DNWG
DEPARTMENT OF DEFENSE
NOISE WORKING GROUP

Improving Aviation Noise Planning, Analysis and Public Communication with Supplemental Metrics

Guide to Using Supplemental Metrics

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1.0 Introduction

The Military Services of the U.S. Department of Defense (DoD) have long relied on traditional methods of analyzing aircraft noise using the Day Night Average Sound Level (DNL) metric, and in California the similar Community Noise Equivalent (CNEL). Recently, however, a need has been identified to use other supplemental analysis tools and noise metrics for two reasons: (1) to produce more detailed noise exposure information for the decision process; and (2) to improve communication with the public about noise exposure from military activities. Better communication with all stakeholders and the general public is clearly a benefit to both the Military and the adjacent communities.

Toward this end, the Department of the Navy has contracted with Wyle Laboratories to develop tools to improve aviation noise planning, analysis, and public communication through the use of noise metrics (and analysis techniques) other than DNL, generally referred to as supplemental metrics or supplemental analysis. Phase I of this contract is to develop a “Guide to Using Supplemental Metrics” that will enable the military services to communicate more effectively with the public. Phase II will include upgrades to current military noise models to facilitate the use of supplemental metrics in analyzing noise and producing a wider variety of noise exposure maps and materials.

Two working papers, prepared with oversight from the members of the Department of Defense Noise Working Group (DNWG), have formed the basis from which this “Guide to Using Supplemental Metrics” was developed. Working Paper No. 1, which was completed in February 2005, provides a look at existing procedures at military bases and public attitudes about aviation noise impacts. Working Paper No. 2, completed in January 2006, examines a broad range of traditional and supplemental metrics and tools that have been used, at not only military bases and air carrier airports in the U.S., but throughout the world.

1.1 Intent of this Guide

The intent of this guidelines document is to guide the Military Services in providing more useful information on the noise environment than is available through solely using the long-term, cumulative metrics such as DNL. (All references to DNL throughout this Guidelines document also apply to CNEL when applied to noise analysis for facilities located in California). Supplemental analysis with additional metrics is not intended to replace the DNL metric as the primary descriptor of cumulative noise exposure in an Environmental Assessment (EA) or Environmental Impact Statement (EIS) performed under the National Environmental Policy Act (NEPA). Furthermore, this guideline document is not intended to replace the minimum Federal land use/noise compatibility guidelines that are produced during the Navy, Marine Corps, and Air Force Air Installation Compatible Use Zones (AICUZ) studies, Army Installation Operational Noise Management Plan (IONMP) studies, and Joint Land Use Studies (JLUS). Further research is needed to determine if there a causal relationship between metrics other than DNL and long-term community effects such as annoyance.

Therefore, any suggested noise level thresholds herein should be considered as useful tools for describing the potential effects on the environment to supplement the impact information disclosed by the DNL metric. Project officials must caution the stakeholders that DoD is not endorsing any metric other than DNL to determine whether some type of future action may have significant environmental effects (under NEPA) or whether the minimum Federal guidelines for land-use planning should be modified.

1.2 Contents of this Guide

In keeping with the stated intent of this guide, the contents include the information needed, not only on how to use supplemental metrics in aviation noise analyses, but also on the background from which these metrics have been developed. To this end, Section 3.0 provides the reader with a concise summary of the effects of noise on people. An expanded version of this information is provided in Appendix A for those who wish for more detail. Section 4.0 describes previous and current research related to supplemental metrics. Then, in Section 5.0, the various supplemental metrics in current use are described, with their strengths and weaknesses, and examples given on how they may be used to assess different aspects of noise effects. Finally, Section 6.0 provides a summary of metric usage, describing what metric to use, when, and how. Readers who are knowledgeable of the subject, and are using the guide as a reference document, can proceed directly to this section for information on the application of supplemental metrics.

Following the main text and Appendix A, Appendix B describes the application of supplemental metrics in three military case studies to demonstrate the additional information to be gained from their use. Appendix C then documents 14 case studies of the use of supplemental metrics at civilian airports.

2.0 The Historical Problem of Encroachment – A Way Forward

Historically, DoD has encountered significant problems with encroachment of non-compatible land uses at military installations, to the extent that many base-closure and realignment decisions have been driven at least in part by encroachment. When an installation can no longer fully support its current or future mission because of noise or other impacts on the adjacent community, DoD has little choice but to consider operational alternatives to help reduce noise that could degrade training, or to relocate flying units to other locations.

A better understanding of noise exposure by military personnel, local officials, other stakeholders and the general public may reduce and, possibly over time, minimize encroachment on installations by non-compatible noise sensitive development. When using DNL to communicate noise exposure to the average citizen residing near a military airfield, a typical response is, "I don't hear averages, I hear individual airplanes." Airport neighbors often become angry and frustrated trying to understand explanations of noise exposure solely in terms of average sound energy with the DNL metric, particularly when they are trying to grasp the impact of flight pattern changes resulting from new runways, new flight corridors, runway closures, increased operations, and aircraft changes.

DoD and FAA guidelines define noise-sensitive land uses in areas where the DNL is 65 decibels (dB) or higher to be non-compatible with aircraft operations. Noise-sensitive uses below DNL 65 dB are considered to be compatible "without restrictions." FAA policy regards noise to be so intrusive on one side of that pencil-thin line on a map that Federal funding is provided to sound insulate or possibly acquire residences and other noise-sensitive structures, such as schools, churches and hospitals; but outside that line on the map the Federal guidelines suggest that noise sensitive development is perfectly acceptable without restriction. Clearly, it is not the intent of Federal policy to communicate that noise stops at that boundary, and a number of forward thinking communities have effectively addressed this circumstance by establishing buffer areas between these non-compatible and fully compatible areas, where if noise-sensitive development is permitted, it is allowed to occur only "with restrictions." Where such airport buffer zones have been established between noise-sensitive land use areas and areas regarded as fully compatible for noise sensitive development without restriction, controversy over aviation noise impacts has been substantially reduced. Supplemental metrics that show how many events comprise DNL at various dB levels, and how much time out of the day those events are present, helps to identify and communicate the benefits of establishing and maintaining a buffer zone between the non-compatible and fully compatible areas around an installation.

The Federal government adopted DNL because it is the best single system of noise measurement that can be uniformly applied in measuring noise in the communities and around airports, and for which there is a relationship between projected noise and surveyed reaction of people to the noise. While the Federal agencies have accepted DNL as the best metric for land use compatibility guidelines, reducing the description of noise exposure to a single value of DNL may not help the public understand noise exposure. Simply looking at the location of their home on a DNL contour map does not answer the important questions: how many times airplanes fly over, what time of day, what type of airplanes, or how these flights may interfere with activities, such as sleep and watching television. The number and intensity of the individual noise events that make up DNL are critically important to public understanding of the effects of noise around airports. What is needed is a better way to communicate noise exposure in terms that are more easily understood. Supplementing DNL with additional metrics will help the public better understand noise exposure.

This Guidelines document is designed to provide the user an understanding of the purpose and need to quantify and communicate noise exposure in the clearest possible terms over an adequate geographic area around their installation, and to facilitate efforts to protect the installation from encroachment by non-compatible noise sensitive development. The Military Services execute several programs, such as Air Installation Compatible Use Zones (AICUZ) and Joint Land-Use Studies (JLUS), in order to work with neighboring communities. The Services typically conduct meetings with community members to address flight operations and noise impacts in order to foster comprehensive land-use development in the vicinity of DOD airfields. The use of supplemental metrics and analyses will facilitate these on-going programs.

3.0 Effects of Noise on People – Review of Scientific Research, Policy, and Guidelines

In order to apply these guidelines effectively to specific local circumstances, project staff should have at least a basic understanding of the effects of noise on people. This section provides an introduction to the noise effects included in a typical noise analysis; more detailed, technical explanations and information on all noise effects be contained in Appendix A.

Within the context of the U.S. Federal noise control regulations and guidance, the term *health* has been defined, not simply by the absence of disease, but as the total psychological and physiological well-being of the community. The term *public health* indicates that the common interests of society must be taken into account when evaluating potential noise effects. In other words, noise effects must be related to the long-term, cumulative effects of the population as a whole, not the isolated, occasional impacts on individuals.

The reaction of people to a given noise environment is extraordinarily complex. This is particularly evident when evaluating the potential health effects of people exposed to aircraft noise, with its intermittent nature and character, and where noise levels fluctuates significantly with time. Another important element is the complex psychological and physiological reaction of people to the noise environment, as well as their attitude toward the source of the noise. Further exacerbating this complex issue is the possibility that short-term community response can be different from the long-term community reaction.

In an effort to understand people's response to noise, the scientific-medical community has divided the noise effects on people into two general categories of responses. The first of these, psychological response, refers to behavioral reactions that are indicators of the population's "well-being" — essentially, people's psychological reaction to their noise environment and their reaction to interference with their various day-to-day activities. Primary examples are the effects on long-term community annoyance, speech interference (including effects in the home, school, churches, and auditoria), sleep disturbance (home), effects on children's learning (school), and interference with work performance. The second indicator for human response to noise is physiological — essentially, effects on the human body's systems. Examples are noise-induced hearing loss, and other medical health effects such as cardiovascular disease, which have been postulated by various researchers.

For each of these indicators that attempt to describe the long-term community reaction to noise, the scientific community has spent considerable effort since the mid-1950s researching the noise metrics and associated noise levels that best relate to individual and community response. The following sub-sections discuss the main noise effects to be considered when planning and performing noise analysis for a typical project. Appendix A presents a comprehensive review of the range of global research studies that have attempted to address the array of potential effects, with particular emphasis placed on those studies that have served as guidance for U.S. noise policy. Note that this review is intended only as a guideline for better understanding this complex issue. The reader is encouraged refer to the references for more detailed study.

3.1 Psychological Effects

3.1.1 Annoyance

The primary effect of aircraft noise on exposed communities is one of long-term annoyance, defined by the Environmental Protection Agency (EPA)[1] as any negative subjective reaction on the part of an individual or group. The scientific community has adopted the use of long-term annoyance as a primary indicator of community response because it attempts to account for all negative aspects of effects from noise, e.g., increased annoyance due to being awakened the previous night by aircraft and interference with everyday conversation.

Numerous laboratory studies and field surveys have been conducted to measure annoyance and to account for a number of the variables, many of which are dependent on a person's individual circumstances and preferences. Laboratory studies of individual response to noise have helped isolate a number of the factors contributing to annoyance, such as the intensity level and spectral characteristics of the noise, duration, the presence of impulses, pitch, information content, and the degree of interference with activity. Social surveys of community response to noise have allowed the development of general dose-response relationships that can be used to estimate the proportion of people who will be highly annoyed by a given noise level. The results of these studies have formed the basis for criteria established to define areas of compatible land use.

A wide variety of responses have been used to determine intrusiveness of noise and disturbances of speech, sleep, audio/video entertainment, and outdoor living, but the most useful metric for assessing people's responses to noise is the percentage of the population expected to be "highly annoyed." The concept of "percent highly annoyed" has provided the most consistent response of a community to a particular noise environment. In his synthesis of several different social surveys that employed different response scales, Schultz[2] defined "highly annoyed" respondents as those respondents whose self-described annoyance fell within the upper 28% of the response scale where the scale was numerical or un-named. For surveys where the response scale was named, Schultz counted those who claimed to be highly annoyed, combining the responses of "very annoyed" and "extremely annoyed. Schultz's definition of "percent highly annoyed" (%HA) became the basis for Federal policy on environmental noise.

Daily average sound levels are typically used for the evaluation of community noise effects, such as long-term annoyance. In general, scientific studies and social surveys have found a correlation between the percentages of groups of people highly annoyed and the level of average noise exposure measured in DNL. The classic analysis is Schultz's original 1978 study[2], whose results are shown in Figure 3-1. This figure is commonly referred to as the Schultz curve. It represents the synthesis of a large number of social surveys (161 data points in all), that relates the long-term community response to various types of noise sources, measured using the Day-Night Average Sound Level (DNL) metric.

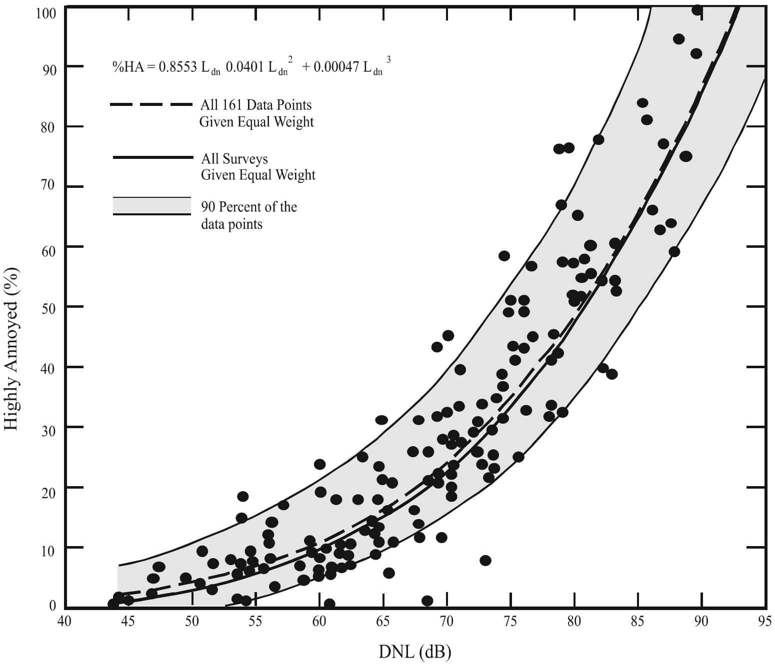


Figure 3-1. Community Surveys of Noise Annoyance

An updated study of the original Schultz data based on the analysis of 400 data points collected through 1989 essentially reaffirmed this relationship[3]. Figure 3-2 shows an updated form of the curve fit[4] in comparison with the original Schultz curve. The updated fit, which does not differ substantially from the original, is the current preferred form in the U.S. The relationship between %HA and DNL is:

$$\%HA = 100/[1+ \exp(11.13 – 0.141L_{dn})]$$

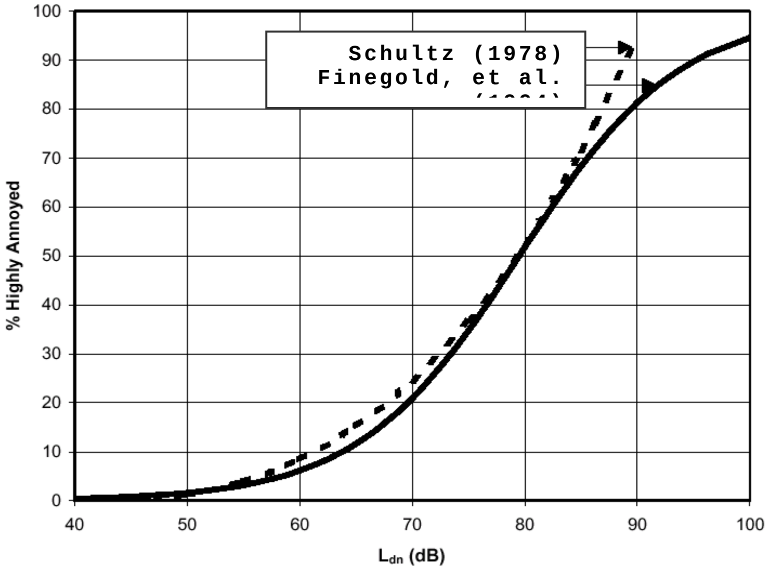


Figure 3-2. Response of Communities to Noise; Comparison of Original (Schultz, 1978) and Current (Finegold, et al. 1994) Curve Fits

In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. However, the correlation coefficients for the annoyance of individuals are relatively low, on the order of 0.5 or less. This is not surprising, considering the varying personal factors that influence the manner in which individuals react to noise.

A number of non-acoustic factors have been identified that may influence the annoyance response of an individual. Newman and Beattie[5] divided these factors into emotional and physical variables:

Emotional Variables:

- Feelings about the necessity or preventability of the noise;
- Judgment of the importance and value of the activity that is producing the noise;
- Activity at the time an individual hears the noise;
- Attitude about the environment;
- General sensitivity to noise;
- Belief about the effect of noise on health; and
- Feeling of fear associated with the noise.

Physical Variables:

- Type of neighborhood;
- Time of day;
- Season;
- Predictability of noise;
- Control over the noise source; and
- Length of time an individual is exposed to a noise.

The low correlation coefficients for individuals' reactions reflect the large amount of scatter among the data drawn from the various surveys and point to the substantial uncertainty associated with the equation representing the relationship between %HA and DNL. Based on the results of surveys it has been observed that noise exposure can explain less than 50 percent of the observed variance in annoyance, indicating that non-acoustical factors play a major role. As a result, it is not possible to accurately predict individual annoyance in any specific community based on the aircraft noise exposure. Nevertheless, *changes* in %NA can be useful in giving the decision maker more information about the relative effects that different alternatives may have on the community.

The original Schultz curve and the subsequent updates do not separate out the annoyance from aircraft noise and other transportation noise sources. This was an important element, in that it allowed Schultz to obtain some consensus among the various social surveys from the 1960s and 1970s that were synthesized in the analysis. In essence, the Schultz curve assumes that the effects of long-term annoyance on the general population are the same, regardless of whether the noise source is road, rail, or aircraft. In the years after the classical Schultz analysis, additional social surveys have been conducted to better understand the annoyance effects of various transportation sources.

Miedema & Vos[6] present synthesis curves for the relationship between DNL and percentage "Annoyed" and percentage "Highly Annoyed" for three transportation noise sources. Separate, non-identical curves were found for aircraft, road traffic, and railway noise. Table 3-1 illustrates that, for a DNL of 65 dB, the percent of the people forecasted to be Highly Annoyed is 28% for air traffic, 18% for road traffic, and 11% for railroad traffic. For an outdoor DNL of 55 dB, the percentage highly annoyed would be close to 12% if the noise is generated by aircraft operations, but only 7% and 4% respectively if the noise is generated by road or rail traffic. Comparing the levels on Miedema's curve to those on the updated Schultz curve[4] indicates that the percentage of people highly annoyed by aircraft noise may be higher than previously thought when the noise is solely generated by aircraft activity.

Table 3-1. Miedema's Annoyance Curves – Percent Highly Annoyed for Different Transportation Noise Sources

DNL	Percent Highly Annoyed (%HA)			
	Miedema			Schultz
	Air	Road	Rail	Combined
55	12	7	4	3
60	19	12	7	6
65	28	18	11	12
70	37	29	16	22
75	48	40	22	36

(Source: Miedema, JASA 1998)

As noted by WHO[7], even though aircraft noise seems to produce a stronger annoyance response than road traffic, caution should be exercised when interpreting synthesized data from different studies. WHO noted that five major parameters should be randomly distributed for the analyses to be valid: personal, demographic, and lifestyle factors, as well as the duration of noise exposure and the population experience with noise.

The Federal Interagency Committee on Noise (FICON)[8] found that the updated "Schultz Curve" remains the best available source of empirical dosage effect information to predict community response to transportation noise without any segregation by transportation source; a position still held by the Federal agencies on the Federal Interagency Committee on Aircraft Noise (FICAN). However, FICON also recommended further research to investigate the differences in perceptions of aircraft noise, ground transportation noise (highways and railroads), and general background noise.

3.1.2 Interference with Speech Communication

Speech interference associated with aircraft noise is a primary cause of annoyance for communities. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is particularly important in classrooms, offices, and industrial settings and can cause fatigue and vocal strain in those who attempt to communicate over the noise.

The disruption of speech in the classroom is a primary concern, due to the potential for adverse effects on children's learning ability. There are two aspects to speech comprehension:

(1) *Word Intelligibility* - the percent of words transmitted and received. This might be important for students in the lower grades who are learning the English language, and particularly for ESL students.

(2) *Sentence Intelligibility* – the percent of sentences transmitted and understood. This might be important for high-school students and adults who are familiar with the language, and who do not necessarily have to understand each word in order to understand sentences.

For teachers to be clearly understood by their students, it is important that regular voice communication is clear and uninterrupted. Not only does the background sound level have to be low enough for the teacher to be clearly heard, but intermittent outdoor noise events need to be minimized also. It is therefore important to evaluate the steady background level, the level of voice communication, and the single-event level due to aircraft overflights that might interfere with speech.

Several research studies and guideline documents have been conducted over the last 30 years resulting in a fairly consistent set of noise level criteria for speech interference. This section provides an overview of the results of these studies.

U.S. Federal Criteria for Interior Noise

In 1974, the EPA[1] identified a goal of an indoor 24-hour average level $L_{eq(24)}$ of 45 dB to minimize speech interference based on the intelligibility of sentences in the presence of a steady background noise. Intelligibility pertains to the percentage of speech units correctly understood out of those transmitted, and specifies the type of speech material used, i.e. sentences or words[9]. The curve displayed in Figure 3-3 shows the effect of steady indoor background sound levels on sentence intelligibility. For an average adult with normal hearing and fluency in the language, steady background sound levels indoors of less than L_{eq} 45 dB are expected to allow 100% intelligibility of sentences.

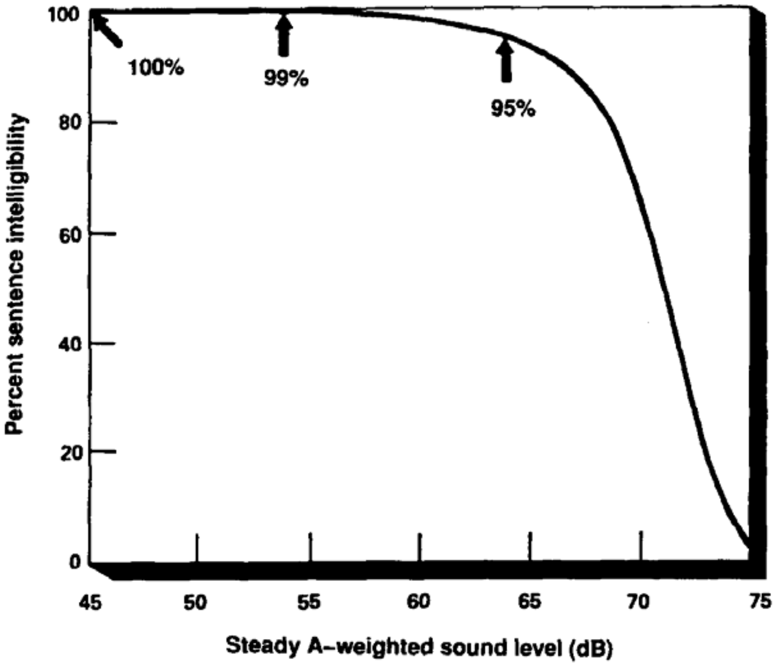


Figure 3-3. Speech Intelligibility Curve

(Source: EPA 1974)

The curve shows 99 percent sentence intelligibility for background levels at a L_{eq} of 54 dB, and less than 10 percent intelligibility for background levels above a L_{eq} of 73 dB. Note that the curve is especially sensitive to changes in sound level between 65 dB and 75 dB - an increase of 1 dB in background sound level from 70 dB to 71 dB results in a 14 percent decrease in sentence intelligibility, whereas a 1 dB increase in background sound level from 60 dB to 61 dB results in less than 1 percent decrease in sentence intelligibility.

Classroom Criteria for Steady State Noise

For listeners with normal hearing and fluency in the language, complete sentence intelligibility can be achieved when the signal-to-noise ratio (i.e., the difference between the speech level and the level of the interfering noise) is in the range 15-18 dB[10].

Both the American National Standards Institute[11] (ANSI) and the American Speech-Language-Hearing Association[12] recommend at least a 15 dB signal-to-noise ratio in classrooms, to ensure that children with hearing impairments and language disabilities are able to enjoy high speech intelligibility. As such, provided that the average adult male or female voice registers a minimum of L_{max} 50 dB in the rear of the classroom, the ANSI standard requires that the continuous background noise level indoors must not exceed a L_{eq} of 35 dB (assumed to apply for the duration of school hours).

The WHO[7] reported that, for a speaker-to-listener distance of about 1 meter, empirical observations have shown that speech in relaxed conversations is 100 percent intelligible in background noise levels of about 35 dB, and speech can be fairly well understood in the presence of background levels of 45 dB. The WHO recommends a guideline value of L_{eq} of 35 dB for continuous background levels in classrooms during school hours.

Bradley[13] suggests that in smaller rooms, where speech levels in the rear of the classroom are approximately L_{max} 50 dB, steady-state noise levels above 35 dB may interfere with the intelligibility of speech.

The FAA[14] guidelines state that the design objective for a classroom environment is a time-averaged A-weighted sound level L_{eq} of 45 dB resulting from aircraft operations during normal school hours for the purposes of determining eligibility for noise insulation funding.

Intermittent Noise

The noise measured near an airfield is not continuous, but consists of individual events where the sound level exceeds the background level for a limited time period as the aircraft flies over. Thus, the classroom criteria described in the previous subsection is not applicable to aircraft noise exposure. Since speech interference in the presence of aircraft noise is essentially determined by the magnitude and frequency of individual aircraft flyover events, a time-averaged metric alone, such as L_{eq}, is not necessarily appropriate when evaluating the overall effects. In addition to the background level criteria described above, single-event criteria, which account for those sporadic intermittent noisy events, are also essential to specifying speech interference criteria.

In 1984, Sharp and Plotkin, in a report to the Port Authority of New York and New Jersey, recommended utilizing the Speech Interference Level (SIL) metric for classroom noise criteria[15]. This metric is based on the maximum sound levels in the frequency range (approximately 500 Hz to 2,000 Hz) that directly affects speech communication. Their study identified an SIL (the average of the sound levels in the 500, 1000, and 2000 Hz octave-bands) of 45 dB as the desirable goal, which was estimated to provide 90 percent word intelligibility for the short time periods during aircraft overflights. Although early classroom level criteria were defined in terms of SIL, the use and measurement of L_{max} as the primary metric has since become more popular. Both metrics take into consideration the maximum sound levels associated with intermittent noise events and can be related to existing background levels when determining speech interference percentages. An SIL of 45 dB is approximately equivalent to an A-weighted L_{max} of 50 dB for aircraft noise[16].

In 1998, Lind, Pearsons, and Fidell[17] also concluded that if an aircraft noise event's maximum indoor noise level (L_{max}) reached the speech level of L_{max} 50 dB, 90 percent of the words would be understood by students seated throughout the classroom. Since intermittent aircraft noise does not appreciably disrupt classroom communication at lower levels and other times, Lind et. al. also adopted an indoor L_{max} of 50 dB as the maximum single-event level permissible in classrooms[17]. Note that this limit was set based on students with normal hearing and no special needs; at-risk students may be adversely affected at lower sound levels.

Bradley[18] recommends SEL as a better indicator of estimated speech interference in the presence of aircraft overflights indoors. For acceptable speech communication using normal vocal efforts, Bradley suggests that the indoor aircraft SEL be no greater than 64 dB. Assuming a 26 dB outdoor-to-indoor noise reduction that equates to 90 dB SEL outdoors. Aircraft events producing outdoor SEL values greater than 90 dB would result in disruption to indoor speech communication. Bradley's work indicates that, for speakers talking with a casual vocal effort, 95% intelligibility would be achieved when indoor SEL values did not exceed 60 dB, which translates approximately to an L_{max} value of 50 dB.

In the presence of intermittent noise events, ANSI[121] states that the criteria for allowable background noise level can be relaxed since speech is impaired only for the short time when the aircraft noise is close to its maximum value. Consequently, they recommend that when the background noise level of the noisiest hour is dominated by aircraft noise, the indoor criteria (L_{eq} 35 dB for continuous background noise) can be increased by 5 dB to an L_{eq} of 40 dB, as long as the noise level does not exceed 40 dB for more than 10 percent of the noisiest hour.

WHO[7] does not recommend a specific indoor L_{max} criterion for single-event noise, but does place a guideline value at L_{eq} of 35 dB for overall background noise in the classroom. However, WHO does report that "for communication distances beyond a few meters, speech interference starts at sound pressure levels below 50 dB for octave bands centered on the main speech frequencies at 500 Hz, 1kHz, and 2 kHz." One can infer that this can be approximated by an L_{max} value of 50 dB.

The United Kingdom Department for Education and Skills (UKDFES) established in its classroom acoustics guide[19] a 30-minute time-averaged metric [$L_{eq(30min)}$] for background levels and $L_{A1,30\ min}$ for intermittent noises, at thresholds of 30-35 dB and 55 dB respectively. $L_{A1,30\ min}$ represents the A-weighted sound level that is exceeded 1 percent of the time (in this case, during a 30 minute teaching session) and is generally equivalent to the L_{max} metric.

Summary

As the previous section demonstrates, research indicates that it is not only important to consider the continuous background levels using time-averaged metrics, but also the intermittent events, using single-event metrics such as L_{max}. Table 3-2 provides a summary of the noise level criteria recommended in the scientific literature.

Table 3-2. Indoor Noise Level Criteria Based on Speech Intelligibility

Source	Metric/Level (dB)	Effects and Notes
U.S. FAA (1985)	L_{eq}(during school hours) = 45 dB	Federal assistance criteria for school Sound Insulation; supplemental single-event criteria may be used
Lind et al. (1998), Sharp (1984), Wesler (1986)	L_{max} = 50 dB / SIL 45	Single event level permissible in the classroom
WHO (1999)	L_{eq} = 35 dB L_{max} = 50 dB	Assumes average speech level of 50 dB and recommends signal to noise ratio of 15 dB
U.S. ANSI (2002)	L_{eq} = 40 dB, Based on Room Volume	Acceptable background level for continuous noise/ relaxed criteria for intermittent noise in the classroom
U.K. DFES (2003)	$L_{eq(30min)}$ = 30-35 dB L_{max} = 55 dB	Minimum acceptable in classroom and most other learning environs

When considering intermittent noise caused by aircraft over-flights, a review of the relevant scientific literature and international guidelines indicates that an appropriate criteria is a limit on indoor background noise levels of L_{eq} 35 to 40 dB, and a limit on single events of L_{max} 50 dB.

3.1.3 Sleep Disturbance

The disturbance of sleep is a major concern for communities exposed to nighttime aircraft noise. Although there is no current scientific evidence for establishing a direct relationship between nighttime aircraft noise and irreversible long-term health effects (particularly stress-induced illnesses such as cardiovascular disease), sleep disturbance is none-the-less a major cause of annoyance for the public. Consequently, there have been numerous research studies that have attempted to quantify the complex effects of noise on sleep. This section provides an overview of the major noise-induced sleep disturbance studies that have been conducted, with particular emphasis placed on those studies that have influenced U.S. federal noise policy. The studies have been separated into two groups:

1. Initial studies performed in the 1960s and 1970s, where the research was focused on laboratory sleep observations.
2. Later studies performed in the 1990s up to the present, where the research was focused on field observations, and correlations to laboratory research were sought.

Background

The relationship between noise levels and sleep disturbance is complex and not fully understood. The disturbance depends not only on the depth of sleep, but also on the previous exposure to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on sleep is the number of arousals or awakenings, and so the body of scientific literature has focused on predicting the percentage of the population that will be awakened at various noise levels. Fundamentally, regardless of the tools used to measure the degree of sleep disturbance (awakenings, arousals, etc.), these studies have grouped the data points into bins to predict the percentage of the population likely to be disturbed at various sound level thresholds.

FICON[8] produced a guidance document that provided an overview of the most pertinent sleep disturbance research that had been conducted throughout the 1970s. Literature reviews and meta-analysis conducted by Lukas[20], Griefahn and Muzet[21], and Pearsons et al. [22], made use of the existing datasets that indicated the effects of nighttime noise on various sleep-state changes and awakenings. FICON noted that various indoor A-weighted sound levels – ranging from 25 to 50 dB – were observed to be thresholds below which significant sleep effects were not expected. Due to the large variability in the data, FICON did not endorse the reliability of the results.

However, FICON did recommend the use of an *interim* dose-response curve—awaiting future research—which predicted the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in terms of SEL. This curve was based on the research conducted by Finegold[4] et al. for the U.S. Air Force. The dataset included most of the research performed up to that point, and predicted that 10 percent of the population would be awakened when exposed to an interior SEL of approximately 58 dB. The data utilized to derive this relationship were primarily the results of controlled laboratory studies.

Recent Sleep Disturbance Research – Field and Laboratory Studies

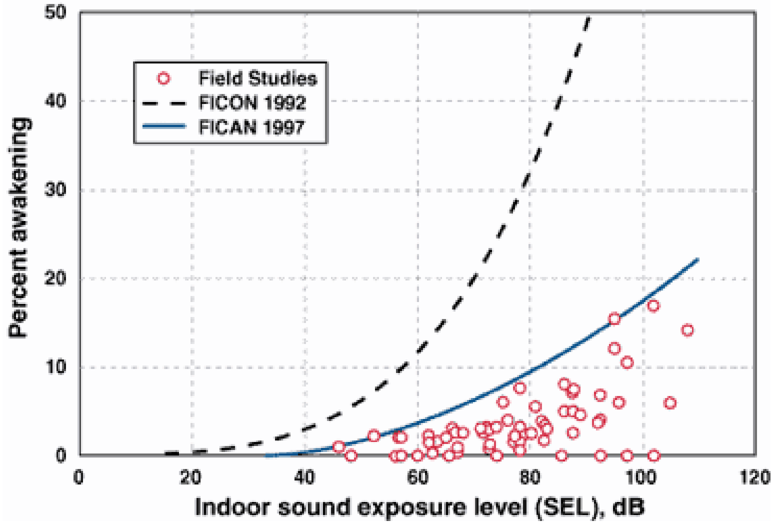
It was noted in the early sleep disturbance research that the controlled laboratory studies did not account for many factors that are important to sleep behavior, such as habituation to the environment and previous exposure to noise and awakenings from sources other than aircraft noise. In the early 1990s, field studies were conducted to validate the earlier laboratory work. The most significant finding from these studies was that an estimated 80 to 90 percent of sleep disturbances were not related to individual outdoor noise events, but were instead the result of indoor noise sources and other non-noise-related factors[23]. The results showed that there was less of an effect of noise on sleep in real-life conditions than had been previously reported from laboratory studies[24].

FICAN[25]

The interim FICON dose-response curve[8] that was recommended for use in 1992 was based on the most pertinent sleep disturbance research that was conducted through the 1970s, primarily in laboratory settings. After that time, considerable field research was conducted to evaluate the sleep effects in peoples' normal, home environment. Laboratory sleep studies tend to show higher values of sleep disturbance than field studies because people who sleep in their own homes are habituated to their environment and, therefore, do not wake up as easily[25].

Based on the new information, FICAN updated its recommended dose-response curve in 1997, depicted as the lower curve in Figure 3-4[25]. This figure is based on the results of the 1992 UK Field Study[26], Fidell, et al.'s 1992 Los Angeles/Castle Air Force Base Field Study for the USAF[27], Fidell's 1995 Denver Study[28], along with the datasets from six previous field studies[25].

The new relationship represents the higher end, or upper envelope, of the latest field data. It should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened" or the "maximum percent awakened" for a given residential population. According to this relationship, a maximum of 3 percent of people would be awakened at an indoor SEL of 58 dB, compared to 10 percent using the 1992 curve. An indoor SEL of 58 dB is equivalent to outdoor SEL's of 73 and 83 dB respectively assuming 15 and 25 dB noise level reduction from outdoor to indoor with windows open and closed.



(Source: FICAN 1997)

Figure 3-4. FICAN's 1997 Recommended Sleep Disturbance Dose-Response Relationship

The FICAN 1997 curve is represented by the following equation:

$$\text{Percent Awakenings} = 0.0087 \times [\text{SEL} - 30]^{1.79}$$

The first reaction the members of the public have in seeing curves like those presented in Figure 3-4 is disbelief at the low percentage of awakenings to fairly high noise levels. People think they are awakened by a noise event, but usually the reason for awakening is otherwise. For example, the 1992 UK CAA study found the average person was awakened about 18 times per night for reasons other than exposure to an aircraft noise – some of these awakenings are due to the biological rhythms of sleep and some to other reasons that were not correlated with specific aircraft events.

Number of Events and Awakenings

In recent years, there have been studies and proposals that attempted to determine the effect of multiple aircraft events on the number of awakenings. The German Aerospace Center (DLR) conducted an extensive study published in July 2004, focused on the effects of nighttime aircraft noise on sleep and other related human performance factors. The DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance, and involved both laboratory and in-home field research phases. The DLR investigators developed a dose-effect curve that predicts the number of aircraft events at various Maximum A-weighted Sound Level values, which would be expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies. However, the DLR work has not yet been studied and approved by the scientific community and is simply a proposal only to be used with caution at this time.

Recognizing the need to devise a method to assess sleep disturbance to overcome concerns with the DLR study described above, in July 2008 the American National Standards Institute published ANSI/ASA S12.9-2008/Part 6: *Methods for Estimation of Awakenings with Outdoor Noise Events Heard in Homes,* which provides a method to estimate the percent of the exposed population that will be awakened by multiple aircraft noise events based on statistical assumptions about the probability of awakening (or not awakening). This approach, which relies on probability theory rather than direct field research/experimental data, was developed by and gained consensus among the subject experts who comprise ANSI's Accredited Standards Committee S12, Noise.

Figure 3-5 depicts the sleeping awakening data and equations that form the basis of ANSI S12.9-2008. The curve labeled 'Eq. (B1) - FICAN 1997' is the relationship between noise and awakening endorsed by FICAN in 1997. The ANSI recommended curve labeled 'Eq. (1) - ANSI 2008' quantifies the probability of awakening for a population of sleepers who are exposed to an outdoor noise event as a function of the associated indoor SEL in the bedroom. This curve was derived from studies of behavioral awakenings associated with noise events in "steady state" situations. The data points in Figure 3-5 come from these studies. Unlike the FICAN curve, the ANSI 2008 curve represents the average of the field research data points.

