the presence of this average room noise. The masking spectrum in this case, and in general, is not contant with frequency. It depends on the pressure level and the nature of the masking sounds.

Experiments indicate that low pitched tones, especially if they are of considerable loudness, produce a marked masking effect upon high pitched tones, whereas high pitched tones produce only little masking upon low pitched tones. The auditory masking of one tone upon another is greatest when the masking tone is almost identical with the masked tone. In general, all tones, especially if they are loud, offer considerable masking for all tones of higher frequency than the masking tone. Therefore, very intense low frequency hums or noises are especially troublesome sources of interference for the hearing of speech or music since they mask nearly the entire audible range of frequencies.

1.3.5 <u>Hearing Loss Due to Noise</u>

Deafness may be classified into three basic types, namely, conductive, perceptive (neural) and functional. Conductive hearing loss is caused by a disorder in the external and/or middle ear which prevents the normal amount of sound energy from reaching the inner ear. This pathology may vary from excessive wax being formed in the external ear canal to a bony sclerosis or hardening of tissue around the footplate of the stapes in the oval window (called otosclerosis). Most conductive-type impairments are amenable to treatment and can be corrected. Perceptive deafness refers to disorders in the inner ear and/or along the VIIIth cranial nerve. Such pathology may range from disturbance in the cochlear fluids to degeneration of the hair cell receptors and nerve supply. These types of loss are not capable of being restored through surgical or other medical means. Functional deafness is applied to a hearing loss that has no organic basis. In other words, the individual does not fully utilize his hearing capacity despite the fact that there is no actual damage to his hearing mechanism.

Hearing loss from noise exposure can be either conductive or neural in nature. Occasionally, it may even be a combination of the two. Noise-induced hearing loss of a conductive type, termed acoustic or blast trauma, can result from an explosion which may rupture the eardrum. The inner ear is infrequently damaged in such instances, but the ossicular chain may be dislodged. The perceptive type of noise-induced hearing loss results from prolonged exposure to excessive amounts of noise such as may be found in industry. The eardrum or ossicular chain is rarely affected in these cases, the site of this disorder is in the cochlea. Initial exposure to excessive industrial-type noise produces a temporary loss in hearing which is recovered after a short time away from noise. With repeated or prolonged exposure for months or years, the likelihood of the ear recovering all of its temporary noise-induced loss is diminished. The residual or non-recovered part of the loss constitutes a permanent hearing impairment due to noise.

The mechanism responsible for deafness from noise exposure remains to be more fully determined. One author suggests that since the Organ of Corti has no direct blood supply, its capacity for rapid exchange of cell nutrients and waste products is quite limited. Thus, even short periods of acoustic overstimulation can cause cellular depletion with consequent decreased cell sensitivity. It is this effect that seems manifest in temporary hearing loss or temporary threshold shift (TTS). While in this lowered physiological state, continued acoustic overstimulation will cause still more cellular depletion to a point where complete recovery cannot take place. The result is reflected as a permanent loss in hearing sensitivity (PTS).

Histological studies have shown that the regions of cellular injury due to excessive noise exposure are localized on the basilar membrane, the location and width of such regions depending on the characteristics of the overstimulating sound. Generally speaking, however, the cellular areas of the membrane mediating high frequency sensitivity (more basal in direction) show more vulnerability to noise-induced damage than do those receptor regions underlying low frequency sensitivity (more apical in direction). There are several reasons for this differential finding. Among these are: (1) the high frequency membrane regions give higher amplitudes and more sharply concentrated patterns of response to incoming stimulation; (2) the middle ear reflex shows less attenuation (hence, less protection) for high frequency as compared with low frequency sounds; and (3) the resonant frequency of the external ear canal will give added amplification to high frequency relative to low frequency sounds.

Regardless of the site of the basilar membrane, the process of noise-induced damage is essentially the same. Damage occurs first to the outer hair cells and their supporting structures. The inner hair cells seem generally to be the last sensory structure damaged. The final irreversible stage of the process is the complete dissolution of the Organ of Corti, leaving a denuded section of the basilar membrane. Subsequently, these damaged sections are replaced by a layer of epithelial cells.

As already mentioned, perceptive-type deafness is not curable. Noise-induced losses of the perceptive-type can be prevented, however, and all feasible efforts must be taken to insure such prevention.

1.3.5.1 Audiometry

Hearing losses can be measured by a pure-tone audiometer which describes threshold intensity levels for hearing different frequency sounds relative to intensity values representing the average hearing of a normal listener. (Note: These reference settings are not to be confused for sound pressure level measurements. Actually, the reference values for normal hearing on the audiometer are different for different test frequencies.) Pure-tone air conduction audiometery is most commonly used in hearing testing although bone conduction and other more elaborate tests (e.g., noise-masked thresholds or pure-tone discrimination) are also used for purposes of diagnosing a given hearing disorder.

The two graphs below show typical audiograms for ears with conductive and perceptive hearing losses, respectively. Note that in the conductive case the losses for low frequency sounds are greater than those for the higher frequencies. In contrast, the perceptive hearing disorder shows relatively greater losses at the higher frequencies.

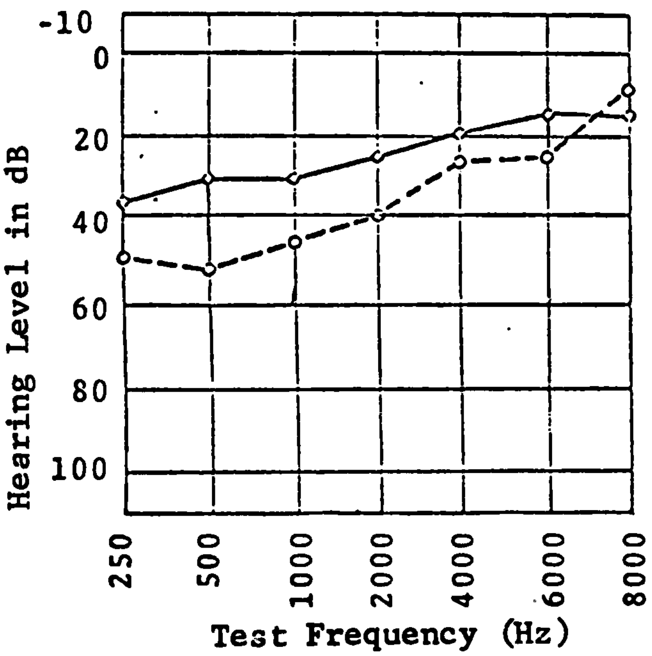


Figure 1.25 A DIAGRAM SHOWING CONNECTIVE HEARING IMPAIRMENT

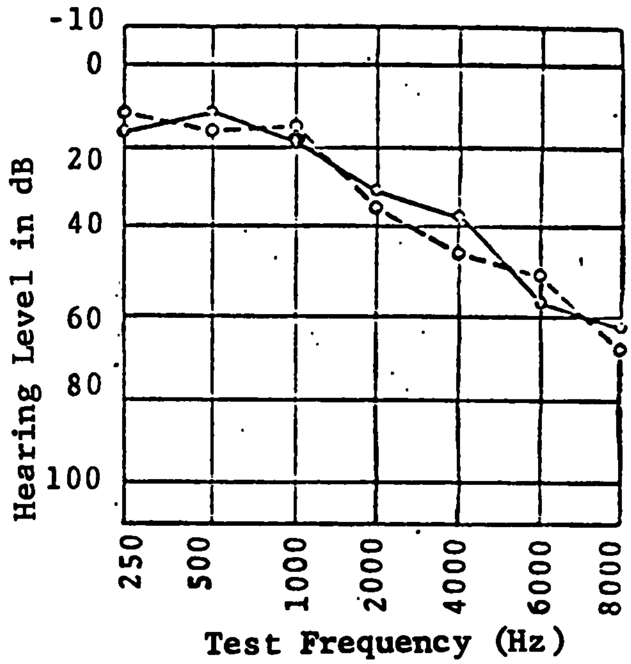


Figure 1.26 A DIAGRAM SHOWING PERCEPTIVE TYPE HEARING IMPAIRMENT

The graph on the following page describes the development of permanent noise-induced hearing loss as a function of exposure time to excessive noise. Early in the development, the losses are most prominent for frequencies of 3000 to 6000 Hz and show a peak of 4000 Hz. With continued exposure significant losses appear at other neighboring frequencies as well as increases still further in the 3000-6000 Hz range. Deafness due to aging (presbycusis) also shows losses in the audiogram at those frequencies severely affected by noise exposure. This raises the problem of how much of a given hearing loss at a test frequency is due to noise and how much is due to age. Hearing data acquired from noise-free population of listeners, classified by age, are presently being used to estimate the extent of hearing loss due to the age factor only. Such losses are deduced from audiometric measurement on noise-exposed individuals, leaving a value which is believed to more accurately reflect the extent of the noise-induced loss. In actuality, however, their procedure may give invalid results since age and susceptibility to noise-induced hearing loss may be subject to unique interactions.

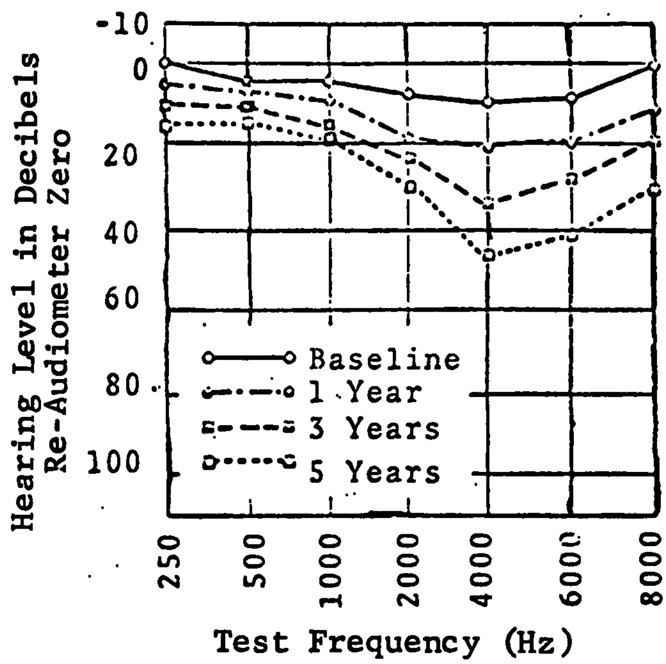


Figure 1.27 HEARING LOSS FROM NOISE AS A FUNCTION OF EXPOSURE TIME

1.3.5.2 Levels Producing Damage to Hearing

An important consideration in most industries is that the noise levels in factory spaces be low enough so that no damage should occur to the hearing of employees who are exposed to the noise over a long period of time. Tentative criteria have been established for no damage to hearing based on an analyses of all reliable information on the subject in the literature.