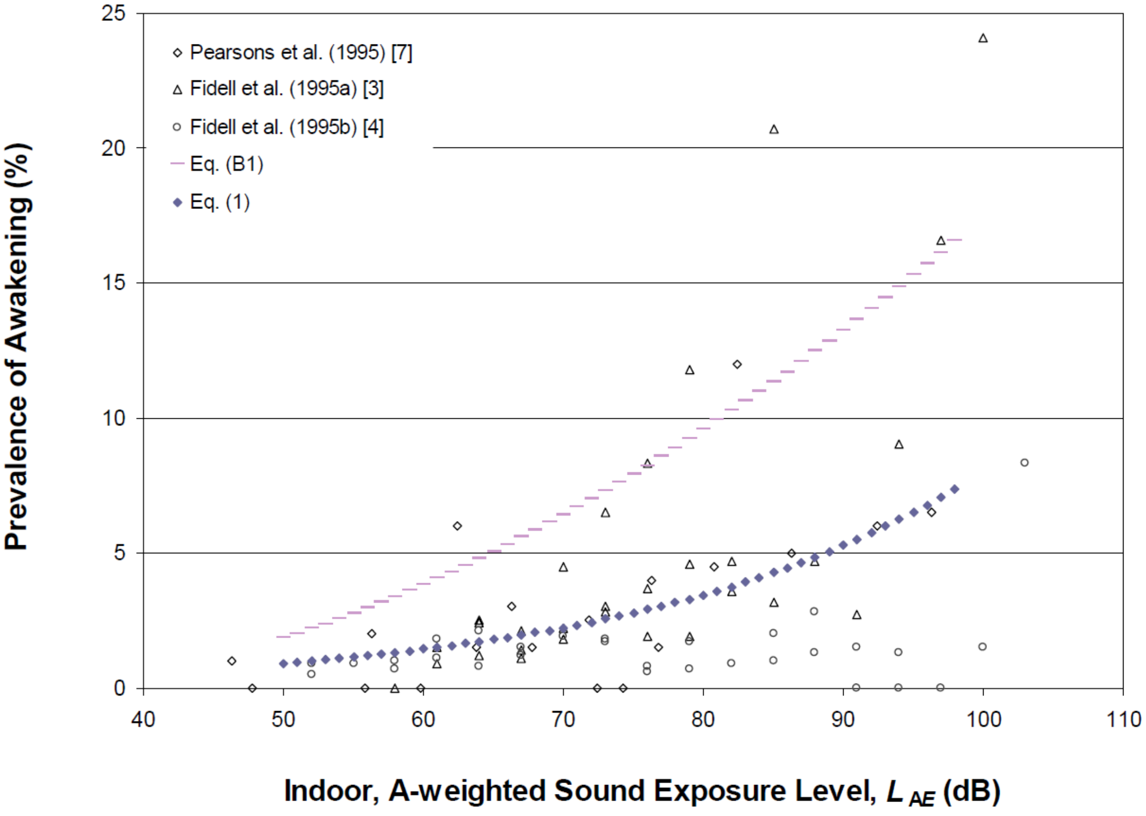


Figure 3-5. ANSI S12.9-2008 Plot of Sleep Awakening Data versus Indoor SEL

In December 2008, FICAN recommended the use of this new estimation procedure for future analyses of behavioral awakenings from aircraft noise. In that statement, FICAN also recognized that additional sleep disturbance research is underway by various research organizations, and results of that work may result in additional changes to FICAN's position. Until that time, FICAN recommends the use of ANSI S12.9-2008.

Summary

Table 3-3 summarizes the noise levels and corresponding effects documented in the research and literature discussed above and in Appendix A. As different criteria were discussed in different metrics, all levels in this table have been converted to an outdoor L_{max} values for comparison. These conversions assume that the outdoor-to-indoor Noise Level Reduction (NLR) with windows open is 15 dB and the SEL values are assumed to be 10 dB greater than the L_{max} values.

Table 3-3. Current Sleep Disturbance Research Summary

Source	Noise Metric & Referenced Threshold Level	Effects and Notes	Outdoor Sound Level
UK Field Study (1992)	L_{max} < 80 dB (outdoors) L_{max} = 80-95 dB (outdoors)	No detectable increase in the probability of sleep disturbance Probability of awakening = 1 in 75	L_{max} < 95 dB L_{max} = 95-110 dB
FICAN (1997)	SEL=58 dB/L_{max}=48 dB (indoors) SEL=80 dB/L_{max}=70 dB (indoors) SEL=90 dB/L_{max}=80 dB (indoors)	3% Awakenings 10% Awakenings 13% Awakenings * Upper envelope of field data	L_{max} = 63 dB L_{max} = 85 dB L_{max} = 95 dB
Fidell, et al. (2000)	SEL=58 dB/L_{max}=48 dB (indoors SEL=80 dB/L_{max}=70 dB (indoors) SEL=90 dB/L_{max}=80 dB (indoors)	1% Awakenings 4% Awakenings 5% Awakenings *Synthesized results of several field studies	L_{max} = 63 dB L_{max} = 85 dB L_{max} = 95 dB
German Aerospace Center/ DLR (2004)	L_{max} = 48 dB (indoors) L_{max} = 60 dB (indoors) L_{max} = 69 dB (indoors	2% Awakenings/34 nighttime events will induce 1 additional awakening 5% Awakenings/17 nighttime events will induce 1 additional awakening 9% Awakenings/12 nighttime events will induce 1 additional awakening *Based on results of field study	L_{max} = 63 dB L_{max} = 75 dB L_{max} = 85 dB
WHO (1999)	L_{eq} = 30 dB (indoors) L_{max} = 45 dB (indoors)	No Awakenings - Continuous noise No Awakenings - Intermittent noise	L_{max} = 60 dB
Griefahn, et al./ Frankfurt (2002)	L_{night} = 30 dB (indoors) L_{night} = 35 dB (indoors) L_{night} = 40 dB (indoors) L_{max} = 40 dB (indoors) L_{max} = 53 dB (indoors) L_{max} = 60 dB (indoors)	Marginal Level – Continuous Noise Preventive Guidance Level – Continuous Noise Critical Tolerance Level – Continuous Noise Marginal Level – 23 nighttime events Preventive Guidance Level – 13 nighttime events Critical Tolerance Level – 6 nighttime events	L_{night} = 45 dB L_{night} = 50 dB L_{night} = 55 dB L_{max} = 55 dB L_{max} = 68 dB L_{max} = 75 dB

3.2 Physiological Effects

3.2.1 Noise-Induced Hearing Impairment

Residents in communities immediately adjacent to airfields may express a concern regarding the effects of aircraft noise on hearing. Considerable data on hearing loss have been collected and analyzed by the scientific/medical community, and it has been well established that continuous exposure to high noise levels will damage human hearing[1].

Hearing loss is generally interpreted as a decrease in the ear's sensitivity or acuity to perceive sound; i.e. a shift in the hearing threshold to a higher level. This change can be either a Temporary Threshold Shift (TTS), or a Permanent Threshold Shift (PTS)[29]. TTS can result from exposure to high noise levels over time, yet the hearing loss is not necessarily permanent. An example of TTS might be a person attending a loud music concert. After the concert is over, the person may experience a threshold shift that may last several hours, depending upon the level and duration of exposure. While experiencing TTS, the person becomes less sensitive to sounds at certain frequencies in the speech range, typically above 4,000 Hertz[30]. Normal hearing ability eventually returns, as long as the person has enough time to recover within a relatively quiet environment.

PTS usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover from the strain and fatigue of exposure. A common example of PTS is the result of working in a high-noise environment such as a factory. It is important to note that TTS can eventually become PTS over time. Thus, even if the ear is given time to recover from TTS, repeated occurrence of TTS may eventually lead to permanent hearing loss. The point at which a Temporary Threshold Shift results in a Permanent Threshold Shift is difficult to identify and varies with a person's sensitivity. In general, hearing loss (be it TTS or PTS) is determined by the duration and level of the sound exposure. See Appendix A for additional discussion of TTS and PTS.

Because it is unlikely that people will remain outside their homes 24 hours per day for extended periods of time, there is little possibility of hearing loss below a day-night average sound level of 75 dB.

3.2.2 Non-Auditory Health Effects of Noise

The reaction of people to a given noise environment is extraordinarily complex. This is particularly evident when trying to evaluate the potential health effects of people exposed to aircraft noise. One reason for this is the intermittent nature and the character of aircraft noise, in which noise levels fluctuates significantly from high to low over time. Another important element is the complex psychological and physiological reaction of people to not only the actual noise environment, but also the attitude toward the source of the noise. Further exacerbating this complex issue is the possibility that short-term community reaction can be different from the long-term community reaction.

In an effort to better understand people's response to noise, the scientific community has divided the noise effects on people into two general categories of responses. Psychological effects refer to behavioral reactions that are indicators of the population's "well-being" – essentially, people's psychological reaction to their noise environment and their reaction to interference with their various day-to-day activities. The primary examples are the potential effects on long-term community annoyance, speech interference (includes effects in the home, school, churches, and auditoria), sleep disturbance (home), effects on children's learning (school), and interference with work performance.

The second type of indicators for human response to noise is the physiological effects – essentially, real medical effects on the human body's systems. The primary example of this is noise-induced hearing loss, although other medical health effects such as cardiovascular disease have been postulated by various researchers and communities over the years. For each of these indicators that attempt to describe the long-term community reaction to noise, the scientific community has spent considerable effort since the mid-1950s researching the noise metrics and associated noise levels that best relate to community response.

Non-auditory effects of noise can be defined as those physiological effects on health that are caused by exposure to aircraft noise, but excluding the effects on hearing. The physiological effects discussed in this Guide include:

Stress Response -- The human stress response is a natural coping mechanism that occurs when there is a perceived threat. For people who are susceptible, the stress response triggers a sudden release of stress hormones. These hormones can cause temporary changes in heart rate and blood pressure. The postulate is that, for some people, a sudden or uncontrollable intense noise may be enough to cause a stress response. In most cases, the stress response is short-term, and the person's heart rate and blood pressure soon return to normal.

Cardiovascular Effects – Hypertension and Heart Disease --The postulate is that noise exposure causes hypertension (elevated blood pressure) and other stress-related effects on humans. Ischemic heart disease is characterized by insufficient perfusion of oxygen to the heart muscle, which could lead to angina or heart attack (myocardial infarction).

Birth Defects -- The postulate is that high aircraft noise exposure leads to increased incidences of central nervous system defects in the offspring of parents residing near airports.

Mortality Rates -- The postulate is that stress-related effects of high aircraft noise exposure lead to increased incidences of deaths due to strokes (sudden disruption in blood flow to the brain) and deaths due to cirrhosis of the liver (primarily attributed to alcoholism).

Exposure to very loud noise, at levels far greater than those produced by aircraft in the community, can elevate blood pressure and also stress hormone levels[31]. However, the response to such loud noise is typically short in duration: after the noise goes away, the physiological effects reverse and levels return back to normal.

In the case of repeated exposure to aircraft noise, the connection is not as clear. The results of most cited studies are inconclusive, and it cannot really be stated that a causal link exists between aircraft noise exposure and the various type of non-auditory health effects that were studied. The results of early studies conducted in the United States, primarily concentrating on cardiovascular response to noise, have been contradictory. The results of human and animal experiments show that average or intrusive noise can act as a stress-provoking stimulus. Prolonged stress is known to be a contributor to a number of health disorders[33]. Kryter and Poza state, "It is more likely that noise-related general ill-health effects are due to the psychological annoyance from the noise interfering with normal everyday behavior, than it is from the noise eliciting, because of its intensity, reflexive response in the autonomic or other physiological systems of the body.[32]" Psychological stresses may cause a physiological stress reaction that could result in impaired health.

Most studies of nonauditory health effects of long-term noise exposure have found that noise exposure levels established for hearing protection will also protect against any potential nonauditory health effects, at least in workplace conditions[33].

The WHO[7] has concluded that long-term aircraft noise exposure in the range of $L_{eq,24h}$ values of 65-70 dB or more may be associated with some cardiovascular effects. However, the WHO guidelines note that the causal relationships are weak. The guidelines further point out that the findings on other physiological effects are too inconsistent to draw conclusions.

Von Gierke and Eldred[34] summarize the nonauditory health effects of aircraft noise most succinctly when they write, "there is no unambiguous scientific evidence to relate quantitatively any noise environment with the origin of or contribution to any clinical non-auditory disease".

In September 2008, the Transportation Research Board (TRB) published Airport Cooperative Research Program Synthesis Report #9, "Effects of Aircraft Noise: Research Update on Selected Topics." This synthesis study is intended to inform airport operators, stakeholders, and policymakers of updated information about aviation noise effects. In the decades since FAA Report FAA-EE-85-2 "Aviation Noise Effects" was first published in 1985 much has changed in the understanding of this complex issue. Increased air travel, new and quieter civilian and some but not all military aircraft, increased awareness of land use planning and aviation noise, and mitigation of previously incompatible land uses are just a few of the changes. Knowledge of the effects of aviation noise has also changed. The greatest increases in knowledge have come in the areas of health effects, annoyance, sleep disturbance, and potential effects on children's learning

As noted in the ACRP Synthesis, trying to identify and quantify any potential effects of aviation noise on health is a complex and difficult field of study. Variations on how to identify and measure the noise exposure and attempting to separate the effects from other life events are difficult at best. For example, lifestyles, life's stressors, hereditary factors, and genetic composition are just a few factors that may distort potential results of an aviation noise health effects study (also called confounding factors).

The ACRP Synthesis summarized the research in the following subject areas: stress response, cardiovascular effects (hypertension and heart disease), birth defects, and mortality. Each is discussed separately in Appendix A, Subsection A 2.2.

The ACRP Synthesis best summarizes the state of knowledge:

"Despite decades of research, including review of old data and new research efforts, health effects of aviation noise continue to be an enigma. Most, if not all, current research concludes that it is as yet impossible to determine causal relations between health disorders and noise exposure, despite well-founded hypotheses."

Appendix A, Subsection A.2.2. Non-Auditory Health Effects of Noise provides additional discussion and detail.

4.0 Review of International Research and Policy/ Guidance on Supplemental Metrics

This section provides a review of the research and policy/guidance, independent of the effort conducted for this DoD project that is being conducted internationally.

4.1 FAA/NASA Center of Excellence for Aircraft Noise & Aviation Emissions Mitigation (PARTNER)

The Center of Excellence (COE) for Aircraft Noise & Aviation Emissions Mitigation (PARTNER) was established in September 2003. PARTNER is sponsored by FAA's Office of Environment and Energy in partnership with NASA and Transport Canada, with MIT as the lead university. The intent of the COE is to facilitate collaboration with government, university and industry sponsors, and a broad range of stakeholders, with an overall goal of enhancing the understanding of aviation environmental issues, thereby working toward a quieter and cleaner environment.

PARTNER is currently performing a project to develop metrics that can be used to evaluate the impact of airport and other noise sources on a community, and to understand the relationship between noise annoyance, physiological responses, cognitive performance, and sleep quality. The plan to achieve these objectives is as follows[35]:

- Develop a method to predict airport noise in a community based on individual aircraft landing and takeoff noise time histories.
- Determine the level-based metric that best predicts community response to noise.
- Determine whether sound characteristics, other than Loudness, play a role in annoyance due to airport noise, and whether the sound metrics (Sharpness, Roughness, Fluctuation Strength, and Tonality) are useful for measuring these characteristics.
- Determine the influence of room panel/window/floor vibration on low frequency sound perception and annoyance, and develop a method of modifying noise annoyance models to account for vibration.
- Develop a data collection system that can be used to create health-effects and annoyance maps of the community that could then be compared with community noise maps.
- Develop tools that relate land usage and the impact of noise on communities; and
- To develop an understanding of response to noise in National Parks and other special low-level noise environments.

Successful completion of these tasks is expected to:

- Facilitate generation of a sound time history database that can be used by researchers to develop and improve community noise metrics, and in software that predicts community noise as a result of airport operations.

- Provide metrics that can be used by the airports and the FAA to evaluate airport and aircraft noise and noise mitigation strategies.
- Provide an understanding of how the time-of-day and desired activity factor into annoyance, providing tools to plan land usage to minimize annoyance.
- Provide an understanding of how vibration affects noise annoyance.
- Facilitate study of airport noise long-term impact.

The project effort also includes gathering information and perspectives on the use of supplemental metrics. Efforts to date have not produced a final set of findings on the use of supplemental metrics; but should meaningful results emerge, they will eventually be incorporated into future versions of this Guidelines document. Purdue University is leading the project, with participation by Penn State University and a number of industry partners. Research efforts to date have focused on items (2), (3), and (4), above.

4.2 Australian Government, Department of Transport and Regional Services (DOTARS)

In recent years, the Australian Department of Transport and Regional Services (DOTARS) has pioneered the use of supplemental metrics for communicating aircraft noise to the community. In 2000, DOTARS published a discussion paper entitled "Expanding Ways to Describe and Assess Aircraft Noise"[36], in which they discuss the problem of describing noise exposure to the public, stating:

> "In simple terms people want to be told about aircraft noise exposure in their own language – where flight paths are, how many movements, what time of day, etc. – but the official response has been to provide information in the form of a single figure Australian Noise Exposure Forecast (ANEF) value, similar in concept to the DNL metric. Not unnaturally there has frequently been a breakdown in communication between the 'noise expert' and the community, which we consider has been at the expense of both parties."

The paper describes approaches developed to address the communication problems. Their proposed solution is to encourage airports, acoustical professionals and planners to use the same terminology that non-experts use when talking to each other. To achieve this, the Department of Transport and Regional Services developed descriptors based on treating aircraft noise as a series of single events rather than through cumulating and computing average noise energy, which is the basis of the ANEF.

These descriptors enabled them "to move beyond the conventional thinking on aircraft noise where on one side of the line, the noise is described as being 'acceptable' while on the other it is termed 'unacceptable.'" The use of the new noise descriptors enabled people to 'visualize' aircraft noise such that they can decide "whether they are likely to find future noise acceptable."

Applied to airport growth projects they state:

> "Providing 'real' aircraft noise information for all of the areas likely to be subject to changes in aircraft noise enables the community to actively and meaningfully participate in any public consultation process. It also gives the decision makers a much

> clearer picture of what the outcomes will be if they approve the project. In effect it enables a community to decide on what it believes are 'acceptable' operating and flight path arrangements for its airport."

However, DOTARS emphasizes that these descriptors do not replace ANEF as a planning tool:

> "This paper is not an attempt to replace the ANEF system as a planning tool. The ANEF system continues to be the most technically complete means of portraying aircraft noise exposure and the Department is not proposing any changes to the land use planning principles and restrictions embodied in Australian Standard AS2021."

The Department of Transport and Regional Services implemented all of the methods for describing noise exposure envisioned in their discussion paper. Much of the new noise exposure information provided in the form of graphics that show flight path maps, runway end movement information, flight corridor movements, respite time between movements and exposure for larger areas. They very deliberately "placed emphasis on giving information on noise exposure as far away as possible from an airport recognizing that the information will be less reliable for areas distant from the airport." The main supplemental noise metric they implemented is the Number-of-Events that exceed and outdoor noise level of L_{max} 70 dB, which they labeled as the "N70" metric. DOTARS chose the 70 dB threshold as a level that is likely to minimize interference with conversation or listening to radio or television indoors. This metric is same as the Number-of-events Above (NA) metric described in Section 5 in this document.

The Australian experience with this approach and the N70 metric has been highly successful. Public dialogue over noise exposure from airports, including proposed growth projects, has been far more productive than previously; and this approach has substantially resolved most controversy over noise exposure in Australia in a 5-year period.

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5.0 Supplemental Analysis Tools and Metrics

Aircraft noise exposure is complex and results from a series of individual aircraft events that occur over time. A complete description of the noise exposure includes the total number of noise events, the frequency of the events (i.e., do they occur continuously with little-to-no respite or are the operations sporadic?), what time of day the events occur, the noise levels of individual events from different aircraft types, along with other minor factors.

The tools and metrics proposed in this section are a way forward from the single noise metric approach to aviation noise description of the past 25+ years. Instead of relying solely on a single, long-term, cumulative metric (DNL), which is sufficient to define land-use compatibility, but may not adequately define the overall noise environment nor sufficiently explain noise exposure to the community, this document identifies and recommends additional metrics and tools as part of a more comprehensive and effective means of managing aviation noise. An important additional point – the recommended metrics and tools are as important to the project stakeholders as they are to communicating with the general public, because they enable the project managers and decision makers to make better-informed decisions.

5.1 Supplemental Analysis Tools

This section describes several supplementary graphics, maps, tables, and other tools that have been used with success around the world.

5.1.1 DNL Contours – Color Shading Techniques

The public, project stakeholders, and even the on-base staff that deal with the community noise issues have raised concern about the traditional noise analysis that simply overlays the DNL 65, 70, 75, and 80 dB noise contours on a study area map. While this serves a purpose in defining areas where land-use controls are recommended (AICUZ), it sends the message that noise impacts do not exist below the DNL 65 dB threshold.

An alternative mapping technique using gradual color shading has recently been used successfully in presenting noise exposure to civilian airport communities. An example is shown in Figure 5-1. The technique conveys a much better sense of the overall noise exposure throughout a large study area by combining both hard contour lines and gradual color shading. The color shading clearly shows that noise does not stop at the contour lines. This technique better acknowledges and communicates actual noise exposure, which in turn improves the credibility of the project owners, managers and the military. It should be noted that presenting the information in this way does not imply that additional DNL contour lines should be included or that any significance attached to the DNL 65 dB or higher contours has changed. Instead, the intended message is that aircraft are flying outside the DNL 65 dB contour and they may also have a negative impact on noise sensitive areas outside that contour.

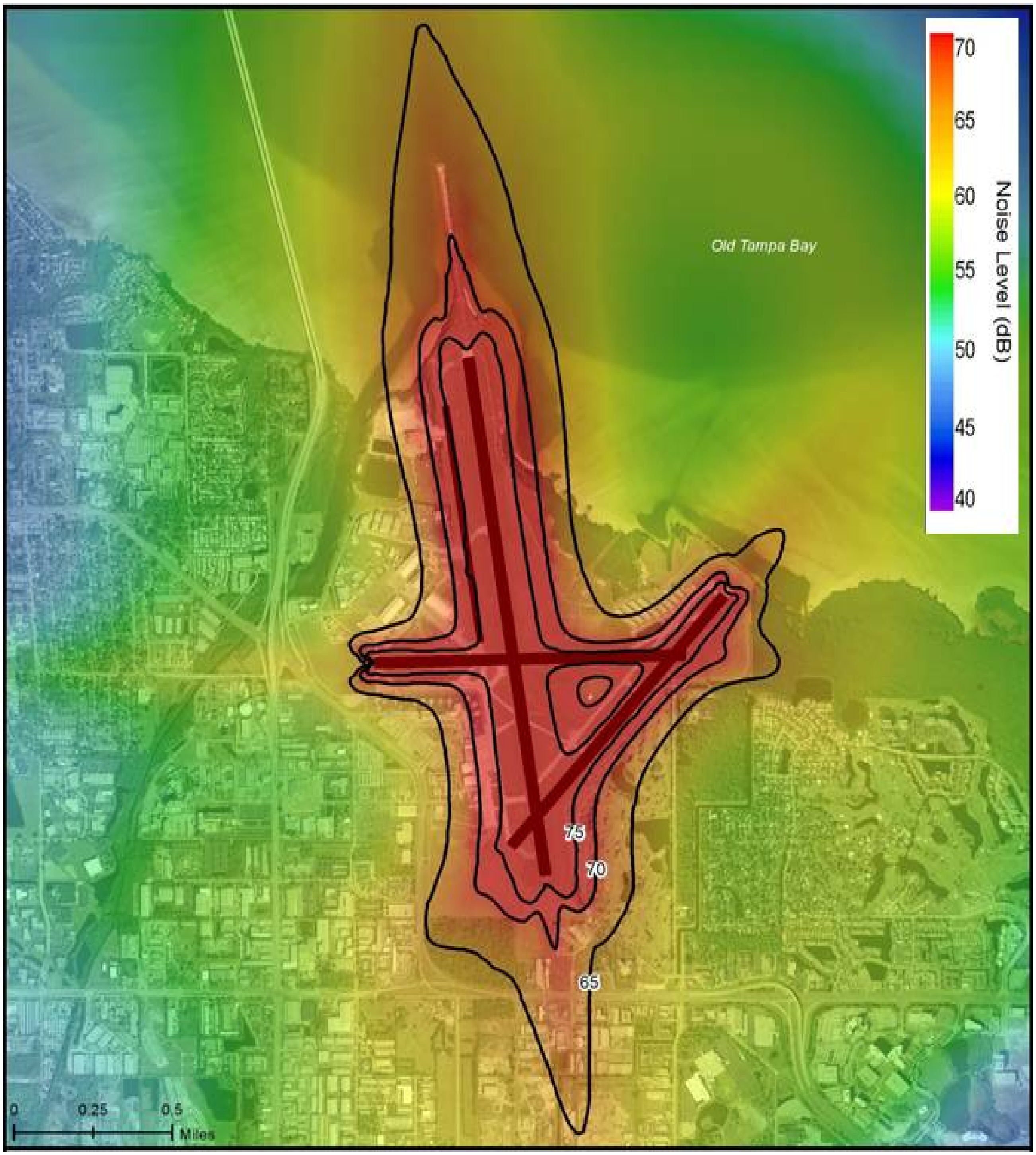


Figure 5-1. An Example of the DNL Color Shading Technique

(Source: St. Petersburg/Clearwater Airport)

5.1.2 Flight Track Maps

One of the fundamental questions asked about the noise environment is - where do the aircraft fly now, and where will they fly in the future? To answer the question it has been standard practice to overlay a set of flight tracks over a standard base map (or aerial photograph). In the public's mind, the advantage is that the tracks are obtained from radar data and not from computer models. The maps show that aircraft noise can extend beyond the immediate vicinity of the airbase. Disadvantages are that it might imply that noise exists only under the flight path, and that the graphic does not give any indication of how many aircraft are expected to use the flight tracks.

To overcome this problem, several civilian airport projects have recently began to use flight frequency maps to marry the operations and tracks onto a single graphic. The intent is to convey both the flight corridors and the number of operations associated with the flight tracks. Caution should be exercised in the use of this tool in that the non-technical stakeholders and the public can be led to believe that the aircraft will fly on "rail lines in the sky" with no deviation from the modeled tracks. DoD personnel and the contractors should be well informed on this type of issue, as the depiction of modeled flight tracks on a base map on many studies in the past has often resulted in a similar misunderstanding. It is highly recommended that the project include pertinent areas of discussion on the development of modeled flight tracks and the relation to the real world noise environment and the airspace.

An example of a flight-frequency diagram is shown in Figure 5-2, which provides a quick and easy-to-understand map of the main arrival flows for a particular runway at a major U.S. airport hub. Even someone with little knowledge of the air traffic system or noise modeling can quickly see that the dominant arrivals are in a west-flow configuration and those immediately east of the parallel runways would expect to realize anywhere from 26-100 arrivals on an average annual day.

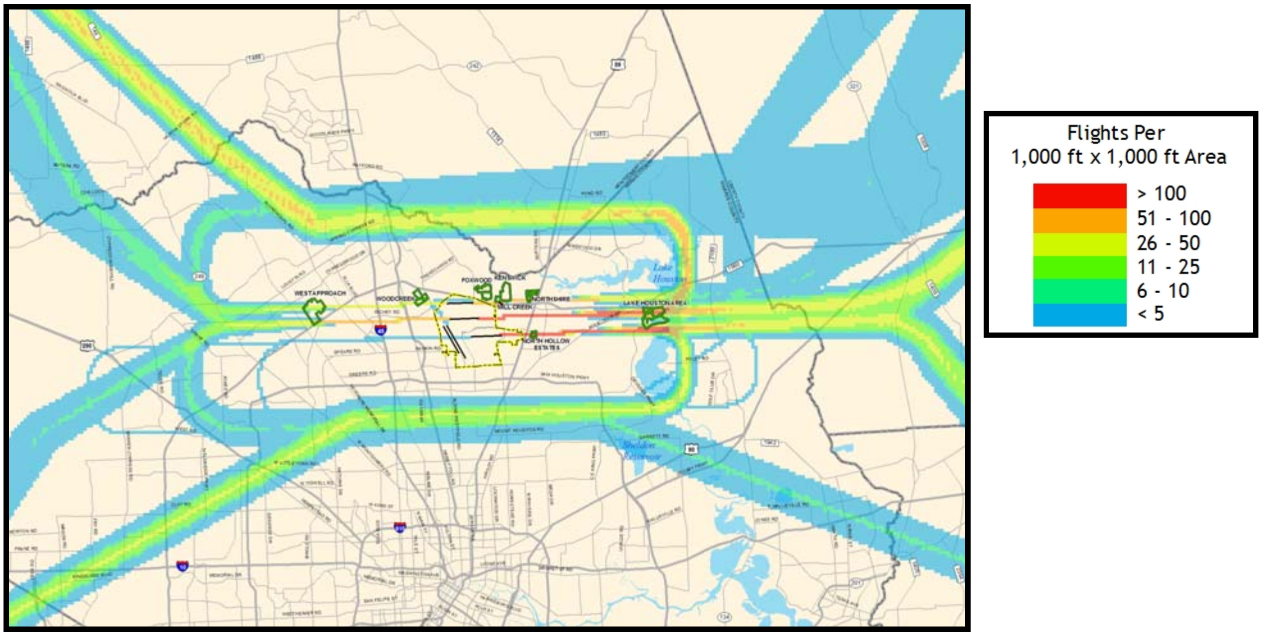


Figure 5-2. An Example of a Flight Frequency Diagram – Arrivals Only

(Source: Houston/George Bush Intercontinental Airport)

Arrival and departure corridors can be combined, but this information may be confusing on a single graphic. Separate graphics to show arrival and departure corridors best facilitate a complete understanding of the information. Presenting the flight corridors with gradual color shading to show the graduation of the frequency of operations can be effective in disclosing noise exposure throughout the entire selected study area, and effectively communicates the distribution of operations on the various flight tracks. While noise levels are not quantified, it clearly communicates the general area that can expect exposure to aircraft noise, both close in and far-away from the airport. In essence, this type of analysis is both a surrogate and a supplement to the noise analysis. Anecdotal information indicates that this type of disclosure is what the stakeholders have increasingly been demanding.

5.2 Supplemental Noise Metrics

The supplemental noise metrics that have been useful to supplement DNL analysis for both military and civilian aircraft noise exposure around airfields and other noise sensitive areas include the following:

- Maximum A-weighted Sound Levels (L_{max});
- Sound Exposure Level (SEL);
- Equivalent Sound Level (L_{eq});
- Time Above a Specified Sound Level (TA);
- Number-of-events Above a Specified Sound Level (NA); and
- Respite.

The appropriateness and effectiveness of each of these metrics to communicate noise exposure varies depending on the audience and their specific concerns, such as sleep disturbance and speech or activity interference. A number of noise studies have employed various supplemental metrics, and in each case, they communicated useful information that enhanced public understanding of the noise exposure and provided the decision makers with additional information upon which to make more informed decisions. The most appropriate metric(s) to use in any particular situation depends on the purpose of the noise analysis, the audience, and other details and circumstances that are unique to each noise analysis – see Section 6.

The following section describes the supplemental metrics, methods of presentation, strengths and weaknesses, and technical requirements.

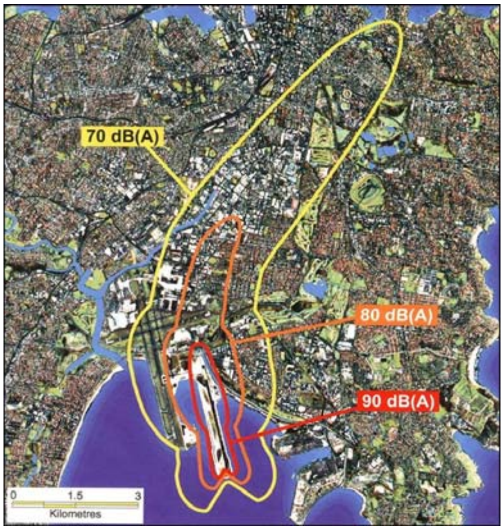
5.2.1 Maximum A-Weighted Sound Level, L_{max}

A common metric that is used to help in describing a single aircraft noise event is the Maximum Sound Level, or L_{max}, measured in decibels (dB). During an aircraft over-flight, the noise level starts at the ambient or background noise level, rises to the maximum level as the aircraft flies closer to the observer, and returns to the background level as the aircraft recedes into the distance. L_{max} is the highest A-weighted sound level that occurs during the aircraft overflight. It can be presented as a level at discrete locations during a given aircraft overflight, or it can be presented as a contour for a single complete overflight.

Strengths and Weaknesses

L_{max} is a useful metric for comparing the levels of different aircraft types, either as a contour or at discrete locations. It is used in the assessment of speech intelligibility and interference. It is also one of the few noise metrics that people can understand and easily measure with simple equipment, and so it can be useful in communicating with the public.

L_{max} describes the maximum level of a noise event, but does not take into account its duration, so that it provides some, but not a complete, measure of the intrusiveness of the event. An event with a relatively low L_{max} but a longer duration can be just as intrusive as a short duration event with a higher L_{max}. A contour or value at a discrete location is valid for only the one aircraft for the flight track simulated, and does not provide any information on the frequency of operations.



Technical Requirements

L_{max} analysis in terms of contours or discrete values from flight events is not available in the publicly available version of DoD's NOISEMAP program suite for analyzing noise. It has recently been incorporated as an optional metric and this update will be available soon after publication of this Guide. It will also be available in the Advanced Acoustics Model (AAM), which will also be released in the near future. Map production requires specialized GIS expertise and the use of associated software.

5.2.2 Sound Exposure Level (SEL)

The Sound Exposure Level (SEL) measured in decibels (dB), is a composite metric that represents both the magnitude and duration of a time-varying noise event, such as an aircraft overflight. As such, it represents the noise exposure of a small aircraft overflight. The duration of the event is the time from which the sound level exceeds a threshold level, rises to a maximum noise level during the aircraft flyover, and then decreases back to the threshold level. The SEL metric is a measure of the total acoustic energy in the event, but it does not directly represent the sound level heard at any given time. It is the building block for calculating DNL, which is the logarithmic sum of the SEL's for a day's worth of operations, averaged over 24 hours, and with a 10 dB weighting applied to nighttime events. The numerical value of the SEL for a single aircraft event is on average 10 dB above the L_{max} for that event.

Strengths and Weaknesses

An SEL contour, (generally referred to as a single-event noise contour) can be generated to illustrate the noise footprint of an individual aircraft event and is useful for comparing the relative noise levels produced by various aircraft. SEL can be useful in analyzing the single event benefits of various noise abatement measures under consideration. SEL contours can also be used to facilitate public understanding of the DNL metric, accomplished by graphically illustrating and comparing the SELs of the various aircraft in the fleet. An example of a typical aircraft event SEL contour is shown in Figure 5-3. Since it is the combination of level and duration, it is not quite as simple to comprehend as L_{max}. Moreover, it is not so easily measured with simple equipment. A contour or value at a discrete location is valid for only the one aircraft for the flight track simulated, and does not provide any information on the frequency of operations.

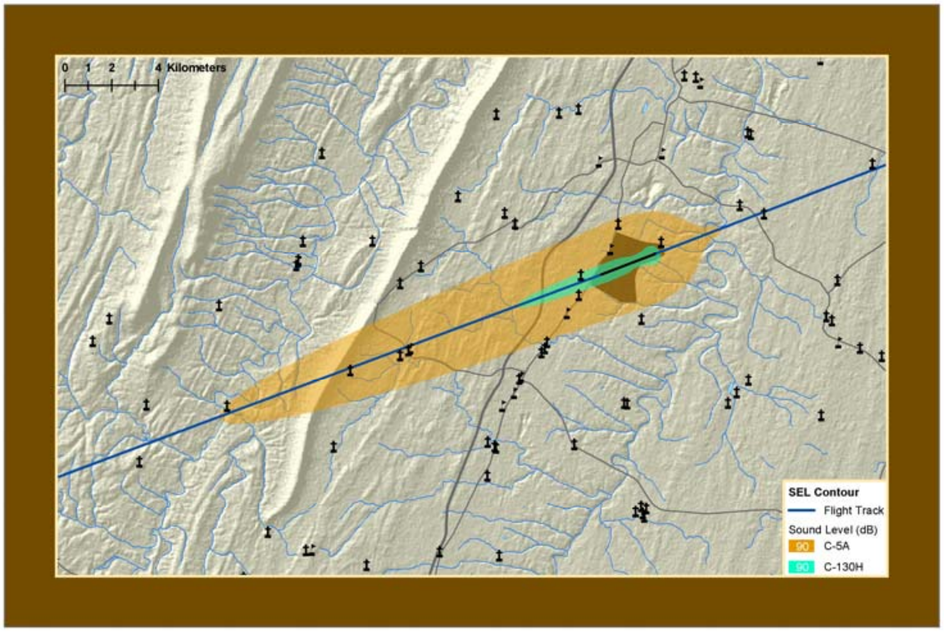


Figure 5-3. An Example of a Sound Exposure Level (SEL) Contour Map

(Source: Aircraft Noise Study for Eastern WV Regional Airport/Shepherd Field, Martinsburg, West Virginia, Environmental Impact Statement (EIS) independent review for the Air National Guard Readiness Center (ANGRC) C-5 Aircraft Conversion, Wyle Technical Note TN 03-03, July 2003)

The SEL has proven to be a good number to compare the relative exposure of different transient sounds. However, no set series of guidelines exists for impacts based on SEL. In general, for aircraft, an SEL less than 75 dBA would not be considered a loud event, while most people would regard an SEL greater than 100 dBA to be a loud event. Research suggests that SEL is the metric to consider when determining sleep disturbance. The SEL of the event seems to correlate better with sleep disturbance than does the peak noise level of the event.

Technical Requirements

A working knowledge is required of the NOISEMAP program suite, and in the near future, the AAM. Map production requires specialized GIS expertise and the use of associated software.

5.2.3 Equivalent Sound Level (L_{eq})

The Equivalent Sound Level (L_{eq}), measured in decibels (dB), is a cumulative noise metric that represents the average sound level (on a logarithmic basis) over a specified period of time; for example, an hour, a school day, daytime, nighttime, weekend, facility mission rush periods, or a full 24-hour day. Technically, L_{eq} is the constant sound level that contains the same sound energy as the time-varying sound level over the prescribed time period.