The table on the following page is a listing of various frequencies and their relative intensities showing the maximum permissible levels for various octaves and octave bands.

TABLE 1.7

DAMAGE RISK CRITERIA

Frequency, Hz	Pure Tone Levels or Critical Band Levels of Continuous Noise	Octave-Band Frequencies, Hz	Octave-Band Levels of Continuous Noise	Half-Octave-Band Frequencies, Hz	Half-Octave-Band Levels of Continuous Noise	Third-Octave-Band Frequencies, Hz	Third-Octave-Band Levels of Continuous Noise
50	110	63	110	63	108	50	107
100	95	125	102	125	100	100	99
200	88	250	97	250	94	200	93
400	85	500	95	500	91	400	90
800	84	1000	95	1000	91	800	90
1600	83	2000	95	2000	91	1600	90
3200	82	4000	95	4000	91	3200	90
6400	81	8000	95	8000	91	6400	90

1.3.5.3 Thresholds of Audibility and Age

As noted the threshold of audibility for a specified signal is the minimum effective sound pressure of that signal that is capable of evoking an auditory sensation (in the absence of any noise) in a specified fraction of the tests. It is usually expressed in decibels re 0.00002 pascals. The threshold of audibility varies with a great many factors. It is different from person to person. Even for the same person, it varies from day to day and hour to hour. After exposure to even a moderate noise level, temporary, though slight, deafness occurs which shifts the threshold upward. One of the principal factors affecting the threshold of audibility is age. The graph on the following page shows the results of studies of progressive loss of aural sensitivity with increasing age. A loss in actuity of hearing is manifested by the required increase in the sound level at which a pure tone is just audible. Furthermore, it has been shown that this shift in threshold is a fairly good measure of the loss of ability to understand speech. By definition, the hearing loss of an ear at a given frequency, expressed in decibels, is the difference between the threshold of audibility for that ear and the normal threshold of audibility at the same frequency. The normal threshold of audibility is the model value of the minimum audible threshold of a large sample of the general population in the United States.

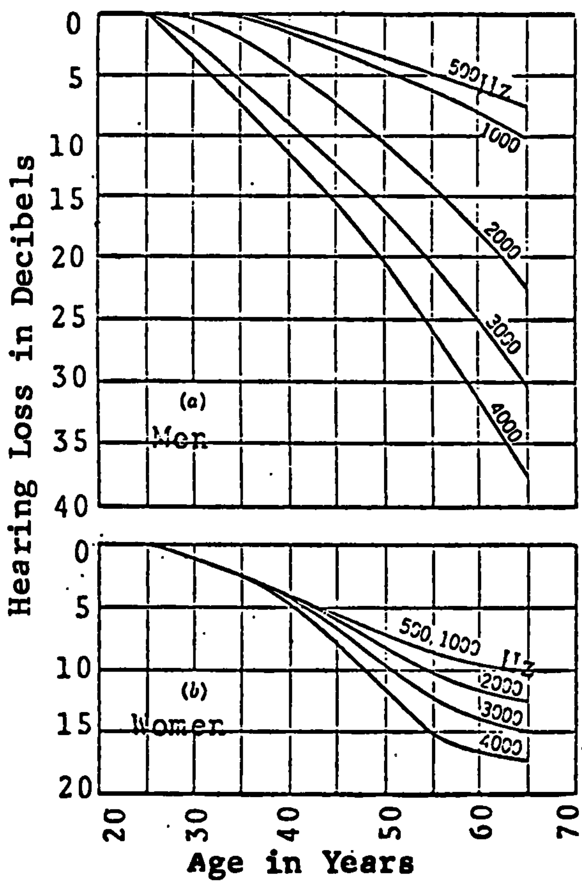


Figure 1.28 SHIFT IN AVERAGE THRESHOLD OF HEARING WITH AGE AS A FUNCTION OF FREQUENCY FOR MEN AND WOMEN

The relationship between the hearing loss and various inabilities to hear has been investigated by the U.S. Public Health Service. In its survey, nearly 9000 persons were asked to classify their hearing ability into one of the five following groups:

(1) Normal hearing; no noticeable difficulty.

(2) Unable to understand speech in a public place such as a church or theater.

(3) Unable to understand speech from a person speaking two or three feet away.

(4) Unable to understand speech from a telephone.

(5) Total deafness; unable to understand speech under any condition.

The hearing loss in the speech-frequency range of those in each of the above groups was measured. The average results are shown below. It will be seen, for example, that the group reporting an inability to understand speech in a typical church or theater shows an average hearing loss of about 25 db.

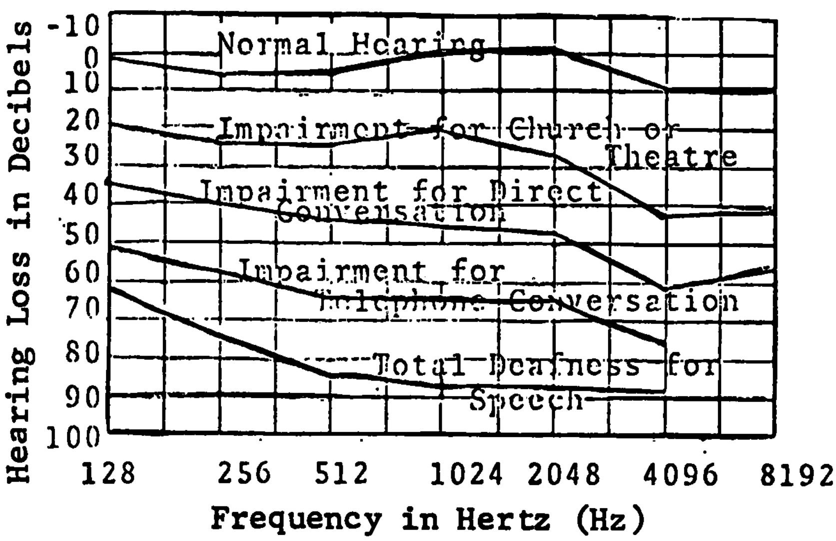


Figure 1.29 AVERAGE AUDIOGRAMS FOR GROUPS REPORTING DIFFERENT DEGREES OF HEARING

It is of interest to know what percentage of a group of people have various degrees of hearing loss. Such data may be obtained from the comprehensive survey conducted on a large sample of the population -- visitors to the 1939-1940 World's Fair in New York and San Francisco. A series of curves (on the following page) has been constructed from these data by Steinberg, Montgomery, and Gardner. The curves give the percentage of the population having a hearing loss of at least 20 db for frequencies below 1000 Hz.

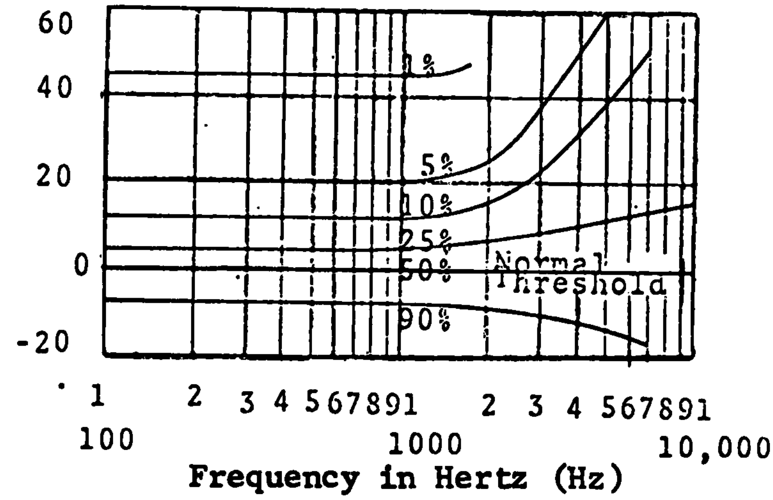


Figure 1.30 PERCENTAGE OF POPULATION HAVING A HEARING LOSS AT LEAST AS GREAT AS THAT INDICATED BY THE CONTOUR LINES. (BASED ON DATA OF J.C. STEINBERG H.C. MONTGOMERY, AND M.B. GARDNER.)

In other words, for a pure tone to be just audible for this five percent of the population, it would be necessary to raise the level of the tone at least 20 db above the level required for a person with "normal" hearing. The loss in the acuity of hearing generally increases with age. This is shown in the table on the following page. It gives the percentages of the population, according to age groups having a hearing loss of at least 45 db at the several frequencies indicated; these frequencies are representative of the important frequency range for the proper reception of speech. For example, sixteen percent of the male population between the ages of 40 and 49 has a loss at 3520 Hz of 45 db or more. Note that, in a given age group, the loss at the higher frequencies is greater for men than it is for women. The table on the following page euumerates the percentage of the population classified by age having at least a 45 db hearing loss at various frequencies.

1.3.5.4 Temporary and Permanent Shifts in Auditory Threshold

The prevalence of hearing loss among workers in noisy industries has been recognized since ancient times, and a popular description of excessively loud noise is "deafening." Yet, it is still not adequately appreciated by the general public that there is a causal link between

TABLE 1.8

PERCENTAGE OF THE POPULATION HAVING A HEARING LOSS OF AT LEAST 45 DB

AGE GROUP	LOSS IN DECIBELS / FREQUENCY 880 Hz	1760 Hz	3520 Hz
10-19			
Men	0.6	0.6	1.8
Women	0.6	0.4	0.3
20-29			
Men	0.1	0.3	2.7
Women	0.4	0.3	0.7
30-39			
Men	0.3	0.6	6.0
Women	1.2	0.8	1.6
40-49			
Men	1.4	2.6	16.0
Women	2.1	1.5	3.0
50-59			
Men	2.6	6.0	27.0
Women	4.0	3.0	7.0

noise exposure and hearing loss. If the hazard is understood, it is perhaps, regarded by many as a remote contingency or as one that has little consequence for those afflicted. It is possible, too, that while people exposed to intense noise frequently experience a substantial Noise-Induced Temporary Threshold Shift (NITTS), sometimes accompanied by tinnitus (ringing of the ears), the fact that very often such symptoms largely disappear within a short time may mislead people into believing that no permanent damage has been done by the noise.

Observations in animals as well as in man show that noise reaching the inner ear attacks directly the hair cells of the hearing organ (the organ of Corti). As the intensity of the noise and the time for which the ear is exposed to it are increased, a greater proportion of the hair cells are damaged or eventually destroyed. The function of the hair cells is to transduce the mechanical energy reaching the ear into neuro-electrical signals, which are then carried by the auditory nerves to the brain. In general, progressive loss of hair cells is inevitably accompanied by progressive loss of hearing as measured audiometrically.

There is a great deal of individual variation in susceptibility to noise damage. However, any man, woman, or child whose unprotected ears are exposed to noise of sufficient intensity is, in the long run, likely to suffer some degree of permanent noise-induced hearing loss for which there is no forseeable cure.

It remains an open question as to the level of noise that is within safe limits for all ears. In this connection, it is important to bear in mind the fact that neither the subjective loudness of a noise, nor the extent to which the noise causes discomfort, annoyance, or interference with human activity, are reliable indicators of its potential danger to the hearing mechanism.

Clinical observations of noise-induced hearing loss have been reported over more than a century. However, the problem has received intensive study only during the past three or four decades. Since World War II, substantial data have been gathered on the effects of intense sound (particularly industrial noise) on the ear. Based upon the available data, numerous criteria and noise limits have been established for the purpose of hearing conservation. Some of these have received national or international acceptance or standardization and some have been embodied in state and federal legislation. An important present difficulty for the legislator, administrator or noise control engineer concerned with protecting human hearing against noise is the fact that confusing and sometimes conflicting guidance is offered by the multiplicity of official or semiofficial standards, regulations or guidelines now in existence. Clearly, there is an urgent need for one set of guidelines to be elevated and urged for universal adoption.

The major topics to be discussed in this section will relate to the degree to which ear damage occurs in the wake of noise exposure. There will also be some discussion of the mechanism of noise damage in the ear, damage-risk criteria and related calculation, and factors influencing the incidence of Noise-Induced Permanent Threshold Shift. (NIPTS)

There are a large number of causes of permanent hearing damage, many of which are beyond the control of the individual who is victimized by destruction in his ear(s). Noise exposure, for the most part, can be avoided or reduced in a number of ways. Therefore, the damaging effects of noise upon the ear must be regarded as a preventable influence -- preventable by abatement of the noise, by alteration of operations in and around the noise, or by protection of the ear with the use of sound reducing materials or devices.

1.3.5.4.1 Theories Relating Noise Exposure and Hearing Loss

Because most of our data concerning the long-term hazard of noise come from 8-hour industrial type noise exposures, there is a relative lack of information about shorter-term intermittent or incomplete daily exposures, and virtually no data about continuous exposure to noise going on longer than 8 hours, or around the clock. One is accordingly driven to interpolations and extrapolations on the basis of theories of noise trauma. Two main theories have been supported by substantial amounts of field observation and experimental work. A continuing difficulty in setting guidelines for safe noise exposure is that predictions among these theories conflict in some circumstances. Because the conflict is not resolvable in many circumstances, an empirical decision has to be faced as to which theory to follow in evaluating a particular noise hazard.

The "equal-energy" hypothesis argues that the hazard to the hearing is determined by the total energy (a product of sound level and duration) entering the ear on a daily basis. This rule is basic to the damage-risk criteria embodied in certain important and widely used regulatory or guiding documents, notably the 1956 U.S. Air Force Regulation AF 160-3 (Ref. 5). The "equal-energy" rule allows a 3-dB increase in sound pressure level (expressed in dB) for each halving of the duration (below 8 hours) of continuous daily steady-state exposure. Extrapolation to durations of continuous noise exceeding 8 hours daily exposure and extension to extremely brief exposures or impulses have only recently been proposed. In practice, a cutoff is introduced by the widely recognized mandatory absolute limit of 135 dB (Ref. 6) for unprotected exposure, irrespective of duration. Botsford (Ref. 7) has remarked, there is still a lack of experimental or empirical verification of the "equal-energy" hypothesis except perhaps for overall durations of daily occupational exposures extending over years, the only application for which the equal energy rule was originally proposed. The theory has the attraction of simplicity and a certain a priori reasonableness. (See Proceedings of the International Conference on Noise as a Public Health Problem, Ref. 8).

The "equal temporary effect" hypothesis originally based largely on the work of Ward, et al., (Refs. 9 and 10) argues that the long-term hazard (of PTS) of steady-state noise exposure is predicted by the average TTS produced by the same daily noise in the healthy young ear. As Botsford has noted in a recent review, this hypothesis is plausible because (unlike the "equal-energy" rule) it relates to an observable physiological function of the ear. Moreover, recent work suggests that a unifying hypothesis of metabolic insufficiency induced in the hearing organ by noise may underlie both the temporary and permanent hearing defects caused by excessive noise. The essence of the supporting data is that noise intense enough to cause PTS in the long run is intense enough to produce TTS in the normal ear, while noise that does not produce measurable TTS is not associated with NIPTS, (Ref. 11) TTS studies also tend to support the observation (reflected in industrial studies of PTS) that intermittent noise is less harmful than unbroken exposure to steady-state noise at the same level (Refs. 12 and 13). Adoption of this theory has led to a number of current criteria, including that of the Committee of Hearing and Bioacoustics of the National Research Council (CHABA)(1966), considered on the following page.

CHABA's criterion is based essentially upon the hypothesis of "equal temporary effect" already alluded to. In essence it states that a noise exposure is unsafe if, upon testing the normal ear two minutes after the cessation of the exposure, an average TTS_2 of 10 dB is exceeded at audiometric frequency up to 1000 Hz, 15 dB at 2000 Hz, or 20 dB at 3000 Hz and above (Ref. 14). According to Ward (Ref. 15) this criterion reflects the empirical observation that in most normal-hearing people, a TTS_2 of 20 dB or less recovers completely within 16 hours (when the worker would be due to renew a typical 8-hour industrial exposure). The corollary to that is that is is deemed unlikely that any PTS is building up when the TTS recovers completely before the commencement of the next waking day. (A fraction of "sensitive" ears, of course, will not recover completely.) This makes no allowance for postwork, nonoccupational exposure, however.

1.3.5.4.2 Data on Affects of Noise on Hearing

Data on the effects of noise on hearing are given for two main types of noise, namely, continuous (or steady-state) and impulsive noise. For purposes of hearing conservation criteria, noise refers to airborne sound contained within the frequency range of 16 Hz to 20,000 Hz (20 kHz). Sound energy outside that range (ultrasonics, infrasonics, vibration) has been considered in a prior section.

Although some other noise-measurement units are alluded to, this section, in general, adopts A-weighted sound level (in dBA) for the specification of steady-state noise levels, and peak sound pressure level (SPL) in decibels (dB) relative to standard reference sound for the specification of impulse or impulsive type noises. When A-weighted sound levels are given, the use of international standard measurement techniques, instrumentation, and weighting characteristics is assumed.

Procedures for calculating Equivalent Continuous Sound Level (Leq) in dBA, in the cases of a typical, interrupted or intensity-modulated, steady-state noise exposure are given in a recent EPA-Air Force publication (Ref. 16). This source also may be used to determine exposures in dBA from octave band sound levels measured in decibels relative to 0.00002 N/m^2 = 0.00002 pascals.

The concept of Equivalent Sound Level was developed in both the United States and Germany over a period of years. Equivalent level was used in the 1957 original Air Force Planning Guide for noise from aircraft operations, as well as in the 1955 report on criteria for short-time exposure of personnel to high intensity jet aircraft noise, which was the forerunner of the 1956 Air Force Regulation on "Hazardous Noise Exposure". A more recent application is the development of CNEL (Community Noise Equivalent Level) measure for describing the noise environment of airports. This measure, contained in the Noise Standards, Title 4, Subchapter 6, of the California Administrative Code (1970) is based upon a summation of L_{eq} over a 24-hour period with weightings for exposure during evening and night periods.

The Equivalent Noise Level was introduced in 1965 in Germany as a rating specifically to evaluate the impact of aircraft noise upon the neighbors of airports. It was almost immediately recognized in Austria as appropriate for evaluating the impact of street traffic noise in dwelling and in schoolrooms. It has been embodied in the National Test Standards of both East Germany and West Germany for rating the subjective effects of fluctuating noises of all kinds, such as from street and road traffic, rail traffic, canal and river ship traffic, aircraft, industrial operations (including the noise from individual machines), sports stadiums, playgrounds, etc. It is the rating used in both the East German and West German standard guidelines for city planning. It was the rating that proved to correlate best with subjective response in the large Swedish traffic noise survey of 1966-67. It has come into such general use in Sweden for rating noise exposure that commercial instrumentation is currently available for measuring L_{eq} directly; the lightweight unit is small enough to be held in one hand and can be operated either from batteries or an electrical outlet.

The concept of representing a fluctuating noise level in terms of a steady noise having the same energy content is widespread in recent research, as shown in the EPA report on Public Health and Welfare Criteria for Noise (1973). There is evidence that it accurately describes the onset and progress of permanent noise-induced hearing loss, and substantial evidence to show that it applies to annoyance in various circumstances. The concept is borne out by Pearson's experiments on the trade-off of level and duration of a noisy event and by numerous investigations of the trade-off between number of events and noise level in aircraft flyovers. Indeed, the Composite Noise Rating is a formulation of L_{eq}, modified by corrections for day vs. night operations. The concept is embodied in several recommendations of the International Standards Organization, for assessing the noise from aircraft, industrial noise as it affects residences, and hearing conservation in factories.

1.3.5.4.3 Industrial Experience

There is a plethora of published information about the effects of long-term noise exposure upon the hearing of workers in the manufacturing and construction industries, as well as that of aviators and others in noisy occupations: several recent monographs and surveys have been published on this topic (Refs. 17 and 22). A recent survey by the National Institute of Occupational Safety and Health (NIOSH) (Ref. 23) contains a descriptive summary of some of the more important.

Temporary hearing loss attibutable to fatigue of the inner ear (or Noise-Induced Temporary Threshold Shift, NITTS) lasting from a few seconds to a few days can occur after brief exposure to high sound levels or from day-long exposure to more moderate levels of on-going noise. Regular (day-by-day) exposure to such levels over a long period (days to years) can result in damage to the inner ear, a sensorineural hearing loss (NIPTS) that is permanent and so far as is presently known, irreversible. It can be prevented only by protecting the ear from excessive noise exposure.

NIPTS is usually preceded by, and may at any time be accompanied by, NITTS. The typical pattern of NIPTS seen in the audiogram is maximum loss in the range 4000 to 6000 Hz, with a somewhat smaller loss, (initially) at higher and lower test frequencies. Because the loss is sensorineural, it is seen in both air- and bone-conduction audiograms.