Strengths and Weaknesses

L_{eq} is a useful metric to describe the total aircraft noise exposure over an extended period of time, although it may not be the best metric to correlate directly with annoyance and other types of activity interference for people. For example, to better illustrate the difference between daytime and nighttime noise weightings in the DNL metric, 15-hour day average sound level (DL) and 9-hour night average sound level (NL) contours can be generated. The European Union (EU) has selected NL as the common environmental noise indicator to assess sleep disturbance[37]. A presentation of one-hour L_{eq} values for each hour throughout the 24-hour day can show the variation in average sound level with the number of flight operations, allowing the community to understand how sound levels are affected by high mission levels during various portions of the day.

L_{eq} can be shown in terms of noise contours on a map, or in combination with other metrics in tabular format for discrete locations of interest. Figures 5-4 and 5-5 provide examples of DL contours and NL contours, respectively. Similar to DNL, many studies have shown L_{eq} contours in 5 dB increments ranging from 55 dB to 75 dB.

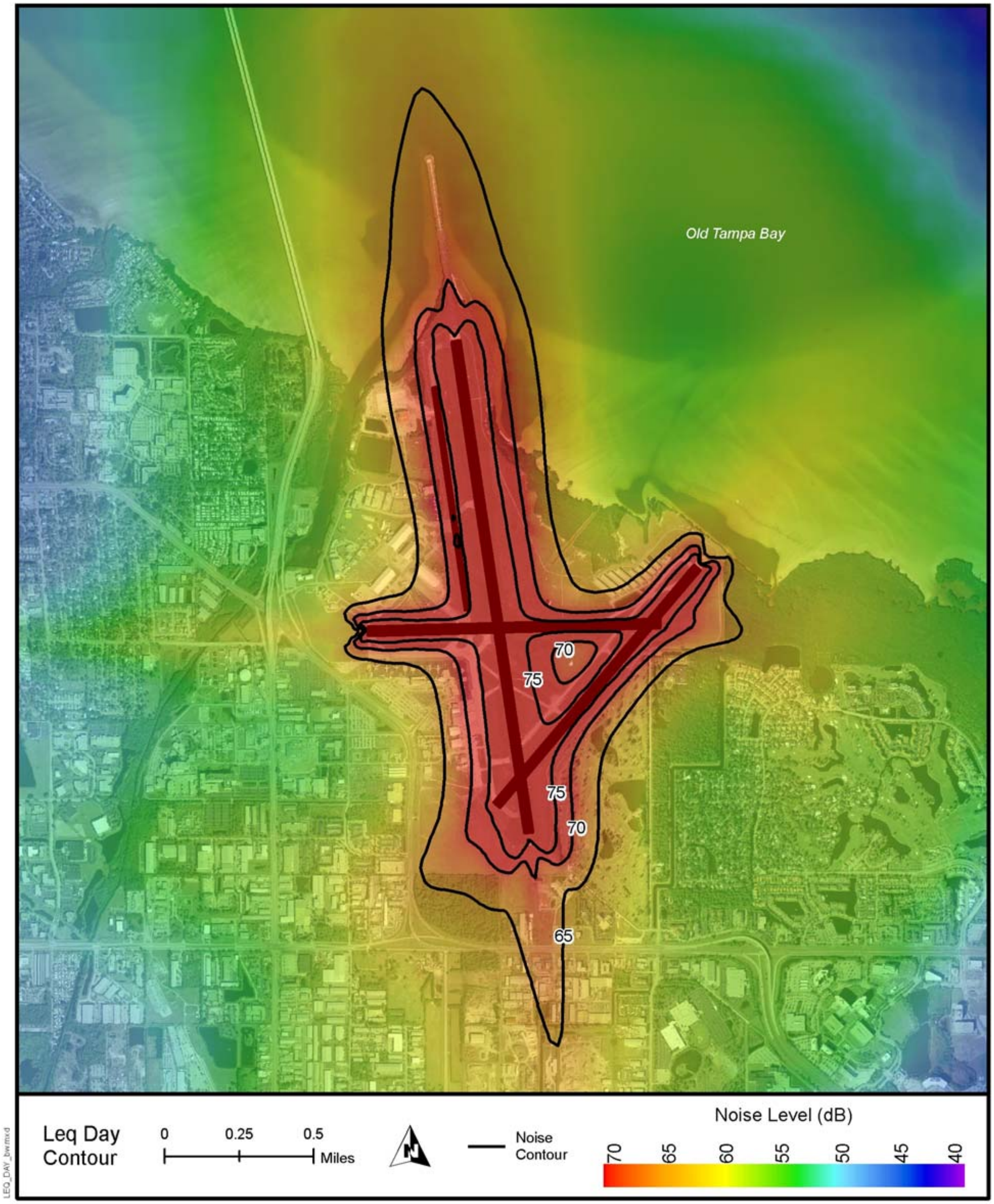
Technical Requirements

A working knowledge is required of the NOISEMAP program suite, and in the near future, the AAM. Operational data is required for the time period of interest. Map production requires specialized GIS expertise and the use of associated software.

5.2.4 Time Above a Specified Level (TA)

The Time Above metric (TA) is a measure of the total time that the A-weighted aircraft noise level is at or above a defined sound level threshold. Combined with the selected threshold level (L), the TA metric is symbolized as TAL. TA is not a sound level, but rather a time expressed in minutes. TA values can be calculated over a full 24-hour annual average day, the 15-hour daytime and 9-hour nighttime periods, a school day, or any other time period of interest, provided there is operational data to define the time period of interest. As with NA, when labeling a contour line or POI on a map, the TAL will be followed by the number of minutes in parentheses for that contour line or POI. As an example, TA65dBA(60) calculated over a 24-hour day for a specific location indicates that the sound level at that location exceeds 65 dBA for a total of 60 minutes spread over a 24-hour day.

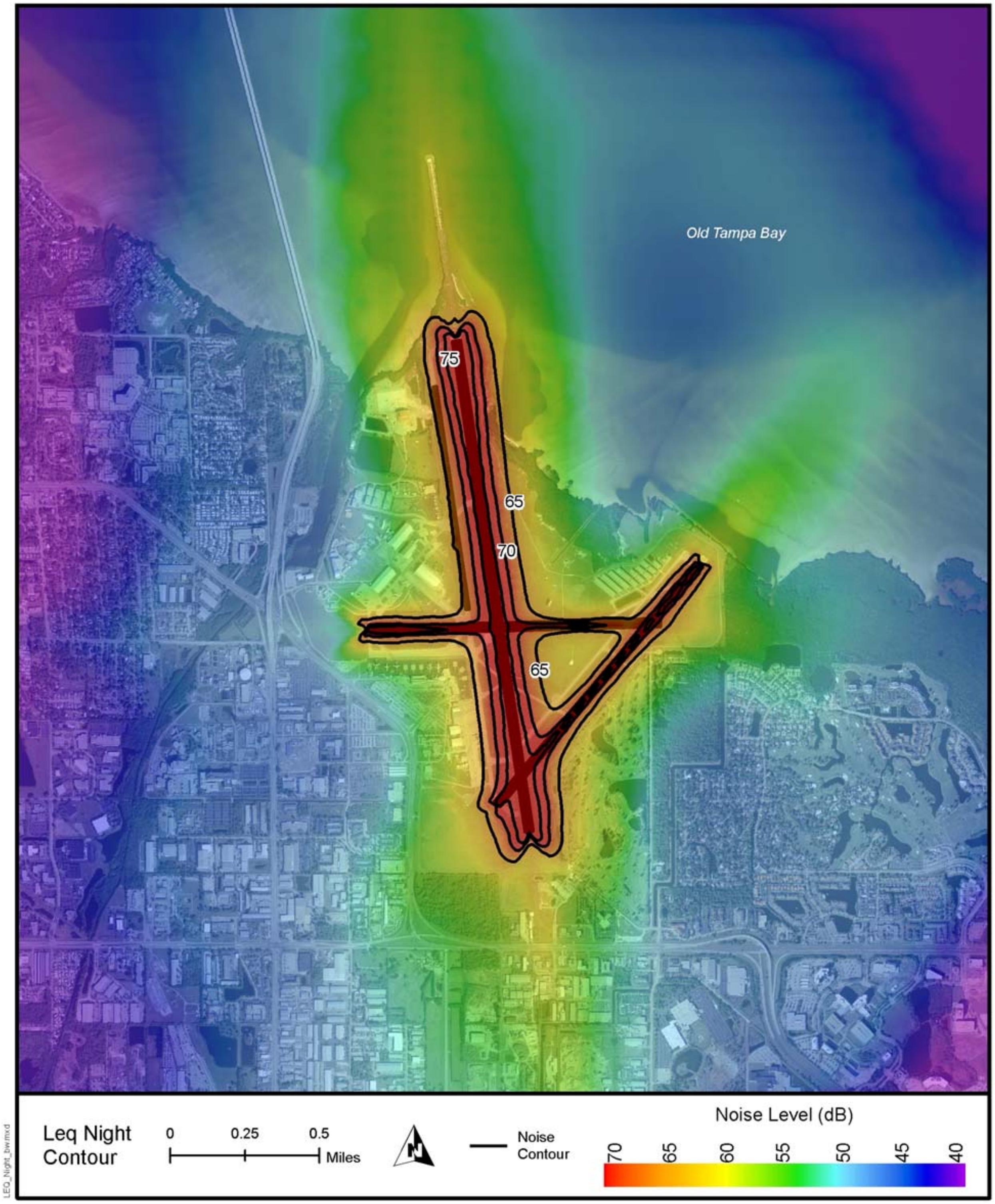
TA has application for describing the noise environment in schools, particularly when comparing the classroom or other noise sensitive environments for different operational scenarios. TA can be portrayed by means of noise contours on a map similar to the common DNL contours.



Source: US Census TIGER/Line 2000, Wyle Laboratories, INM 6.1
Geographic Reference: 1983 State Plane Coordinate System, Florida West, Feet

Figure 5-4. An Example of Daytime Average Sound Level (DL, LAeq,15h) Noise Contours

(Source: Noise Study for the St. Petersburg-Clearwater International Airport Phase I, Wyle Laboratories, Inc. Wyle Report WR 05-15, December 2005)



Source: US Census TIGER/Line 2000, Wyle Laboratories, INM 6.1
Geographic Reference: 1983 State Plane Coordinate System, Florida West, Feet

Figure 5-5. An Example of Nighttime Average Sound Level (NL, LAeq,9h) Noise Contours

(Source: Noise Study for the St. Petersburg-Clearwater International Airport – Phase I, Wyle Laboratories, Inc. Wyle Report WR 05-15, December 2005)

For analysis purposes, a threshold level (or series of thresholds, which require multiple contours/maps or a table with a separate column for each threshold) should be selected that best meets the need for that situation – i.e., a predicted speech interference or sleep disturbance threshold value. An alternative presentation is to map a series of thresholds (e.g., 60 db, 70 dB, and 80 dB) that corresponds to a single amount of time that is exceeded (e.g., 30 minutes per day).

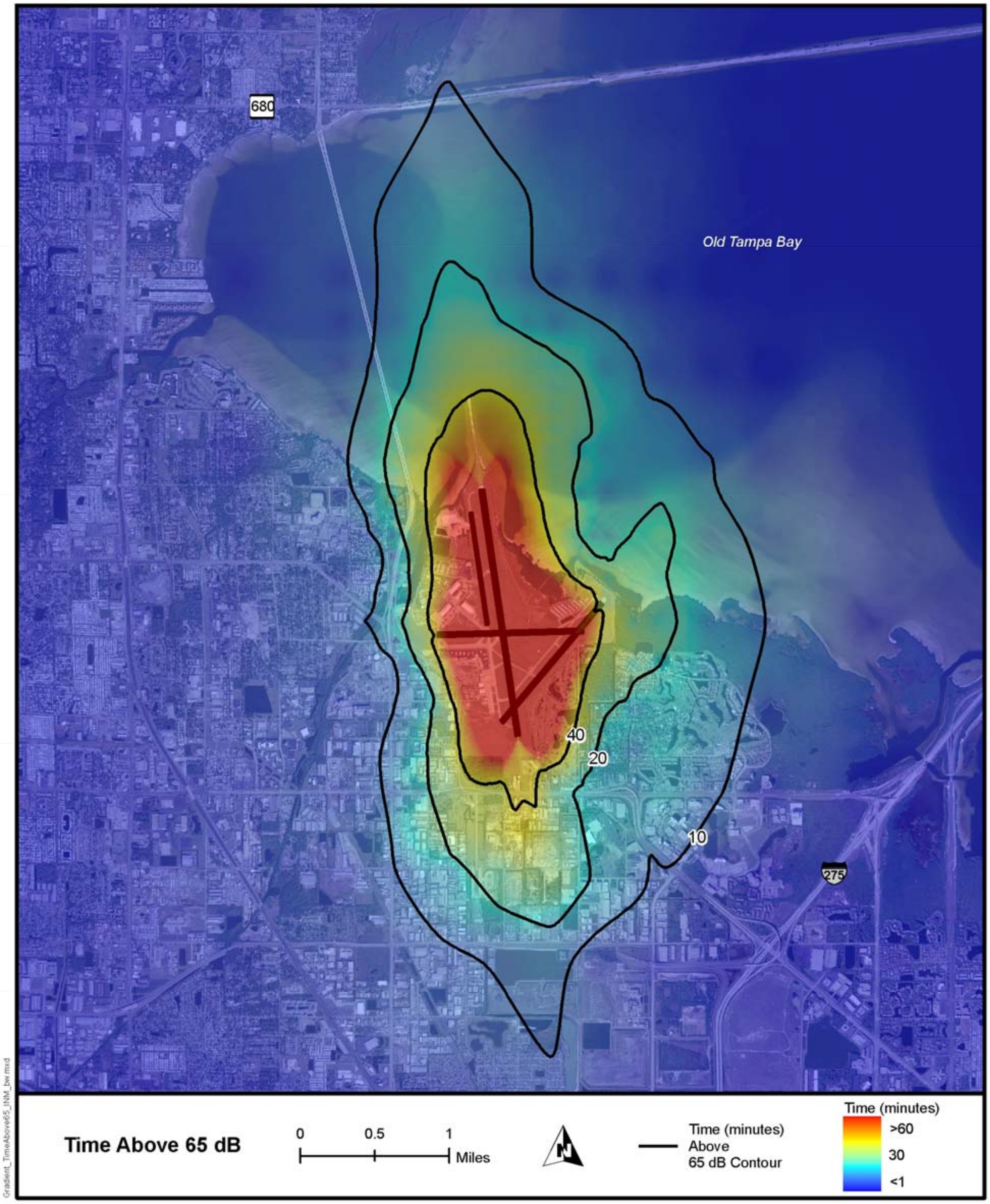
Table 5-1 shows a tabular presentation of TA for a wide range of threshold levels at the study area POIs. The most comprehensive results can be shown by presenting the TA contours on a map that also identifies the POIs in the study, with corresponding tables presenting the computed TA values for those specific points.

Table 5-1. Time Above Sound Level Threshold for a 24-hour Period

Point	Time Above Sound Level Threshold (Minutes):							
	55 dB	60 dB	65 dB	70 dB	75 dB	80 dB	85 dB	90 dB
1	133	68	27	8	3	0	0	0
2	143	65	29	12	4	1	0	0
03	21	11	6	2	1	0	0	0
4	23	14	9	5	2	1	0	0
5	6	3	1	0	0	0	0	0
6	6	3	1	0	0	0	0	0
7	6	2	1	0	0	0	0	0
8	18	10	5	2	0	0	0	0
9	20	11	5	2	1	0	0	0
10	23	13	6	3	1	0	0	0
11	208	134	84	53	29	13	5	1
12	117	74	47	29	18	9	5	2
13	131	85	54	29	15	9	4	2
14	136	65	24	13	6	2	1	0
15	18	10	4	2	0	0	0	0
16	7	4	1	0	0	0	0	0
17	17	9	4	1	0	0	0	0
18	19	12	7	3	1	0	0	0
19	9	4	1	0	0	0	0	0
20	8	4	1	0	0	0	0	0
21	106	48	17	3	1	0	0	0
22	41	15	6	2	1	0	0	0
23	126	57	22	8	2	0	0	0
24	5	2	0	0	0	0	0	0
25	2	1	0	0	0	0	0	0
26	6	2	0	0	0	0	0	0
27	17	9	4	2	1	0	0	0
28	67	24	8	2	1	0	0	0
29	14	7	3	1	0	0	0	0
30	13	7	4	2	1	0	0	0
31	12	6	3	1	0	0	0	0
32	4	1	0	0	0	0	0	0
33	3	1	0	0	0	0	0	0
34	12	5	2	0	0	0	0	0
35	10	5	2	1	0	0	0	0
36	11	6	3	1	0	0	0	0
37	7	4	2	1	0	0	0	0

Other TA-based descriptors are time above ambient level (TALA) and time audible (TAUD), which have been merged into FAA’s Integrated Noise Model (INM) 6.2 release series (see note in Technical Requirements). These metrics require the model user to provide input of 1/3 octave-band spectral files mapped to A-weighted sound levels at all the study area grid points. The current NOISEMAP program suite does not contain the algorithms to produce time-based descriptors.

In order to better understand the variation in a Time-Above metric throughout a given study area, it is possible to make use of the gradual color shaded mapping techniques described in Section 5.1.1. Hard contour lines are drawn closer in to the airport to reflect selected TA values, such as 10, 20, and 40 minutes above 65 dB as shown in Figure 5-6, using the gradual shading technique to show the variation in time-above values between the contour lines and further away from the airfield.



Source: US Census TIGER/Line 2000, Wyle Laboratories, INM 6.1
Geographic Reference: 1983 State Plane Coordinate System, Florida West, Feet

Figure 5-6. An Example of Annual Average Day Time-Above 65 dB Contours [TA65(x) for 10, 20, and 40 min per day]

(Source: Noise Study for the St. Petersburg-Clearwater International Airport – Phase I, Wyle Laboratories, Inc. Wyle Report WR 05-15, December 2005)

Strengths and Weaknesses

The TA is a useful descriptor of the noise impact of an individual event, or for many events occurring over a certain time period. When computed for a full day, the TA can be compared alongside the DNL in order to determine the sound levels and total duration of events that contribute to the DNL. TA analysis is usually conducted along with NA analysis so the results show not only how many events occur above the selected threshold(s), but also the total duration of those events above those levels for the selected time period.

Although the TA analysis indicates the number of minutes that an A-weighted sound level is exceeded, it does not provide a measure of maximum sound level that occurs during the selected time period. As an example, TA70(60) indicates that a noise level of 70 dB is exceeded for 60 minutes per day, but an individual aircraft overflight could be much higher than 70 dB. When the TA results are displayed using tables to show the multiple POIs throughout the study area, the community can quickly and efficiently see the time that is exceeded for a series of thresholds (e.g., 60, 70, 80, and 90 dB), allowing a good understanding of the increase or decrease in time that will result between different operational scenarios. An additional benefit is that this approach relies less on a "one-size-fits-all" approach that results by establishing a "significant" outdoor sound level threshold level for TA analysis. However, a weakness of the tabular technique is that it only allows a finite number of analysis points throughout the study area. The most comprehensive results can be shown by presenting the TA contours on a map that also identifies the noise sensitive points of interest in the study, with corresponding tables presenting the computed TA values for those specific points.

Technical Requirements

NOISEMAP is an integrated noise model that computes the overall noise exposure by combining the SEL's for all aircraft events within a particular time period. Time-based descriptors such as TA cannot be accurately modeled within NOISEMAP because the time history of each event is unknown. The TA can be approximated by assuming a standard time history for each aircraft event; however, NOISEMAP was never programmed to make TA estimates. TA can only be accurately calculated from a noise simulation model, such as AAM, that portrays the time histories of each event.

5.2.5 Number-of-Events Above a Threshold Level (NA)

The Number-of-events Above metric (NA) provides the total number of noise events that exceed the selected noise level threshold during a specified period of time. Combined with the selected threshold level (L), the NA metric is symbolized as NAL. The threshold L can be defined in terms of either the SEL or L_{max} metric, and it is important that this selection is reflected in the nomenclature. When labeling a contour line or POI on a map the NAL will be followed by the number of events in parentheses for that line or POI. For example, the noise environment at a location where 10 events exceed an SEL of 90 dB, over a given period of time, would be represented by the nomenclature NA90SEL(10). Similarly, for L_{max} it would be NA90L_{max}(10). The period of time can be an average 24-hour day, daytime, nighttime, school day, or any other time period appropriate to the nature and application of the analysis.

The NA descriptor was first developed in Australia in the 1970s and was used in dose-response research studies to assist in defining noise/land-use compatibility for the Commonwealth of Australia[38]. The 1995 Senate Select Committee on Aircraft Noise in Sydney identified a multitude of problems in how aircraft noise information was conveyed to the public. As a result, the Australian government has made widespread use of N70 (Number-of-events Above L_{max} 70 dB) contours as one tool to supplement their long-term, cumulative noise metric.

NA can be portrayed for single or multiple locations, or by means of noise contours on a map similar to the common DNL contours. A threshold level is selected that best meets the need for that situation. An L_{max} threshold is normally selected to analyze speech interference, whereas an SEL threshold is normally selected for analysis of sleep disturbance.

Strengths and Weaknesses

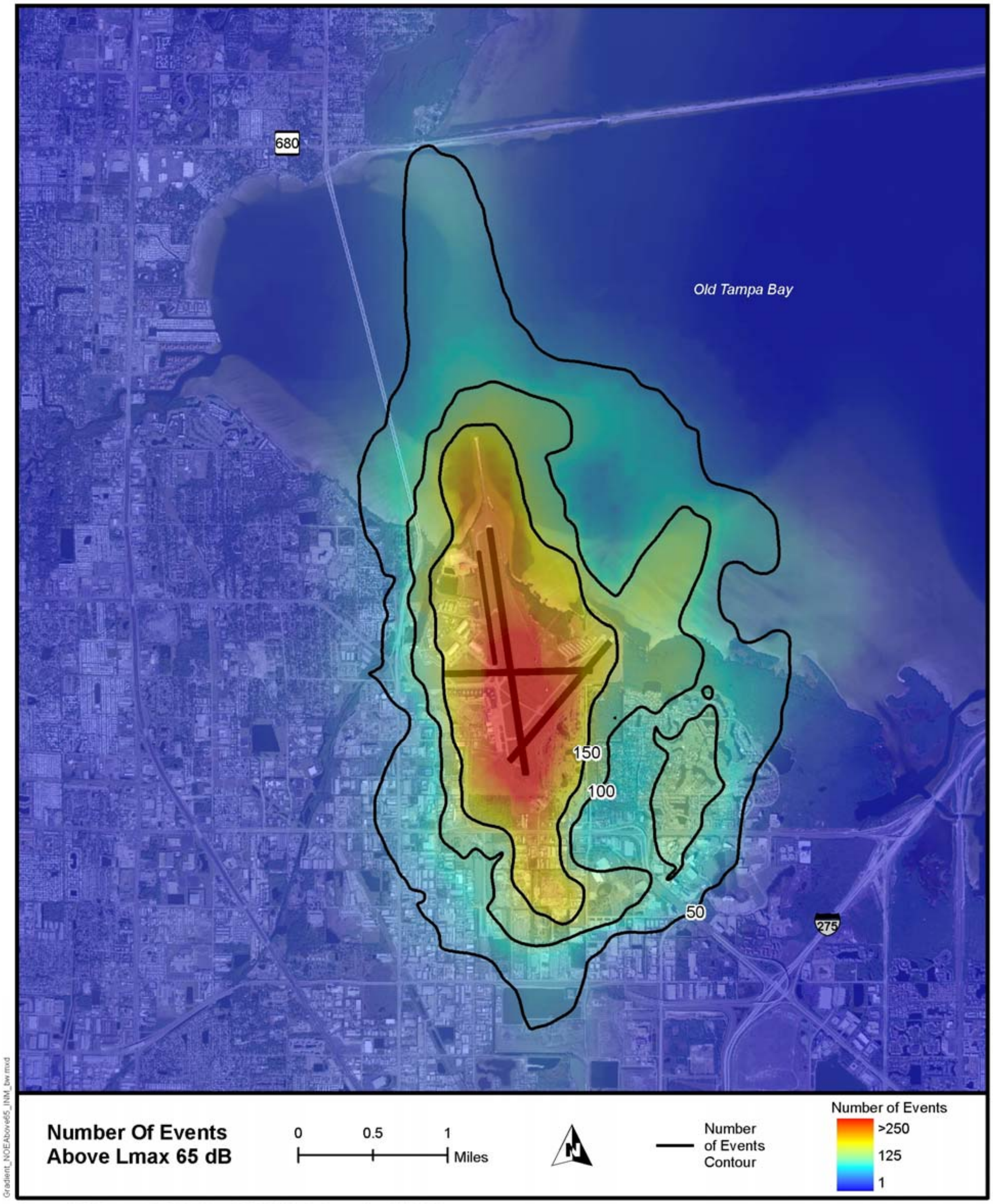
The NA metric has a distinct advantage in communicating current and projected noise exposure in a way not available through the use of other metrics or tools. It is the only supplemental metric that has been developed that combines single-event noise levels with the number of aircraft operations. In essence, it answers the question of how many aircraft (or range of aircraft) fly over a given location or area at or above a selected threshold noise level. Anecdotal evidence has shown that the public easily relates this metric to their everyday experience. When used in a comparison of scenarios, the public can more easily comprehend a change in numbers of events than they can changes in noise level.

NA has proven useful as a good indicator of the effects that airport noise will have on certain human activities – specifically, the number of times per day (or other time period) that speech could be interfered with, or the number of nighttime aircraft events that may cause some level of sleep disturbance.

NA analysis can also be communicated through the use of equal number of event noise contours overlaid on a local area map using the color shading technique. A threshold level (or series of thresholds, which require multiple contour maps) is selected for analysis that best meets the need for that situation – i.e., speech interference may be best "predicted" by L_{max}, while sleep interference factors usually require SEL threshold values – where the total number of events that exceed that threshold are calculated. An example of this method is shown in Figure 5-7, where the NA contours detail the areas that encompass 50, 100, and 150 aircraft events (over an average 24-hour day) for a threshold value of 65 dB L_{max}. Note that the contours for different noise level thresholds should be mapped separately to avoid confusion. A word of caution and lesson learned - it is best to rely on one or maybe two threshold levels, because adding more may confuse the public and non-technical project officials and managers. Simply increasing the amount of information and level of detail will not necessarily help the intended audience.

The results can be displayed using tables showing various NA values for the selected threshold levels for each of the operational scenarios or alternatives at POIs throughout the study area. Table 5-2 is an example for seven POIs where the DNL is presented together with the number of events exceeding different L_{max} values ranging from 55 to 85 dB (NA55L_{max} to NA85L_{max}. In this case, the component parts of DNL are shown by extracting the aircraft events that occur above a range of threshold levels during the average annual day at a number of locations.

Essentially, we are "looking inside" a given DNL at a specific location by computing the number of aircraft events that exceed the specified thresholds (i.e., 55, 60, 65, 70, etc. decibels [dB]).



Source: US Census TIGER/Line 2000, Wyle Laboratories, INM 6.1
Geographic Reference: 1983 State Plane Coordinate System, Florida West, Feet

Figure 5-7. An Example of Number-of-Events Above (NA) Contours Above 65 dB L_{max}

(Source: Noise Study for the St. Petersburg-Clearwater International Airport – Phase I, Wyle Laboratories, Inc. Wyle Report WR 05-15, December 2005)

Table 5-2. An Example of NA L_{max} Values Exceeded at Locations Along the DNL 60/65 dB Contours

Location	DNL (dB)	L_{max} 55 dB+	L_{max} 60 dB+	L_{max} 65 dB+	L_{max} 70 dB+	L_{max} 75 dB+	L_{max} 80 dB+	L_{max} 85 dB+
1	60	155	76	36	11	3	1	0
2	60	201	104	46	13	2	0	0
3	60	204	106	49	16	1	0	0
4	60	171	95	49	19	4	0	0
5	65	254	139	83	44	18	3	0
6	65	235	131	81	44	19	4	0
7	65	253	170	98	50	19	4	0

The community can quickly see the number of exceedances for a series of thresholds (e.g., 55 dB through 85 dB L_{max}), allowing a good understanding of the increase or decrease in the Number-of-Events that will result between two (or more) different operational scenarios. An additional benefit is that this allows less dependence on establishing a "significant" outdoor sound level threshold level for the analysis. There is less reliance on a "one-size-fits-all" approach. However, a weakness of the tabular technique is that it only allows a finite number of analysis points throughout the study area.

Figure 5-8 shows a map that compares the NA values above 70 dB L_{max} for two different operational scenarios. Note that although the NA analysis indicates the total number of times the threshold A-weighted sound level threshold was exceeded, it does not provide a measure of maximum sound level that occurred during the selected time period. As an example, an NA70 of 60 indicates that 60 events per day will exceed 70 dB L_{max}, but an individual aircraft overflight could be much higher than 70 dB.

The Number-of-Events can also be presented for different sound level ranges by organizing the event values into bins (60-65 dB, 65-70 dB, etc.). An example is shown in Table 5-3, for the same situation as shown in Table 5-2, where the event values are broken down into 5 dB increments ranging from a low threshold value (55-60 dB) up to a higher threshold (80 dB and greater).

Table 5-3. An Example of NA L_{max} Values at Locations Along the DNL 60/65 dB Contours

Location	DNL (dB)	L_{max} 55-60 dB	L_{max} 60-65 dB	L_{max} 65-70 dB	L_{max} 70-75 dB	L_{max} 75-80 dB	L_{max} 80-85 dB
1	60	79	40	25	8	2	1
2	60	97	58	33	11	2	0
3	60	98	57	33	15	1	0
4	60	76	46	30	15	4	0
5	65	115	56	39	26	15	3
6	65	104	50	37	25	15	4
7	65	83	72	48	31	15	4

The most comprehensive results can be shown by presenting the NA contours on a map that also identifies the noise sensitive points of interest in the study and then presenting the computed NA values for those specific points in separate supporting tables.

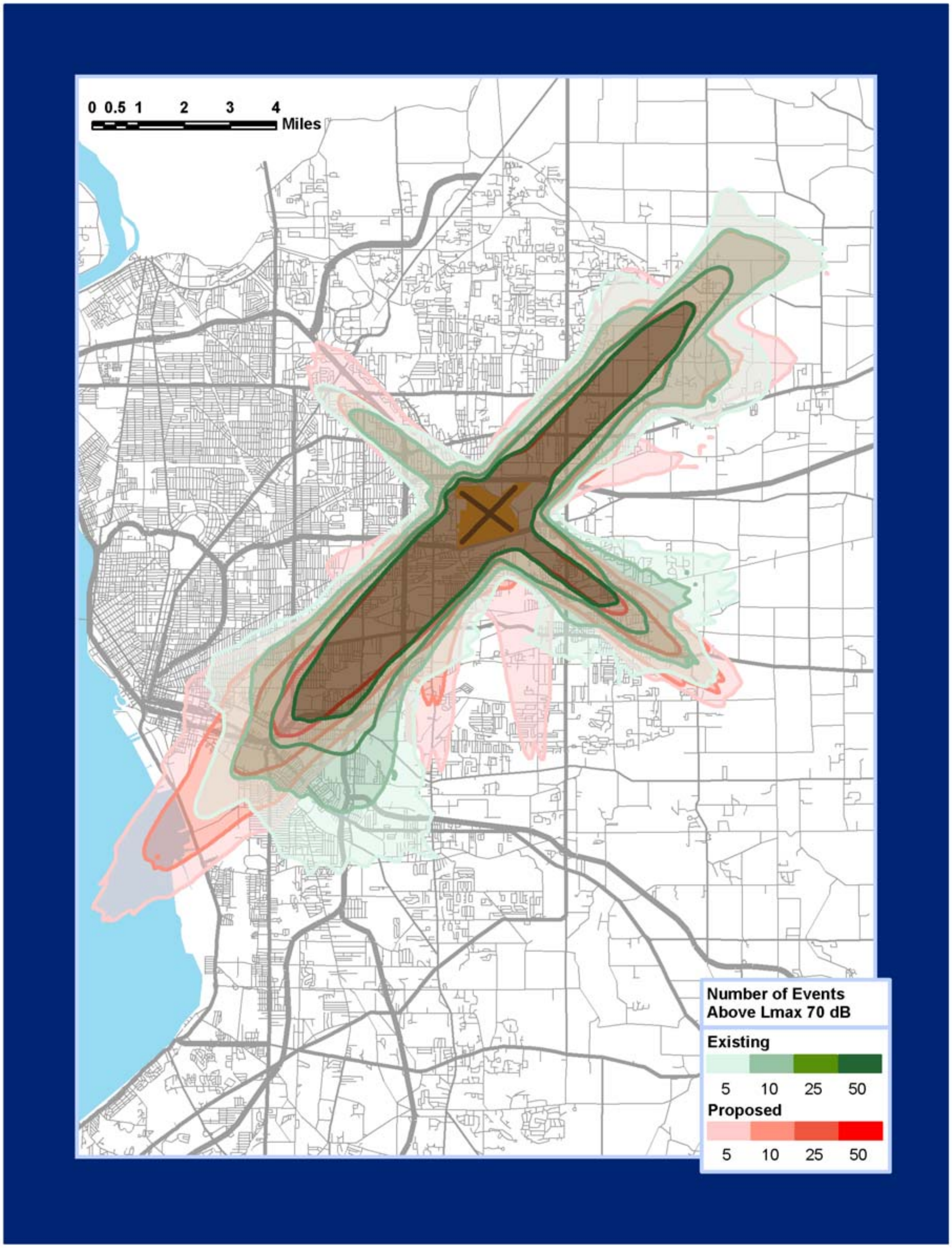


Figure 5-8. An Example of Number-of-Events Contours Above 70 dB L_{max} – Comparison of Existing and Proposed Conditions

(Source: Buffalo Niagara International Airport, FAR Part 150 Noise Compatibility Study, Niagara Frontier Transportation Authority (NFTA), PB Aviation and Wyle Laboratories, October 2004)

The main advantage to using this technique is that the stakeholders can better understand the cumulative noise exposure from the individual aircraft events that occur over a given period of time over a wide range of threshold levels. In other words, this approach answers the question "is the noise environment at this location comprised of an equal number of events at low, mid, and high sound levels, or are there more events at low sound levels than at the mid or higher sound levels?" The general concept is to breakout the component parts of the DNL values into NA values at associated sound levels, thereby better explaining the overall noise environment and any changes that are expected to occur with each alternative.

The example above also shows the potential that the NA analysis can have for the stakeholders in the decision-making process. The change at each threshold level for this alternative provides the project decision makers and other stakeholders with additional information that may improve the understanding of the various alternatives under consideration.

NA Change Maps

The full effectiveness of the NA approach is realized when evaluating changes in noise exposure that will result from an operational change, particularly when comparing alternatives that will shift noise.

A small increase or decrease in the DNL does not effectively communicate to the affected individuals how many more or less intrusive events to expect, nor does it equip them or the decision makers with sufficient information to identify and select the best alternative. In addition to showing the changes at specific locations, detailing the changes in the numbers of events overlaid on a study area map can be instructive. These types of maps are a representation of the difference between two study area files (an existing and future case, for example), from which one can quickly visualize the change in the noise environment at all locations throughout the chosen study area, albeit at one sound level threshold.

Figure 5-9 shows a proposed change to the departure flows from Runway 9 at Boston-Logan International Airport that was evaluated as a potential noise-reduction alternative in an airspace study. In this example, the concept behind the proposed alternative is to move the departing aircraft further east over the water before turning back over land (to the north and south). Since the aircraft would be moving further out over water, the aircraft would be at higher altitudes when they cross back over the shoreline, thereby producing lower noise levels on the ground. As one can clearly see from this change map, large portions of the north and south shore communities (the areas in purple) could receive very positive benefits under this alternative (15 or fewer events per day at sound levels of 60 dB or greater). On the other hand, a portion of the north and south communities (the green areas) are likely to receive anywhere from 1-15 more events per day at sound levels of 60 dB or greater.

Compare this to the results of a DNL change map for the same scenario in Figure 5-10 which shows the increase in DNL values for the north shore communities (light green and green shaded areas). The map also shows some areas to the north where the DNL values will decrease. However, clearly absent is the large area of reductions in the number of overflights for both the south and north shore communities. This example shows that the use of the DNL metric alone in this context reveals far less detail regarding noise exposure changes throughout the study area than the NA change comparison map.

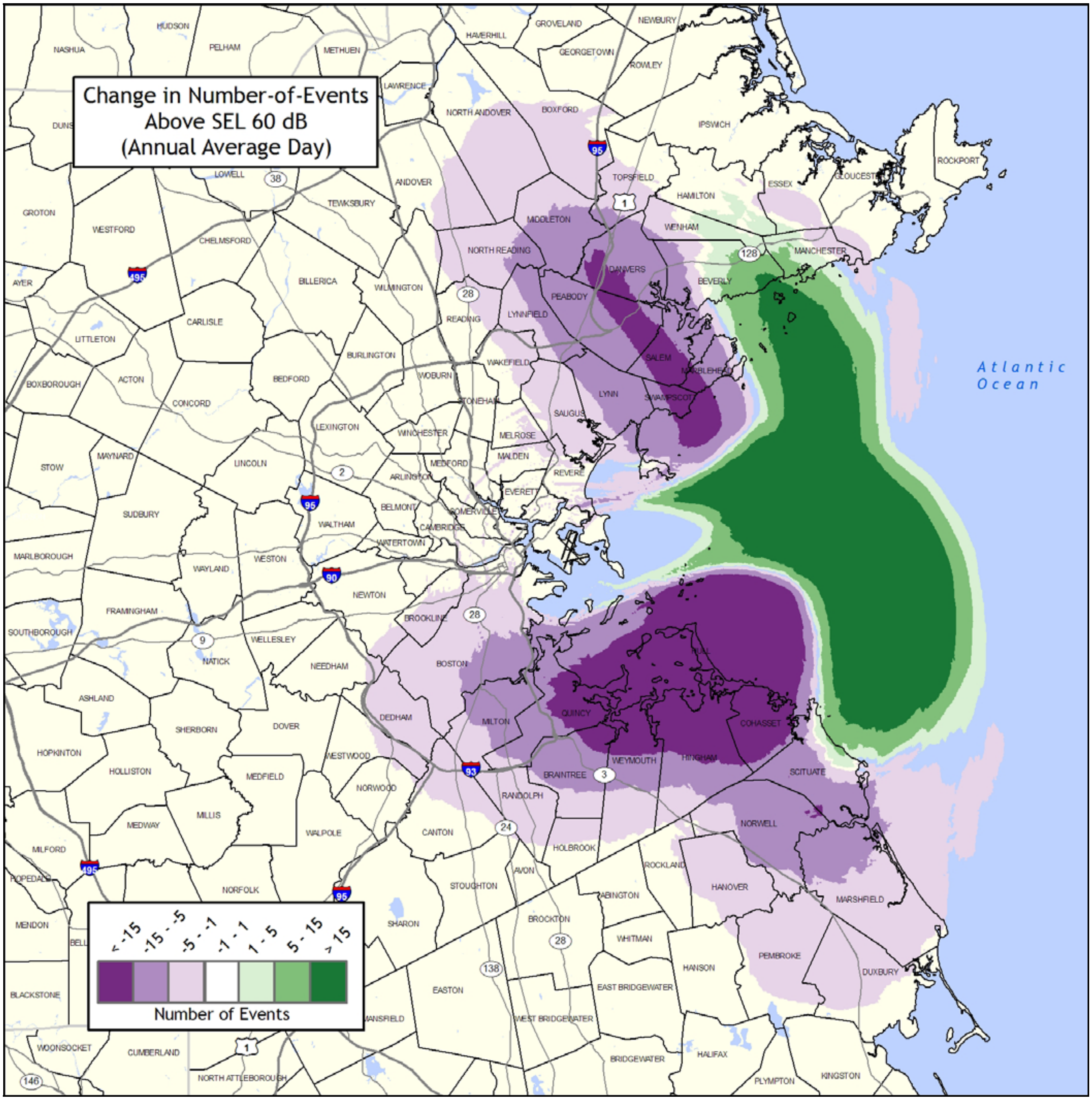


Figure 5-9. An Example of an NA Change Map

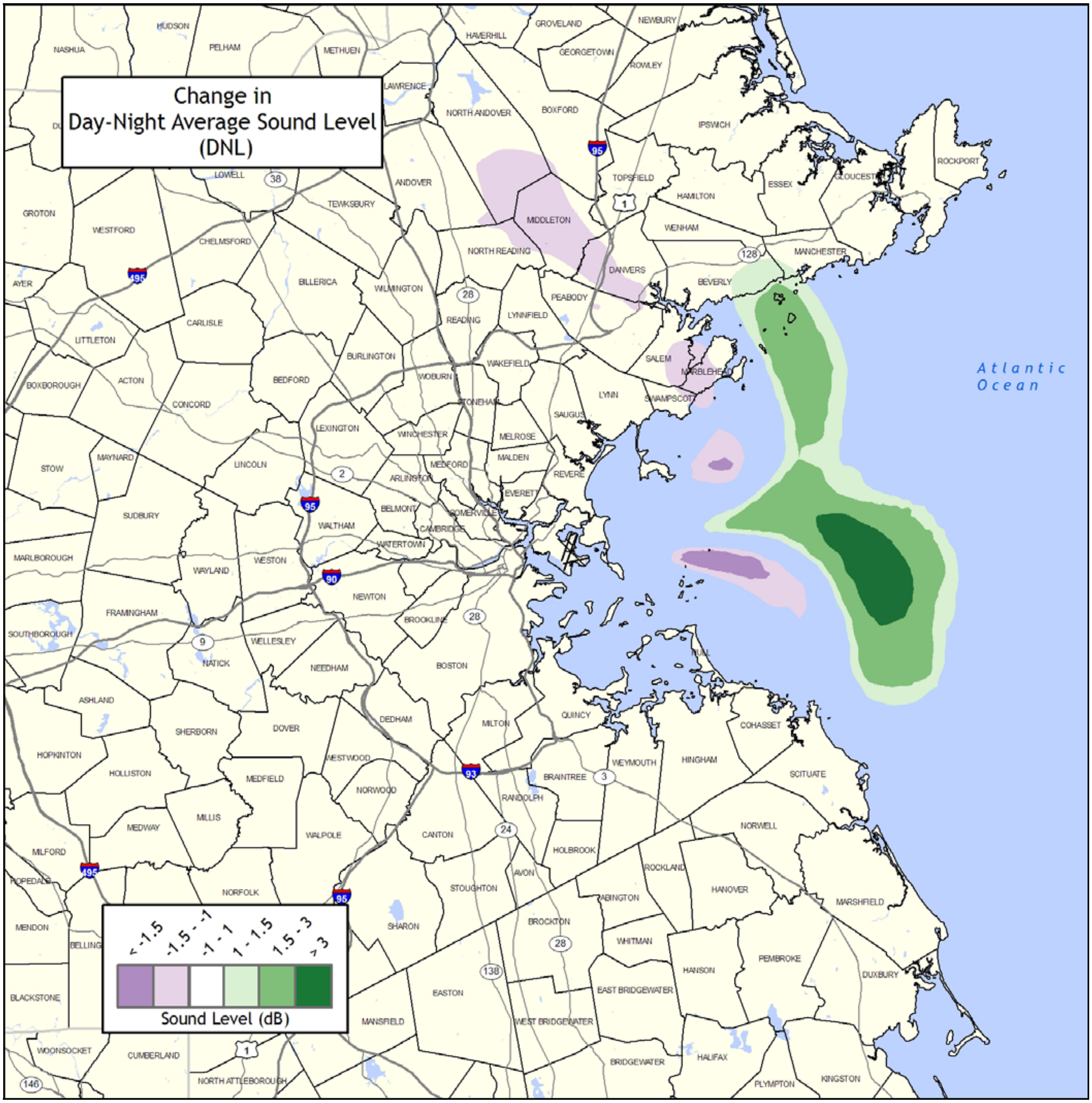


Figure 5-10. An Example of a DNL Change Map

Technical Requirements

NA analysis was recently incorporated as an optional metric in the NOISEMAP program suite, and this update will be available shortly. NA analysis will also be available in the new AAM. Operational data for the time period of interest is required. Map production requires specialized GIS expertise and the use of associated software.

NA analysis was recently incorporated as an optional metric in the NOISEMAP program suite, and this update will be available shortly. NA analysis will also be available in the new AAM. Operational data for the time period of interest is required. Map production requires specialized GIS expertise and the use of associated software.

5.2.6 Respite

In the context of aviation noise, the time interval between noticeable levels of aircraft noise at any receptor location is a period of respite (a measurable absence of aircraft noise). The use of this term in relation to aviation noise originated in Australia.

When a new runway opened at Sydney Airport a few years ago, the total number of operations to the north increased from 160 per day to about 370. For many people in that area the prime issue became not only one of how many operations and how much noise they received, but when and how often they were able to get a break from the noise. Using trial and error, Australian DOT officials settled on a definition of respite to be a full hour without an operation. They settled on a system of reporting respite monthly as the percent of hours (% Respite) in a month for the operations off each runway end, further broken down into morning, daytime, evening and weekend time periods. Monthly reports are then averaged to produce an annual report. Figure 5-11 graphically shows respite for Sydney Airport for 1998[38].

Respite can be defined in various ways, but should be defined in cooperation with the local stakeholders in a way that best fits the local noise environment. To provide a measure of respite from noticeable or intrusive events, consider the use of histograms or tables to highlight the variations in sound levels or number of events over time. This type of analysis could include NA analysis for a low-level threshold (perhaps 60 to 70dB L_{max}), TA analysis for a low-exposure threshold, and L_{eq}, and L_{max} calculations on hourly intervals throughout the course of an average (or, perhaps busy/active) day.

This analysis can be further refined to include departures only or arrivals only for each runway at an airbase or range. Note that this type of analysis requires hourly operations data for each runway. Results can be reported periodically or for a selected time period suitable for a noise study report.

Respite Metrics in Use

Another metric used in Australia to quantify respite is the Median Quiet Interval (MQI), defined as the average time between aircraft events that exceed a selected threshold. This metric can be useful in the description of noise exposure, because it quantifies “respite” or relief from potentially intrusive noise events. For the selected threshold level(s), MQI can be calculated by subtracting the TA from the total time of selected time period (for example, a 24-hour period) and dividing the remainder by the NA for that same threshold sound level (again, over the same 24-hour period). As an example, consider a point of interest that is defined by TA65(30) (30 minutes per day above an L_{max} of 65 dB) and is also defined by NA65(100) (100 events per day above an L_{max} of 65 dB). This results in an MQI of 14.1 minutes. The calculation would be as follows: (24 hours total time minus 0.5 hours above L_{max} of 65 dB)/(100 events above L_{max} of 65 dB) = 0.235 hours or 14.1 minutes.

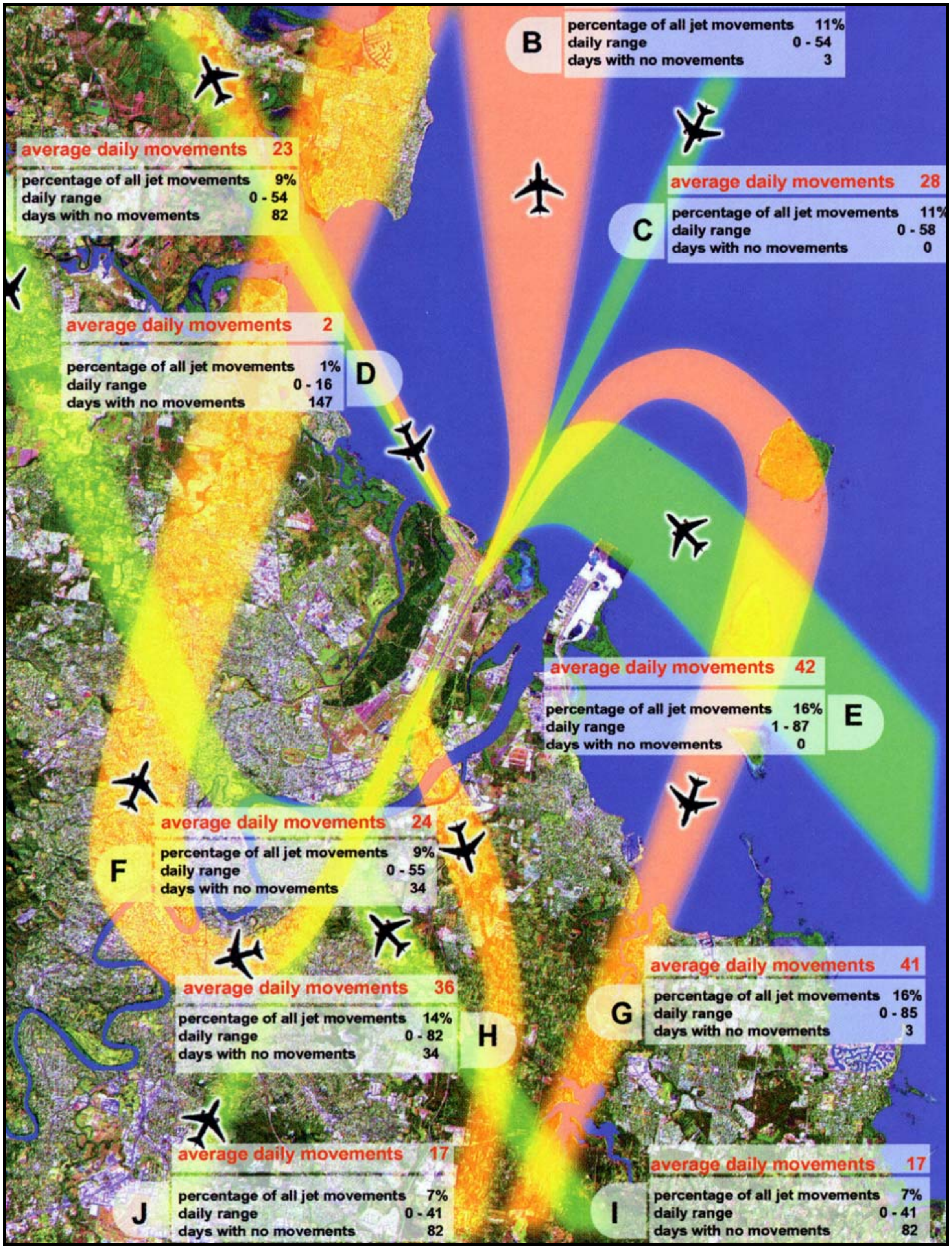


Figure 5-11. 1998 Respite from Jet Movements at Sydney Airport

(Source: "Ways to Describe and Assess Aircraft Noise" Australian DOT)

Technical Requirements

The TA and NA metrics necessary to quantify respite are discussed in previous subsections above

5.3 Application of Supplemental Tools and Metrics

The previous section of the report provides the noise analyst with some specific and useful supplemental metrics and tools, all of which have proven to be useful in helping civilian airports more effectively interact with the surrounding communities, both in a NEPA (EA/EIS/EIR) study environment or in Part 150 Noise Compatibility Studies, and also in day to day noise management. The next important step is how to convey what those metrics mean in terms of effects and impacts, and how they can be applied to specific situations.

5.3.1 Supplemental Analysis of Annoyance

As noted in Section 3 and Appendix A, Effects of Noise, the primary effect of aircraft noise on residential communities is annoyance and FICAN recommends the updated "Schultz Curve" as the best available source of empirical dose-response information to predict community response to transportation noise. A supplemental analysis of annoyance should complement the DNL analysis of the changes in aircraft noise exposure due to a proposed project. Understanding the implications of the changes in aircraft noise exposure in terms of changes in the proportion of the residents likely to be highly annoyed could lead the decision maker and affected public to a common understanding of the impacts, not readily apparent when looking at DNL contours alone.

The updated Schultz curve[4] is a statistical regression equation indicating that an increase in DNL causes an increase in the proportion of a community that would be highly annoyed by the aircraft noise. Given the large uncertainty associated with the relationship (see Figure 3-1), it is important to communicate to the community that the %HA at any given DNL is a prediction which may vary considerably with the actual %HA that would be found in the study area if a survey were to be performed locally. The annoyance expressed by individuals in the community may be related to factors other than just noise – factors such as fear of aircraft accidents, distrust of airbase or airport motives, and feelings that their concerns are not being addressed. Noise may be a catalyst that reminds people of these other factors. However, while the actual %HA for the current condition and future alternatives may vary considerably from the predicted %HA, the change in %HA using the predicted values when comparing alternatives can provide an insight into the change in annoyance experienced by the community.

While the updated Schultz equation cannot accurately predict the number of highly annoyed persons in any specific residential community, it can play an important role as a policy tool to understand and control aircraft noise impacts. Miedema[6], in supporting his model of noise annoyance, states that "the prediction on the basis of a norm curve that is valid for the entire population is a more suitable basis for policy than the actual annoyance of a particular individual or group." He asserts that equitable and consistent application of a noise policy is not served if in each case the actual annoyance is taken as the only basis for the evaluations. The supplemental analysis of annoyance in this guideline provides a consistent tool for the examination of the increase in proportion of the residents highly annoyed to an increase in noise exposure.

To predict the change in the number of highly annoyed people resulting from an increase in DNL the graph in Figures 3-1 can be used together with the %HA expression in Section 3.1.1. Consider the situation presented in Table 5-4 where increases in noise levels at fifteen locations are predicted between the current condition (starting DNL) to a future alternative scenario (ending DNL). Using the relationship between %HA and DNL defined in Section 3.1.1, the %HA can be estimated for the two conditions, and hence the increase in %HA can be estimated. This table shows how %HA can provide a different perspective on the effects of noise to supplement the DNL analysis.

At Location 1, for example, the DNL increase of 14 dB (from 50 dB to 64 dB) is the highest increase at any location, but is ranked only seventh in terms of an increase in %HA with a value of 9%. At Location 15 the ending DNL is the highest with a value of 75.5 dB, but the increase in %HA is higher at Location 10 with a value of 18% (versus 16%) even though the ending DNL at this location is 73 dB. Again, it is important to emphasize that the absolute values of %HA in any particular community, as predicted by the average relationship in Section 3.1.1, should only be used as general indicators of the actual community annoyance, providing a basis from which the predicted increases in %HA can be assessed.

Table 5-4. An Example of Supplemental Analysis of Annoyance

Location	Starting DNL, dB	%HA from Schultz Curve*	Ending DNL, dB	Change in DNL, dB	Increase in %HA
1	50.0	2%	64.0	14.0	9%
2	50.0	2%	58.0	8.0	3%
3	50.0	2%	47.0	-3.0	-
4	55.0	3%	62.0	7.0	5%
5	55.0	3%	57.5	2.5	2%
6	55.0	3%	60.0	5.0	3%
7	60.0	6%	68.0	8.0	12%
8	60.0	6%	67.0	7.0	10%
9	60.0	6%	58.5	-1.5	-
10	65.0	12%	73.0	8.0	18%
11	65.0	12%	64.0	-1.0	-
12	65.0	12%	71.0	6.0	13%
13	70.0	22%	74.5	4.5	13%
14	70.0	22%	72.0	2.0	5%
15	70.0	22%	75.5	5.5	16%

The typical presentation of exposure in DNL is thus complemented by estimates of the percentage increase in highly annoyed people in the community. This type of analysis also reveals that there are people who are highly annoyed by aircraft noise when the exposure is less than DNL 65 dB, which would not be as evident when just looking at DNL contours. Note also that Locations 4 and 8 with identical increases in DNL (7 dB) show much different changes in annoyance due to the higher starting DNL exposure at Location 8.

A factor that must be considered in such an analysis is that the relationship between annoyance and DNL is based on long-term exposure to the noise. It is likely that the response of the affected community is tempered by habituation to the noise climate. Habituation is the ability of humans to acclimate to incremental increases in sound levels, intermittent increases in sound levels such as aircraft flyovers, and high ambient sound levels. Thus, the supplemental analysis of annoyance identifies the possible long-term reactions of the residential communities, while their immediate reactions to the implementation of the project may be more severe.

The supplemental analysis of annoyance is intended to evaluate the effect of an increase in DNL not decrease in DNL. In Table 5-4, for example, Locations 3, 9, and 11 do not have values of increases in %HA because the ending DNL is lower than the starting DNL. The guideline places this limit on the application given the uncertainty in the underlying exposure-effect relationship due in large part to the influence of non-acoustic factors. It is reasonable to conclude that since noise exposure is a factor then an increase in noise should produce some increase in the amount of people highly annoyed. However, it is not reasonable to conclude that a decrease in noise exposure will result in a decrease in the number of people highly annoyed because the factors affecting these people may be non-acoustic.

5.3.2 Speech Interference

Interference with speech communication in the home and particularly in classrooms is often an issue for communities exposed to aircraft noise. The effects of speech disruption are certainly included in some way in the general annoyance that a person expresses about aircraft noise, and this can be addressed using the approach described in the previous section. However, as noted in that section, the term "annoyance" may include many factors, some of which are not directly related to noise. Speech interference is directly related to noise alone, and can be addressed separately using established noise criteria.

Section 3.1.2 of this report indicates that an appropriate set of criteria for speech interference in schools is an indoor noise level of L_{eq} of 40 dB (for intermittent noise), and a single event level of L_{max} 50 dB. These criteria can be applied in the analysis of classroom noise using the L_{eq} and NA metrics. An example of such an analysis is shown in Table 5-5 (this example is taken from an assessment for five day-care centers, identified as Locations A through E, in Toronto described in more detail in Appendix C, Section C.11). It was assumed (more or less arbitrarily) that L_{max} should be exceeded only once per hour during the 10-hour school day, so that an indoor number of events threshold of NA50(10) was applied for the 10-hour period (1 per hour for 10 hours). Assumptions were made as to how much outdoor-to-indoor noise level reduction is typically provided by a building, given both "windows closed" (25 dB noise reduction) and "windows open" (15 dB noise reduction) scenarios. Using these assumptions, the indoor noise exposure levels at each of the five sites were modeled for the existing and two alternative traffic scenarios with the results as shown in Table 5-5.

Under the current annual average scenario for Location A the interior L_{eq} is 30 dB with windows closed, increasing to 33.1 dB under Traffic Scenario A, and decreasing to 30.6 dB for Traffic Scenario B. However, the number of events exceeding L_{max} 50 dB increases from 19 to 56, and then down to 17 respectively, reflecting the different operations and flight tracks for these Scenarios. Note the large effect that closing windows has on the number of events exceeding L_{max} 50 dB in this example. Since closing the windows reduces the noise level by 10 dB on average, the windows open indoor L_{max} noise level of most events in this example is less than 60 dB.

Table 5-5. Number-of-Events Analysis at Specific Location Points – Effects on Speech

Location Point	Annual Average Scenario *654 Total Operations*[2]				Northeast Peak Traffic Scenario[1] *722 Total Operations*[2]				Southwest Peak Traffic Scenario[1] *730 Total Operations*[2]			
	Indoor L_{eq} (dB) *Windows Closed**	Indoor L_{eq} (dB) *Windows Open***	Indoor NA50 L_{max} *Windows Closed**	Indoor NA50 L_{max} *Windows Open***	Indoor L_{eq} (dB) *Windows Closed**	Indoor L_{eq} (dB) *Windows Open***	Indoor NA50 L_{max} *Windows Closed**	Indoor NA50 L_{max} *Windows Open***	Indoor L_{eq} (dB) *Windows Closed**	Indoor L_{eq} (dB) *Windows Open***	Indoor NA50 L_{max} *Windows Closed**	Indoor NA50 L_{max} *Windows Open***
A	30.0	40.0	19	101	33.1	43.1	56	157	30.6	40.6	17	108
B	27.6	37.6	6	75	25.4	35.4	0	89	30.3	40.3	14	106
C	29.1	39.1	18	120	30.2	40.2	36	149	28.2	38.2	8	140
D	29.4	39.4	9	107	28.1	38.1	3	85	29.4	39.4	9	145
E	26.8	36.8	5	94	28.0	38.0	5	127	26.7	36.7	3	91

Notes:
[1] Operations are based on one specific day, and reflect the specific runway use and fleet mix from that day
[2] Number of operations during school hours only (7:30 am to 5:30 pm)
* Assuming a room NLR of 25 dB
** Assuming a room NLR of 15 dB

The example shows that, while an argument can be made to allow schools and day care centers based on L_{eq} values alone, the results of the NA analysis should be carefully considered. The noise analysis determined that more than 10 noise events would likely interrupt normal speech in a classroom at two of the five sites, assuming that the windows were closed during a 10-hour day care/school day. The NA50(10) threshold was exceeded at all five modeled locations with a "windows open" assumption.

By performing this in-depth analysis of noise exposure using supplemental noise metrics, it is possible to make more technically defensible policy decisions regarding whether or not to allow schools and day care centers to be located in certain areas.

Note that Noise Level Reduction values should be adjusted to suit specific local conditions as required; the NLR values shown in these guidelines are average values across the nation.

Previous project experience has shown that the key to presenting this information is to make it as simple and easy-to-understand as possible. It is highly recommended that the project managers consider placing the detailed breakout of the NA analysis (Table 5-5) in an appendix to the noise study report for those readers who are interested in more technical detail and want a detailed understanding of the overall noise environment. Again, experience has shown that most of the intended audience wants to know simply what the effects are on them and what they should expect.

5.3.3 Sleep Disturbance

The literature review of many of the global research studies in Section 3.1.3 shows the breadth and depth of the sleep research and the evolution of the work over time. It also gives a good indication of the complexity of the issue. Summarizing the sleep research, a broad consensus linking detrimental health effects to sleep disturbance from aircraft noise does not exist. Consequently, U.S. noise policy has not focused on establishing criteria exclusively for sleep effects. Instead, the Federal agencies have endorsed the disclosure of potential sleep effects as a supplemental tool beyond the typical DNL analysis – refer to the 1997 FICAN Report[25], ANSI S12.9-2008[73], and Section 3.1.3 in this guidance. It should be well understood that the loss of sleep is an irritant to the general population and is a very important component in long-term community annoyance.

It is important to understand that there is no exact single threshold or set of thresholds that will provide a complete understanding of the sleep disturbance attributable to aircraft noise in a complex noise environment that includes multiple aircraft noise events over the course of the average or typical night. Rather, this guidance proposes to rely on three selected sound level threshold ranges to help explain the effects.

The first range is described by single aircraft events that will produce SEL values of 50-60 dB in the bedroom. Based on the various research studies, particularly the most recent work done by FICAN, Fidell, and DLR, any single aircraft event that produces indoor SEL values of 50-60 dB has the probability of awakening 1 to 3 percent of the general population.

The second range is SEL 60-80 dB. Within this range, the literature indicates that approximately 3-10 percent of the population can be expected to be awakened by a single event.

The third and final range is contained by indoor SEL values of 80 dB and greater where 10 percent or more of the population on average experience sleep disturbance when exposed to an individual aircraft event. Note that these ranges have not been chosen to be the sole indicators of all awakenings. Rather, they have been chosen as the best available indicators of the overall effects on sleep throughout the residential areas subject to those exposure levels. It is certainly possible to evaluate many more thresholds and place that information in a report appendix. In addition, it is important to understand that even if only one event per night were to occur at any of these levels, the same people are not necessarily affected each night. While the same percentage of the community may be disturbed on a daily basis, they are not always the same people. Thus, the total number of persons who experience sleep disturbance over time may be substantially greater than the single day number.

While there is no widely accepted sleep disturbance criterion, the outdoor NA90(1) has been used in several studies to define locations at which one event above an exterior SEL of 90 dB will occur during an average night. The indoor SEL would be approximately 25 dB lower (at 65 dB) with doors and windows closed, and approximately 15 dB lower (at 75 dB) with doors or windows open. At this level of exposure, the probability of sleep disturbance would be about 5 percent and 8 percent of the exposed population respectively, according to the FICAN recommended curve.

FICAN recommended in December 2008 use of the July 2008 American National Standard Institute's and Acoustical Society of America's method discussed in this Guide to predict the percent of an exposed population that may be awakened from multiple noise events at least once during a night-long period. See Appendix A, Subsection A.1.4.3. for more information on the ANSI Standard.

Table 5-6. Number-of-Events Above Threshold SEL (Events per 8-hour night)

Location (DNL)	Threshold SEL								
	60 dB	65 dB	70 dB	75 dB	80 dB	85 dB	90 dB	95 dB	100 dB
Point 1 (61)	398	299	198	116	50	14	4	1	0
Point 2 (63)	373	285	200	156	86	22	5	1	0
Point 3 (62)	413	305	198	99	42	14	3	1	0
Point 4 (64)	387	284	206	168	105	47	15	3	0
Point 5 (63)	398	292	204	122	55	19	5	1	0
Point 6 (65)	433	307	171	74	33	15	5	1	0

Only one proposed location, Point 6, has a DNL of 65 dB or greater; all other points have DNL less than 65 dB. Thus, the NA metric provides important additional detail about the noise exposure at each point. On average, at least 1 event per night exceeding SEL 95 dB would occur at five of the locations, with a corresponding probability of awakening of about 6 percent, assuming the typical outdoor to indoor NLR of 25 dB. The NA90(1) criterion would be exceeded at all 6 locations.

If the sleeping quarters were designed with a Noise Level Reduction (NLR) of 30 dB, the outdoor criterion can be increased from NA90(1) to NA95(1) to achieve an interior SEL of 65 dB, which would probably be acceptable at five of the six locations. Increasing the NLR in the sleeping quarters even further to 35 dB would be sufficient to preclude anything but minor sleep disturbance.

5.3.4 Other Noise Effects

Section 3 and Appendix A of this report provide a review of the range of global research studies on the psychological and physiological effects of aircraft noise. This section provides information that relates supplemental noise metrics to annoyance, speech interference, and sleep disturbance. On any given project, the public may ask about the other noise effects. Table 5-7 summarizes the state of knowledge.

Table 5-7. Other Noise Effects and State of Knowledge

Effect	State of Knowledge
Children's learning	The findings are inconclusive and do not point definitively toward a sound level or threshold that must be met in order to ensure an optimal (or even acceptable) learning environment. Researchers did find that during aircraft noise events with a maximum indoor noise level of 50 dB or less, word intelligibility was 90 percent throughout the classroom. (see Appendix A for further discussion of noise impacts on children's learning)
Performance and Mental Activity	Provided aircraft noise does not result in interference with communication or does not pose a risk for hearing impairment, then the potential for negative effects on task performance and mental activities are expected to be minimal to none.
Hearing Loss	There is little possibility of hearing loss below a day-night average sound level of 75 dB, and this level is extremely conservative. OSHA Workplace Noise Standards permit exposure to 90 dB for 8 hours per day without hearing protection.
Non-auditory Health Effects (Stress, Hypertension, Cardiovascular disease, Mortality, and Birth defects)	There is no clear scientific evidence to relate any noise threshold levels and durations with any clinical non-auditory disease.

5.3.5 Local Land-Use Controls

Including supplemental analyses with alternative metrics in the noise analysis sections of NEPA documents may be useful in providing a clearer or more complete presentation of aviation noise exposure. Inclusion of supplemental noise analysis in AICUZ, IONMP, and JLUS studies improves the potential of building a strong working relationship with nearby communities and local officials concerned about aircraft noise exposure.

One of the main objectives of these programs is to improve and preserve compatibility between the military installation and the adjacent communities. Disclosure of noise exposure only out to the DNL 65 dB contour may communicate to these adjacent communities that unrestricted noise sensitive development is invited up to that line on the map. All too often, the DNL 65 dB contour rapidly grows with a sudden change in the aircraft fleet mix or number of operations, such as the Air National Guard replacement of A-10 aircraft with F-15 aircraft at the Westfield, MA, airbase. Where unrestricted noise sensitive development has occurred up to the DNL 65 dB contour, any increase in the size of that contour increases the number of non-compatible uses.

By showing noise exposure beyond the DNL 65 contour with gradual color shading of DNL exposure over the study area (see Subsection 5.1) and also with supplemental metrics, DoD officials will have additional information to present to local officials to encourage them to create and preserve a buffer area around the DNL 65 contour where noise sensitive development is permitted, but not without some restrictions. These local land use-zoning restrictions might merely be in the form of noise disclosure or they might also require extra sound insulation and/or noise easements for new noise sensitive development in the buffer area.

A good example of recommending a sufficient buffer zone to accommodate future mission changes is the recommendations in the JLUS for NAS/JRB Willow Grove. In that case, the updated AICUZ showed a dramatic decrease in the noise contours because of a change to quieter aircraft. The JLUS recommended to Horsham Township, PA that they adopt a zoning requirement for extra sound insulation for new noise sensitive development in the DNL 60 – 65 dB contours and to disclosure of noise, accident potential and other impacts from the facility over the entire study area selected for the JLUS, which included the much larger previous AICUZ noise contours. The supporting justification stated that, though unforeseen at the present time, the facility could support significant increases in operations by many aircraft types, and potentially, future noise contours could increase to a size even greater than those shown in the previous AICUZ. An additional justification for the large disclosure (buffer) area is the fact that historically six of the 13 aircraft accidents at the facility occurred outside the APZs. The DoD Office of Economic Adjustment has promoted adoption of similar concepts and recommendations in future Joint Land Use Studies.

Another good example of this proactive approach is the study of nighttime noise undertaken by the City of High Point, NC summarized in Appendix C, Section 10. High Point is a few miles south of the Piedmont Triad Airport, which is designated to become the east coast hub for FedEx. The project EIS presented the DNL 65 dB contour that will result from full operation of the hub with over 120 new night operations. While most local officials accept the results without question and plan their land use actions based on whatever noise exposure is provided in an EA or EIS, High Point officials were concerned that the DNL 65 dB contour might not provide sufficient protection from the future night noise impacts. They performed a Number-of-Events analysis tied to the latest sleep disturbance studies and as a result implemented a more stringent zoning noise overlay ordinance than would have resulted from reliance on the future DNL 65 dB contour alone. Not only does the Highpoint ordinance preclude new noise sensitive development beyond the future DNL 65 dB contour, but includes disclosure and extra sound insulation restrictions on new development in a buffer area beyond their no-build zone.

DoD can encourage and facilitate local jurisdictions to take similar proactive actions to prevent future encroachment of non-compatible development on military installations by including noise exposure information in ACUIZ and JLUS documents at least out to the logical boundaries of a buffer area even beyond their future DNL 65 dB noise contour. In addition, the disclosure of the overall noise exposure through the use of the supplemental analysis tools in a NEPA study sets the tone for the local officials to better understand the expected results of the DoD action and to begin a proactive approach that best considers their individual community's approach to local land use controls. Conducting a complete noise analysis over a large study area using alternative metrics to supplement DNL analysis can help local officials conclude that it is in the best interest of the community to preclude non-compatible encroachment on the military installations.

6.0 Summary of Metric Usage

6.1 Introduction

There are a few basic considerations and questions that need to be evaluated before deciding which tools and metrics are most appropriate for any given project or noise study. Although there are similarities among projects, each project is somewhat unique. The toughest challenge comes in deciding which metrics and tools will contribute the greatest understanding of noise exposure, ensure consistent application agency-wide and extract the most value for the project. This expertise will be built over time as the DoD experience with these metrics and tools expands.

A strong word of caution: experience in the civilian airport world has shown that simpler is better. Most project stakeholders and the general public do not want to wade through pages of technical data. They respond most positively and proceed more quickly toward project completion when the most straightforward noise exposure data is presented in the main text and the detailed tabular data in an appendix for those wishing to see the complete technical information. For instance, if the noise effects in an educational setting are of primary concern, the analysis should focus on the one sound level threshold that best equates to speech interference and leave more-detailed information on other effects or thresholds to an appendix to the analysis.

It is important for the analyst or planner to place themselves in the position of a project stakeholder or interested citizen. Regardless of whether the person in question is a planning board member, an average citizen, or the base commander, it is quite possible that they have little or no technical training. They really want to understand their noise environment in the simplest terms so they can better understand the expected outcome, including:

- Flight Tracks - Where do the aircraft fly now and where will they fly in the future?
- Time of Day - When do events occur? Are there variations between day, night, evening, or are there typical periods of higher operations?
- Noise exposure beyond the DNL contours - What is the noise exposure beyond the DNL 65 dB contour line where noise exposure levels are in the moderate range?
- Number of Events - How many aircraft events are there today and how many are likely to occur in the future?
- Aircraft Noise Levels – What are the most frequent and maximum noise levels for the events today and will they change in the future?
- Wrapping it all up – Do we understand what this all means on a day-to-day basis?

6.2 Operations Data Considerations

Many military facilities have distinct seasonal, daily, or mission-specific (surge) fluctuations in their annual operations schedules. Unlike their civilian airport counterparts that maintain relatively constant operation schedules, military operations can vary significantly over the course of the year due to deployments, detachments, or other training events. A simple example is a joint-use air base where general aviation activity dominates the weekday schedule, but the weekends are dominated by air reserve activity. More common, however, are overseas or carrier deployments, and detachments for training purposes that result in squadrons leaving their home base for extended periods of time. Thus the DNL for a given day, week, month or season may vary greatly with the annual-average day (AAD) DNL contour.

DoDs' noise policy is moving towards considering operations levels in terms of AAD in the development of DNL contours. Calculation of supplemental analysis of operations for both the AAD and other representative time periods will enable the DoD decision-makers and the other stakeholders to better understand the changes that will result from their decision, particularly when operation levels on a daily basis vary widely from the AAD. The need to better understand changes in noise exposure is greater for contentious projects where significant changes in exposure and/or significant public reaction are expected. Project officials should consider what specific supplemental analysis will facilitate better understanding of the changes in noise exposure that will result from wide variations in operations and runway or flight track usage; and also if DNL contours for some time period other than the AAD are appropriate to supplement the AAD DNL contours.

There are several considerations for this type of analysis:

- Are there seasonal or weekday/weekend operational fluctuations, and are the existing and future projections (unclassified) data available?
- Is the data available to evaluate the operations over the course of a school day?
- Are there significant nighttime flights to consider a separate nighttime analysis?
- Does the facility experience significant changes in runway use over the course of the year? If so, some consideration should be given to developing separate noise modeling efforts for each operational mode to supplement the AAD and average runway utilization.
- Is the facility expected to have changes in mission or aircraft over the course of the year or for future years?
- Are there additional relevant considerations not listed above?

Ultimately the supplemental analysis needs to specifically address the recurring public response to traditional AAD analysis with the DNL metric; i.e., "I don't hear average sound levels, I hear individual airplanes flying over my house."

6.3 Selection of Metrics

The primary objective of this Guide is to encourage planners to consider the application of supplemental tools both as a means of taking more proactive measures to work with local communities and to more effectively address encroachment by non-compatible land uses. Simply disclosing a set of DNL contours is usually not adequate to convey the total picture. Planners first have to decide on what applications (i.e., DOD noise policy, annoyance, speech interference, sleep disturbance, etc) are the most important to their needs for a particular analysis. Having defined the application, the planner can then select the most appropriate metric from the summary information in Table 6-1.

Table 6-1. Guideline Values for Land-Use Studies (Outdoor Levels)

Application	Metric	Unit	Time Period	Recommended Outdoor Unit Values*
Policy Metric	DNL**	dB	24 Hrs	60, 65, 70, 75, 80 dB
Annoyance	DNL	dB	24 Hrs	60, 65, 70, 75 dB
Aircraft Comparison	L_{max}	dB	None	75, 80, 85 dB
	SEL	dB	Single Event	85, 90, 95 dB
Variation/Comparison of Average Levels	L_{eq}	dB	1hr, 15hr Day, 9hr Night	65 dB
Speech Interference	NA (L_{max})	Number Of Events	15hr Day	15, 30, 45, 60 events (Above 75 dB)
Sleep Disturbance	NA (SEL)	Number Of Events	9hr Night	1, 3, 5, 9, 18, 27events (Above 90 dB)
Classroom Speech Interference	L_{eq}	dB	School Hours (8hr)	60 dB (for scoping)
	NA (L_{max})	Number Of Events	School Hours (8hr)	8,16,24,32 events (Above 75 dB)
	TA	Minutes	School Hours (8hr)	2, 4, 6, 8 minutes (Above 75 dB)

*Unit values for plotting contours on study area map.