Gallo and Glorig (Ref. 24) examined audiometric data from 400 men (aged 18-65) and 90 women (18-35) exposed regularly to high-level industrial plant noise (102 dB SPL overall; 89, 90, 92, 90, 90 and 88 dB, respectively, in the octave bands spanning 150 to 9600 Hz). These subjects were selected from larger groups of 1526 male and 650 female employees, using a screening process designed to exclude otological abnormalities and irrelevent noise exposure (e.g., to military noise), and to maintain in the men a high correlation between age and time on the job. The purpose of the study was to look specifically at age and duration of steady-state noise exposure as factors in PTS. It showed quite clearly that hearing level tends to rise relatively rapidly over the first 15 years of exposure but then to level off as reflected in the higher audiometric frequencies, 3, 4 and 6 kHz. By contrast, hearing level at 500 Hz, 1 and 2 kHz rose more slowly but continued to rise in an essentially linear manner over exposures up to some 40 years.

A comparison of data for 4 kHz in the men with equivalent data from non-noise-exposed males showed that the effects of the age and noise were not simply additive. Examination of individual differences showed that the spread of hearing level within groups tends to increase with both increasing exposure time and with audiometric frequency (a similar effect has been reported by Taylor, et al (Ref. 25). Also, the time and frequency dependence of noise-induced hearing level change was found to be similar for most subjects. Gallo and Glorig concluded from this study that early evidence of PTS at 4000 Hz is the best indicator of susceptibility to noise-induced PTS on either a group or individual basis. A cognate study by Taylor et al, in female jute weavers supported Gallo and Glorig's finding that noise-induced deterioration in hearing takes place rapidly and mainly in the first 10 to 15 years of exposure, with, however, further deterioration at the speech frequencies continuing in later years.

Taylor, et al, carried out retrospective audiometric studies of groups of women working in or retired from the jute weaving industry in Scotland. The contributions to their group hearing levels attributable to the regular noise (99-102 dB SPL overall with higher peaks) to which they had been exposed were evaluated by comparison with non-noise-exposed control subjects and by corrections for presbycusis using Hinchcliffe's (Ref. 26) median data. Generally, this study supported the conclusions of Gallo and Glorig. Namely, these findings were that the effect of noise on hearing levels is greatest, earliest and most rapid at the higher audiometric frequencies (4 and 6 kHz), where it mostly takes place in the first 10 or 15 years of occupational exposure, (Ref. 19) but that further deterioration involving frequencies in the range of 1 to 3 kHz (being most marked at 2 kHz) becomes manifest during the third decade of noise exposure. After as few as 10 years of on the job exposure in areas of high-level (90 dB SPL) industrial plant noise, men as young as 30 years old may have hearing levels worse than non-noise-exposed men twice their age and may, in some cases, already suffer impaired speech perception (Ref. 24).

PTS produced by noise exposure and PTS produced by aging (presbycusis) may not be distinguishable on either a group or individual basis (Ref. 24). NIPTS is found primarily among industrial workers who have been exposed repeatedly and over a long period to high-intensity noise. Provided that the ears affected are otologically normal, the PTS found in noise-exposed people may be attributed to the combined effects of aging and habitual noise exposure. Moreover, the component attributable to noise exposure may be viewed as the result of repeated noise-induced TTS. Some audiologists subscribe to the view that noise-exposure merely hastens the aging process, although such a hypothesis can be based only upon circumstantial evidence.

Gallo and Glorig have summarized some general characteristics of NIPTS, as seen in occupational contexts, namely:

1. The magnitude of the resulting PTS is related to the noise levels to which the ear has habitually been exposed.

2. The magnitude of the resulting PTS is related to the length of time for which the ear has habitually been exposed.

3. The growth of occupationally related PTS at 4000 Hz is most rapid during the first 10 to 15 years of exposure, after which it tends to slow down (see also Passchier-Vermeer (Ref. 27).

4. There are large individual differences in susceptibility to noise-induced PTS.

Compare variability is seen in individual hearing levels and in the effects of aging (presbycusis). Summar and Fletcher (Ref. 28) have contended that age at the time of exposure is probably not a significant factor in industrial NIPTS.

Tinnitus Associated with Occupational NIPTS

Tinnitus (ringing in the ears) may be, at first, the only symptom in many cases of occupational hearing loss; and it is fairly frequently associated with the condition. Chadwick (Ref. 29) has reported an incidence of 30 percent in one industrial survey in Britain.

Patients with occupational NIPTS frequently notice symptoms upon changing from one noisy job to another, or from a noisy job to a quiet one, possibly because they have adapted to or learned to cope with any handicaps due to the noise in a familiar situation.

Social Significance of Hearing Loss at Retirement

Kell, et al (Ref. 30) have reported that more than two thirds of a surveyed group of elderly (mean age 64.7 years) women who had worked as weavers (with steady daily noise exposures of approximately 100 dBA) for up to 50 years had difficulty with such social intercourse as understanding conversation, using the telephone, and attending to public meetings or church services. By contrast, fewer than one in six age-matched women who had not been in a noisy occupation was similarly disadvantaged.

The Reliability of the Data from Industrial Studies

Unfortunately much hearing loss data from industry is heavily "contaiminated by" what Glorig and others (Ref. 15) have called "sociocusis" factors (e.g., undeterminable losses due to non-occupational noise exposure in military, recreational or other pursuits, or to disease affecting the ear). The data was further contaminated by the effect of presbycusis, which is inextricably bound up with the time dependent effect of noise exposure (and shift presumed largely of a priori rather than evidential reasoning to be simply additive); and even within the setting of industrial noise exposure, by lack of continuity (e.g., personnel changing jobs) affecting both retrospective studies.

1.3.5.4.4 Effects of Loud Music

Several recent studies have confirmed that the overall sound levels of very loud rock and roll and similar music frequently exceed current hearing damage-risk criteria and can produce large amounts of TTS in both musicians and listeners (Refs. 31 and 37). Flugrath's (Ref. 33) and other measurements have shown that typical rock music can be regarded, when considering the hair cells, as a steady-state noise with interruptions. Typically, the maximum acoustic output from the band's amplifiers lies in the region of 2000 Hz. Dey (Ref. 36) found that typical exposures averaging 100 to 110 dBA for up to 2 hours produced TTS_2 exceeding 40 dB in 16 percent of young adults tested. Rintlemann and Borus (Ref. 32) measured typical levels of 105 dBA and found that some 5 percent of musicians (mostly quite young) showed evidence of NIPTS attributable to their music. Clearly, the hazard is an occupational one for the performer and usually a recreational one for the listener.

Lipscomb (Refs. 34 and 35) has demonstrated cochlear damage in guinea pigs exposed to 88 hours of recorded rock and roll music adjusted to peak at 122 dB, a level that can be exceeded at the ears of musicians and nearby listeners in some instances where excessive amplification of the music is used in reverberent rooms or dance halls. Dangerous levels can also be reached using domestic stereos (Ref. 38). In a comparative study of the noise hazard in young people's recreation, Fletcher (Ref. 39) found playing rock-bands to be exceeded in degree of hearing hazard only by motorcycle and drag racing and by intensive sport shooting with inadequate ear protection. Fletcher showed incidentally, that young men and women are equally at risk of hearing damage when exposed to over-amplified rock music. A similar conclusion was reached by Smithley and Rintelmann (Ref. 40).

Measurements of Permanent Threshold Shift (PTS)

There have been many studies of musicians who, as a class, would be expected to have the greatest exposure, i.e., not only are they closest to the loudspeakers, but they are also exposed for the greatest periods. Once again extremely variable results are found, some studies showing large groups of musicians with no signs of hearing loss. However, in six studies covering some 145 musicians, approximately 22% of these showed evidence of hearing damage.

Some studies of young people entering an American University have shown a hearing loss greater than 15 dB at 6 kHz in 29.4% of the sample in 1968 rising to 54.9% of the sample in 1969. While such studies may result from general exposure to noisy recreational pursuits, they cannot be specifically related to exposure to loud music.

An English study in which the permanent hearing level of 102 attenders at pop music performances was compared with that of a group of 53 nonattenders has shown, on the average, 3 dB more hearing loss among the attenders than among the nonattenders. Consideration of only the 10% most affected by the noise raised the difference between the two groups to 5 dB. Additional evidence of the relevance of these results was obtained by examining more closely the pattern of attendance. It was found that subgroups which attended progressively more frequently showed correspondingly higher levels of hearing loss. While these losses are extremely small, it should be remembered that the average length of attendance was only two years and that the hearing loss is incurred in preindustrial exposure.

Comparison of Measured Levels with Existing Damage Risk Criteria

Early American studies showed that the average level of rock and roll music recorded during performances by many American groups exceeded the Walsh-Healey damage risk criteria, while octave band levels were found that exceeded the Californian damage risk criteria and were considered to exceed levels felt to be safe for prolonged exposure.

These studies and others like them took little or no account of the duration of the exposure; Whittle and Robinson, however, have derived the likely noise levels from all the published information and have associated these with estimates of the duration of exposure, both in weekly attendance and in cumulative terms over the years. They compare the means of calculated hearing levels at 0.5, 1, and 2 kHz with the so-called "low fence" value of 25 dB proposed by the AAOO (or, which is nearly equivalent, the U.K. DHSS value of 34 dB for the mean of 1, 2, and 3 kHz), and show that several possible combinations of attendance and noise levels are likely to exceed these values.

Measurements of Temporary Threshold Shift (TTS) on Exposed Persons

Measurements of the TTS shown by those attending live performances are extremely difficult to carry out. The provision of adequately quiet surroundings for audiometry, the inevitable delays in testing the subjects, and their variable exposure while in the discotheques, all lead to considerable uncertainties. Some of the tests under these conditions have shown a TTS which exceeds the CHABA criteria.

Measurements in the laboratory provide adequately controlled conditions, but most experimenters have not used extreme values of exposure nor large numbers of subjects. However, some of the studies show that considerable threshold shift can result.

1.3.5.5 Summation

Ongoing noise has been proven to cause permanent hearing loss in industrial settings and among young people exposed to loud music over extended periods of time. Noise is also known to cause temporary hearing loss and ringing in the ears (tinnitus).

However, since there is a relative lack of information about the effect of shorter-term intermittent or incomplete daily exposures, several theories have been postulated to relate noise exposure to hearing loss in these situations.

One theory that has been fairly widely used is the Equal-Energy Hypothesis, which postulates that hearing damage is determined by the total sound energy entering the ear on a daily basis.

Another theory suggests that the long term hazard is predicted by the average temporary threshold shift produced by daily noise exposures. There is evidence to support both of these theories within reasonable limits of extrapolation.

Impulsive noise (such as gunshots) has also been shown to cause damage. CHABA has recently developed a noise hazard numerical weighting system that takes into account such factors as intensity, duration, and number of noise impulses.

Averaging the NIPTS predictions over various industrial noise hazard prediction methods gives a fairly dependable measure of the hearing risk of noise-exposed populations. Hearing damage has been noted at levels as low as 75 dBA after 10 years.