The guideline values in Table 6-1 assume an annual average day condition, but could also be applied for a peak operations period or some other condition. Note that the suggested time period for each metric in the table varies. If a greater range of values is necessary to fully communicate exposure levels to all stakeholders in the selected study area, presenting results in tabular form or on multiple graphics is recommended. In California, CNEL would be used instead of DNL with time periods of 12 hours for day and 3 hours for evening.

The applications listed in the table are further explained below:

Policy Metric

DoD policy requires analysis of aviation noise impacts in the vicinity of airfields to include DNL contours. Showing contours in 5 dB increments from 65 dB to 80 dB is required, but additional contours (e.g., 60 dB) may be provided to fully communicate exposure in certain circumstances if local conditions warrant discussion of these noise levels or where significant noise complaints have been received in areas exposed to DNL less than 65 dB.

Annoyance

DNL is the best available metric to relate aircraft noise to long term annoyance. Therefore, DNL contours in 5 dB increments from 60 dB to 75 dB are generally sufficient to communicate the noise exposure levels associated with the community annoyance. It should be noted that the dose-response relationship between DNL and annoyance varies over a wide range and is extremely location dependent. **Thus it is inadvisable to use the average annoyance curve to predict the specific number or percentage of the local exposed population who are expected to be highly annoyed by aircraft operations at a given DNL**. As described in Subsection 5.3.1, the preferred approach is to calculate the likely **increase** in the percentage of the population who will be highly annoyed at a given

DNL level. The relationship between noise and community annoyance is also addressed in greater detail in Appendix A, Subsection A.1.1.

Aircraft Comparison

Comparison of aircraft single event noise levels is useful in communicating the difference in noise exposure between aircraft types, particularly when a new aircraft type is being introduced to an airfield. Noise exposure comparisons showing single event L_{max} footprints (contours) at 75, 80 and 85 dB are generally sufficient to identify locations around the airfield where single event noise levels may be intrusive, such as in classrooms. If nighttime operations are a concern, a comparison using the SEL metric should be considered because sleep disturbance predictions are correlated to the SEL metric. SEL contours are in the range 5 to 10 dB larger than the L_{max} contours for a given aircraft at the same numeric dB level. For this reason, the recommended levels for plotting SEL contours are 85, 90 and 95 for most aircraft. Higher levels may be necessary to fully communicate the exposure of the highest performance aircraft.

Variation/Comparison of Average Levels

The annual average day DNL cannot show the variations in average noise level between peak operation times and times with fewer operations. When operations vary considerably from the average, calculating the average noise level of operations occurring in various time periods using the L_{eq} metric is recommended to communicate the average noise level for operations during selected periods. An appropriate time period, such as the peak operation day, peak hour of the day, or daytime vs. nighttime should be selected. Plotting these time average levels contours at L_{eq} 65 dB is recommended. Plotting contours at additional levels is recommended if necessary to fully communicate the variations in exposure between selected time periods.

Speech Interference

To communicate how often speech interference may occur during the 15 hour daytime period for the average annual day, busy day, or other selected time period, the $NA75L_{max}$ metric is recommended. Plotting contours for 15, 30, 45, and 60 events at or above 75 dB reflects an average of 1-4 events per hour at or above a level that many people find intrusive to communication and other activities in the outdoor environment. The 75 dB threshold also reflects indoor noise levels recommended by EPA, and includes the effect of a 25 dB building noise reduction with windows closed. Presenting NA results for POIs in a study area in tabular form over a range of threshold levels is effective in communicating how often noise events may be intrusive at various POIs in a study area. This method is particularly useful to compare the noise exposure changes that will occur among various operational scenarios.

Sleep Disturbance

Prediction of sleep disturbance is advisable when nighttime operations are a concern. Sleep disturbance is not just a factor of how loud, but also the duration of each noise event. Thus, sleep disturbance is best reflected with the SEL metric, which captures the total energy of each noise event no matter how loud and how long or short the duration. Similar to the speech interference discussion above, displaying the NA contours of 1, 3, 5, 9, 18, and 27 events correspond to 1, 3, and 5 events per night and 1, 2, and 3 events per hour, respectively, over the course of the nighttime period (2200-0659).

The American National Standards Institute (ANSI) and the Acoustical Society of America (ASA) have jointly approved a standard, ANSI/ASA S12.9-2008/Part 6, to predict awakenings associated with outdoor noise events heard in the home. The standard suggests methods for calculating the probability of awakening at least once to the sound from distributions of single noise events. The following table relates the recommended NA90 contour levels with the probability of each person exposed awakening at least once as calculated by the ANSI/ASA Standard Formula where all events are at SEL 90 dB.

Probability of Awakening at Least Once From Multiple Events at SEL 90 dB

NA90SEL	Windows Closed*	Windows Open**
1	1%	2%
3	4%	6%
5	7%	10%
9	12%	18%
18	22%	33%
27	32%	45%

*' Windows Closed' assumes that there is a 25 dB noise level reduction (NLR) between the outdoors and indoors, e.g., 90 SEL outdoors is 65 SEL indoors.

**' Windows Open' assumes that there is a 15 dB NLR between the outdoors and indoors, e.g. 90 SEL outdoors is 75 SEL indoors).

The derivation of these predications of awakenings is explained in Appendix A, Subsection A.1.4.3.

Classroom Speech Interference

If the study area defined during the scoping phase includes schools and operations during school day hours can be segregated out from the total day operations counts, then a school-day period (typically 8 hours) should be used in place of a 24-hour average to assess classroom speech interference. The next step is to identify the portion of the study area where aircraft noise could be a problem in classrooms.

The ANSI S12.60-2002 Standard recommends for the most common size of classroom a maximum one-hour-average A-weighted background noise level of 35 dB for steady noise, and 40 dB for unsteady noise from transportation sources. For this scoping task, the more conservative value of 35 dB is selected. In a windows closed school environment with an average noise level reduction (NLR) of 25 dB, 35 dB in the classroom is equivalent to 60 dB outdoors. Thus, the 60 L_{eq} contour provides a first indication that aircraft noise might be a problem because the classroom noise levels could exceed the 35 dB background noise level. Once the schools have been identified, the next step is to assess the magnitude of classroom interference using NA75.

The NA75L_{max} (outdoor level) is recommended because in a 'windows closed' school environment with an average NLR of 25 dB, the resulting 50 dB level is the widely accepted single event criteria threshold level for classroom speech interference. The recommendation of producing NA75 for events in multiples of 8 events (i.e., 8, 16, 24, 32) per 8-hour time period is given to simulate the effects of multiple aircraft events per hour (1, 2, 3, and 4 or more).

If classroom speech interference is of particular concern, additional analysis can be conducted to supplement the NA analysis with a TA analysis. TA analysis would show the number of minutes on average that class time is interrupted by the aircraft intrusions.

By computing the number of minutes in the time period selected for the NA analysis using the TA metric, the noise exposure communicated includes not only how many events occur, but the total time they will be above 75 dB (corresponding to the NA analysis threshold discussed above) or other threshold level. While NA analysis alone is effective in communicating noise exposure, TA results without NA results are much less effective. NA and TA results can be presented in contour format and in more detail in tabular format. If TA is presented in contour format, then the increments in minutes should be selected based on operational levels. The more operations during the selected time period, the larger the increments can be to best show the amount of time noise will exceed the selected threshold level. If operations are few, then one-minute increments should be used.

Presenting NA and TA results for selected geographic locations in a study area in tabular form over a range of threshold levels is highly effective in communicating the number and duration of noise events that may be intrusive at each school located in a study area. This method is particularly useful to compare and show the noise exposure changes that will occur among various operational scenarios, and it highlights the smaller changes that are difficult to communicate by comparing DNL contours alone on a background map. NA and TA break the total sound energy that comprises DNL into its component parts, and these supplemental metric results are much easier for the average person to comprehend than DNL. When these results show that the number (NA) and total time (TA) of intrusive noise events in the classroom is low, public acceptance of the proposed action is more likely.

Presenting Noise Effects

Separately, in the text of the study documentation, but not on the contours themselves, the contour values can be ascribed to average effects (in terms of annoyance, speech interference, percentage of awakenings), with the clear statement that these are averages of data that may or may not accurately reflect the effects in the study area.

One of the stated goals of this Guide is to encourage local officials to consider the application of supplemental tools as a means of taking proactive measures to address encroachment. However, simply disclosing a set of DNL contours, NA contours that relate to sleep disturbance, and NA contours that relate to classroom speech effects may not be adequate. A more complete indication of the total effects can be provided by combining all the effects into a blended set of contours.

Figures 6-1 through 6-4 presents an example from one of the case studies in Appendix C. The four figures show how the annual average noise contours (presented in terms of the Canadian Noise Exposure Forecast, or NEF, metric – see the footnote on this page[1]), daytime NA contours, and nighttime NA contours can be combined to produce a blended set of contours. This forms the basis for discussions of what the local officials could consider as the best overall basis for determining the appropriate zoning.

The reader is encouraged to refer to the summary in Appendix C, Section 13, regarding the City of Richmond, BC and how Richmond made use of supplemental tools in this fashion. It is an excellent example of how an airport has chosen to recommend to a local jurisdiction a protection mechanism for its citizens.

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[1] NEF is similar in concept to DNL in that it represents an annual average sound level taking into account the number of daytime and nighttime flights, and applying a 12 dB weighting to nighttime events. Noise levels for individual events are expressed in terms of the Effective Perceived Noise Level, or EPNL. Numerically, NEF is approximately equal TO DNL – 35 dB.

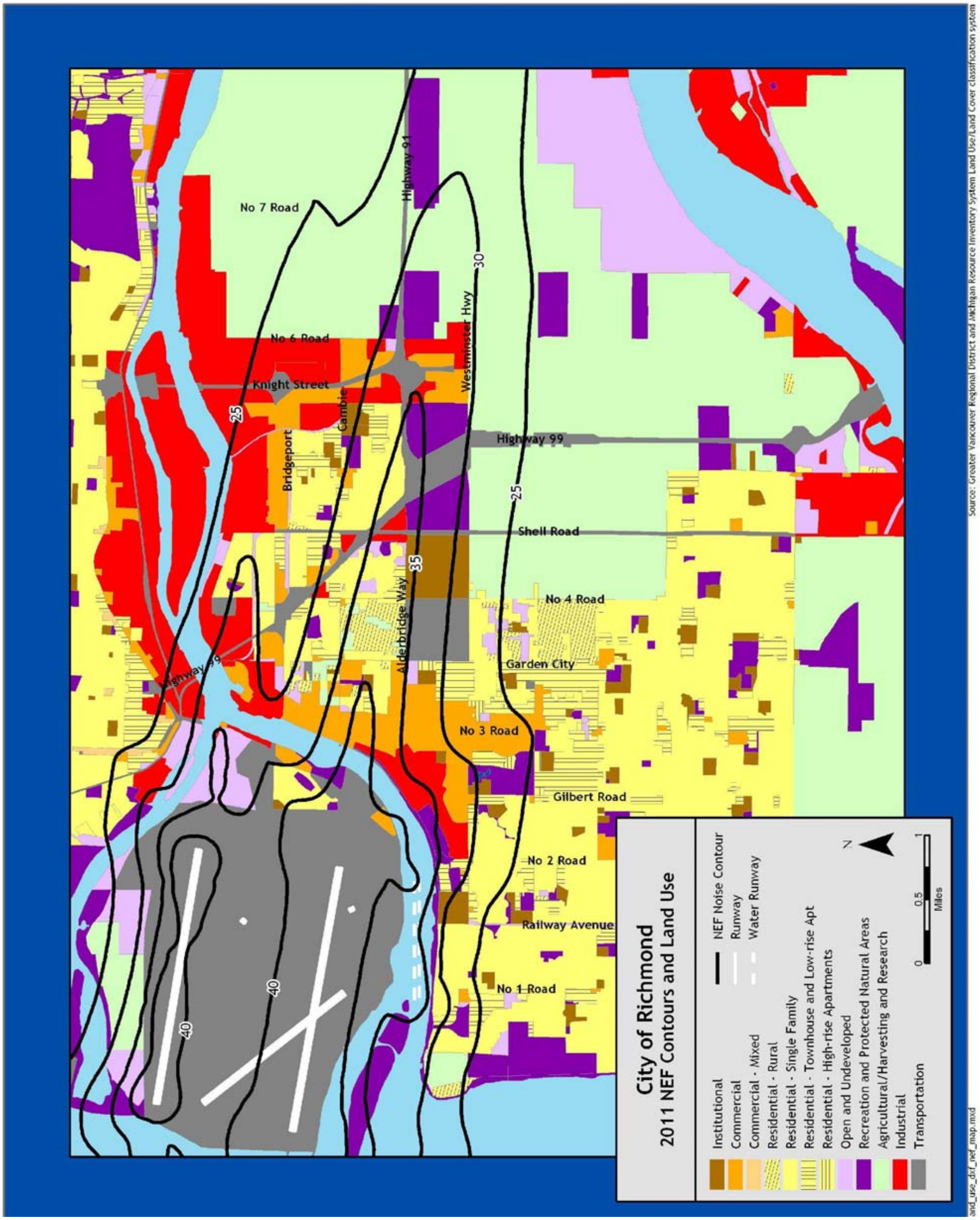
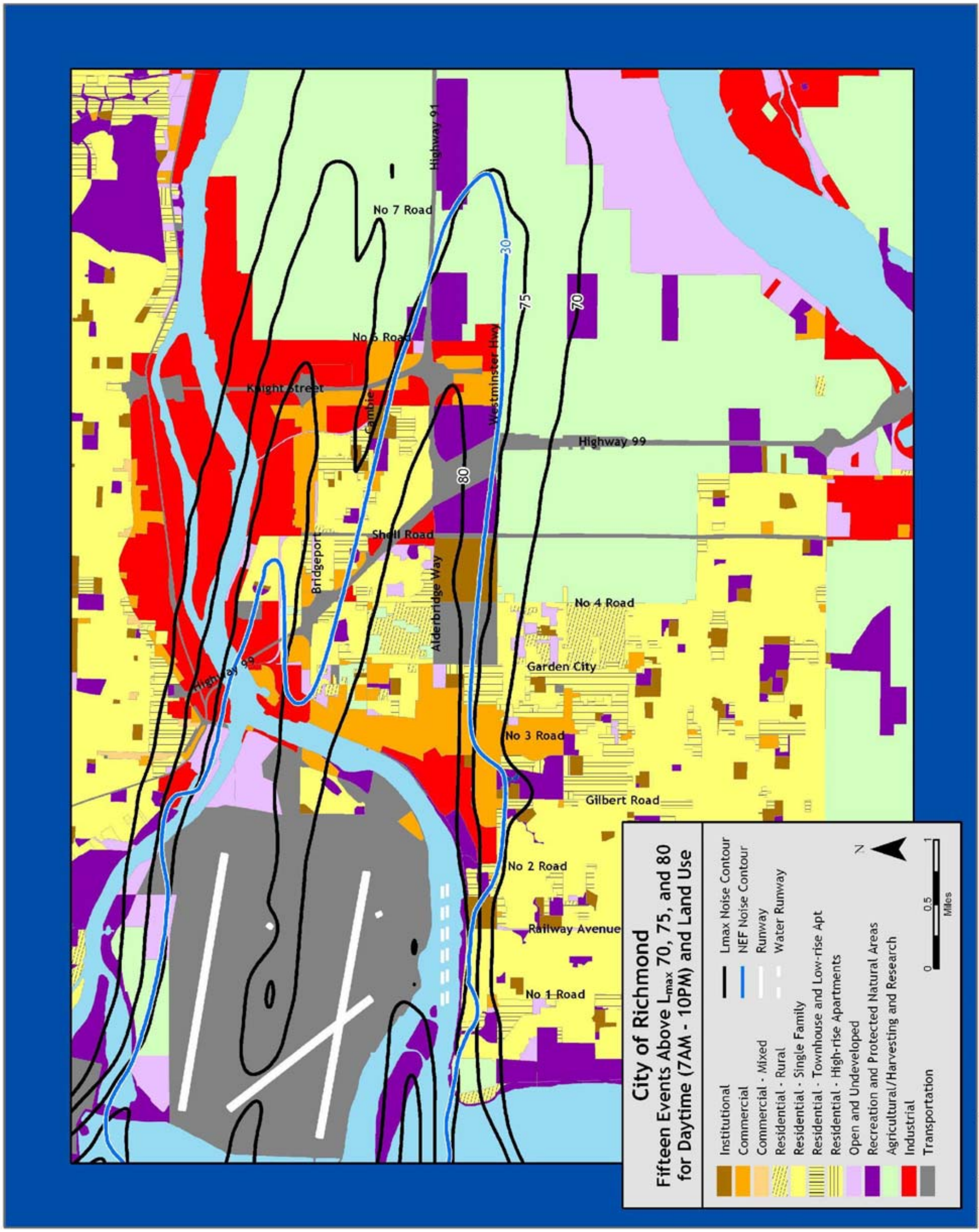


Figure 6-1. Example of NEF Contours



Source: Greater Vancouver Regional District and Michigan Resource Inventory System Land Use/Land Cover classification system

Land_use_nalmax_map.mxd

Figure 6-2. Example of Daytime NA Contours (Classroom Speech Effects)

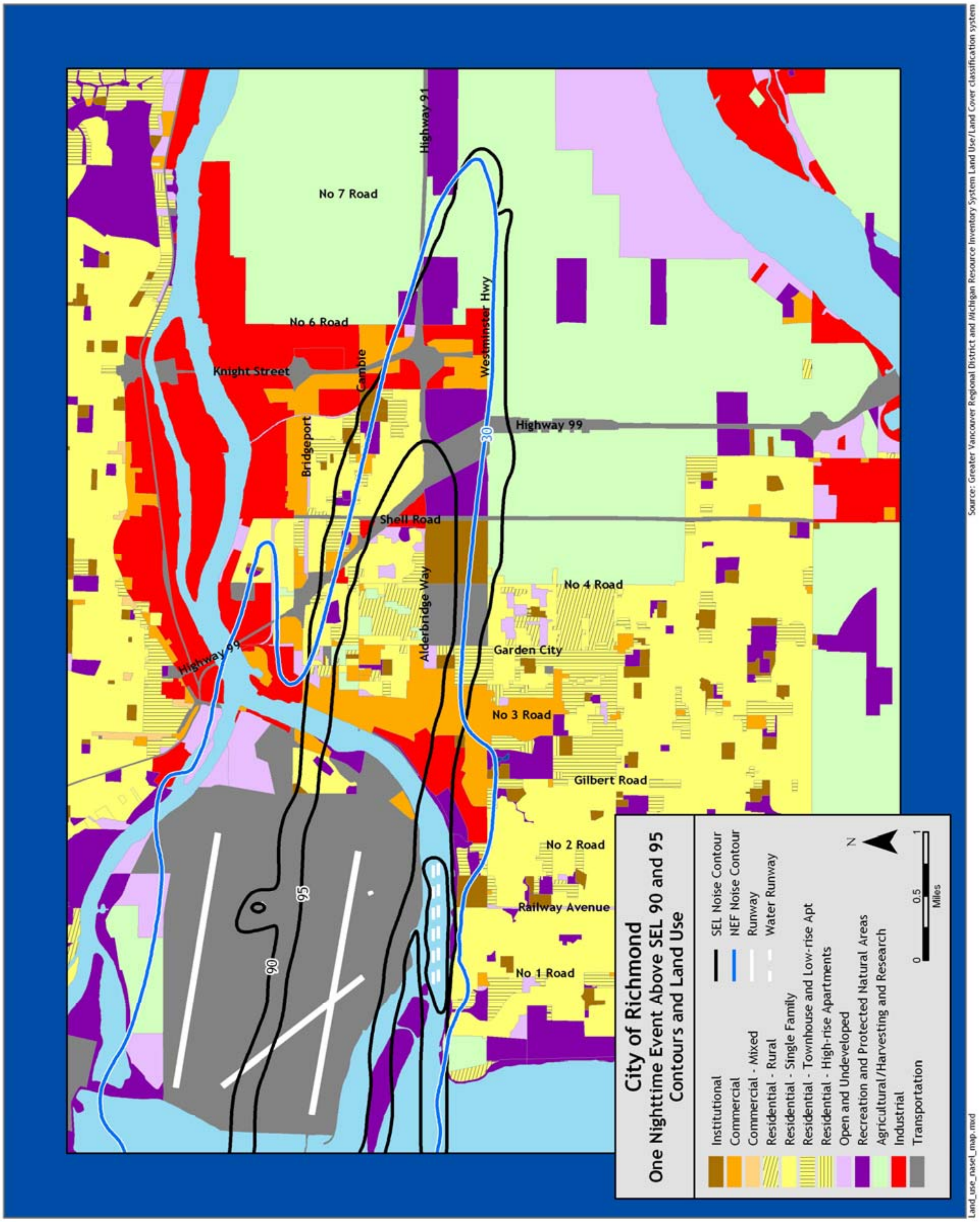
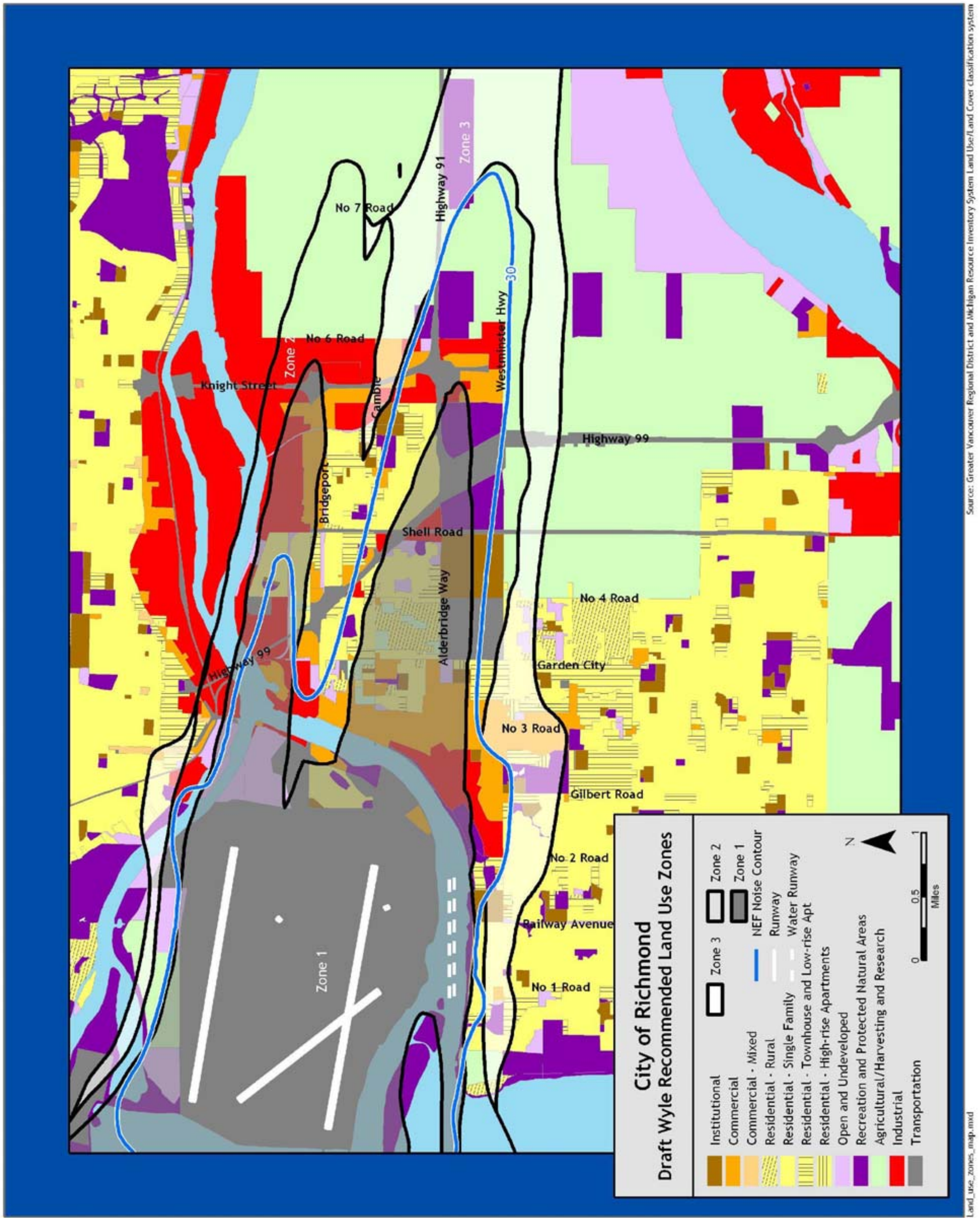


Figure 6-3. Example of Nighttime NA Contours (Residential Sleep Effects)



Source: Greater Vancouver Regional District and Michigan Resource Inventory System Land Use/Land Cover classification system

Land_use_zones_map.mxd

Figure 6-4. Example of Blended Contours

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APPENDIX A

Effects of Noise on People – Review of Scientific Research, Policy, and Guidelines

APPENDIX A
Effects of Noise on People – Review of Scientific Research, Policy, and Guidelines

Within the context of the U.S. Federal noise control regulations and guidance, the term *health* has been defined, not simply by the absence of disease, but as the total psychological and physiological well-being of the community. The term *public health* indicates that the common interests of society must be taken into account when evaluating potential noise effects. In other words, noise effects must be related to the long-term, cumulative effects of the population as a whole, not the isolated, occasional impacts on individuals.

The reaction of people to a given noise environment is extraordinarily complex. This is particularly evident when trying to evaluate the potential health effects of people exposed to aircraft noise. One reason for this is the intermittent nature and the character of aircraft noise, in which noise levels fluctuates significantly from high to low over time. Another important element for this is the complex psychological and physiological reaction of people to the actual noise environment, as well as their attitude toward the source of the noise. Further exacerbating this complex issue is the possibility that short-term community reaction can be different than the long-term community reaction.

In an effort to better understand people's response to noise, the scientific-medical community has divided the noise effects on people into two general categories of responses. The first of these, psychological response, refers to behavioral reactions that are indicators of the population's "well-being"— essentially, people's psychological reaction to their noise environment and their reaction to interference with their various day-to-day activities. The primary examples are the potential effects on long-term community annoyance, speech interference (includes effects in the home, school, churches, and auditoria), sleep disturbance (home), effects on children's learning (school), and interference with work performance. The second type of indicator is physiological response—essentially, effects on the human body's systems. The primary example of this is noise-induced hearing loss, although other medical health effects such as cardiovascular disease have been postulated by various researchers and communities over the years.

For each of these indicators that attempt to describe the long-term community reaction to noise, the scientific community has spent considerable effort since the mid-1950s researching the noise metrics and associated noise levels that best relate to community response. This Appendix presents a review of the range of global research studies that have attempted to address the array of potential effects, with particular emphasis placed on those studies that have served as guidance for U.S. noise policy. Note that this review is intended only as a guideline for better understanding this complex issue. The reader is encouraged refer to the references for more detailed study.

A.1 Psychological Effects

A.1.1 Annoyance

The primary effect of aircraft noise on exposed communities is one of long-term annoyance. Noise annoyance has been defined by the Environmental Protection Agency (EPA)[1] as any negative subjective reaction on the part of an individual or group. The scientific community adopted the use of long-term annoyance as a primary indicator of community response because it attempts to account for all negative aspects of effects from noise, e.g., increased annoyance due to being awakened the previous night by aircraft and interference with everyday conversation.

Annoyance is a psycho-social response to an auditory experience, which has its roots in the unpleasantness of noise, the disruption by noise of ongoing activities, and/or the meaning or message carried by a given noise[1]. Numerous laboratory studies and field surveys have been conducted to measure annoyance and to account for a number of the variables, which are dependent on each person's individual circumstances and preferences. Laboratory studies of individual response to noise have helped isolate a number of the factors contributing to annoyance, such as the intensity level and spectral characteristics of the noise, duration, the presence of impulses, pitch, information content, and the degree of interference with activity. Social surveys of community response to noise have allowed the development of general dose-response relationships that can be used to estimate the proportion of people who will be highly annoyed by a given noise level. Results of these studies have been the foundation for land use criteria established to define areas of compatible land use.

The results of the social surveys have proven to be fairly uniform and consistent, but have shown considerable scatter. The most useful metric for assessing people's responses to noise impacts is the percentage of the exposed population expected to be "highly annoyed." A wide variety of responses have been used to determine intrusiveness of noise and disturbances of speech, sleep, audio/video entertainment, and outdoor living. The concept of "percent highly annoyed" has provided the most consistent response of a community to a particular noise environment. In annoyance surveys, people are asked to rate their annoyance about noise on a numerical scale. For example on a five point scale, the descriptors are usually "not annoyed", "slightly annoyed", "moderately annoyed," "very annoyed" and "extremely annoyed." Schultz found a reliable relationship between the percentage of people choosing the top two descriptors ("very annoyed" and "extremely annoyed" which are combined within the term "highly annoyed") and residential noise exposure[2]. In his synthesis of several different social surveys that employed different numerical response scales, Schultz defined "highly annoyed" respondents as those respondents whose self-described annoyance fell within the upper 28% of the response scale. Schultz's definition of "percent highly annoyed" (%HA) became the touchstone of Federal policy on environmental noise. The response is remarkably complex, and when considered on an individual basis, widely varies for any given noise level[3]. However, the various sociological surveys that were conducted among residents of the U.S. and other developed countries were designed to reflect long-term community annoyance, not the individual response to individual noise events.

Daily average sound levels are typically used for the evaluation of community noise effects (i.e., long-term annoyance), particularly aircraft noise effects. In general, scientific studies and social surveys have found a correlation between the percentages of groups of people highly annoyed and the level of average noise exposure measured in DNL[4,5]. The classic analysis that relied on this correlation is Schultz's original 1978 study, whose results are shown in Figure A-1. This figure is commonly referred to as the Schultz curve. It represents the synthesis of a large number of social surveys that relates the long-term community response to various types of noise sources (161 data points in all), measured using the Day-Night Average Sound Level (DNL) metric.

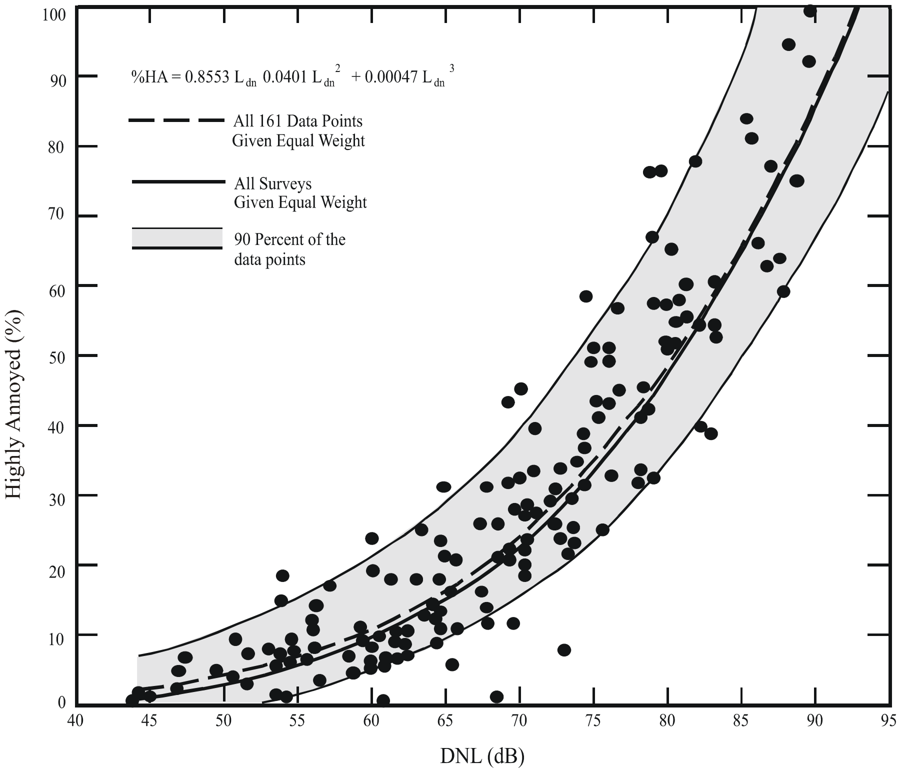

Figure A-1. Community Surveys of Noise Annoyance

An updated study of the original Schultz study that was based on the analysis of over 400 data points collected through 1989 essentially reaffirmed this relationship[5]. Figure A-2 shows an updated form of the curve fit[6] in comparison with the original Schultz curve. The updated fit, which does not differ substantially from the original, is the current preferred form in the U.S. In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. However, the correlation coefficients for the annoyance of individuals are relatively low, on the order of 0.5 or less. This is not surprising, considering the varying personal factors that influence the manner in which individuals react to noise.

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To understand annoyance it is also necessary to appreciate the compexity of the factors that influence the relationship between aircraft noise and communitiy reaction including:

- Reactions to indivudal transportation sources (air, road, and rail);
- Habituation;
- Background noise einvrionment (urban vs. rural);
- Non-acoustic factors; and
- Community Attitudes and Experience.

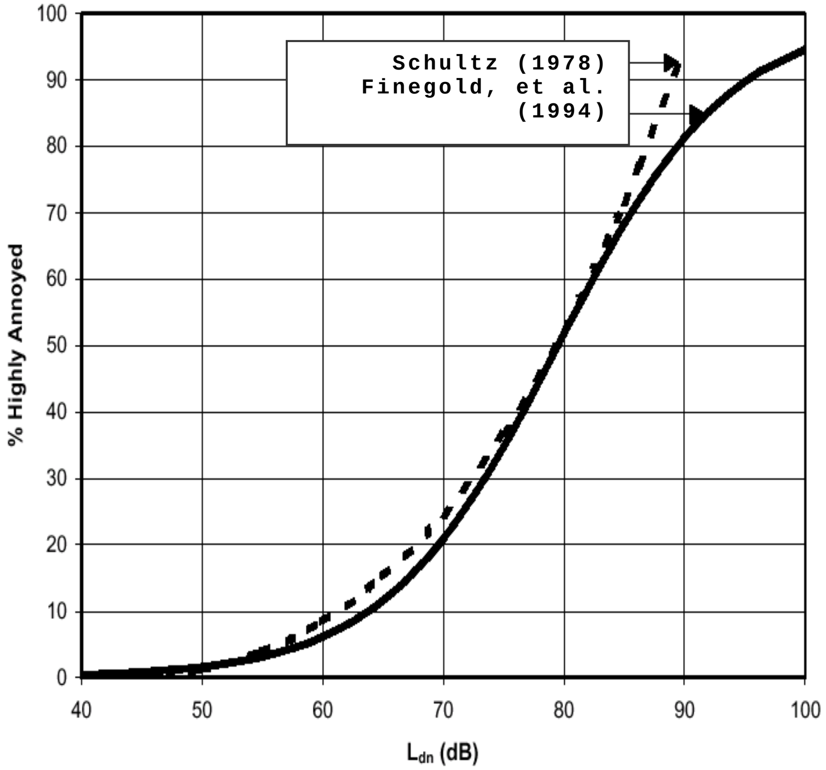


Figure A-2. Response of Communities to Noise; Comparison of Original (Schultz, 1978) and Current (Finegold, et al. 1994) Curve Fits

Reactions to Individual Transportation Sources

The original Schultz curve and the subsequent updates assumed that the relationship between percent highly annoyed and DNL was independent of the noise source. This was an important element, in that it allowed Schultz to obtain some consensus among the various social surveys from the 1960s and 1970s that were synthesized in the analysis. In essence, the Schultz curve assumes that the effects of long-term annoyance on the general population are the same, regardless of whether the noise source is road, rail, or aircraft. In the years after the classical Schultz analysis, additional social surveys have been conducted to better understand the annoyance effects of various transportation sources.

Miedema & Vos[7] present synthesis curves for the relationship between DNL and percentage "Annoyed" and percentage "Highly Annoyed" for three transportation noise sources. Separate, non-identical curves were found for aircraft, road traffic, and railway noise. Table A-1 illustrates that, for a DNL of 65 dB, the percent of the people forecasted to be Highly Annoyed is 28% for air traffic, 18% for road traffic, and 11% for railroad traffic. For an outdoor DNL of 55 dB, the percentage highly annoyed would be close to 12% if the noise is generated by aircraft operations, but only 7% and 4% respectively if the noise is generated by road or rail traffic. Comparing the levels on Miedema's curve[8] to those on the Schultz curve indicates that the percentage of people highly annoyed by aircraft noise may be higher than previously thought.

Table A-1. Miedema's Annoyance Curves – Percent Highly Annoyed for Different Transportation Noise Sources

DNL	Percent Highly Annoyed (%HA)			
	Miedema			Schultz Combined
	Air	Road	Rail	
55	12	7	4	3
60	19	12	7	6
65	28	18	11	12
70	37	29	16	22
75	48	40	22	36

(Source: Miedema, JASA 1998)

As noted by WHO[8], even though aircraft noise seems to produce a stronger annoyance response than road traffic, caution should be exercised when interpreting synthesized data from different studies. WHO noted that five major parameters should be randomly distributed for the analyses to be valid: personal, demographic, and lifestyle factors, as well as the duration of noise exposure and the population experience with noise. The Federal Interagency Committee on Noise (FICON)[3] found that the updated "Schultz Curve" remains the best available source of empirical dosage effect information to predict community response to transportation noise without any segregation by transportation source; a position still held by the Federal agencies on the Federal Interagency Committee on Aircraft Noise (FICAN). But, DoD and FICAN recogognize the need for further research to investigate the differences in perceptions of aircraft noise, ground transportation noise (highways and railroads), and general background noise.

Habituation

A dictionary definition of habituation is "the gradual decline of a response to a stimulus resulting from repeated exposure to the stimulus." For example, a novel sound in one's environment, such as a new ring tone, may initially draw attention or even become distracting. After becoming accustomed to this sound, less attention is paid to the noise and the degree of response to the sound will diminish. This diminished response is "habituation." Some people are highly noise sensitive compared to others. Repetitive loud noises over a period of time become less intrusive to most (but not all) people, because they habituate to their noise environment. Those citizens who are least able to habituate generally comprise the "highly annoyed" group, who are more likely to register complaints with airport and elected officials. The length of time required for individuals to habituate to repetitive noise and their degree of habituation varies considerably within each exposed community.

The opening of the new Denver Airport in the mid 90's provides a good example of habituation. Rather than a gradual shift of operations from Denver's Stapleton Airport to the new Denver International Airport, the entire shift of all operations occurred overnight. The first year noise complaints exceeded 200,000, many coming people residing 20 or more miles from the airport. Over time complaints have dwindled to almost none. This initial public response to the sudden noise shift was predictable, as was the eventual habituation of the majority of exposed citizens.

The noise histories of airports around the world consistently show that shifting flight tracks or introducing new corridors over noise sensitive areas for the first time provoke the strongest opposition to new airports and the expansion of existing airports. While this discussion draws on aviation noise for examples, similar shifts or changes in other military operations that produce noticeable or intrusive noise levels is equally predictable.

It is generally assumed that the noise exposures of interest for policy-making purposes are recurring and that the population has had sufficient time to habituate to major changes in their community-wide noise exposure. Thus, community annoyance is the aggregate community response to long-term, steady-state exposure conditions. Case studies indicate that no matter how large the protection area around a new or expanding airport, there will be considerable noise complaints until the majority of the newly impacted population becomes habituated. Overall, it is clear that habituation is an important factor that should be considered when determining threshold levels of annoyance and activity interference from aircraft noise.

Rural vs. Urban Environments

A fundamental characteristic of noise from aircraft overflight and from many other military operations is that high sound levels typically occur for short periods of time. These events are experienced against a background sound level that varies considerably, depending on the local environment, be it non-urban (rural) or urban. The background noise level is a slowly varying combination of all the nearby and distant noise sources. Transportation, construction, military or industrial, and other human activity are the main background noise contributors in an urban or suburban area. In a rural setting, wind, moving water, and animals comprise a larger part of the background sound level, and human activity comprises less of the total. People are generally unaware of the background noise level unless they specifically try to listen for it. Because background noise levels depend so much upon activities of people, and especially on ground traffic, the level varies from one community to another, but is typically lower at night in all settings.

A given noise event will be perceived by most people to be more intrusive if heard against a lower background noise level, and thus, will generally be more noticeable or intrusive in a quiet non-urban (or rural) community than in a busy urban area.

It seems intuitive that most people are more aware of a noise event if it stands out clearly above the general background noise level. However, with regard to aviation noise, the findings and conclusions of the various studies conducted to date are not consistent, perhaps because, aircraft noise levels near airports are typically so much higher than the background noise level that the absolute magnitude of the background noise may be immaterial.

Non Auditory Contributors to Annoyance

As shown in Figure A-1, the large scatter among the data drawn from the various surveys reflects the low correlation coefficients for individuals' reactions. Thus, considerable uncertainty is associated with the equation representing the relationship between %HA and DNL. Base on this wide variation of data in the survey results, noise exposure explains only about half of the observed variance in annoyance. Thus, researchers generally agree that non-acoustical factors also play a major role in annoyance responses to transporation noise.

Since research studies to date have not produced a process to accurately attibute annoyance responses to acoustic and non-acoustic factors, it is not possible to accurately predict annoyance responses to aircraft noise exposure in any specific community.

Several studies have identified a number of non-acoustic factors that influence individual annoyance responses. Newman and Beattie[9] divided these factors into emotional and physical variables:

Emotional Variables include:

- Feelings about the necessity or preventability of the noise;
- Judgment of the importance and value of the activity that is producing the noise;
- Activity at the time an individual hears the noise;
- Attitude about the environment;
- General sensitivity to noise;
- Belief about the effect of noise on health; and
- Feeling of fear associated with the noise.

Physical Variables include:

- Type of neighborhood;
- Time of day;
- Season;
- Predictability of noise;
- Control over the noise source; and
- Length of time an individual is exposed to a noise.

Community Attitudes and Experience

Individual and community attitudes toward the source of noise, previous exposure levels and trends, may influence perceptions that noise levels are higher or lower than they actually are. Some of these perceptions are fueled by: relationships with the installation, increasing quality of life standards as time progresses, ability to relate to the noise sources, and other factors; particularly the type or necessity of operations.

The general perception of the community towards the purpose of operations that generate noise complaints is very important. A study performed for the Massachusetts Airport Commission (MAC) in 1978 concluded that the public will tolerate higher noise levels if they are generated by military rather than civilian operations. Especially in the U.S., immediately after the events of September 11, 2001, the sight of military aircraft over U.S. cities generated a sense of safety and generated few noise complaints. The same phenomenon can be seen from air ambulance or law enforcement aircraft operations.

Some studies have found that fewer complaints occurred at airports with a history of cooperation between the community and the airport. When community members feel that the airport operator (whom they blame for the annoying sound) is unresponsive to their complaints, noise becomes a catalyst that reminds people of the airport's unresponsiveness, motivating some to complain when noise is only noticeable rather than intrusive. Conversely, if people believe that good faith efforts are being made to address noise problems, their attitude is likely to be more neutral and they will be less like to complain when noise events are less than intrusive. This phenomenon is generally applicable to all military facilities that conduct operations that expose nearby populations to noise.

A.1.2 Interference with Speech Communication

Speech interference associated with aircraft noise is a primary cause of annoyance for communities. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is also important in classrooms, offices, and industrial settings and can cause fatigue and vocal strain in those who attempt to communicate over the noise.

The disruption of speech in the classroom is a primary concern, due to the potential for negative effects on children's learning, which have been postulated by various groups over the years. Speech comprehension can be considered in two ways:

For teachers to be clearly understood by their students, it is important that regular voice communication is clear and uninterrupted. Not only does the steady background sound level have to be low enough for the teacher to be clearly heard, but intermittent outdoor noise events also need to be minimized. It is therefore important to evaluate the steady background level, the level of voice communication, and the single-event level due to aircraft over-flights that might interfere with speech.

Several research studies and guideline documents have been conducted over the last 30 years resulting in various noise level criteria for speech interference. This section provides an overview of the results.

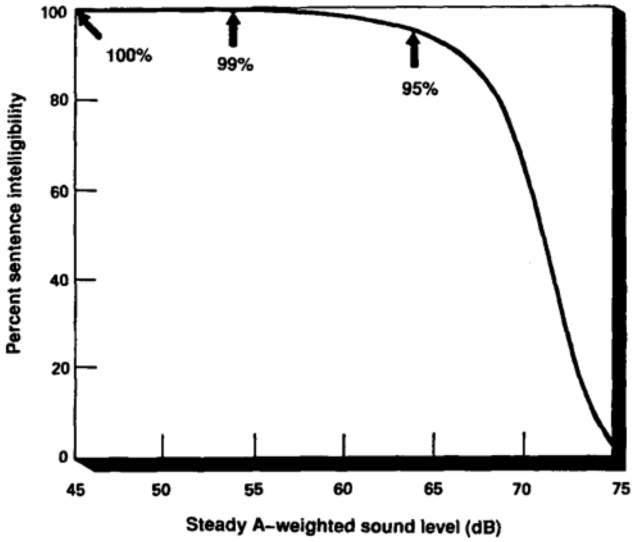
A.1.2.1 U.S. Federal Criteria for Interior Noise

In the Levels Document, the EPA[1] identified a goal of an indoor 24-hour average level $L_{eq(24)}$ of 45 dB to minimize speech interference based on the intelligibility of sentences during steady noise. Intelligibility pertains to the percentage of speech units correctly understood out of those transmitted, and specifies the type of speech material used, i.e. sentences or words[10]. The curve displayed in Figure A-3 shows the effect of steady indoor background sound levels on sentence intelligibility. For an average adult with normal hearing and fluency in the language, steady background sound levels indoors of less than an L_{eq} of 45 dB are expected to allow 100% intelligibility of sentences.

The curve shows 99 percent sentence intelligibility for background levels at an L_{eq} of 54 dB, and less than 10 percent intelligibility for background levels above an L_{eq} of 73 dB. Note that the curve is especially sensitive to changes in sound level between 65 dB and 75 dB - a 1 dB increase in background sound level from 70 dB to 71 dB results in a 14 percent decrease in sentence intelligibility, whereas, a 1 dB increase in background sound level from 60 dB to 61 dB results in less than 1 percent decrease in sentence intelligibility.

A.1.2.2 Classroom Criteria for Steady State Noise

For listeners with normal hearing and fluency in the language, complete sentence intelligibility can be achieved when the signal-to-noise ratio (i.e., the difference between the speech level and the level of the interfering noise) is approximately 15-18 dB[11].



(Source: EPA 1974)

Figure A-3. Speech Intelligibility Curve

Both the American National Standards Institute[12] (ANSI) and the American Speech-Language-Hearing Association[13] recommend at least a 15 dB signal-to-noise ratio in classrooms, to ensure that children with hearing impairments and language disabilities are able to enjoy high speech intelligibility. As such, provided that the average adult male or female voice registers a minimum of L_{max} 50 dB in the rear of the classroom, the ANSI standard requires that the continuous background noise level indoors must not exceed a L_{eq} of 35 dB (assumed to apply for the duration of school hours).

The WHO[9] reported that, for a speaker-to-listener distance of about 1 meter, empirical observations have shown that speech in relaxed conversations is 100 percent intelligible in background noise levels of about 35 dB, and speech can be fairly well understood in the presence of background levels of 45 dB. The WHO further recommends a guideline value of L_{eq} of 35 dB for continuous background levels in classrooms during school hours.

Bradley[14] suggests that in smaller rooms, where speech levels in the rear of the classroom are approximately L_{max} 50 dB, steady-state noise levels above 35 dB may interfere with the intelligibility of speech.

The FAA[15] guidelines state that the design objective for a classroom environment is a time-averaged A-weighted sound level L_{eq} of 45 dB resulting from aircraft operations during normal school hours for the purposes of determining eligibility for noise insulation funding.

A.1.2.3 Intermittent Noise

The noise near an airport or airbase is not continuous, but consists of individual events where the sound level exceeds the background level for a limited time period as the aircraft flies over. Thus, the classroom criteria described in the previous subsection is not applicable to aircraft noise exposure. Since speech interference in the presence of aircraft noise is essentially determined by the magnitude and frequency of individual aircraft flyover events, a time-averaged metric alone, such as L_{eq}, is not necessarily appropriate when evaluating the overall effects. In addition to the background level criteria described above, single-event criteria, which account for those sporadic intermittent noisy events, are also essential to specifying speech interference criteria.

In 1984, Sharp and Plotkin, in a report to the Port Authority of New York and New Jersey, recommended utilizing the Speech Interference Level (SIL) metric for classroom noise criteria[16]. This metric is based solely on the maximum sound levels in the frequency range (approximately 500 Hz to 2,000 Hz) that directly affects speech communication. Their study identified an SIL of 45 dB as the desirable goal, which provided 90 percent word intelligibility for the short time periods during aircraft over-flights. Although early classroom level criteria were defined in terms of SIL, the use and measurement of L_{max} as the primary metric has since become more popular. Both metrics take into consideration the maximum sound levels associated with intermittent noise events and can be related to existing background levels when determining speech interference percentages. An SIL of 45 dB is approximately equivalent to an A-weighted L_{max} of 50 dB for aircraft noise[17].

In 1998, Lind, Pearsons, and Fidell[18] also concluded that if an aircraft noise event's maximum indoor noise level (L_{max}) reached the speech level of L_{max} 50 dB, 90 percent of the words would be understood by students seated throughout the classroom. Since the intermittent nature of aircraft noise does not appreciably disrupt classroom communication at lower levels and other times, Lind et al. also adopted an indoor L_{max} of 50 dB as the maximum single-event level permissible in classrooms[18]. Note that this limit was set based on students with normal hearing and no special needs; at-risk students may be adversely affected at lower sound levels.

Bradley[19] recommends SEL as a better indicator of estimated speech interference in the presence of aircraft overflights indoors. For acceptable speech communication using normal vocal efforts, Bradley suggests that the indoor aircraft SEL be no greater than 64 dB. Assuming a 26 dB outdoor-to-indoor noise reduction, this equates to 90 dB SEL outdoors. Aircraft events producing outdoor SEL values greater than 90 dB would result in disruption to indoor speech communication. Bradley's work indicates that, for speakers talking with a casual vocal effort, 95% intelligibility would be achieved when indoor SEL values did not exceed 60 dB, which approximately translates to an L_{max} value of 50 dB.

In the presence of intermittent noise events, ANSI states[12] that the criteria for allowable background noise level can be relaxed since speech is impaired only for the short time when the aircraft noise is close to its maximum value. Consequently, they recommend that when the background noise level of the noisiest hour is dominated by aircraft noise, the indoor criteria (L_{eq} 35 dB for continuous background noise) can be increased by 5 dB to an L_{eq} of 40 dB, as long as the noise level does not exceed 40 dB for more than 10 percent of the noisiest hour, for a room with a volume less than 20,000 cubic feet (assuming 8-foot ceilings, this could be a room 50-feet long and 50-feet wide).

WHO[9] does not recommend a specific indoor L_{max} criterion for single-event noise, but does place a guideline value at L_{eq} of 35 dB for overall background noise in the classroom. However, WHO does report that "for communication distances beyond a few meters, speech interference starts at sound pressure levels below 50 dB for octave bands centered on the main speech frequencies at 500 Hz, 1kHz, and 2 kHz." One can infer that this can be approximated by an L_{max} value of 50 dB.

The United Kingdom Department for Education and Skills (UKDFES) established in its classroom acoustics guide[20] a 30-minute time-averaged metric [$L_{eq(30min)}$] for background levels and $L_{A1,30\ min}$ for intermittent noises, at thresholds of 30-35 dB and 55 dB respectively. $L_{A1,30\ min}$ represents the A-weighted sound level that is exceeded 1 percent of the time (in this case, during a 30 minute teaching session) and is generally equivalent to the L_{max} metric.

A.1.2.4 Summary

As the previous section demonstrates, research indicates that it is not only important to consider the continuous background levels using time-averaged metrics, but also for intermittent events, using single-event metrics such as L_{max}. The most recent criteria documents recommend thresholds for speech interference using both a time-averaged metric and a single-event metric. Table A-2 provides a comprehensive summary of the noise level criteria recommended by various organizations and scientific experts.

Table A-2. Indoor Noise Level Criteria Based on Speech Intelligibility

Source	Metric/Level (dB)	Effects and Notes
U.S. FAA (1985)	L_{eq}(during school hours) = 45 dB	Federal assistance criteria for school Sound Insulation; supplemental single-event criteria may be used
Lind et al. (1998), Sharp (1984), Wesler (1986)	L_{max} = 50 dB / SIL 45	Single event level permissible in the classroom
WHO (1999)	L_{eq} = 35 dB L_{max} = 50 dB	Assumes average speech level of 50 dB and recommends signal to noise ratio of 15 dB
U.S. ANSI (2002)	L_{eq} = 40 dB Based on Room Volume	Acceptable background level for continuous noise/ relaxed criteria for intermittent noise in the classroom
U.K. DFES (2003)	$L_{eq(30min)}$ = 30-35 dB L_{max} = 55 dB	Minimum acceptable in classroom and most other learning environs

In summary, when considering intermittent noise caused by aircraft over-flights, a review of the relevant scientific literature and international guidelines indicates that an appropriate criteria is to limit indoor background noise levels to L_{eq} of 35 to 40 dB and single events to L_{max} values of 50 dB.

A.1.3 Effects on Children's Learning

This section describes key concepts related to the effects of aircraft noise on school children. Research in this field has been reviewed with particular emphasis placed on research conducted over the last 15 years. The literature focused on the following aircraft noise effects:

- Memory and Reading Comprehension;
- Motivation;
- Annoyance/Attention; and
- Physiological Effects: Stress Response and Hearing Loss.

In most of the research studies *low-noise* control groups (children in quieter schools experiencing less aircraft exposure) were compared with *high-noise* experimental groups (children in noisier schools with more frequent aircraft exposure). The studies examined the effects of aircraft noise exposure over time, sometimes over several years. Tests were not administered to the children in the midst of aircraft flyovers. Instead, the tests were designed to study the after-effects of aircraft noise, and not necessarily the momentary distraction caused by passing planes. The range and types of aircraft noise exposure (sound levels) for each study are described in Table A-3 at the end of this section, along with a description of the general outcome of the particular study.

It is important to note that much of the research uses the term *chronic aircraft noise exposure* to describe long-term noise exposure over a period of months or years. The term is not intended to describe noise qualitatively or subjectively, as would the terms *loud* or *annoying*.

The findings described in the succeeding sections below raise important issues, but are inconclusive. Some studies only provide results in relative terms and do not identify specific levels about which cognition impairment occurs, while others fall short of declaring a noise threshold. There is also the question of whether the studies fully considered the potential confounding factors that can also affect the ability to learn.

A.1.3.1 Memory and Reading Comprehension

Studies conducted in Germany, Spain, the United Kingdom, the Netherlands, and the United States found that chronic exposure to aircraft noise impaired long-term memory, reading comprehension and problem-solving skills in children ages 8 through 14. For example, a study conducted in Munich[21], showed that school children exposed to high noise levels near a recently opened airport performed worse on word-list recognition tests than a low-noise control group. The research assessed the children's cognitive performance before and after the opening of the airport. The children's performance (compared to the control group) worsened in the years following the opening of the airport. Also, children located near an airport that closed down actually improved their long-term memory and word-recognition in the years following that airport's closing. The researchers in this study concluded that for tasks requiring "central processing," such as long-term memory and reading, deficits occurred in the chronically-exposed children. Also, it was concluded that these deficits can take several years to develop.

Another control group study examined schools located in West London, near Heathrow Airport[22], and it also shows a link between chronic aircraft noise and impaired reading comprehension. A study conducted in Los Angeles[23] yielded similar results with respect to puzzle-solving ability. The study showed that high-noise children (compared to the low-noise control) took longer to solve a puzzle where the children had to assemble nine pieces into a familiar shape. This difference in performance became more pronounced the longer the children were exposed to aircraft noise. Children exposed to high noise levels for up to 4 years took much longer to solve the puzzle than children exposed for only 2 years. This supports the claim that cognition impairment increases with the time exposed to aircraft noise.

One study, termed the RANCH project (Road traffic and Aircraft Noise exposure and Children's cognition and Health)[24], used a different approach to measure the effects of aircraft noise exposure. The project studied impairments in reading comprehension for children located in schools near three major airports (Heathrow in the United Kingdom, Schipol in the Netherlands, and Barajas in Spain). Schools were chosen according to increasing levels of aircraft noise exposure, which were determined with contour maps, modeling, and/or external on-site noise measurements. Standardized tests were administered to measure reading comprehension. The results showed a decrease in reading scores as the noise level increased, identifying a "linear exposure-effect association between exposure to aircraft noise and impaired reading comprehension and recognition memory in children."

Another study[25] examined the effects of sound attenuation in a day care center by testing the pre-reading skills of 90 children ages 4 and 5. The children were tested before and after the completion of sound attenuation modifications on the classroom, thus lowering the overall sound level. Although the study did not address aircraft noise per se, it still touched upon the concept of chronic noise exposure relevant to this discussion. Letter-number-word recognition was tested, as well as the tendency for motivational deficits. The children in the quieter classroom scored higher than those in the noisier classroom for recognizing numbers, letters, and words. The quiet-room children were also able to complete a puzzle much faster than the noisy-room children. Again, although this study did not mention aircraft noise, the findings are similar to other studies that were reviewed. Most importantly, though, this study applies to children of day care age. This provides some evidence to support the claim that younger children respond similarly to older children, as far as chronic exposure to noise is concerned.

A.13.2 Motivation

A few studies, including the Munich airport study[26], also identify links between aircraft noise and motivational depletion in children. There is evidence that suggests chronic aircraft noise contributes to "learned helplessness", a concept whereby people "give up," because their environment imposes too many stressful situations that are beyond their control. Such a person starts to develop coping mechanisms for explaining/excusing unsuccessful results (such as when people continually attribute failure on tests to bad luck). The person thinks that, even if they were to try harder at solving a problem, they would still unavoidably fail.

In the Munich study[26], high-noise and low-noise control groups were given an insoluble puzzle. Each group was scored on the basis of how many attempts they made at solving the puzzle. High-noise children attending school near the new Munich airport made fewer attempts than the low-noise control group.

A Los Angeles study[23] conducted a slightly different test, but yielded similar results. Children in the two groups (noise and control) were given four minutes to solve a puzzle that was not impossible to solve. The high-noise school children showed greater failure rates (53% failed) over the low-noise control group children (36% failed). Additionally, the high-noise school children were more likely to give up entirely. The results showed that 31% of the high-noise school children who failed the test gave up. In contrast, only 7% of the low-noise school children who failed the test gave up.

A.13.3 Annoyance

Studies have shown a link between aircraft noise and annoyance in school children. Researchers study annoyance and attention because of possible links to impairments in cognition. The West London schools study[22], the Munich airport study[26], and the RANCH study[24] all show that chronic aircraft noise exposure is associated with increased levels of annoyance in children. The control group approach was used in both the West London and Munich studies. Those studies employed questions from an "environmental perception list" to gauge the degree to which children were annoyed by aircraft noise. Both studies showed that annoyance was higher among children from the high-noise group. For example, in the Munich study before the airport opened, the annoyance scores (on a scale of 0 to 9, 9 being high) for high-noise children was 3.6 versus 3.8 for the control group. Two years after the airport opened, the high-noise score was 5.6 versus 2.2 for the low-noise control. The West London schools study also found, consistently, that "children exposed to high levels of aircraft noise at school have higher levels of noise annoyance than children in low noise exposed schools."

The RANCH study revealed a non-linear relationship between annoyance and aircraft noise level. Annoyance was plotted as a function of 5 dB bands of annoyance, according to a curve fit using data gathered from questionnaires. The curve shows a clear increase in annoyance as the noise level increases.

A.13.4 Physiological Effects: Stress Response and Hearing Loss

Several studies have shown that chronic aircraft noise can affect physiological responses. Most of the research relates to elevated blood pressure readings among children in noise-exposed environments. The Los Angeles study[23] determined that blood pressure was higher for children in the noisier schools versus the quiet schools. However, hearing loss is probably the more obvious physiological effect. The EPA Levels Document[1] recommends a 24-hour L_{eq} of 70 dB (unweighted) as the noise limit that will not result in significant hearing loss. The aircraft sound levels at the potential day care and school sites will not be a concern in terms of hearing loss.

A.13.5 Summary of Noise Effects on Children

It is important to note the difference between the three studies in Munich, West London, and Los Angeles versus the RANCH study. The first three compared high-noise subjects versus low-noise control subjects. Those three studies only provide results in relative terms. They do not identify a specific sound level or noise contour above which cognition impairment is certain to occur. In contrast, the RANCH study made an attempt to identify an exposure-effect relationship between noise exposure and cognitive impairment. It utilized a "cross-sectional" method which focused on a narrow pool of subjects, but it considered subjects within areas of increasing aircraft noise levels: from 30 dBA to 70 dBA. However, the RANCH project does not declare a certain threshold noise level above which causes learning impairment. In short, the findings from the literature review are inconclusive, as far as establishing a criterion for day care centers and land-use planning. The results do not point definitively toward a sound level or threshold that must be met in order to ensure an optimal (or even acceptable) learning environment.

In February 2000, FICAN held a public forum to address the issue of the effects of noise on children[27] including presentations by authors of many of the studies cited above. Members of FICAN agreed on the following:

(1) Further work should be done to establish whether school day L_{eq} is the appropriate measure for determining the effect of aircraft noise on classroom learning.

(2) In the absence of appropriations for specific research, FICAN encourages "before" and "after" evaluations of the effectiveness of noise mitigation in schools.

(3) FICAN will undertake a pilot study to evaluate the effectiveness of school sound insulation programs.

(4) FICAN supports the work of the American National Standards Institute in its efforts to develop a standard for classroom noise.

As a result of the forum, FICAN sponsored a pilot study on the relation between aircraft noise reduction in schools and standardized test scores.[28] The study found a relationship between noise reduction and test scores, it also identified several caveats and potential limitations associated with the methodology.

Table A-3. Summary of Studies of Noise Effects on Children

Study	Metric/Level (dB)	Effects/Conclusion
Munich Airport Noise Study (Cognition Study)	*Airport Closing:* Low-noise control: 59-60 dBA (Outdoor 24-hr L_{eq}) before and after closing High-noise experimental: 68-70 dBA (Outdoor 24-hr L_{eq}) before close, 58 dBA (Outdoor 24-hr L_{eq}) after close (10 dB drop) *Airport Opening:* Low-noise control: 53 dBA (Outdoor 24-hr L_{eq}) before opening, 61 dBA (Outdoor 24-hr L_{eq}) after opening High-noise experimental: 53 dBA (Outdoor 24-hr L_{eq}) before opening, 70 dBA (Outdoor 24-hr L_{eq}) after opening (17 dB increase)	High-noise group performed worse than control group for reading tests and long-term memory in years following an airport opening. High-noise group improved reading and memory performance in years following an airport closing.
Munich Airport Noise Study (Motivation and Annoyance Study)	*Airport Closing:* Low-noise control: 53 dBA (Outdoor 24-hr L_{eq}) before closing High-noise experimental: 68 dBA (Outdoor 24-hr L_{eq}) before closing, 49 dBA (Outdoor 24-hr L_{eq}) after closing (19 dBA drop) *Airport Opening:* Low-noise control: 53 dBA (Outdoor 24-hr L_{eq}) before, 53 dBA (Outdoor 24-hr L_{eq}) after High-noise experimental: 53 dBA (Outdoor 24-hr L_{eq}) before opening, 62 dBA (Outdoor 24-hr L_{eq}) after opening (9 dBA increase)	Chronic aircraft noise shown to increase annoyance and contribute to motivational deficits similar to “learned helplessness.”
RANCH Study (Reading Comprehension, Annoyance)	Aircraft Noise Level Range: 30 – 77 dBA (Outdoor 16-hr Outdoor L_{eq})	Linear relationship between impaired reading comprehension and aircraft noise level; non-linear exposure-response between aircraft noise and annoyance.
Pre-Reading Skills (Evans, Maxwell)	Average for loud classroom (indoor): L = 75.8 – 77.1 dBA Average for treated classroom (indoor): L = 69.4 - 73.9 dBA	Children in a quieter classroom performed better on cognition tests than children in a noisier classroom. Pre-reading skills such as number, letter, and word recognition were tested. As well, puzzles designed to test motivation (helplessness) were administered.
West London Schools Study (Annoyance Study)	L_{eq}16hr > 63 dBA (high noise, Outdoor) L_{eq}16hr < 57 dB (low noise, Outdoor)	Study determined that chronic aircraft noise exposure is linked to raising annoyance in children ages 8-11.
West London Schools Study (Cognition Study)	L_{eq}16hr > 66 dBA (high noise, Outdoor) L_{eq}16hr < 57 dB (low noise, Outdoor)	Study determined that chronic aircraft noise exposure is linked to reading comprehension impairment in children ages 8-11.
Los Angeles (Physiological, Motivation, Cognition, and Attention)	$L_{MeanPeak}$ = 74 dBA for high-noise school (indoor, no children present), L_{Peak} = 95 dBA (indoor, no children present) $L_{MeanPeak}$ = 56 dBA for quiet school (indoor, no children present), L_{Peak} = 68 dBA (indoor, no children present) Sound levels monitored for 1 hour in morning and 1 hour in afternoon 300 over flights a day (approx. 1 flight every 2.5 minutes)	Study showed that chronic aircraft noise exposure can cause higher blood pressure in children (compared to control group). Exposure to aircraft noise was also determined to increase the amount of time needed to solve a puzzle. This was linked to “learned helplessness.” Study also shows an increase in distraction among children exposed to chronic aircraft noise for several years.

A.1.4 Sleep Disturbance

The disturbance of sleep is a major concern for communities exposed to nighttime aircraft noise. Although there is no current scientific evidence for establishing a direct relationship between nighttime aircraft noise and irreversible long-term health effects (particularly stress-induced illnesses such as cardiovascular disease), sleep disturbance is none-the-less a major cause of annoyance for the public. Consequently, there have been numerous research studies that have attempted to quantify the complex effects of noise on sleep. This section provides a literature review and overview of the major noise-induced sleep disturbance studies that have been conducted worldwide, with particular emphasis placed on those studies that have influenced U.S. federal noise policy, and attempts to place a framework around the results. The studies have been separated into two groups:

(1) Initial studies performed in the 1960s and 1970s, where the research was focused on laboratory sleep observation.

(2) Later studies performed in the 1990s up to the present, where the research was focused on field observations, and correlations to laboratory research were sought.

A.1.4.1 Background

In common-sense terms, a good night's rest is vital to the recovery of a person's physical, mental, and emotional well-being. The overall sleep quality is dictated not only by total sleep duration throughout the night, but also by the quality of sleep during each sleep stage.

As we sleep, the human body and mind cyclically move through various stages of sleep, all with varying degrees of sleep depth. In general, sleep moves from being awake to lighter sleep to deeper sleep to progressing toward wakefulness, all occurring in various cycles over the course of a night. These sleep stages are classified by the medical community into "Awake", "Rapid Eye Movement (REM) sleep", and "non-REM sleep", with non-REM sleep further sub-divided into sleep stages S1, S2, S3, and S4. The sleep stages S1 and S2 refer to light sleep, while sleep stages S3 and S4 refer to deep sleep. As as might be expected, people are more easily awakened during light sleep than deep sleep.

Sleep experts generally classify noise-induced effects into primary and secondary effects. Primary effects refer to how people could react instantaneously to an aircraft noise event – e.g., vegetative arousals, brief awakenings (typically lasting 15-45 seconds that are not remembered the next day), awakenings (typical lasting 1 minute or more and that can be recalled the morning after), or elevated stress hormones. Secondary sleep disturbances are results that could occur the following day – e.g., increased fatigue, daytime sleepiness, an increase in aircraft noise annoyance, or less efficiency in task and work performance.

There is no widely-accepted model amongst sleep experts for predicting the irreversible long-term health effects (i.e., cardiovascular disease, stroke, high blood pressure) that could occur as a direct result of sleep disturbance. The scientific and medical literature is not clear whether or not there is a causal relationship and at what sound level thresholds and how many individual noise events might predict such a so-called "dose-response" relationship, if one even exists. Consider the enormous cost, feasibility, and complexity that such a research study would entail – medical researchers would have to follow a controlled group of the population exposed to varying levels of aircraft and other forms of environmental noise, with some portion exposed to lower levels or not at all. At the same time, researchers would have to match this control group for all other long-term heath factors in attempt to extract out this hypothesized dose-response relationship, all studied over an undetermined but lengthy time period.

The disturbance caused by an intruding sound depends not only on the depth of sleep, but also on the background noise level, previous exposure to aircraft noise, familiarity with the surroundings, the physiological and psychological condition of the recipient, and a host of other situational factors. The most readily measurable effect of noise on a sleeping person is the number of arousals or awakenings. The body of scientific literature has focused on predicting the percentage of the population that will be awakened at various noise levels. Fundamentally, regardless of the tools used to measure the degree of sleep disturbance (awakenings, arousals, etc.), these studies have grouped the data points into bins that predict the percentage of the population likely to be disturbed at various sound level thresholds.

A.1.4.2 Early Sleep Disturbance Research – Laboratory Studies

A number of studies conducted from the early 1960s through the 1970s attempted to quantify the noise levels that interfere with sleep. In the early years of aircraft noise research, field studies conducted with people in their normal living situations were rare, and consequently much of the data on the impact of noise exposure on sleep originated primarily from experimental research in controlled laboratory environments.

The EPA "Levels Document"[1] and the earlier "Criteria Document"[29] are regarded as the foundation for noise level criteria in the U.S. Quoting the Levels Document and referring to the indoor L_{dn} of 45 dB criteria, "the nighttime portion of this L_{dn} will be approximately 32 dB, which should in most cases, protect against sleep interference." Although neither document proposes specific criteria as a protection mechanism exclusively for sleep, there is a review of sleep research findings from the 1960s through the early 1970s. Both documents recommend caution in drawing conclusions for the general population, since most of the early work came from laboratory experiments on only a few people.

The Criteria Document summarized the findings of several research studies. Referencing Beland, et al.'s work[30], data from many early studies indicated that the effects of noise on sleep generally become more problematic as the indoor ambient noise levels exceed 35 dB. Another contemporary study by Thiessen[31] predicted a probability of awakening of 5 percent of the population at a peak noise level of 40 dB, which increased to 30 percent at 70 dB. Karagodina[32], et al.'s research showed that, for people who slept well in a 35 dB noise environment, 40 dB caused reported sleep disturbance, and 50 dB resulted in difficulty falling asleep. As a result, the authors recommended 30 dB as the maximum allowable nighttime noise limit.

Griefahn[33] reviewed a large number of sleep disturbance studies and produced a set of curves to summarize the overall trends. This showed that the threshold of noise-induced awakenings (i.e., the lowest sound level where awakenings are expected) indicated indoor L_{max} values in a wide range of values from 45 to 68 dB. The author's explanation for this wide range in the research was due to a host of factors, including differences in sex, age, sleep state, habituation, and the total number of noise events, among others. The study further filtered the existing data to disregard ten percent of the most noise-sensitive portion of the population. Finally, the researchers analyzed the data to account for the most sensitive portion of the night and the most sleep-sensitive portion of the population, the elderly.

Similar to Griefahn's work, other studies indicate that for a good night's sleep, the number of noise events plays a role as important as the level of the noise. Vallet and Vernet[34] recommend that, to avoid any adverse effects on sleep, indoor noise levels should not exceed approximately 45 dB L_{max} more than 10–15 times per night. For 25 events per night, their research indicates that indoor L_{max} values should not exceed 42 dB. A further recommendation is that individual noise events not exceed an L_{max} value of 48 dB. The authors suggest that lower levels might be appropriate to provide protection for sensitive people.

FICON[3] produced a guideline document that provided an overview of the most pertinent sleep disturbance research that had been conducted throughout the 1970s. Several studies, particularly the literature reviews and meta-analysis conducted by Lukas[35], Griefahn and Muzet[36], and Pearsons et al.[37], made use of the existing datasets that indicated the effects of nighttime noise on various sleep-state changes and awakenings. FICON noted that various indoor A-weighted sound levels – ranging from 25 to 50 dB – were observed to be thresholds below which significant sleep effects were not expected. Due to the large variability in the data, FICON did not endorse the reliability of the results.

FICON[3] further recommended the use of an *interim* dose-response curve—awaiting future research—which predicted the percent of the exposed population expected to be awakened (% awakening) as a function of the exposure to single event noise levels expressed in terms of SEL. This curve was based on the research conducted by Finegold[6] et al. for the U.S. Air Force. This dataset included most of the research performed up to that point, and indicated that 10 percent of the population was predicted to be awakened when exposed to an interior SEL of approximately 58 dB. The data utilized to derive this relationship were primarily the results of the many laboratory studies performed up until that time.

A.1.4.3 Later Sleep Disturbance Research (1990-2004) – Field and Laboratory Studies

It was noted in the early sleep disturbance research that the controlled laboratory studies did not account for many factors that are important when analyzing sleep behavior, such as habituation to the environment and previous exposure to noise and awakenings from sources other than aircraft noise. In the early 1990s, field studies were conducted to validate the earlier laboratory work. The most significant finding from these studies was that an estimated 80 to 90 percent of sleep disturbances were not related to individual outdoor noise events, but were instead the result of indoor noise sources and other non-noise-related factors[38]. Moreover, it was found that there was less of an effect of noise on sleep in real-life conditions than had been previously reported from laboratory studies[39].

1992 UK CAA Field Study[40]

The UK's first large-scale field study on sleep disturbance due to aircraft noise was conducted in 1991. It was led by the Civil Aviation Authority (CAA) Policy Directorate, in conjunction with research teams from the Universities of Loughborough, Manchester Metropolitan, and Southampton, for the Department of Transport. The study report was issued in 1992 and is commonly referred to as the 1992 UK Field Study[40].

The researchers recruited 211 women and 189 men, ranging in age from 20-70 years, who resided in eight areas surrounding four major UK airports: London-Heathrow, London-Gatwick, London-Stansted, and Manchester. The eight areas were specifically chosen to:

(1) Represent a wide array of nighttime noise exposure in terms of the number of nighttime aircraft events and noise levels of those events.

(2) Provide a statistically-significant sample size.

(3) Present lower levels of other non-aircraft noise sources that could interfere with the results. A social survey was also conducted in tandem with the sleep study to develop a pool of potential subjects and yield additional information on other personal and situational factors that might affect sleep.

The CAA researchers relied on the use of actimeter measurements to gather the field data in people's homes. Actimeters are small devices typically worn on the wrist that measure and store fine arm movements during the night, and hence can be used to measure sleep disturbance. The authors point out that the traditional method for monitoring sleep is through the use of electroencephalography (EEG) in which brainwave patterns are measured directly by electrodes attached to the scalp. Due to the high cost and complexity of using EEG within the bedrooms of actual residents, the CAA research team developed a relationship between EEG measurements and actimetry that allowed them to identify 88% of awakenings from the actimetry measurements. This approach has been criticized in the literature, specifically because actimetry may not identify all awakenings.

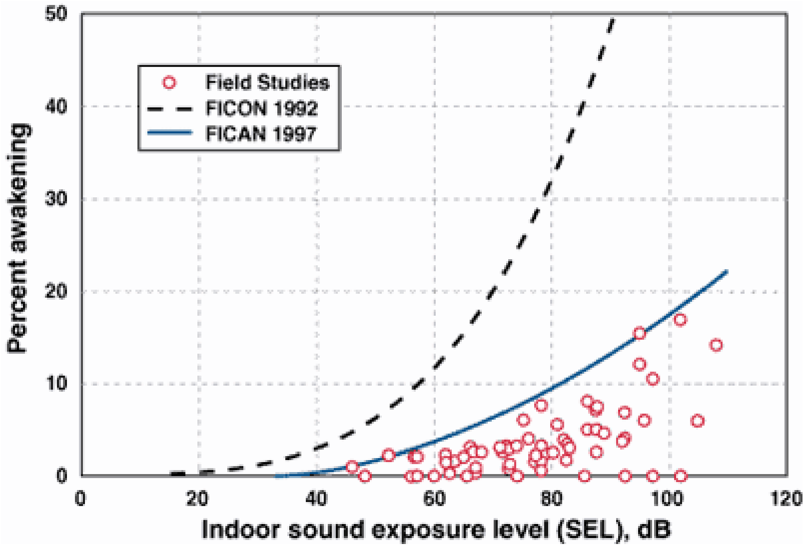
It was found that the average subject experienced 46 arousals per night. Of these, about 40% lasted 10-15 seconds or more, and could be considered as significant awakwenings. The remainder represented brief arousals that are most likely of no consequence. Few of the awakenings were related to aircraft noise events. In other words, the study found that the average person was awakened about 18 times per night for reasons other than exposure to an aircraft – some of this is due to the biological rhythms of sleep and some to other reasons.