The only important factor in increasing hearing risk appears to be noise exposure, and artificial ear protection devices do appear to be of value in preventing damage. Neither sex-related nor cultural differences appear to significantly affect hearing risk due to noise exposure.

It is evident from the noise exposure data that noise can damage hearing and can cause both NITTS and NIPTS. The relationship between noise exposure and hearing loss is well understood in industrial settings and in the case of high intensity impulsive sound (i.e. gunshots). However, in the case of fluctuating or intermittent noise, data is generally lacking and it is necessary to rely on data extrapolations to estimate effects.

1.3.6 Effects of Noise on Other Physiological Responses

Aside from damage to the hearing mechanism, noise conditions are not considered to produce any other physiological impairments. Recent reports, however, suggests a tie-up between noise, hearing loss, and cardiovascular disorders although the inter-relationship between these variables is still unclear. Even moderate levels of noise appear to cause constriction in peripheral blood circulation. The significance of such changes to health has not been determined. Individuals working under intense noise conditions (ball-bearing manufacturing plants) showed some functional disturbances of the cardiovascular system including instability of arterial pressure, slowed heart beat (bradycardia). A fatty diet appears to be associated with both circulatory disorders and hearing loss. Perhaps hearing loss is due to a reduction in nutriment to the hearing sense organ resulting from noise-induced constriction in blood flow or from a cardiovascular disorder of another origin. Obviously, there is a need for more research in this area.

It should be mentioned that intense noise of sudden onset will cause marked physiological changes including a rise in blood pressure, increase in sweating, changes in breathing, and sharp contractions of muscles in the body. These changes are generally regarded as an emergency reaction of the body, increasing the effectiveness of any muscular exertion which may be required. Although perhaps useful in emergencies, these changes may be harmful for long periods since they would interfere with other necessary activities or produce undue amounts of fatigue. Fortunately, these physiological reactions subside with repeated presentations of the noise.

It has often been stated that in order for performance on a task to remain unimpaired man must exert greater effort in a noisy environment than necessary under more quiet conditions. Measures of energy expenditure, e.g., oxygen consumption, pulse rate, muscle potential, do show changes in the early stages of work under noise conditions which are indicative of increased effort. With continued exposure, however, these responses return to their normal level.

Intense (or extremely high) levels of sound (over 140 dB) are capable of causing dizziness or loss of equilibrium since the balancing organs (semicircular canals) are stimulated. Such high intensity exposures may also cause alternations with other types of sensory behavior, and will definitely cause pain, perhaps even traumatic damage in unprotected ears. Examples of such extreme noise conditions are few; possibly in jet engine test cells would these high levels be reached.

1.3.6.1 <u>Impairments in Performance Efficiency</u>

Contrary to popular thinking, there is little evidence to support the notion that noise degrades performance. Laboratory studies of this problem have shown that tasks may be initially decreased by noise, such effects tend to vanish as exposure time and/or practice on the task increases. There have been reports, however, which show noise to cause significant losses on vigilance-type tasks. Such tasks require the subject to keep a constant watch over a number of dials or indicators so as to report changes that may occur on any dial at any time. Noise-related losses in vigilance performance are important because of their implications for automated jobs which involve the monitoring of control panels with many indicators displaying information about an ongoing machine process. This finding also has practical importance for jobs requiring the inspection of items passing on a conveyor belt. In such situations a single item must be viewed within a short period of time before passing on to the next.

Field studies concerned with efficiency changes associated with reductions in noise have yielded data that are suspect. Some investigators have noted increased output consequent to noise control treatment in select work areas. This improved performance level was maintained, however, with the restoration of the original noisier conditions. The effects on performance in these cases are probably due to morale changes. That is, the workers see that an interest is being taken in them or their working conditions and respond with increased effort, leading to greater output. The fact that field studies cannot control factors such as morale motivation, worker attitudes toward job or supervisor makes it difficult to obtain valid and reliable data reflecting the effects of manipulation of the occupational noise conditions upon performance. For the same reasons, it is difficult to establish cause and effect relationships between industrial noise conditions and accident rate, absenteeism, and employee turnover.

1.3.7 Closure

Adverse effects of noise on man include temporary and permanent hearing loss, speech disruption, loss in performance capacity, and annoyance. Factors believed critical in evaluating a potential noise hazard to hearing are the noise, total exposure duration, time and frequency distribution of short term exposure periods, and susceptibility of an individual's ears to noise-induced hearing loss. Specifications for valid damage risk criteria for noise exposure must take account of these factors. Measures for predicting speech interference of noise are available and have been used as a guide for establishing limiting noise conditions in rooms where effective speech communication is needed. Performance changes and nonauditory physiological changes due to noise have been reported but will require further substantiation. As more data filters in from various studies on noise effects in industry and business, the actual process of hearing degradation will undoubtedly become more evident. Until such time the aforementioned material should serve as a guide to the Indiana Dunes National Lakeshore in answering inquiries regarding noise in the Park and its environmental control.

1.4 Measurement Techniques and Instrumentation Utilized in the Study

Three measurement methodologies were utilized in the performance of this program, each designed to reveal a different facet of the man-made noise impact on natural sounds. These three measurement methodologies are discussed in this subsection.

1.4.1 Linear Tape Recording in Real Time

Tape recordings were made of actual sound levels in various sections of the Lakeshore for temporal periods of such duration as to capture both the sounds of nature as well as man-made noises in each particular area of evaluation. Normally 10 to 15 minutes of data were taped for heavily man-made noise impact areas, whereas a 5 to 10 minute recording of data was sufficient for defining the natural sound ambient. Recordings at particular sites took place four times a day; morning (8:00 am - 12 noon), afternoon (12 noon - 6:00 pm), evening (6:00 pm - 10:00 pm), and late night (10:00 pm - 2:30 am). In total nearly 300 tape recordings were made during the study. The results of these data reductions produced the impact of man-made noise on natural sounds in one-third octave band analysis format, allowing for an exploration of man-made and natural emissions by frequency characteristics. This then related the objective quality of the data gathered to the potential subjective impact on IDNL personnel and Lakeshore visitors.

1.4.2 Twenty-four Hour Analysis Format

The second data taking technique consisted of placing a digital data recorder at a stationary location for 24 continuous hours of sampling, thus recording all sound events at the position chosen for an entire daytime and nighttime sequence. The tape thusly encoded does not contain information understandable to human ears, since it is recorded in computer language, but when interpreted by the computer, the percentage of time a certain level of sound is exceeded (L_1, L_{10}, L_{50}, L_{90}, L_{99}) as well as L_{eq} is decoded and automatically printed out for 15 minute, hourly daytime (7:00 am - 10:00 pm) and nighttime (10:00 pm - 7:00 am), and total 24-hour temporal periods. The levels printed out are in A-weighted rather than octave levels, but the A-weighted scale has been found to be a just descriptor of the manner in which animals and man relate to a total acoustic climate. As previously noted, the A-weighted scale adds up the frequencies of interest in an environment in similar fashion to the way animal and human auditory senses will interpret the energy. In order to determine the impact of man-made noise on natural sound for a continuous 24 hours, the first methodology tape recordings were used in conjunction with the 24-hour sampling. This provided a backup interpretive device in which to relate low level statistical data from the 24-hour continuous monitor surveys to that data recorded in real time using the human interpretable tape recording technique. Forty-two 24-hour studies were performed in four seasons of the year including 12 repeats in various areas of the Park. The repeats allowed for an investigation of any long-term changes in acoustic climate during the 2-year sequence of the program.

1.4.3 Walkaround Analysis Technique

The final methodology used for the study consisted of one or two human observers visually monitoring a small portable precision sound level meter for A-weighted values of man-made noise impact on natural sound over a wide sampling area. For purposes of the program a wide area could include a 2000 by 5000 meter square grid to as large an area as 5 km in circumference. Man-made noise impact on natural sound as studied with this technique included:

- the effect of the two major interstate highways which run through or in proximity to Park land,
- the impact of traffic from major U.S. highways and arterial roads,
- the impact from smaller side road vehicle traffic,
- the impact of aircraft flyover and two major railroad right-of-ways,

- impact of industrial/commercial interests abutting Park land,
- sound level of natural sources, and composite natural sound and man-made noise source identification.

The walkaround sampling technique consists of choosing four or five site locations per survey, each of which doubles its respective distance from a chosen man-made noise source. For example, if an interstate highway is chosen as the source, typical sampling locations could be; 1000, 2000, 4000, 8000, and 16000 meters from the expressway. If a local steel mill or power plant is chosen, locations of 500, 1000, 2000, 4000, and 8000 meters would be more statistically valuable. At each sampling location, sound level recordings were performed for 10 minutes of continuous recording, visually monitoring the SLM once every 6 seconds and thus collecting 100 samples per 10 minutes of data. Once 10 minutes of data are plotted on the specially designed data sheets, the human observers move to the next location which is a double the distance point. According to laws of acoustic propagation, the impact of a particular sound will decrease by 50 percent for every doubling of distance, though this will vary according to the type of sound (a highway contains much more acoustic energy than a single power plant or steel mill) and the terrain over which it propagates.

In total seven of the above type surveys were performed for the study. In each instance one of the five sampling site locations contained a 24-hour stationary sampling monitor with which the data could thus be correlated to the other two methodologies. The advantages of the walkaround survey technique include:

- ability to identify the man-made source impact in real time,
- immediate analysis of statistical nature of man-made noise impact on natural sound,
- real time definitions of ambient,
- identification of source impact make-up and wide area analysis nature of such impact.

1.4.4 Instrumentation

The IITRI Acoustics Section used a wide selection of sound measuring equipment which was available for this program. General Radio and Bruel and Kjaer sound level meters were used in noise survey and analysis work. In performing field tests, IITRI standard procedure was to tape record noise levels for later diagnostic analysis. The following table shows a comprehensive list of the equipment available to the Acoustics Section:

TABLE 1.9
EQUIPMENT LIST

Description (Model Number)	Manufacturer
Real Time Analyzer (SD 301-C)	Spectral Dynamics
Ensemble Averager (SD 302-C)	Spectral Dynamics
Octave Converter (SD 305)	Spectral Dynamics
Real Time Analyzer (Model 1921)	General Radio
Vibration Calibrator (1557-A)	General Radio
Spectrum Analyzer (315)	Tektronix
Noise Analyzers, Sound Level Meters	General Radio
Statistical Distribution Analyzer (4420)	B&K
Sound Level Meters (2203, 2209)	B&K
Octave Filter Set (1613, 1614)	B&K
1/3-Octave Filter Set (1616)	B&K
Precision Microphones (4133/34, 4144/45, 4149, 4161, 4165)	B&K
Vibration Pickup Systems	General Radio
Accelerometers	B&K, Columbia, Kistler, Masea, Glennite
Magnetic Tape Recorders	Ampex, General Radio, Nagra SJ
24-Hour Outdoor Field Digital Data Recorder (181)	B&K
Graphic Level Recorder (1512-A)	General Radio
Chart Level Recorders (2305, 2306, 2307)	B&K
X-Y Recorders	Honeywell, Hewlett-Packard
Computer Interfaced Digital Data Translator (182)	B&K

EQUIPMENT LIST, Continued

Description (Model Number)	Manufacturer
Audio Frequency Spectrometers (2112)	B&K
Wave Analyzers	H.P., Quan. Tech.
Reference Sound Sources	ILG
Signal Correlator (101)	P.A.R.
Impact-Noise Analyzer (1556-B)	General Radio

Breakdown of equipment in regard to survey methodology usage will be found in Table 1 of the Noisexpo article provided in Appendix B. All data analysis reductions took place at IITRI Chicago and IITRI Riverbank Laboratory in Geneva, Illinois. Univac 1108 and Digital Corporation PDP 11/45 computer systems were utilized for statistical A-weighted analysis reductions.

A General Radio Model 1921 real time analyzer was employed for analysis of Nagra SJ scientific linear recordings, and said data reduction produced the third octave frequency/energy characterizations of man-made noise impact on natural sounds. The format of reporting these results as found in Section 2 of the report is discussed in Section 1.5.

The Spectral Dynamics Real Time Analyzer was used basically for narrow band spectrum analysis. Sampling time was quite short. For example, for a 0 to 10 kHz frequency range where the bandwidth is 30 Hz, a sample was compiled in only 60 msec. Several frequency range settings were available from 0 to 10 Hz to 0 to 50 kHz. Respective bandwidths were 0.03 Hz and 150 Hz for these two ranges. When random noise was present, ensemble averaging made it possible to enhance the components of the spectra which were of interest. The number of ensembles was set from one to 4096. The Octave Converter accessory was used to display the data in octave or one-third octave band increments. The major advantages of the RTA were:

- Rapid spectral display for diagnostic purposes.
- Narrow band analysis identified discrete frequency components.
- Short analysis time made multiple spectra readings possible.
- Noise reduction techniques were quickly evaluated.

The General Radio 1921 Real Time Analyzer was used when one-third octave comparison of source components, as recorded on Nagra SJ, Ampex, or General Radio Analog Tape Recorders, were required. Through a special program developed in our Riverbank Lab facility, the one-third octave data were quickly converted to octave equivalence for comparison of natural sound and man-made noise impacts. Integration times for the 1921 range from 1/8-second sampling to 32 seconds when low frequency components were present in the acoustic spectrum. Hard copy printout from the 1921 RTA was achieved through use of a Hewlett-Packard X-Y Recorder and identification of one-third octave comparisons of various sources on tape was achieved through use of different color pens for printing on the data output sheets. The 1921 RTA is also utilized at Riverbank for transmission loss analysis and sound power testing of various small, medium, and large machinery and appliances per various government and industrial specifications.

IITRI's sound level meters are Type 1 ANSI specification instruments and were factory calibrated and certified once every 6 months by the manufacturer to attest to their scientific operational conditions. Bruel & Kjaer Model 2209 and 2203 SLM's were used for walkaround and digital tape analysis, and the precision microphones used in conjunction with the meters were also frequency response analyzed and tested once every 6 months for certification purposes. The 2209 Meter was capable of true impulse hold analysis of natural or man-made noise sources of impulsive nature, and the 2203 Meter was utilized during nighttime surveys since the meter has a built in light for easy taking of data in rural or unlighted urban areas. For special environmental studies in which data must be taken in inclement weather, new all weather microphones with rain proofing and dehumidification devices were acquired. The B&K 4149 and 4161,65 series of microphones are quartz coated and back vented and were utilized in wet conditions up to 98% relative humidity. These microphones were also interfaced to IITRI's Nagra SJ Analog Magnetic Recorder when permanent documentation of noise sources was required for later laboratory analysis The Nagra SJ Recorder was capable of recording data at 1.5, 3-3/4, 7-1/2, and 15 inches per second, thus making 10 to 1 frequency transfering of data a possibility for very low frequency (5 to 30 Hz) analysis. The Nagra Recorder has both amplitude and frequency modulated recording capabilities.

Portable field graphic level recorders recently acquired by IITRI were utilized in the program. The B&K 2206 Recorders were utilized for hard copy printout of 24-hour studies in real time in the field, requiring only one change of batteries per survey. The 2206 Recorders can also be carried easily to rural dunes or back road areas of the State Park when noise survey applications in real time are required for the immediate comparison of source components in a particular acoustic climate. For these types of analyses, the AC output of the 2209 or 2203 Meters were fed directly to the 2206 Graphic Level Recorder and frequency spectrum analysis is effected either by direct mechanical setting of octave or one-third octave filters or through automatic sequences via synchronization circuitry.

Statistical assessments of "A" Weighted acoustic climates for 24-hour or small temporal periods ourdoors were achieved with two different instrumentation configurations. Each system utilized a different computer oriented data output approach. Results from parallel analysis of identical sources indicate that the two instrumentation statistical data gathering systems were within 1 dB of each other in accuracy. A description of the two systems now follows.

The Univac 1108 computer oriented sampling methodology consisted of slightly older but well tested acoustical instrumentation and essentially monitors the changes in noise level in a given natural park area at a particular point for a continuous sampling period. Twenty-four hours was usually chosen for the time duration outdoors. The following set of instrumentation was utilized for this statistical technique:

1. One chart level recorder (2305/7) capable of simulating "slow" to "fast" sound level meter response.
2. One statistical distribution analyzer (4420) to count time-amplitude changes recorded by the chart recorder.
3. One Type 1 sound level meter (2209, 2203) or audio frequency spectometer (2112/13) device to set relative levels for the chart recorder and also "A"-Weight the incoming signal.
4. One 1-inch condenser microphone (4145, 4165, 4161) and heated preamp dehumidifier mounted with windscreen and random incidence correction. This microphone must be located at least 50 feet from any reflecting surface.
5. One time-lapse eight millimeter motion picture camera used to visually record data from the statistical distribution analyzer.
6. Associated power supplies, tripods, cables, etc.

The heated preamp and dehumidifier were used to prevent moisture from condensing on the microphone outdoors during brief periods of rain, snow or sleet, or during dewpoint conditions. The stationary mike was set up in a typical natural sound or man-made noise environment for 24 hours. It was set far enough away from any particular stationary noise source so as to monitor only the overall background noise level. Stationary outdoor noise sources in some areas included power line transformers, street light ballasts, ventilation equipment from buildings and noise generated by the sampling equipment itself (such as the statistical distribution analyzer or any remote power supplies). Indoor extraneous near field sources could include air conditioners, heaters, or other nondiffuse components.

A suitable cable was run from the microphone location to the sound level meter which was set to A-weighting or linear. The output of this meter was fed to a chart level recorder which yielded a visual picture of the noise at the site for 24 hours of continuous running. The paper speed of the chart level recorder was set so that 24 hours of running yielded a 25.7 cm long strip chart or approximately 2.45 cm for every 2 hours of data. This produced a very distinct "acoustical" picture of the man-made noise climate generally revealing higher noise intensities during the day and lower noise intensities during early morning hours (3:00 a.m. to 6:00 a.m.). The output of the chart recorder via a slide switch mounted over the writing stylus drove a statistical distribution analyzer which automatically counted the changing intensities of sound pressure in 5 dB increments over a 60 dB dynamic range (12 counter windows of 5 dB each).

An eight millimeter motion picture camera set to time-lapse single-frame shooting took a picture of the statistical distribution analyzer every 7 minutes. Upon development of the 8 millimeter reel, loudness levels (deciles) for 1, 10, 50, 90, and 99 percent of the time for every 7 minutes over 24 hours were derived and plotted by reading the data via Fortran coding into a UNICAC 1108 computer.

Typical output from the program consisted of the following types of statistical noise information

1. Each 20 minute interval in terms of L_1, L_{50}, L_{90} and L_{99}.
2. Each 1 hour interval in terms of L_1, L_{10}, L_{50}, L_{90} and L_{99}.
3. Each cumulative hour interval in terms of L_1, L_{10}, L_{50}, L_{90}, and L_{99}.
4. Each cumulative 24 hour interval, as well as day and night cumulative loudness levels.
5. Equivalent loudness (L_{eq}) for each 20 minute time interval.

6. L_{eq} for each hour.
7. L_{eq} for each hour taken cumulatively.
8. 24 hour cumulative L_{eq} and finally L_{DN} (day and night).

The newer statistical data analysis technique also provided the U.S. EPA one number day-night equivalent loudness energy level number L_{DN}. This instrumentation consisted of a field data recorder, B&K Model 181, which recorded the A-weighted output of a precision outdoor all-weather microphone onto a computer cassette in digital format. In this manner up to 32 hours of data at ½-second sampling rate were placed on one cassette. Set up time for the Model 181 24-hour outdoor survey was typically 20 minutes. The outdoor site configurations were identical to the older system with the advantage that the Model 181 unit is battery operated and could be placed anywhere in the Dunes environment, free from near field static noise sources, and had the extra advantage of being capable of separating from the total acoustic climate, particular man-made noise source components which might be of particular statistical interest. This technique was achieved through use of an extraneous event marker which placed a digital signal on the Model 181 cassette tape, marking the beginning and end point of the temporal period in which the source component of interest was acoustically active. This switch was either manually activated or automated to turn on and off with the cycling of a particular source. Outdoor source components which were of separate interest in statistical analyses of noise climates included:

- train passby
- aircraft flyover
- heavy truck passby
- barking dogs
- marshalling yard activities
- sirens
- exterior industrial or commercial machinery activities
- motorcycles or other off-road vehicles

The Model 181 Outdoor Statistical Noise Gathering System was totally weather proof and was capable of measuring the acoustic climate in temperatures ranging from -10°C to 45°C over a range of humidity to 98% relative.

Once the data for temporal periods of 24 hours or less was encoded on the Model 181 cassette, the digital recorder itself was either placed on overnight charge or connected to an exterior battery pack for continued operation in another location (typically only an hour was spent in breakdown, moving to new location, and set-up) in the field. The cassette was sent back to IITRI's computer noise analysis laboratory. Here a B&K 182 Digital Cassette Data Translator played the tape through a DEC Interface into a PDP-11/45 Computer utilizing 9 track tape hardware and disk pack sortware external memory. The computer program was stored on the disk and was capable of presenting the output described previously. In addition, the extraneous event mark allowed IITRI to present the statistical nature of an acoustic climate with all noise events included (meaning the total noise environment) as well as with a description of what the environment would be in the absence of certain candidate chosen noise sources indigenous to that acoustic climate. The output of the PDP-11/45 (via matrix plotter) yielded two columns of decile and L_{eq}, L_{DN} data, one for the total all-inclusive acoustic climate, and one for the noise environment with the candidate sources removed.