Overall, the study found a low rate of sleep disturbance directly attributed to aircraft noise sources. For individual aircraft events below an outdoor L_{max} value of 80 dB (SEL 90 dB), there was no detectable increase in the probability of sleep disturbance. For outdoor events producing L_{max} values of 80-95 dB (SEL 90-105 dB), the chance of the average person being awakened was found to be about 1 in 75. However, the authors emphasize that these are based on 'average' effects, and that there are more susceptible individuals and there are periods during the night when people are more sensitive to noise, especially during the lighter stages of sleep.

FICAN[41]

Based on updated information, FICAN updated its recommended dose-response curve in 1997, depicted as the lower curve in Figure A-4. The individual data points in this figure are from the results of the 1992 UK Field Study[40], Fidell, et al.'s 1992 Los Angeles/Castle Air Force Base Field Study for the USAF[42], Fidell's 1995 Denver Study[43], along with the datasets from six previous field studies[39].

The new relationship represents the higher end, or upper envelope, of the latest field data. It should be interpreted as predicting the "maximum percent of the exposed population expected to be behaviorally awakened" or the "maximum % awakened" for a given residential population[40]. According to this relationship, a maximum of 3 percent of people would be awakened at an indoor SEL of 58 dB, compared to 10 percent using the 1992 curve. An indoor SEL of 58 dB is equivalent to an outdoor SEL of 73 dB, assuming a 15 dB Noise Level Reduction (NLR) from outdoor to indoor with open windows.



(Source: FICAN 1997)

Figure A-4. FICAN's 1997 Recommended Sleep Disturbance Dose-Response Relationship

The FICAN 1997 curve is represented by the following equation:

$$\text{Percent Awakenings} = 0.0087 \times [\text{Indoor SEL} - 30]^{1.79}$$

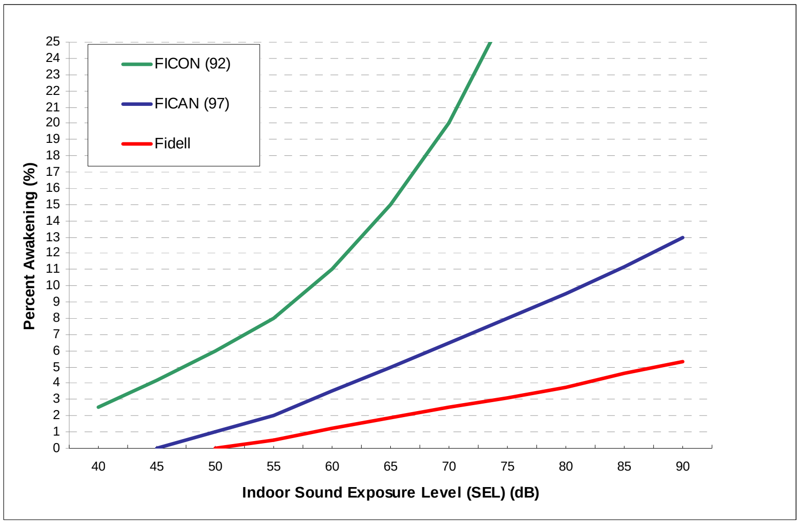
Fidell: Effects on Sleep Disturbance from Changes in Aircraft Noise[44]

Fidell et al.[43] developed a relationship to identify the sound levels that cause awakenings based on data from several field studies:

- 1992 U.K. Field Study[40].
- Fidell et al.'s 1995 study[45] that analyzed data from previous studies in Denver, Colorado (DEN and DIA); deKalb (Peachtree) Airport, Georgia; AX/Castle Air Force Base, California.
- Pearsons, et al.'s 1995 meta-analysis of six field studies[39].

Although the results of these studies are incorporated into the 1997 FICAN relationship, that curve only represents the upper envelope of the field data.

Fidell's 2000 curve in Figure A-5 is essentially drawn through the data points in Figure A-4, and suggests that even fewer people are awakened than the FICAN 1997 curve indicates. For example, an indoor SEL of 58 dB corresponds to approximately one percent of the population being awakened, versus three and ten percent for the same level on the FICAN 1997 and 1992 curves respectively. This supports Shultz's statement[2] that, "Aircraft noise interferes more with speech than with sleep," and explains the response of many survey participants who, when asked if they noticed a decrease in night time noise events at Los Angeles International Airport during a field study answered, "How would I know, I was asleep?"[46]



(Source: FICON 1992, FICAN 1997, Fidell 2000)

Figure A-5. Comparison of Sleep Disturbance Dose-Response Relationships

Effects of Nocturnal Aircraft Noise, German Aerospace Center (DLR)[47]

Between September 1999 and June 2003, the German Aerospace Center (DLR) conducted an extensive study focused on the effects of nighttime aircraft noise on sleep and other related human performance factors. The DLR study, one of the largest studies to examine the link between aircraft noise and sleep disturbance, involved both laboratory and in-home field research phases. DLR published the final results in July 2004.

Both the laboratory and field studies included a comprehensive evaluation of the effects of nighttime aircraft noise. Nighttime awakenings were determined through the simultaneous recording of acoustical signals (i.e., the aircraft noise source in the field or the playback of recorded aircraft in laboratory sleep cabins) and electro-physical signals (respiration, EEG, EMG, EOG, and heart rate, among others). Volunteers were further evaluated through a sampling of stress-related hormones (adrenalin, nor-adrenalin, and cortisol) and electrolytes gathered from urine specimens throughout the night. Finally, human performance tests were conducted the evening before and the morning after the nighttime noise events, with additional psychological testing conducted to determine the nighttime noise effects on annoyance, fatigue, stress, mood, and recuperation.

Laboratory Study

Under controlled laboratory conditions, 112 subjects (ages 18-65; median age of 38; normal hearing; no sleep disorders) were electro-physically monitored while asleep over thirteen consecutive nights, as they were exposed to playback of recorded aircraft events (comprised of both departing and arriving aircraft). In addition, 16 volunteers served as a control group and were not exposed to loudspeaker-simulated aircraft events.

For each set of 13 nights spent by an individual subject, night 1 was an adaptation night (i.e., subjects becoming accustomed to the sleep cabin and environment), night 2 was the baseline night (i.e., representing a normal night's rest), with nights 12 and 13 representing the recovery nights. Subjects were not exposed to simulated aircraft events during these four nights. The resulting dataset comprised a total of 1,072 noise-exposed nights and a total of 592 non-noise nights.

Loudspeakers were used to simulate aircraft noise events (departures and arrivals) between the hours of 2300 and 0700. The sound levels reproduced by loudspeakers in the laboratory sleep cabins were calibrated to approximate a range of actual aircraft sound levels experienced in real home environments (accounting for the noise reduction effects of closed or partially-open windows) around Düsseldorf Airport. The actual number of reproduced aircraft events varied between 4 and 128 (4, 8, 16, 32, 64, or 128 events per night), with sound levels ranging between L_{max} values of 45-80 dB (45, 50, 55, 60, 65, 70, 75, or 80 dB). The simulated events were equally spaced out during the 8-hour time period: 4 events at 120 minute intervals; 8 events/60 min; 16 events/30 min; 32 events/14 min; 64 events/7 min; and 128 events/3 min. In total, more than 30,000 simulated aircraft events were played back during the lab study.

Results of Laboratory Study

A random effects logistic regression model was developed to predict the probability of awakenings (in terms of percent of population awakened) as a function of L_{max}. This particular model only considers the probable percentage awakened by individual aircraft events, not the cumulative effects of multiple aircraft events over the course of a night.

The modeled results predict an awakening probability that ranges from approximately 11% at L_{max} 45 dB to around 65% at L_{max} 80 dB. The results from this study are very similar to those obtained in previous laboratory studies and represented by the upper curve in Figure A-4. Based on the dataset pulled from the non-noise nights, the authors predict that 6.3% of the population will awaken spontaneously with no aircraft events.

Field Study

The field research study was comprised of 64 subjects (ages 19-61; median age of 38; normal hearing; no sleep disorders) who were evaluated in their own homes near the Cologne-Bonn Airport over nine consecutive noise nights, for a total dataset of 576 nights. The study participants were selected such that aircraft noise exposure in their homes was high in contrast to other types of environmental noise. A total of 20 out of the 64 volunteers also participated in the laboratory sleep study. Only the noise generated by real aircraft was used in the data gathering and analysis process.

The field portion of the study evaluated each subject’s electro-physical reaction to noise, correlating the changes (e.g., awakenings) to the aircraft-generated L_{max} values at the ear location while the subject was asleep, from 2400 to 0600 hours. As part of this study, exterior and interior noise levels were measured. The study showed that, on average, the noise level reduction (NLR – the arithmetic difference between interior and exterior noise levels) was 28 dB with windows closed, 18 dB with windows partially open, and 13.5 dB with fully-open windows. This is an important component in predicting seasonal variations of sleep disturbance.

Results of the Field Study

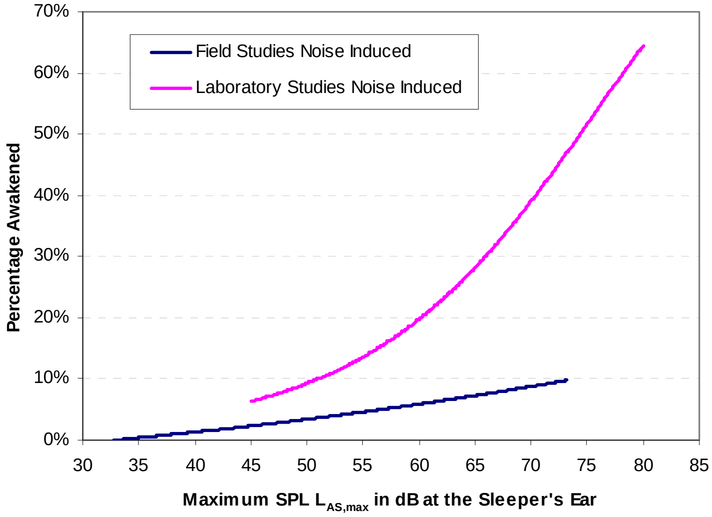
Similar to the laboratory study, the field study data was used to develop a random effects logistic regression model that predicts the relationship between L_{max} values and the percent of subjects awakened. Awakening was reported as physiological changes lasting 15 seconds or more. Similar to the laboratory portion of the study, this model only considers the probable percentage awakened by individual aircraft events, not the cumulative effects of multiple aircraft events over the course of a night.

The modeled results predict an awakening probability that ranges from 8.7% at L_{max} 35 dB to around 19% at L_{max} 73 dB (the highest indoor L_{max} value measured in the field). Based on the dataset pulled from the non-noise nights, the investigators predict that 8.7% of the population will awaken spontaneously in their own homes.

Comparison of Laboratory and Field Results

Figure A-6 shows a comparison of the results generated by the laboratory and field portions of the DLR Sleep Study. The authors have shown a set of dose-response relationships that predict the probability of awakenings that are expected to result from aircraft events alone, i.e. spontaneous awakenings have been subtracted from the analysis. The curves in Figure A-6 show very similar results to the FICON 1992 and FICAN 1997 data shown in Figure A-4.

As expected, the field results predict a much lower probability of awakening than the laboratory results. The authors theorize – a theory that seems to be widely held by other researchers – that the lower awakening probabilities in the field are due to habituation to the subject's home environment (their own bedroom, their own bed, and the general noise environment in their home), but is probably not due to habituation to aircraft noise per se. They also theorize that the simulated noise environment in the lab sleep chambers may not adequately recreate the complex acoustical environment in the home. The DLR investigators further point out that similar phenomenon were also reported by Pearsons[39] and Hume and Whitehead[48].



(Source: DLR 2004 Study)

**Figure A-6. Comparison of Laboratory and Field Study Models -
Random Effects Logistic Regression Model with Awakenings Attributed to Aircraft Events Only**

Some of the other interesting study results include:

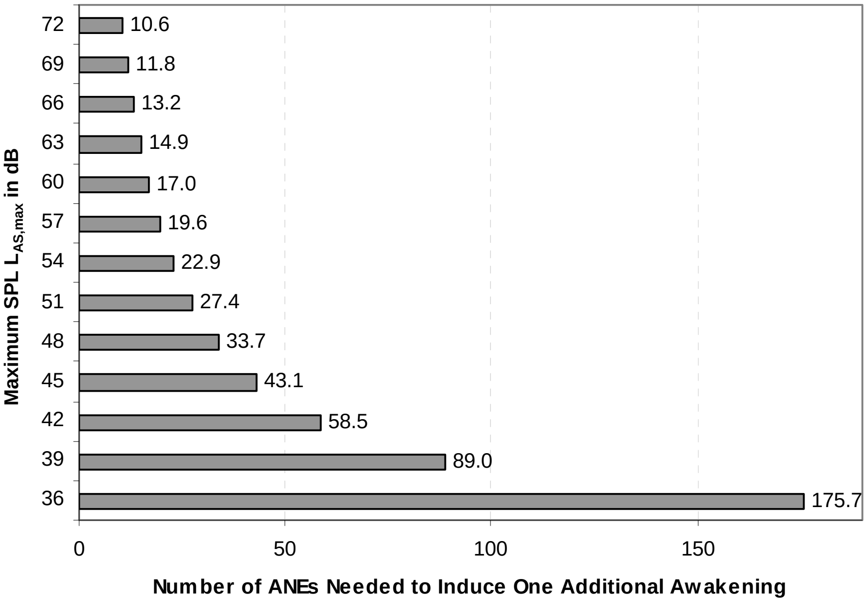
- Aircraft events measuring L_{max} 33 dB or lower did not cause awakenings in the field.
- The awakening threshold in the lab was below L_{max} 45 dB.
- Total sleep time in the laboratory study was shortened by about two minutes per night on average.
- Statistical analysis of the data was not able to establish a relationship between nighttime noise events and human performance the next day.

- A dose-response relationship was not found for the subjective ratings of fatigue, stress, mood, and recuperation.
- A statistically significant dose-response relationship was found between equivalent noise levels (L_{eq}) and moderately- to highly-annoyed individuals.
- The levels of annoyance were far lower in the field study than the laboratory.
- People who reported being annoyed or highly annoyed before the study started were more likely to be awakened by aircraft noise events. It was not possible to determine whether the prior annoyance sensitized participants during the study period or their existing sensitivity to noise is what caused them to be annoyed.

Number-of-Events Above a Specified Threshold (NA) and Awakenings

Most of the sleep studies conducted by the scientific and medical communities have focused on predicting the percentage of the population that will be awakened at various noise levels. These studies have grouped the data points into bins that predict the percentage of the population likely to have this level of sleep disturbance at various sound level thresholds. Most of the sleep studies have not attempted to correlate the number of events (at various sound level thresholds) that will cause more than one awakening.

The DLR investigators developed a dose-effect curve that predicts the number of aircraft events at various L_{max} values that would be expected to produce one additional awakening over the course of a night. The results of the analyses are shown in Figure A-7[47]. As an example, the DLR results indicate that it will take 17 additional nighttime aircraft events (at an L_{max} value of 60 dB) to induce one additional awakening at a single point of interest. The study results also predict that 34 events (again producing L_{max} values of 60 dB) are likely to result in two additional awakenings at the same point of interest. The results are based on the dose-response relationship found in the field studies.



(Source: DLR 2004 Study)

Figure A-7. Number of Aircraft Noise Events (ANEs) Predicted to Cause One Additional Awakening vs. L_{max}

Anderson and Miller[1] have approached the issue of sleep awakenings from multiple aircraft events by generalizing the dose-response relationships and multiplying together all the chances of sleeping through for each event, and then combining them in a mathematical manner. They also include the effect of person-to-person variability.

In recent years, there have been studies and proposals that attempted to determine the effect of multiple aircraft events on the number of awakenings. The DLR conducted an extensive study published in July 2004, focused on the effects of nighttime aircraft noise on sleep and other related human performance factors. This DLR study was one of the largest studies to examine the link between aircraft noise and sleep disturbance, and involved both laboratory and in-home field research phases. The DLR investigators developed a dose-effect curve that predicts the number of aircraft events at various Maximum A-weighted Sound Level values, which would be expected to produce one additional awakening over the course of a night. The dose-effect curve was based on the relationships found in the field studies. However, the DLR work has not yet been studied and approved by the scientific community and is simply a proposal only to be used with caution at this time.

Recognizing the need to devise a method to assess sleep disturbance to overcome concerns with the DLR study described above, in July 2008 the American National Standards Institute published ANSI/ASA S12.9-2008/Part 6: *Methods for Estimation of Awakenings with Outdoor Noise Events Heard in Homes,* which provides a method to estimate the percent of the exposed population that will be awakened by multiple aircraft noise events based on statistical assumptions about the probability of awakening (or not awakening). This approach, which relies on probability theory rather than direct field research/experimental data, was developed by and gained consensus among the subject experts who comprise ANSI's Accredited Standards Committee S12, Noise.

Figure A-8 depicts the sleeping awakening data and equations that form the basis of ANSI S12.9-2008. The curve labeled 'Eq. (B1) is the relationship between noise and awakening endorsed by FICAN in 1997. The ANSI recommended curve labeled 'Eq. (1) quantifies the probability of awakening for a population of sleepers who are exposed to an outdoor noise event as a function of the associated indoor SEL in the bedroom. This curve was derived from studies of behavioral awakenings associated with noise events in "steady state" situations. The data points in Figure A-8 come from these studies. Unlike the FICAN curve, the ANSI 2008 curve represents the average of the field research data points.

In December 2008, FICAN recommended the use of this new estimation procedure for future analyses of behavioral awakenings from aircraft noise. In that statement, FICAN also recognized that additional sleep disturbance research is underway by various research organizations, and results of that work may result in additional changes to FICAN's position. Until that time, FICAN recommends the use of ANSI S12.9-2008.

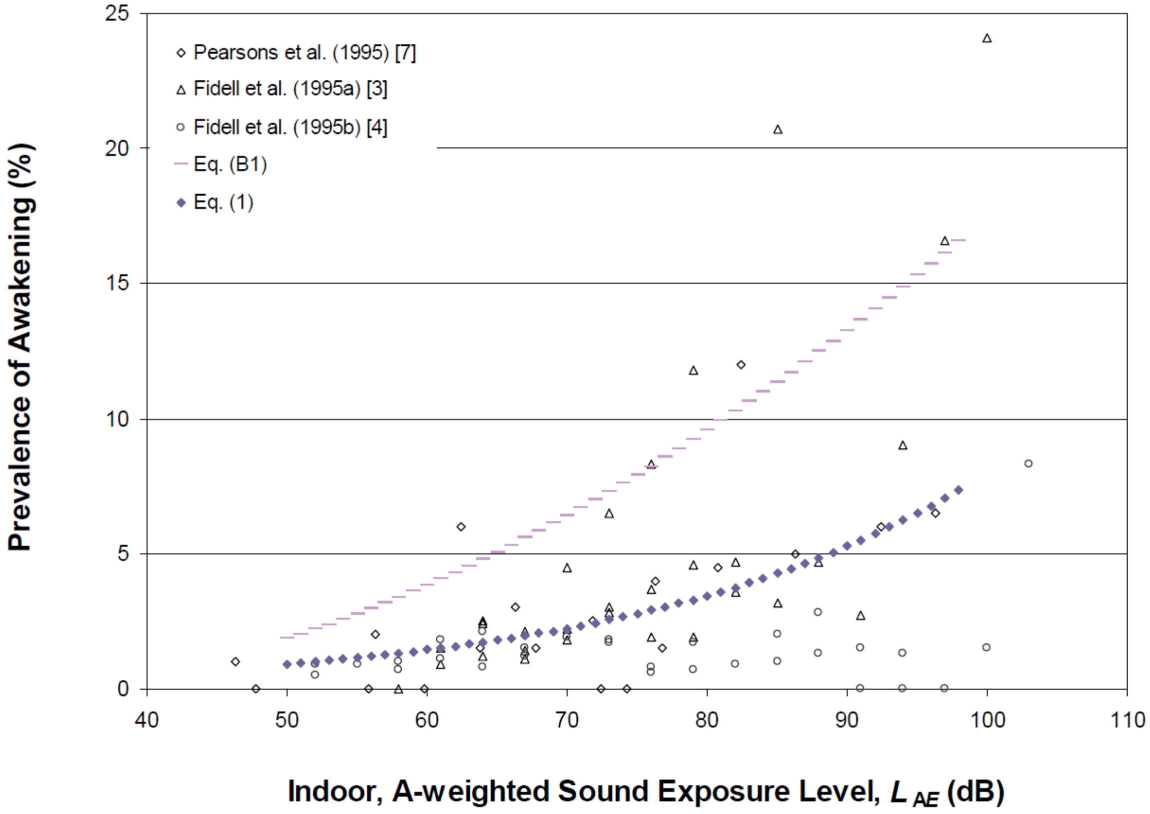


Figure A-8. ANSI S12.9-2008 Plot of Sleep Awakening Data versus indoor SEL

The Standard provides an equation to quantify the night-long probability of awakening at least once for a population of healthy adult sleepers who are exposed to an outdoor noise event as a function of its indoor SEL. The equation was derived from studies of behavioral awakenings associated with noise events in situations where the noise has been present in both level and in frequency of occurrence for a long time (on the order of a year). The Standard recognizes the number of awakenings in response to "new" noise will be higher prior to habituation during the first year, and recommends the use of the FICAN 1997 curve (shown in Figure A-8 above) when assessing awakenings from "new" noise. A rapid, substantial increase in operations in an area currently exposed or introduction of operations to an area where they do not currently occur are both examples of "new" noise.

The probability ($P_{A\ single}$) that a person of average sensitivity to awakening will be awakened by a single noise event is given by the following formula (Equation 1 in ANSI S12.9-2008):

$$P_{A,\sin gle} = \frac{1}{1+e^{-Z}}$$

where $Z = -6.8884 + 0.04444L_{AE}$, and L_{AE} represents the indoor A-weighted sound exposure level (SEL) of an outdoor single noise event. This equation represents the updated dose-response relationship shown by the ANSI 2008 curve in Figure A-8.

Formula notes:

- The indoor single-event SEL may be determined from estimates of the single event or from measurements of SEL caused by representative single events over a minimum of nine hours encompassing the period from 2200 h to 0700 h.
- Any SELs less than 50 dB shall be ignored. That is, the probability of awakening shall be set to zero for any SEL that is less than 50 dB.
- This Standard should be used with caution for indoor SELs in excess of 100 dB, which is the practical extent of the underlying data. The Standard increasingly under-predicts awakenings for SELs in excess of 100 dB. For example, at an SEL of 150 dB, the Standard predicts less than 50% of the population will be awakened. Common experience suggests the percent awakened will be closer to 100% if the indoor SEL were 150 dB. This extension to the curve above 100 dB was made because it was decided that providing data that are too low is preferable to not providing any data at all.
- SEL, if measured, shall be determined with a single microphone located 1.0 m to 1.5 m above the floor and no closer than 1.0 m from any wall within the sleeping quarters.

The Standard provides a procedure for estimating the probability of an exposed population awakening at least once from exposure to multiple nighttime aircraft noise events at different SEL. This is accomplished by multiplying the probabilities of a person of average sensitivity awakening from each single event (using the above equation) over all events at the different SELs. The resulting probability of awakening from the multiple events applies to all persons exposed to those events at the same noise levels.

The Standard also provides a procedure for estimating the probability of awakening as a function of the time of the aircraft event(s) since retiring by subdividing the 9-hour nighttime period into multiple (3 hour) sub-time segments, and determining the probability of awakening for each time segment. When the time distribution of these single noise events during the average nighttime period is unknown (as is the case with most military airfield night operations) the Standard instructs the user to use the above equation to calculate the probability of awakening at least once during the 9-hour nighttime period.

To account for the 7-hour normal sleep period as a single segment during the 9-hour nighttime period, the user is instructed to multiply the number of noise events during the 9-hour nighttime period by 7, and then divide by 9. Detailed procedures for applying the above formula are provided in a Defense Noise Working Group Technical Bulletin entitled “Sleep Disturbance From Aviation Noise.”

An analysis of potential sleep disturbance is recommended when nighttime operations are an issue or a concern expressed by the affected communities, using the July 2008 American National Standard Institute’s and Acoustical Society of America’s method to predict the percent of an exposed population that may be awakened from multiple noise events at least once during a night-long period. However, there are two provisions in the ANSI Standard that may not be appropriate for application to military noise analyses.

First, the Standard provides for the division of the 9-hour nighttime period (2200-0700) into multiple time segments, defining the distribution of noise events for each time segment, and determining the probability of awakening as a function of the time since retiring. This procedure is not recommended for analysis of nighttime military aircraft operations, unless the hourly distribution of flight events by aircraft noise is known and varies little from day to day throughout the year.

Second, the Standard recommends the use of the FICAN 1997 probability of awakening curve as an alternative to the ANSI 2008 relationship for the probability of awakening to a sound that is new to an area, i.e., less than a year since introduction. Since the interest in military noise analyses is to assess the long-term impacts of noise exposure, use of this more conservative relationship is not recommended unless there are specific requirements to consider short-term effects.

Currently, there are no established criteria for evaluating sleep disturbance from aircraft noise, although recent studies have suggested a benchmark of an outdoor SEL of 90 dB as an appropriate *tentative* criterion when comparing the effects of different operational alternatives. The corresponding indoor SEL would be approximately 25 dB lower (at 65 dB) with doors and windows closed, and approximately 15 dB lower (at 75 dB) with doors or windows open. According to the ANSI 2008 Standard, the probability of awakening from a single aircraft event at this level is between 1 and 2 percent for people habituated to the noise sleeping in bedrooms with windows closed, and 2 to 3 percent with windows open. The probability of the exposed population awakening at least once from multiple aircraft events at noise levels of 90 dB SEL is shown in Table A-4.

An important element in evaluating nighttime noise exposure is presentation of the results in a format that facilitates decision-making and provides the public with understandable information. Whereas the metric for estimating the probability of awakening from a single aircraft noise event is the SEL, there is a requirement for a supplemental metric to present the probability of awakening from multiple aircraft events. To apply the ANSI Standard, the number of events that occur at or above SEL 90 dBA must be determined. The most appropriate metric for this is the Number-of-events Above (NA) metric.

As its name implies, the NA metric describes the noise exposure at a given location in terms of the number of aircraft events, N, that are equal to or exceed a specified SEL. This description is written as NASEL (N). Thus, NA90(1), would describe the noise exposure at a location where 1 event exceeds an SEL of 90 dB in a given time period. An assessment of potential sleep disturbance in the vicinity of an airbase would then consist of developing NA90 SEL contours for a series of number of events; e.g. NA90(1) for one event, NA90(2) for two events, and so on. DNWG recommends NA90 contours be presented in increments of 1, 3, 5, 9, 18, and 27 per 9-hour nighttime period (using increments of 9 events equates to 1, 2, 3, etc. events per hour over the 9-hour nighttime period). Additional increments of nighttime events can be included if the average nighttime activity is 36 or more per night.

It should be recognized that at a location on a NA90(N) contour, not all the aircraft events will be exactly at 90 dB SEL. At a location where the noise exposure is NA90(5); i.e. 5 events above 90 dB SEL, there will most probably be individual events at higher SELs, say 92, 94, and 98, each of which will have a different probability of awakening depending on the level, as calculated using ANSI 2008 Equation 1 (see Figure A8 above). Assuming all the events occur at *exactly* 90 dB SEL will result in a slightly lower overall probability of awakening at least once from the multiple events. This conservative approach, used in developing Table A-4, is recommended to estimate awakenings. If a more detailed analysis is required, the probability of awakening more than once from the multiple events at different levels can be estimated from the procedure described at the end of this section, which was used to compute the percentages in Table A-4. The ANSI Standard considers the percent awakenings in Figure A1 to also be the probability of an individual awakening from a single event. Thus, the Table A-4 results are both the probability of an exposed individual being awakened at least once and the predicted percentage of an exposed population that will awakened; and this point must be clearly explained in NEPA documentation.

Table A.4. Minimum Probability of Awakening at Least Once from Multiple Aircraft Noise Events at 90 dB SEL

No. of Aircraft Events at 90 dB SEL for Average 9-Hour Night	Minimum Probability of Awakening at Least Once	
	Windows Closed*	**Windows Open****
1	1%	2%
3	4%	6%
5	7%	10%
9 (1 per hour)	12%	18%
18 (2 per hour)	22%	33%
27 (3 per hour)	32%	45%

*'Windows Closed' assumes there is a 25 dB noise level reduction (NLR) between the outdoors and indoors, e.g., 90 dB SEL outdoors is 65 dB SEL indoors.

**'Windows Open' assumes there is a 15 dB NLR between the outdoors and indoors, e.g. 90 dB SEL outdoors is 75 dB SEL indoors).

Sleep disturbance research still lacks sufficient specificity to accurately estimate the population awakened for a specific exposure environment, or the difference in population awakened for a given change in that environment. The procedure described in the ANSI 2008 Standard and endorsed by FICAN is based on probability calculations that have not yet been scientifically validated. While this procedure certainly provides a much better method for evaluating sleep awakenings from multiple aircraft noise events, the estimated probability of awakenings can only be considered approximate. It is for this reason that DNWG recommends against the presentation of contours in terms of percent awakenings. NA90 SEL contours for multiple events can be plotted on a local area map, but the associated percent awakenings should only be presented in narrative or tabular format.

Figure A-9 shows contours plotted in the recommended increments. As the number of events increases, the size of the exposure area decreases and the probability of at least one awakening for each exposed individual increases. For example, in the geographic area between the NA90(5) contour and the smaller NA90(9) contour, the average probability for each exposed person to awakening at least once is between 7 percent and 12 percent for the windows-closed condition.

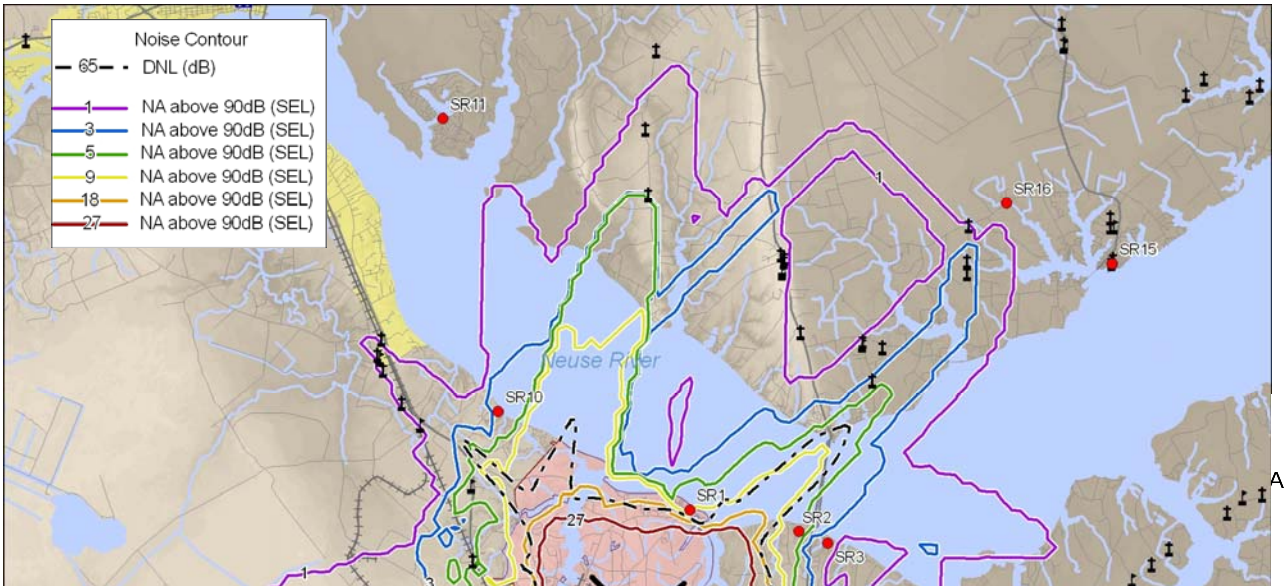


Figure A-9.. MCAS Cherry Point NA90 (SEL) and DNL 65 dB Contours

Interpreting ANSI S12.9-2008

Probability of a person of average sensitivity being awakened by a single event is given in Equation 1 of the Standard:

$$P_{A,\sin gle} = \frac{1}{1+e^{-Z}} \qquad \text{(A1)}$$

Where;

$$Z = -6.8884 + 0.04444 L_{AE,indoors},$$

$L_{AE,indoors}$ is the A-weighted indoor sound exposure level (SEL)

$$L_{AE,indoors} = L_{AE,outdoors} - NLR$$

$L_{AE,outdoors}$ is the A-weighted outdoor sound exposure level (SEL)

NLR (Noise Level Reduction) means the amount of noise level reduction in decibels achieved through noise attenuation (between outdoor and indoor levels) in the design and construction of a structure.

Thus;

$$Z = -6.8884 + 0.04444\left(L_{AE,outdoors} - NLR\right)$$

The probability of being awakened at least once by multiple events is given in Equation C.4 of the Standard:

$$P_{A,multiple} = 1 - \prod_{a=1}^{N}\left(1 - P_{A,\sin gle}\right)_{a} \quad \text{(A2)}$$

Where;

N is the total number of events between 2200 and 0700 hours

$(1-P_{A,single})_a$ is the probability of not being awakened by event a

If each event a produces a sound level at or above the selected threshold outside the residence, then Equation A2 becomes:

$$P_{A,multiple} \geq 1 - \left(1 - P_{A,\sin gle}\right)^{N}$$

According to the Standard:

> "If one elects to retain the 7-h sleep period as a single segment then multiply the number of noise events during the 9-h nighttime period by 7 divided by 9 to account for the 7-h of sleep during the 9-h nighttime period, and use Equation (1) and the method above to calculate the probability of awakening at least once."

Therefore the probability of being awakened at least once by N sound events at or above the selected threshold over the 9-hour nighttime is given by:

$$P_{A,multiple} \geq 1 - \left(1 - P_{A,\sin gle}\right)^{N\, 7/9}$$

Application to NA90 (SEL)

At NA90;

$L_{AE,outdoors}$ = 90 dB

And assuming that NLR = 25 dB for homes with windows closed;

$L_{AE,indoors}$ = 90 – 25 = 65 dB

Then;

$$Z = -6.8884 + 0.04444(65) = -3.9998$$

$$P_{A,\sin gle} = \frac{1}{1+e^{-Z}} = \frac{1}{1+e^{-(-3.9998)}} = .018 = 1.8\%$$

$$P_{A,multiple} \geq 1-\left(1-P_{A,\sin gle}\right)^{N\,7/9} = 1-\left(1-.018\right)^{N\,7/9} = 1-\left(.982\right)^{N\,7/9}$$

NA90		Minimum $P_{A,multiple}$
1	$N = 1$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{7/9} = .014 = 1.4\%$
3	$N = 3$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{21/9} = .041 = 4.1\%$
5	$N = 5$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{35/9} = .068 = 6.8\%$
9	$N = 9$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{63/9} = .119 = 11.9\%$
18	$N = 18$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{126/9} = .224 = 22.4\%$
27	$N = 27$	$\geq 1-(.982)^{N\,7/9} = 1-(.982)^{189/9} = .317 = 31.7\%$

To calculate the 'Windows Open' condition, repeat the above calculations using NLR = 15 dB instead of 25 dB.

A.1.4.4 Guidelines and Criteria

The World Health Organization[9] concluded that high sound levels created by both intermittent and continuous noise leads to sleep disturbance in residential situations. The guidelines state that research indicates that measurable effects on sleep begin when steady-state noise (e.g., noise from air conditioning systems or steady highway traffic flow) exceeds an 8-hour L_{eq} value of 30 dB indoors. Similarly, WHO concluded that research has shown that individual, intermittent noise sources (e.g., aircraft overflights) have a measurable effect on sleep at indoor L_{max} levels of 45 dB or higher. The guidelines simply recommend limiting the number of events, but they do not provide exact guidance on the allowable number of events at the recommended thresholds.

WHO provides additional guidance for specialized situations. For pre-schools or day-care centers that include a period of the day for napping, the guidelines suggest limiting L_{max} values to 45 dB. Similarly, for hospital rooms the WHO recommends limiting individual events to L_{max} values of 40 dB.

A study was conducted on behalf of the Frankfurt/Main Airport[49] to synthesize the best-available scientific understanding in developing allowable noise criteria for German airports. Thresholds were developed for the following adverse noise effects: hearing damage, illness, substantial community annoyance, interference with speech communication, interference with outdoor recreation, and sleep disturbance. The authors developed a hierarchy of threshold levels:

- Critical Tolerance Levels – Highly recommended to protect health and welfare; levels which cannot be exceeded.
- Preventative Guidance Levels – Recommended as a precautionary level where health and welfare are generally protected, and which should not be exceeded; at these levels, interference and annoyance can affect sensitive groups.
- Marginal Levels – Recommended as the minimum allowable levels.

One of the more interesting facets of the report is the recommendation for not only noise level thresholds, but also for the allowable number of events that correspond to those thresholds. The study recommends the following criteria as a mechanism for protecting sleep:

- Critical Tolerance Level: $L_{eq22\text{-}6h}$ = 40 dB and (6) nighttime events at L_{max} = 60 dB;
- Preventative Guidance Level: $L_{eq22\text{-}6h}$ = 35 dB and (13) nighttime events at L_{max} = 53dB; and
- Marginal Level: $L_{eq22\text{-}6h}$ = 30 dB and (23) nighttime events at L_{max} = 40 dB.