1.5 Format for Data Results

The Results Section of the report divides the Park into 12 distinct subsections and places results of the described survey techniques into their respective data categories. In each of the 12 sections the third octave data describing effects of man-made noise on natural sound is first described. Following data discussion of the third octave reductions, a presentation of the 24-hour computer analysis readouts is provided. A discussion of the results for these 24-hour continuous monitor data is presented immediately following the discussion of third octave analysis results.

If the survey of the Park section included a walkaround analysis, these data and associated discussions will be found at the conclusion of each subsection. The data reductions for the walkaround technique include a summary of daytime and nighttime L_{10}, L_{50}, and L_{90} decile levels for the area, further subdividing such temporal periods into categories of man-made noise or natural sounds.

In general if the color of the third octave tape recorded data reduction is blue, green or yellow in the first part of the subsection, it can be reasonably concluded that the area is predominantly natural in acoustic climate; however yellow, brown, or red oriented data indicates that man-made noise may predominate at certain times and as such a more thorough investigation of 24-hour and/or walkaround data results should be made in order to more fully understand such impact on natural sound. A quick overview of natural and man-made noise areas may be discerned by reviewing the pull-out color topographical displays in Section 3 These displays are really a summation of data results from all three methodologies over four seasons of the year. Note that the accuracy of the color noise map is a function of many environmental factors which affect noise propagation as discussed in the previous section of this report. As such the topographical displays should be viewed as a guide to quiet and not-so-quiet Lakeshore areas, rather than as a total predictive tool. For purposes of Park planning and other administrative uses, the color map is an excellent means of determining which areas possess intrinsically man-made noise or natural sound characteristics and the data given therein should be viewed as a best estimate of sound levels which may be found in the respective areas shown. A more accurate description of the acoustic climate of a particular area may be obtained through the aforementioned perusal of Results Section data analysis reductions for the sections .

1.5.1 Division of Park Areas

For purposes of organizing the Park into subsectional areas, within which the many data sites may be described, IITRI has chosen 12 natural subdivisions of the 12,000 acres as survey sites:

- Mount Baldy Area
- Beverly Shores Area
- Furnessville Area
- State Park Area
- Bailly Area
- Dune Acres Area
- Ogden Dunes Area
- Inland Marsh Area
- West Beach Area
- Tolleston Dunes Area
- Miller Woods Area
- Miscellaneous Park Areas: Pinhook Bog Heron Rookery Hoosier Prairie

The above areas appear in the topographic geological survey maps* preceding each subsection. An "X" on the map describes individual data site points for a 24-hour survey, and "– – –" type lines represent a walkaround analysis site. The Ogden Dunes, West Beach, Inland Marsh, and Tolleston Dunes survey site locations appear together on one geological survey map as do the site locations for Furnessville and State Park surveys. Note that the linear tape recordings of data took place at each 24-hour and walkaround location, thus allowing correlation of frequency/ energy characteristics of man-made noise impact on natural sounds with the statistical A-weighted descriptors given by the other two methodologies.

1.5.2 Topography of Areas

The maps given in SectionII , as well as topographical displays, provide information of some significance for the manner in which man-made noise impact may vary on certain Park lands due to change of season or change in meteorological conditions. The proximity of man-made noise sources to Park areas are also depicted on these maps which, together with the other topography discussed above, give a reasonable perspective on the acoustic naturalness of the areas.

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*Some of these maps date from the late 1960's. Interstate 94 may not appear on survey sites given. The color topographical display maps in Section may be referred to for Interstate locations.

Data gathering locations were chosen in each of the topographical areas shown for purposes of determining the variations in man-made noise, both daily, as well as seasonally, and to depict the general acoustic naturalness of the area. Descriptions of these locations and the measurement sites utilized are given in the following subsections.

1.5.2.1 Mount Baldy

General topography is a large dune with oak forest to the south, Lake Michigan to the north, Michigan City and power plant to the east, and hill and valley areas to the west*. The major Interstates are I-94, 6 kilometers to the south and I-80 and I-90, 12 km south. Major arterial roads are U.S. 20, 3 km south and U.S. 12 which runs adjacent to the south boundary of the area. Six 24-hour and one walkaround survey were completed in the area. Two of the 24-hour studies were seasonal repeats. The walkaround survey assessed propagation of man-made noise from the Michigan City Power Plant into the large dune and oak forest areas west of the boundary. The 24-hour analyses assessed the acoustic climate on top of the oak woods dune behind Baldy, in the valley east of Baldy (east Lake Park Avenue, 300 meters from beach) for both summer and winter seasons at the top of the hill south of this valley overlooking east Lake Park Avenue and Beverly Drive, and two surveys at Central Beach, one at the edge of the parking lot, the other 1000 meters back from the beach. Linear tape recordings were performed for each survey, thus providing a three-methodology result. The Results Section format will describe the tape recording results followed by a special discussion of the statistical A-weighted data presented in summary form.

*For purposes of the study, the west border is taken as Central Avenue.

1.5.2.2 Beverly Shores

The general topography is Lake Michigan and adjoining beach on the north, one or two ridges of dunes followed by flat marsh and wooded land to the south. The area is bounded on the east by Central Avenue and on the west by the State Park boundary. One walkaround survey and two 24-hour analyses were performed in this area. The walkaround survey assessed the impact of U.S. 12 power lines and man-made vehicular noise source passby on natural sounds, as propagated from the south boundary (U.S. 12) to the north boundary (Lake Michigan). The two 24-hour analyses measured the statistical variations of man-made noise in a residential area near Wells Road, and the dune and brush-like natural setting near the parking lot on Boundary Road at the State Park Boundary. Data results will follow the format established for Mount Baldy.

1.5.2.3 Furnessville

The topography is generally flat terrain with many wooded areas providing shielding from the Penn Central Railroad tracks and U.S. 20 man-made noise impact sources to the south, and U.S. 12 traffic noise to the north. Four 24-hour surveys with associated linear tape recordings were performed in this area. One survey was performed in the sandy area just east and south of the visitors center, one along the horse trail off of U.S. 20, a third 300 meters south of U.S. 12 and 1000 meters west of the visitors center, and a fourth at the Park maintenance building between U.S. 12 and U.S. 20. In all but the latter site locations, the area chosen was very natural-looking, but as will be discussed in the Results Section, the acoustic climate was less than natural in character.

1.5.2.4 State Park

The topography of this area is perhaps the most natural of all the areas in the IDNL. The area is 6.5 km north of the nearest Interstate, with much wooded terrain between, near field marsh and wooded valley areas to the east and west, 8 km from the nearest large industrial source, and surrounded by massive natural and brush covered sandy dune terrain. Lake Michigan and adjacent beach border on the north, and U.S. 12 borders the south portion. For purposes of data result discussion, the west boundary will be taken as Dune Acres and the east border as Boundary Road. Four 24-hour studies, three of which were seasonal repeats, were performed in the State Park Unit. Two surveys, summer and winter, were performed 350 meters west of the entrance gate to the Park, two surveys were performed on Trail 10, one near the Big Marsh, the other in the Pinery, one survey was placed near the west section of the campground, behind Mt. Holden, another was placed at the east side of the campground, near the nature center, and the final survey site was actually outside the Park's west boundary, 500 meters from Lake Michigan in the Porter Beach area. Linear tape recordings were performed for all of the previously mentioned statistical surveys and the results sections format will consist of a discussion of these tapes followed by a summary of the 24-hour A-weighted decile, L_{eq}, and L_{DN} descriptors.

1.5.2.5 Bailly

The topography of the area is basically flat land with some solid wooded area at the western quadrants, much interspersed trees and foliage with single family residential dwellings, bordered by U.S. 12 and dune areas on the north, U.S. 20 on the south, Indiana 49 on the east, and Indiana 149 on the west. Industrial man-made noise sources include the power plant in the northwest quadrant and the Interstate system in the southwest quadrant. Five 24-hour and one walkaround survey were performed in this area. The walkaround survey analyzed the propagation of interstate noise over the 10,000 meters of Bailly area, stretching from the far southwest boundary through valley areas of Little Calumet River, riverbank, through the Boys' Club (Goodfellow Camp) and up to the mid-north region of the area, near the old Nike Base (now IDNL Headquarters). The only area appearing and sounding natural occurs along the banks of the Little Calumet

River since this is a low lying valley type terrain, thus shielded from highway and train vehicular noise. The 24-hour site locations include one survey performed near the Goodfellow Camp area in winter/spring season, a study made in the Chellborg Farm location, near Bailly homestead, one survey near the intersections of U.S. 12 and Indiana 49 at the far northeast quadrant of the area, one survey performed 800 meters east of Indiana 149 near U.S. 12 and the steel mill/power plant complex to the north, and one survey performed in summer/fall season in the wooded regions just west of the Goodfellow Camp near the power transmission lines.

1.5.2.6 Dune Acres

The topography of this area is basically the same as Beverly Shores, except for a very large natural marsh area known as Cowles Bog lying on the southern boundary, and the mills and power plant industrial noise sources to the west. These sources are separated from the area by large wooded terrain. There is much wooded terrain near the residential dwellings which are equally spaced on narrow roads leading up through hill and valley areas, thus allowing for some "natural" barrier to man-made noise from U.S. 12 and interstates to the south, and the aforementioned sources to the west. Some of the homes in the area are located on top of high hills overlooking the wooded areas west of Dune Acres and so are in direct line-of-sight to some man-made noise sources. Five 24-hour A-weighted surveys and one walkaround study were performed in the Dune Acres area. The walkaround study was performed in the wooded and marsh area east from the power plant, in terrain which rises as much as 100 to 200 meters through valley and hill topography. The starting point for this survey was at the southwest boundary of the Park in direct line-of-sight to the power plant substation, and the end point was on a high hill near the east property line of Dune Acres in the wooded area described above. The walkaround points thus assessed both low and high point topology, allowing for an analysis of man-made noise impact variations on natural sounds in an area where natural shielding effects could be studied. As a planning tool for installation or improvement of trails, the walkaround analysis technique is the most useful, since the data are analyzed in "real time" under a human observer's (meter monitors) watchful eye, with a "natural ear" available to identify exactly what noise is man-made at a particular location and what is natural sound. Four of the five 24-hour studies were placed in both industrial and natural locations within Dune Acres and the fifth was placed at one of the five locations of the walkaround survey described above. One 24-hour survey was placed at the Guard House entrance to Dune Acres approximately 500 meters east of the road, the other three surveys were placed in the highest hill overlooking the southwest quadrant of the area, two of which were in direct line-of-sight to the steel mills and power plant. The third survey was placed at the east property line of the Dune Acres boundary. Thus all types of topography indigenous to the area (except for lake sounds) were covered. As before, linear tape recordings were performed for all walkaround and 24-hour study site locations and a summary of these data will be found in the results section of the report.

1.5.2.7 Ogden Dunes

Ogden Dunes abutts the South Shore and South Bend Railroad and U.S. 12 traffic sources on the south, Lake Michigan on the north, the steel mills on the east, and West Beach unit on the west. The man-made noise sources include the vehicle traffic from U.S. 12 and I-94 I-80--I-90 interstates, the railroad and mills, and residential sources such as air conditioners, automobiles, etc, within the complex itself. Residential housing rests on both low and high terrain much like Dune Acres. Two 24-hour studies were performed on Ogden Dunes, one at the Community Church, 500 m north of the railroad right-of-way and 650 m from U.S. 12, and the second 24-hour study was placed on one of the highest points in the area overlooking Lake Michigan, 200 meters below.

This latter site was in direct line-of-sight to the interstate systems to the south. The two site locations allowed for assessment of man-made noise for both low and high terrain characteristics, for proximate and distant locations. Since the area is very residentially developed, two surveys appear to be sufficient to describe an environment which is man-made noise oriented.

1.5.2.8 Inland Marsh

This is land bordered by U.S. 12 on the north, the interstate highway system on the south, and residential housing on the east and west. The terrain is very "dune like" with high hills and low valley providing locations of natural sound (secluded valleys) and man-made noise dominance (high hills). Presently the area is a haven for dirt bikes and other off-road vehicles. Such use is, of course, prohibited, but nonetheless the existing acoustic climate is thusly impacted on an occasional basis. One 24-hour and one walkaround survey were performed in the area. The walk-around survey assessed levels starting on Old Stagecoach road to the top of the first high hill in the area, along the ridge of this hill, down into the valley below, and to a point beyond a second hill and valley area near U.S. 12, separated from line-of-sight to traffic by another small ridge. The 24-hour study included results showing effect of wind change on interstate noise propagation. Placed in the first valley behind the first high dune off Old Stagecoach Road, the study assessed the effect of natural shielding from the highway noise south of the area. Linear tape recordings were performed in this area for summer and wintertime conditions. Data once again are summarized in the results section.

1.5.2.9 West Beach Unit

The West Beach area contains marsh and wet land with arid plateaus and high dunes terrain in the interior sections close to the Beach itself. Long Lake forms a natural acoustic reflector in wintertime and the man-made noise source impact is very contingent upon wind conditions. This latter effect is due to the fact that the area is very open and bordered on the south by U.S. 12 and the interstate highway to south of the Inland Area. The general borders include the lake on the north, Gary, Indiana on the west, Ogden Dunes on the east, and the aforementioned traffic routes on the south. Two 24-hour studies were performed in the West Beach area, one near Long Lake on the flat plateau area and one at the Beach House on top of the roof overlooking Lake Michigan approximately 1000 meters from the measuring microphone. Wintertime and summertime linear tape recordings were made at each site. These measurements assessed changes in traffic noise impact with distance and fluctuations in temperatures and wind direction, by assessing the acoustic climate on more than just the days of the continuous monitoring studies. Additionally, a repeat analysis was performed in the Long Lake area to analyze the change in interstate traffic noise impact with changes in wind. These differences in man-made noise impact on the West Beach Unit will be found summarized in the results sections.

1.5.2.10 Tolleston Dunes

The area is topographically similar to the Inland Marsh area, but large commercial interests border the south boundary, and industrial areas lie to the north. Thus it is very man-made noise dominated, no matter which way the wind blows, and the result of this is an area that looks quite natural and sounds a bit like a city park, not very noisy but not really quiet either. Some quiet places exist due to dune type valleys affording some shielding, but the overall attenuation is not substantial. One walkaround and one 24-hour study were performed in this area. The walkaround consisted of a total north-south traverse through the middle of the area, thus passing through all types of topography, the 24-hour study was placed almost in the middle of the Tolleston Dune Unit.

1.5.2.11 Miller Woods

Lying in the Marquette Park of Gary, this area is heavily impacted by industrial and traffic (both interstates U.S. 20/12, railroad, etc...) oriented man-made noise sources. The general terrain is sparse wooded area affording little acoustic attenuation, with the beach and Lake Michigan on the north, steel mills on the west, residential communities to the south, and Miller Beach on the east. Once again the area sounds like a city park with a low level of man-made noise ambient in the background. Two 24-hour studies were performed in the area, one on the far southwest boundary near the steel mills and U.S. 12/20 I-94-I-90 interchange, the other was placed in the wooded area 1 km west of the parking lot of Miller Beach, approximately 500 meters from the lake. Linear tape recordings were performed for the surveys and the discussions of these data will be found in the appropriate portion of the results section.

1.5.2.12 <u>Hoosier Prairie, Pinhook Bog, Heron Rookery</u>

These three areas lie off the main portion of the 12,000 acres and depict three different types of terrain. The Blue Heron Rookery is a deeply wooded and vegetative area, 2 km from the nearest interstate, and to the south of same, allowing the prevailing southwesterly winds to blow the traffic noise away from the area (this is the only Park area in which predominant traffic noise sources lie downstream of the land mass). As a result the Heron Rookery is the most natural sounding of all Park areas surveyed. The terrain is flat with the Little Calumet River running through the center of the area, well shielded by trees from occasional side-road car or truck passby, and bordering some farm land on the southeast end. This area may create a little tractor noise in the planting and harvesting time. A 24-hour survey was performed in the middle of this area near the river during both summer/fall and winter/spring seasons. The wintertime analysis consisted of a 48-hour analysis, during which time temperature inversions and changes in wind conditions caused the distant interstate source to produce varying impacts on the environment. Backup linear recordings were also produced concurrent with the 24-hour studies.

Pinhook Bog possesses a terrain unique in its title and certainly unique to the area. Unfortunately, its south boundary is no more than 1000 meters from the toll road (I-80-90) and as such (except in rare instances of a north wind) the sound of man-made noise intrudes on the very natural setting of the bog. The Bog is bounded by Wozniak Road on the west, the toll road on the south, apple orchards on the north, and a small side road on the east. One 24-hour and one walkaround survey were performed in the area. The walkaround survey assessed impact of the toll road and arterial roads on the bog and land to the north of the area, the 24-hour study analyzed the statistical impact of traffic noise at an area near the middle of the bog. Backup linear tape recordings were performed for both survey techniques.

The last survey site assessed for the study was the Hoosier Prairie area which is also a unique terrain, mainly prairie with sparse tree and other vegetative areas. One 24-hour study was completed in the area, which is surrounded by railroad tracks on the north and east, and major arterial roads on the south and west. Once again the acoustic climate depicts a city park with a railroad track nearby.

Since each of the three areas described above is off of the main portion of the IDNL, the results of the data taken for these areas will be cataloged together in the next section of the report. The format will be the same as for the other data analyzed for the 12,000 acres.

1.6 Problems Encountered and Conclusions Drawn

The major problems involved in the physical compiling of the data were created by the necessity to place 50 to 75 kg of acoustic equipment in a natural setting which did not lend itself to easy access by either vehicle or, in many instances, foot travel modes of equipment placement. In some cases the equipment (loaded in backpack arrangement) had to be carried up and over large dunes, which was a rather difficult task considering the nature of such terrain. Securing the equipment once it was located was usually not a problem in secluded areas, however in the State Park or open dunes type environments, (West Beach, etc) special precautions were taken to ensure against tampering. Since the batteries needed to be replaced once every 12 hours, most surveys required a return to check on operational conditions during very late hours. Since the gathering of date in late night conditions was part of the program this was usually not a problem, however after 12 or 14 hours of data gathering, most surveyors have about reached the limit of human endurance, and changing batteries was just one more task added to a list of others.

The second major problem involved weather. Rain and wind, though natural phenomena, produce rather unnatural acoustical effects in measuring equipment. Wind produces very low frequency acoustic energy which quickly overloads even the most selective of acoustic instrumentation. Rain makes the microphone and preamplifier sections short out electrically; rain and electricity just do not mix. The solution to some of these problems involved placing the equipment on nonwindward sides of hills and weatherproofing the survey site without acoustically altering it. In some instances this served the purpose, in others the survey had to be repeated. In one instance (Mound Baldy) the same survey was wind or rained out four times in a row before a full 24 hours of data could be obtained.

Conclusions if any, to be drawn from these physical facts center about choosing the survey season and equipment as a functioning unit. This is to say that rainproof equipment would be useful for summer and fall, but low temperature instrumentation must be used for winter and spring seasons. Sites should be selected which have partial access by automobile or jeep type vehicles with backpacking of 40 to 50 kg loads limited to 2 to 4 km of walking for sandy terrain. Nighttime analyses should be performed by two people minimum, one to hold the light and the other to perform the meter monitoring. Insect spray should be utilized on both surveyor and equipment; the source of mosquitos and other flying insects attracted to light are not natural sounds when the creatures are being unnaturally treated by acoustic equipment or human hands slapping them out of existence.

Finally, and we make this point in passing, it should be realized that even with unlimited funding a complete physical noise inventory of every part of a National Park is a task unfit for the instrumentation and manpower required therein. A good amount of objective/subjective interpretation based upon a small but well organized data base, which may include computer predictive techniques, will yield an accurate acoustic picture of a National Park. Considering the potential damage to terrain or alteration of animal and insect patterns which would definitely come about if 100 or so graduate students were to be let loose with sound level meters in a Park, the concept of a stationary unmanned monitoring site, visited two or three times during the day and night by one or two people, seems to be a much more natural way to achieve equally valid results. As the author proceeds to describe the results of this study in the next section, the reader should bear in mind that as objective as the data collected for the survey has been, the choice of site locations and placement of instrumentation therein were based upon the qualified opinion of a human observer, and so the impact of man-made noise on natural sounds as described by said results may be open to critical review. Suffice it to say that if another qualified acoustician were to repeat the analysis procedure instituted in this program, the scientific objectivity of the equipment and procedures utilized should ensure that the results would be essentially identical to those found in the present study. The above conclusion is of course based upon the supposition that the natural and man-made acoustic sources would not change over the time duration between studies, a not altogether valid presumption. The need for updating and other continuing analysis procedures for IDNL will be covered in Section 4 of the report.