A.1.4.5 Summary

Table A-4 summarizes the noise levels and corresponding effects documented in the research and literature discussed above. As different criteria were discussed in different metrics, all levels in this table have been converted to an outdoor L_{max} values for comparison. These conversions assume that the outdoor-to-indoor Noise Level Reduction (NLR) with windows open is 15 dB and the SEL values are assumed to be 10 dB greater than the L_{max} values.

A.1.5 Effects on Performance and Mental Activity

It is generally assumed that a quiet environment is a requirement for good concentration, task performance, and creative activity, regardless of whether the activity is at home, in school, or in the workplace (refer to the specific discussion on children's learning for a more complete overview of this subject). While it is evident that noise can interfere with these activities (at some noise level threshold), the knowledge developed through various scientific studies has not established an exact causal relationship.

Most of the research regarding the effects of noise on task performance has been performed in high noise environments in military and industrial workplace settings. In these studies, transportation noise producing L_{eq} values up to 60 dB did not have an effect on the efficiency or accuracy of tasks that involved reading, proof-reading, and mathematical calculations[8]. Some aspects of short-term memory and complex brain functions can be momentarily disrupted above noise exposure levels of 95 dB, but the studies have not shown an effect on overall, long-term performance. It is important to note that there have been few, if any, detailed studies on the effects of noise on human productivity in community settings[10].

The consensus within the scientific community is that, provided aircraft noise does not result in interference with communication or does not pose a risk for hearing impairment, then the potential for negative effects on task performance and mental activities are expected to be minimal to none.

Table A-4. Current Sleep Disturbance Research Summary

Source	Noise Metric & Referenced Threshold Level	Effects and Notes	Outdoor Sound Level
UK Field Study (1992)	L_{max} < 80 dB (outdoors)	No detectable increase in the probability of sleep disturbance	L_{max} < 95 dB
	L_{max} = 80-95 dB (outdoors)	Probability of awakening = 1 in 75	L_{max} = 95-110 dB
FICAN (1997)	SEL=58 dB/L_{max}=48 dB (indoors)	3% Awakenings	L_{max} = 63 dB
	SEL=80 dB/L_{max}=70 dB (indoors)	10% Awakenings	L_{max} = 85 dB
	SEL=90 dB/L_{max}=80 dB (indoors)	13% Awakenings * Upper envelope of field data	L_{max} = 95 dB
Fidell, et al. (2000)	SEL=58 dB/L_{max}=48 dB (indoors	1% Awakenings	L_{max} = 63 dB
	SEL=80 dB/L_{max}=70 dB (indoors)	4% Awakenings	L_{max} = 85 dB
	SEL=90 dB/L_{max}=80 dB (indoors)	5% Awakenings *Synthesized results of several field studies	L_{max} = 95 dB
German Aerospace Center/ DLR (2004)	L_{max} = 48 dB (indoors)	2% Awakenings/34 nighttime events will induce 1 additional awakening	L_{max} = 63 dB
	L_{max} = 60 dB (indoors)	5% Awakenings/17 nighttime events will induce 1 additional awakening	L_{max} = 75 dB
	L_{max} = 69 dB (indoors	9% Awakenings/12 nighttime events will induce 1 additional awakening *Based on results of field study	L_{max} = 85 dB
WHO (1999)	L_{eq} = 30 dB (indoors)	No Awakenings - Continuous noise	L_{max} = 60 dB
	L_{max} = 45 dB (indoors)	No Awakenings - Intermittent noise	
Griefahn, et al./ Frankfurt (2002)	L_{night} = 30 dB (indoors)	Marginal Level – Continuous Noise	L_{night} = 45 dB
	L_{night} = 35 dB (indoors)	Preventive Guidance Level – Continuous Noise	L_{night} = 50 dB
	L_{night} = 40 dB (indoors)	Critical Tolerance Level – Continuous Noise	L_{night} = 55 dB
	L_{max} = 40 dB (indoors)	Marginal Level – 23 nighttime events	L_{max} = 55 dB
	L_{max} = 53 dB (indoors)	Preventive Guidance Level – 13 nighttime events	L_{max} = 68 dB
	L_{max} = 60 dB (indoors)	Critical Tolerance Level – 6 nighttime events	L_{max} = 75 dB

A.2 Physiological Effects

A.2.1 Noise-Induced Hearing Impairment

Residents in surrounding communities express concerns regarding the effects of aircraft noise on hearing. This section provides a brief overview of hearing loss caused by noise exposure. The goal is to provide a sense of perspective as to how aircraft noise (as experienced on the ground) compares to other activities that are often linked with hearing loss.

A.2.1.1 Definition of Hearing Impairment

Considerable data on hearing loss have been collected and analyzed by the scientific/medical community. It has been well established that continuous exposure to high noise levels will damage human hearing[4].

Hearing loss is generally interpreted as a decrease in the ear's sensitivity or acuity to perceive sound; i.e. a shift in the hearing threshold to a higher level. This change can either be a Temporary Threshold Shift (TTS), or a Permanent Threshold Shift (PTS)[50].

TTS can result from exposure to loud noise over a given amount of time, yet the hearing loss is not necessarily permanent. An example of TTS might be a person attending a loud music concert. After the concert is over, the person may experience a threshold shift that may last several hours, depending upon the level and duration of exposure. While experiencing TTS, the person becomes less sensitive to low-level sounds, particularly at certain frequencies in the speech range (ypically near 4,000 Hertz)[51]. Normal hearing ability eventually returns, as long as the person has enough time to recover within a relatively quiet environment.

PTS usually results from repeated exposure to high noise levels, where the ears are not given adequate time to recover from the strain and fatigue of exposure. A common example of PTS is the result of working in a loud environment such as a factory. It is important to note that TTS can eventually become PTS over time. Thus, even if the ear is given time to recover from TTS, repeated occurrence of TTS may eventually lead to permanent hearing loss. The point at which a Temporary Threshold Shift results in a Permanent Threshold Shift is difficult to identify and varies with a person's sensitivity. In general, hearing loss (be it TTS or PTS) is determined by the duration and level of the sound exposure.

A.2.1.2 Criteria for Temporary Threshold Shift (TTS)

Table A-6 shows a relationship between noise level and exposure time, as they relate to TTS[52]. The values in the table relate noise exposure and the corresponding exposure times that will result in a 10 dB TTS in the vicinity of 4,000 Hz, measured 2 minutes after the noise ceases.

A.2.1.3 Criteria for Permanent Hearing Loss

The Occupational Safety and Health Administration (OSHA) regulation of 1971[53] standardizes the limits on workplace noise exposure for protection from hearing loss as an average level of 90 dB over an 8-hour work period or 85 dB over a 16-hour period (the average level is based on a 5 dB decrease per doubling of exposure time). Even the most protective criterion (no measurable hearing loss for the most sensitive portion of the population at the ear's most sensitive frequency, 4,000 Hz, after a 40-year exposure) is an average sound level of 70 dB over a 24-hour period.

The EPA established 75 dB for an 8-hour exposure and 70 dB for a 24-hour exposure as the average noise level standard requisite to protect 96% of the population from greater than a 5 dB PTS[4]. The National Academy of Sciences Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) identified 75 dB as the minimum level at which hearing loss may occur[54]. However, it is important to note that continuous, long-term (40 years) exposure is assumed by both EPA and CHABA before hearing loss may occur. Finally, the World Health Organization[9] has concluded that environmental and leisure-time noise below an L_{eq24} value of 70 dB "will not cause hearing loss in the large majority of the population, even after a lifetime of exposure."

Table A-6. Noise Level and Exposure Time to produce a TTS of 10 dB

Level (dB)	Exposure Time (Continuous)
70	12 hr
75	7 hr
80	2 hr
85	20 min
90	7 min
95	5 min
100	3 min
110	1.5 min
120	50 sec

A.2.1.4 Community Hearing Loss and Aircraft Noise

The scientific community has concluded that there is little likelihood that the resulting noise exposure from aircraft noise could result in either a temporary or permanent hearing loss. According to the document entitled "The Effects of Noise on People"[55], the EPA criterion ($L_{eq}24$ = 70 dBA) can be exceeded in some areas located near airports, but that is only the case outdoors. Inside a building, where people are more likely to spend most of their time, the average noise level will be much less than 70 dBA. The authors also report that "several studies in the U.S., Japan, and the U.K. have confirmed the predictions that the possibility for permanent hearing loss in communities, even under the most intense commercial take-off and landing patterns, is remote."

A laboratory study measured changes in human hearing from noise representative of low-flying aircraft on Military Training Routes (MTRs)[56]. The potential effects of aircraft flying along MTRs is of particular concern because of that fact that maximum overflight noise levels can exceed 115 dB, with rapid increases in noise levels exceeding 30 dB/sec. In this study, participants were first subjected to four overflight noise exposures at A-weighted levels of 115 dB to 130 dB. One-half of the subjects showed no change in hearing levels, one-fourth had a temporary 5 dB *increase* in sensitivity, and one-fourth had a temporary 5 dB decrease in sensitivity. In the next phase, participants were subjected to a single overflight at a maximum level of 130 dB for eight successive exposures, separated by 90 seconds or until a temporary shift in hearing was observed. The temporary hearing threshold shift showed an *increase* in sensitivity of up to 10 dB.

In another study of 115 test subjects between 18 and 50 years old, temporary threshold shifts were measured after laboratory exposure to military low-altitude flight (MLAF) noise[57]. According to the authors, the results indicate that repeated exposure to MLAF noise with L_{max} greater than 114 dB, especially if the noise level increases rapidly, may have the potential to cause noise induced hearing loss in humans.

A.2.1.5 Summary

Because it is unlikely that airport neighbors will remain outside their homes 24 hours per day, there is little likelihood of hearing loss below a 24-hour average sound level of 75 dB.

A.2.2 Non-Auditory Health Effects of Noise

The reaction of people to a given noise environment is extraordinarily complex. This is particularly evident when trying to evaluate the potential health effects of people exposed to aircraft noise. One reason for this is the intermittent nature and the character of aircraft noise, in which noise levels fluctuates significantly from high to low over time. Another important element is the complex psychological and physiological reaction of people to not only the actual noise environment, but the attitude toward the source of the noise. Further exacerbating this complex issue is the possibility that short-term community reaction can be different than the long-term community reaction.

In an effort to better understand people's response to noise, the scientific community has divided the noise effects on people into two general categories of responses. Psychological effects refer to behavioral reactions that are indicators of the population's "well-being" – essentially, people's psychological reaction to their noise environment and their reaction to interference with their various day-to-day activities. The primary examples are the potential effects on long-term community annoyance, speech interference (includes effects in the home, school, churches, and auditoria), sleep disturbance (home), effects on children's learning (school), and interference with work performance. The second type of indicators for human response to noise is the physiological effects – essentially, real medical effects on the human body's systems. The primary example of this is noise-induced hearing loss, although other medical health effects such as cardiovascular disease have been postulated by various researchers and communities over the years. For each of these indicators that attempt to describe the long-term community reaction to noise, the scientific community has spent considerable effort since the mid-1950s researching the noise metrics and associated noise levels that best relate to community response.

Non-auditory effects of noise, as dealt with in this bulletin, can be defined as those physiological effects on health and well-being which are caused by exposure to aircraft noise, but excluding the effects on hearing. The physiological effects discussed in this bulletin include:

Stress Response -- The human stress response is a natural coping mechanism that occurs when there is a perceived threat. For people who are susceptible, the stress response triggers a sudden release of stress hormones. These hormones can cause temporary changes in heart rate and blood pressure. The postulate is that, for some people, a sudden or uncontrollable intense noise may be enough to cause a stress response. In most cases, the stress response is short-term, and the person's heart rate and blood pressure soon return to normal.

Cardiovascular Effects – Hypertension and Heart Disease --The postulate is that noise exposure causes hypertension (elevated blood pressure) and other stress-related effects on humans. Ischemic heart disease is characterized by insufficient perfusion of oxygen to the heart muscle, which could lead to angina or heart attack (myocardial infarction).

Birth Defects -- The postulate is that high aircraft noise exposure leads to increased incidences of central nervous system defects in the offspring of parents residing near airports.

Mortality Rates -- The postulate is that stress-related effects of high aircraft noise exposure lead to increased incidences of deaths due to strokes (sudden disruption in blood flow to the brain) and deaths due to cirrhosis of the liver (primarily attributed to alcoholism).

A.2.2.1 Summary of Current Understanding

The results of early studies conducted in the United States, primarily concentrating on cardiovascular response to noise, have been contradictory. Cantrell[1] concluded that the results of human and animal experiments show that average or intrusive noise can act as a stress-provoking stimulus. Prolonged stress is known to be a contributor to a number of health disorders. Kryter and Poza state[1], "It is more likely that noise-related general ill-health effects are due to the psychological annoyance from the noise interfering with normal everyday behavior, than it is from the noise eliciting, because of its intensity, reflexive response in the autonomic or other physiological systems of the body." Psychological stresses may cause a physiological stress reaction that could result in impaired health.

The National Institute for Occupational Safety and Health and EPA commissioned CHABA to study whether established noise standards are adequate to protect against health disorders other than hearing defects. CHABA's conclusion was that:

"Evidence from available research reports is suggestive, but it does not provide definitive answers to the question of health effects, other than to the auditory system, of long-term exposure to noise. It seems prudent, therefore, in the absence of adequate knowledge as to whether or not noise can produce effects upon health other than damage to auditory system, either directly or mediated through stress, that insofar as feasible, an attempt should be made to obtain more critical evidence."[1]

Most studies of nonauditory health effects of long-term noise exposure have found that noise exposure levels established for hearing protection will also protect against any potential nonauditory health effects, at least in workplace conditions. One of the best scientific summaries of these findings is contained in the lead paper at the National Institutes of Health Conference on Noise and Hearing Loss, held on 22 to 24 January 1990 in Washington, D.C.:

"The non-auditory effects of chronic noise exposure, when noise is suspected to act as one of the risk factors in the development of hypertension, cardiovascular disease, and other nervous disorders, have never been proven to occur as chronic manifestations at levels below these criteria (an average of 75 dBA for complete protection against hearing loss for an 8-hour day). At the recent (1988) International Congress on Noise as a Public Health Problem, most studies attempting to clarify such health effects did not find them at levels below the criteria protective of noise-induced hearing loss, and even above these criteria, results regarding such health effects were ambiguous.

Consequently, one comes to the conclusion that establishing and enforcing exposure levels protecting against noise-induced hearing loss would not only solve the noise-induced hearing loss problem, but also any potential nonauditory health effects in the work place[62]."

The conclusion of the WHO[9] is that long-term aircraft noise exposure in the range of $L_{eq,24h}$ values of 65-70 dB or more may be associated with some cardiovascular effects. However, the WHO guidelines note that the causal relationships are weak. The guidelines further point out that the findings on other physiological effects are too inconsistent to draw conclusions.

In September 2008, the Transportation Research Board (TRB) published Airport Cooperative Research Program Synthesis Report #9, "Effects of Aircraft Noise: Research Update on Selected Topics." This synthesis study is intended to inform airport operators, stakeholders, and policymakers of updated information about aviation noise effects. In the decades since FAA Report FAA-EE-85-2 "Aviation Noise Effects" was first published in 1985 much has changed in the understanding of this complex issue. Increased air travel, new and quieter aircraft, increased awareness of land use planning and aviation noise, and mitigation of previously incompatible land uses are just a few of the changes. Knowledge of the effects of aviation noise has also changed. The greatest increases in knowledge have come in the areas of health effects, annoyance, sleep disturbance, and potential effects on children's learning

A.2.2.2 Stress Response

Exposure to high noise levels, far greater than those produced by aircraft in the community, can elevate blood pressure and also stress hormone levels. However, the response to such loud noise is typically short in duration. After the noise stops, the physiological effects reverse and levels return back to normal. In the case of repeated exposure to aircraft noise, the connection is not as clear. The results of most cited studies are inconclusive, and it cannot really be stated that a causal link exists between aircraft noise exposure and the various type of non-auditory health effects that were studied. There are just too few studies, and, among the studies that have been performed, the results are often contradictory. A case in point is study of school children near Munich airport.

The Munich airport study examined stress hormone levels in children attending schools located near a civilian airport, the only study of its kind. The study showed that levels of stress hormones (called catecholamines, which include epinephrine and norepinephrine) became elevated in children attending experimental (exposed) schools, when compared against children in non-exposed schools. Elevated levels of these hormones may result in elevated blood pressure, which is the reason they are of interest to researchers. However, "potential confounding factors" make it unclear as to whether the elevated levels were actually caused by noise.

The ACRP Synthesis cites another German study (1992), which examined effects on children in contrasting geographic regions. These regions differed according to the noise made by jetfighters exercising frequently at low altitude. Neither psychiatric disorders nor environmental factors showed any relationship to noise; however, physiological parameters (e.g., heart rate and muscle tension) demonstrated some relationship to noise. The synthesis notes that the meaning of this is unknown requiring further research.

A.2.2.3 Cardiovascular Effects Hypertension

Several studies have suggested that noise exposure may cause hypertension and other stress-related effects in adults. Near an airport in Stockholm, Sweden, the prevalence of hypertension was reportedly greater among nearby residents who were exposed to energy averaged noise levels exceeding 55 dB and maximum noise levels exceeding 72 dB, particularly for older subjects and those not reporting impaired hearing ability. A study of elderly volunteers who were exposed to simulated military low-altitude flight noise reported that blood pressure was raised by a maximum noise level of 112 dB. Yet another study of subjects exposed to varying levels of military aircraft or road noise found no significant relationship between noise level and blood pressure.

A German study indicated elevated blood pressure levels among children near the experimental schools (compared with the control group). The researchers found a statistically-significant rise in both systolic and diastolic blood pressure. An earlier study of children living near airports, located near Los Angeles International Airport, also showed an increase in blood pressure among children in the experimental group. That study involved peak noise levels of up to 95 dB indoors, within a flight corridor with up to 300 flights per day. However, both studies have received criticism in that they both failed to control for other factors that could have led to increases in blood pressure.

Another frequently cited study failed to control enough situational variables. In that study hypertension was monitored in adults living near Schiphol airport in Amsterdam. The study revealed a possible relationship between hypertension and aircraft noise for people in noise exposure zones exceeding DNL 62 dB. The Schiphol results have been criticized because the researchers failed to control for socioeconomic differences between study subjects. Consequently, a conclusive causal link between aircraft noise and hypertension cannot be claimed.

The ACRP Synthesis also addressed claims concerning hypertension. Several recent studies, through a review of previous work, suggest that increased hypertension or other cardiovascular effects may be associated with particular long-term noise exposure. For example, the WHO Guidelines for Community Noise suggests a weak association between long-term environmental noise exposure and hypertension, but does not establish a dose-response relationship. Another example, a study by Passchier-Vermeer and Passchier (2000), reviewed existing literature that stated there was sufficient scientific evidence that noise exposure can induce hearing impairment, hypertension, and ischemic heart disease. It concluded there were no obvious effects from noise exposure on mean diastolic and mean systolic blood pressure; however, some effects were observed in terms of an increase in the percentage of individuals with hypertension.

Studies related to blood pressure are problematic and inconclusive in general. Blood pressure varies considerably from person to person, and it can also be inconsistent within an individual. It is difficult to control other factors that may affect blood pressure, which makes it hard to identify the exact effects that aircraft noise alone might have. Those other factors, such as family history, diet, or socioeconomic conditions may also affect blood pressure. To control all of those other factors, in the interest of isolating aircraft noise as the only possible cause, is practically impossible.

The ACRP Synthesis came to a similar conclusion. No differences in systolic and diastolic blood pressure have been found in cross-sectional studies comparing areas near an airport with calm, suburban areas. Cross-sectional studies are notoriously difficult to interpret. They often report conflicting results, generally do not identify a cause and effect relationship, and often do not report a dose-response relationship between the cause and effect.

A.2.2.4 Cardiovascular Effects – Heart Disease

Very few studies have been conducted to draw links between aircraft noise and heart disease. The potential for noise to affect the cardiovascular system has been speculated for many years; however, no unequivocal evidence exists to support such claims. Conclusions drawn from a review of health effect studies involving military low-altitude flight noise with its unusually high maximum levels and rapid rise in sound level have shown no increase in cardiovascular disease.

The ACRP Synthesis found that most reviewers concluded that previous studies were not carried out in a systematic way, which makes them prone to bias. Part of the problem seems due to inadequately reporting noise exposure data. For example, Van Kempen et al. (2002) concluded that whereas "noise exposure can contribute to the prevalence of cardiovascular disease, the evidence for a relation between noise exposure and ischemic heart disease is still inconclusive, because of the limitations of exposure characterization, adjustment for important confounders, and occurrence of publication bias." The WHO Guidelines for Community Noise concluded that cardiovascular effects may be associated with long-term exposure; however, the associations are weak albeit the effect is somewhat stronger for ischemic heart disease than for hypertension.

A.2.2.5 Birth Defects

Some decades ago, researchers from University of California at Los Angeles (UCLA) studied the population near Los Angeles International Airport (LAX) and found a higher rate of birth defects for 1970 to 1972 when compared with a control group residing away from the airport. Based on this report, a separate group at the Center for Disease Control (CDC) performed a more thorough study of populations near Atlanta's Hartsfield International Airport (ATL) for 1970 to 1972. They found no relationship in their study of 17 identified categories of birth defects to aircraft noise levels above 65 dB.

The ACRP Synthesis does not address birth defects but does discuss studies on birth weights. The synthesis describes how recent studies have focused on relationships between noise exposure during pregnancy and low birth weights. However, no association was found between personal noise exposure (measured in decibels) and birth weight (Wu et al. 1996; Passchier-Vermeer and Passchier 2000). Other possible noises (e.g., occupational, traffic noise, and history of listening to amplified music) also showed no effect on infant birth.

A.2.2.6 Mortality Rates

A 1979 study performed near LAX identified a substantial increase in mortality rates in the area where noise was the highest. Specifically, the study claimed a 15 percent increase in deaths due to strokes and 100 percent increase in deaths due to cirrhosis of the liver as a result of jet noise. However, a reanalysis of the data published in 1980 did not confirm the original results. Instead, the 1980 study indicated that "once the confounding effects of age, race, and sex were taken into account by direct and indirect methods of standardization, there was little difference in the mortality experience of the airport and control areas."

The ACRP Synthesis does not address mortality. The WHO Guidelines for Community Noise asserts that "Pollution and degradation of the indoor environment cause illness, increased mortality, loss of productivity, and have major economic and social implications," but does not cite any studies that relate noise exposure to mortality. In 1997, researchers from the University of Sydney published a review of the health effects of aircraft noise in the Australian And New Zealand Journal of Public Health (1997, 21 : 221-236). They concluded that "population-based studies have not found strong evidence that people living near or under aircraft flight paths suffer higher rates of clinical morbidity or mortality as a consequence of exposure to aircraft noise. A dearth of high quality studies in this area precludes drawing substantive conclusions."

A.2.2.7 HYENA Project

The European Union (EU) Hypertension and Exposure to Noise near Airports (HYENA) Project deserves special attention because it is a recent major scientific effort (involving several EU member states) that drew considerable publicity (at least in Europe). The ACRP Synthesis provides annotations for two studies conducted under HYENA.

The overall project aim is to assess the impacts on cardiovascular health of noise generated by aircraft and road traffic. The project evaluates the modifying effects of air pollution on noise associated cardiovascular effects, and analyzes the difference in blood pressure resulting from different noise exposure patterns. The project assesses the role of annoyance and sleep disturbances on blood pressure and investigates the impact of aircraft and road traffic noise on stress hormone levels. The project examines acute changes in blood pressure that follow short-term changes in noise levels.

The project includes cross-sectional studies near major airports in Germany (Berlin Tegel), Greece (Athens), Italy (Milano Malpensa), the Netherlands (Amsterdam Schiphol), Sweden (Stockholm Arlanda) and the UK (London Heathrow), including a total of 6,000 study subjects. The studies were conducted in the vicinity of airports with a wide range of exposures, from low to high levels of noise exposure from different sources, which allows for detailed analyses of exposure-response relationships for the general population as well as for susceptible subgroups.

One of the most recent scientific papers on HYENA was published in the Environmental Health Perspectives (Vol. 116, No. 3, March 2008). This study is a corollary to the much larger study described in the previous paragraph. This most recent study, which included 140 middle-aged volunteers with normal blood pressure, was designed to take a closer look at the link between noise and hypertension risk. The authors claimed to have found significant exposure–response relationships between night-time aircraft as well as average daily road traffic noise exposure and risk of hypertension after adjustment for major confounders. Their statistical analysis indicated excess risks of hypertension related to long-term noise exposure, primarily for night-time aircraft noise and daily average road traffic noise.

The online publication of this paper generated some sensationalizing headlines in press releases, such as:

- “Aircraft noise raises blood pressure even whilst people are sleeping, says study” – Imperial College of London, Feb. 13, 2008;
- “Sleepers 'at risk' from jet noise” – BBC News (online), Feb. 13, 2008;
- “Aircraft noise can kill, report claims” – Telegraph.co.uk, Feb. 17, 2008;
- “Airport noise instantly boosts blood pressure” – Reuters (UK), Feb. 13, 2008;
- “Night flight noise linked to hypertension” – The Guardian, Feb. 13, 2008;
- “Aircraft noise raises blood pressure” – The Australian, Feb. 13, 2008;
- “Airplane Noise Boosts Blood Pressure Even During Sleep” – US News & World Report, Feb. 13, 2008;
- “Living near an airport is bad for your health” – MSNBC, Feb. 13, 2008;
- “Sleeping near airports is bad for your health” – EC DG Environment News Alert Service, April 17, 2008;
- “Study: Noise can trigger spike in blood pressure” – BostonHerald.com, Feb. 14, 2008;
- “Is a snoring partner driving you to an early grave?” – Daily Mail Online, Feb. 13, 2008; and
- “Why Sleeping with a Snorer is bad for you” – The Daily Express, Feb. 13, 2008.

A TIME Magazine article on the study offers observations and quotes that provide important perspective on interpreting the findings (Nighttime Noise and Blood Pressure, Sara Song, February 13, 2008, http://www.time.com/time/health/article/0,8599,1713178,00.html). The article notes that “The response was consistent across all sources of sound, whether from the runway or the other side of the bed. …. A snoring partner and road traffic had similar impact. And the effect was dose dependent.” The article quotes one of the study coauthors, Dr. Lars Jarup, who specializes in environmental and occupational medicine at Imperial College London, as saying "It's a small increase in the blood pressure, obviously, but it is significant." The article points out that this increase in blood pressure at night is still a bit of a mystery for the researchers and quotes Dr. Jarup as saying: “"It seems plausible that if you have a lot of these transient [blood pressure] changes during the night — if you live around the airport for many years, for example — that in the end you might get some long-term effects on your blood pressure, but we don't really know." Part of the mystery might be due to problems in the data and methods. The ACRP Synthesis cites this paper, but after closer review of the data for night-time aircraft noise raises some questions about the data and the methods.

A.2.2.8 Summary

What Von Gierke and Eldred wrote in 1993 succinctly summarizes this Section A.2.2 - “there is no unambiguous scientific evidence to relate quantitatively any noise environment with the origin of or contribution to any clinical non-auditory disease”[56]. The 2008 ACRP Synthesis reiterats that 1993 state of the knowledge as follows: “Despite decades of research, including review of old data and new research efforts, health effects of aviation noise continue to be an enigma. Most, if not all, current research concludes that it is as yet impossible to determine causal relations between health disorders and noise exposure, despite well-founded hypotheses.”

Thus, there is no widely accepted scientific basis for a claim that non-auditory health effects exist for aircraft time-average sound levels below 75 dB.

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APPENDIX B

Supplemental Analysis – Military Case Studies

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Supplemental Analysis – Military Case Studies

B.1 Introduction

Three military facilities were chosen for analysis using the Number-of-events Above (NA) supplemental metric as recommended in Section 6.3 of this Guide. Each facility chosen has undergone either a Navy or Marine Corps AICUZ study using the traditional DNL/CNEL analysis approach. This section provides real-world examples of the results produced when the NA metric is used to supplement DNL analysis to more completely define the noise environment around military air installations.

The studies profiled in this section include:

(1) Naval Air Station (NAS) Whidbey Island (AICUZ 2004);
(2) Naval Air Station (NAS) North Island, (AICUZ 2006); and
(3) Marine Corps Base (MCB) Cherry Point (AICUZ 2007).

The baseline noise condition originally used to produce DNL/CNEL contours was used in each of these case studies. The NA analysis of daytime operations was performed with the Maximum Level (L_{max}) metric for evaluation of speech interference and the nighttime NA analysis was performed with the Sound Exposure Level (SEL) metric. (speech interference research is conducted with the L_{max} metric and sleep disturbance research is performed using the SEL metric) The selected threshold level for the daytime NA analysis was L_{max} 75 dB, and the selected threshold for the nighttime NA analysis was SEL 90 dB, as recommended in Section 6.3 (see Table 6-1). NOISEMAP 7.0 was recently modified to calculate NA. No TA calculations were performed in these case studies since the NOISEMAP model does not calculate TA. The results for each case study are described separately below.

For each case study, noise complaint data for 2006 and 2007 was collected from installation staff and the complainant address information was geo-coded to obtain latitude/longitude information. These locations were then input into NOISEMAP and plotted on a background map along with the noise contours.

Next, NOISEMAP was run to calculate the NA at or above the selected L_{max} and the SEL thresholds. NA daytime results relating to speech interference were then plotted on the background map to show the 5, 10 and 15 event contours for the annual average day along with the 2004 base case DNL 65 dB contour. Similarly, the nighttime results relating to sleep disturbance were plotted on the background map to show the 1 event contour compared to the DNL 65 dB contour.

From the complaint data, known residential areas and school locations, geographic points of interest (POI) were then selected for NA analysis. These POI are located both inside and outside of the DNL 65 dB contour. The data points were also plotted on the base map along with the DNL, L_{max} and SEL contours, illustrating the importance of having tools other than DNL to present noise exposure to persons residing "outside" the 65 dB contour.

To produce a complete description of noise exposure, NA was calculated and tabulated over a range of thresholds starting from 55 dB to 90 dB in 5 dB increments for both the daytime hours of 0700 to 2200 using L_{max} and the nighttime hours of 2200 to 0700 using SEL. While these complete results were tabulated, the tables below summarize the results by comparing the DNL at each POI with the NA at or above 75 dB L_{max} and 90 dB SEL, corresponding respectively to the recommended thresholds for speech interference and sleep disturbance analysis. In the North Island results table below, 80 and 85 dB SEL are also shown because none of the POI average even one operation per night above 90 dB SEL.

Select POI are highlighted in the tables. The POI labeled "Noise Complaint" reflect locations from which noise complaints originated and the POI labeled "Area of Concern" reflect residential areas that generate few if any noise complaints. Many of the complaint locations are well outside the DNL 65 dB contour. Daytime events at or above 75 dB L_{max} and nighttime events at or above 90 dB SEL threshold may interfere with speech or disturb sleep, and thus give rise to noise complaints.

B.2 Naval Air Station Whidbey Island and Outlying Landing Field Coupeville

Naval Air Station (NAS) Whidbey Island, or Ault Field, is located in Oak Harbor, Washington, approximately 60 miles north of Seattle, Washington. Outlying Landing Field (OLF) Coupeville, located 9.8 miles south-southeast of Ault Field and 3 miles south of the town of Coupeville, is used primarily for Field Carrier Landing Practice (FCLP).

The US Navy is the primary user of Ault Field facilities and runways. There are 19 active-duty squadrons, 2 reserve squadrons and several other tenants on the field. The two major aircraft types based at NAS Whidbey Island are the EA-6B Prowler and the P-3 in two configurations: the P-3C Orion and the EP-3E Aries II.

Table B-1 shows annual flight operations for the CY2003 conditions at NAS Whidbey Island and OLF Coupeville. During CY2003, 81,959 annual airfield flight operations were conducted at Ault Field and 7,682 annual military flight operations were conducted at OLF Coupeville. The large majority of operations (90 percent) at Ault Field are conducted during the daytime and evening hours (0700-2200); slightly fewer (83 percent) of the operations at OLF Coupeville are conducted during the same time period, and 17 percent operate during the nighttime hours.

The DNL contours and the daytime NA 75 L_{max} daytime contours for the selected thresholds are shown in Figure B-1 together with the complaint locations. They show two-thirds of the complaint locations have exposure less than DNL 65 dB. The DNL contours and the nighttime NA 90 dB SEL contours for 1 operation are shown in Figure B-2. The overall shape of the DNL contours generally follow the shape of both the daytime and nighttime NA contours, indicating that both daytime and nighttime operations contribute to the DNL.

Table B-1. Modeled Flight Operations for NAS Whidbey Island and OLF Coupeville for CY 2003

Aircraft Type	Operation Type	CY03 Operations		
		0700-2200	2200-0700	TOTAL
EA-6B	Departure	4,466	350	4,816
	Arrival	4,445	371	4,816
	Closed Pattern[1]	30,413	6,249	36,662
P-3	Departure	7,957	226	8,183
	Arrival	7,958	225	8,183
	Closed Pattern[1]	17,528	419	17,947
C-9 [2]	Departure	211	114	325
	Arrival	211	114	325
	Closed Pattern	0	0	0
C-12 [2]	Departure	65	35	100
	Arrival	65	35	100
Transient [2,3]	Departure	164	88	252
	Arrival	164	88	252
TOTAL		**73,646**	**8,313**	**81,959**
EA-6B	Closed Pattern at OLF[1]	6,390	1,292	7,682

Source: Brown, 12 August 2004

1 Counted as 2 operations
2 Operation Numbers derived from 2004 ATAC Draft Report - Day/Night Split Percentage (65% / 35%) from WR 94-13
3 Transient aircraft modeled as P-3

A tabulation of the number of events exceeding various noise levels is shown in Table B-2. The yellow shaded POI are located outside the DNL 65 dB contours. Those that are either inside the NA 75 dB L_{max} contours with 5 or more events per day or the 90 dB SEL contours with 1 or more events per night, or both (rounded up to the next whole number of events), are shaded in blue. Four of the noise complaint locations with a DNL less than 65 dB also have very few day or night events above the selected L_{max} and SEL thresholds. Thus, this analysis suggests that not all noise complaints are related to a high number of events at or above intrusive single event noise levels.

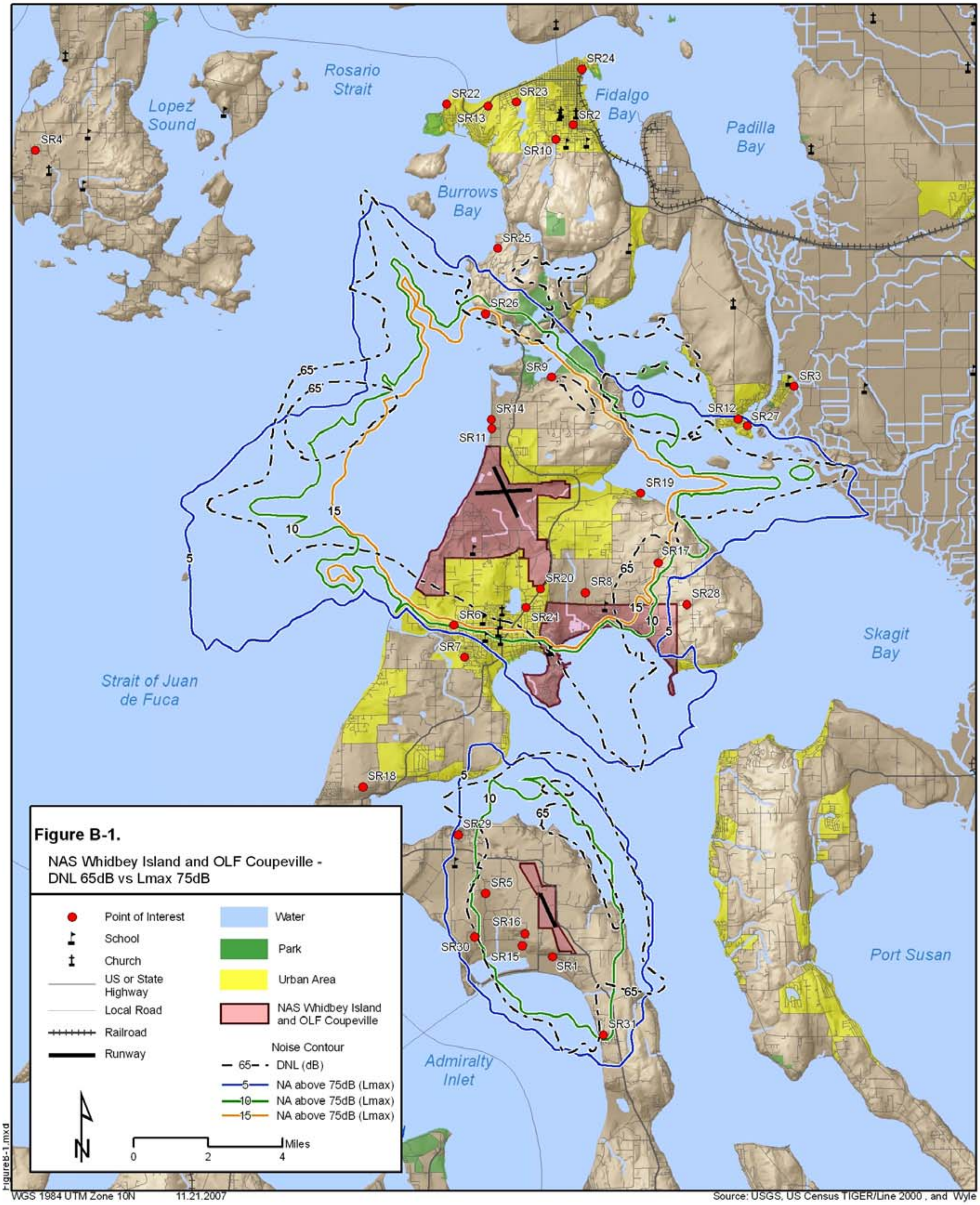


Figure B-1.

NAS Whidbey Island and OLF Coupeville - DNL 65dB vs Lmax 75dB

WGS 1984 UTM Zone 10N 11.21.2007

Source: USGS, US Census TIGER/Line 2000 , and Wyle

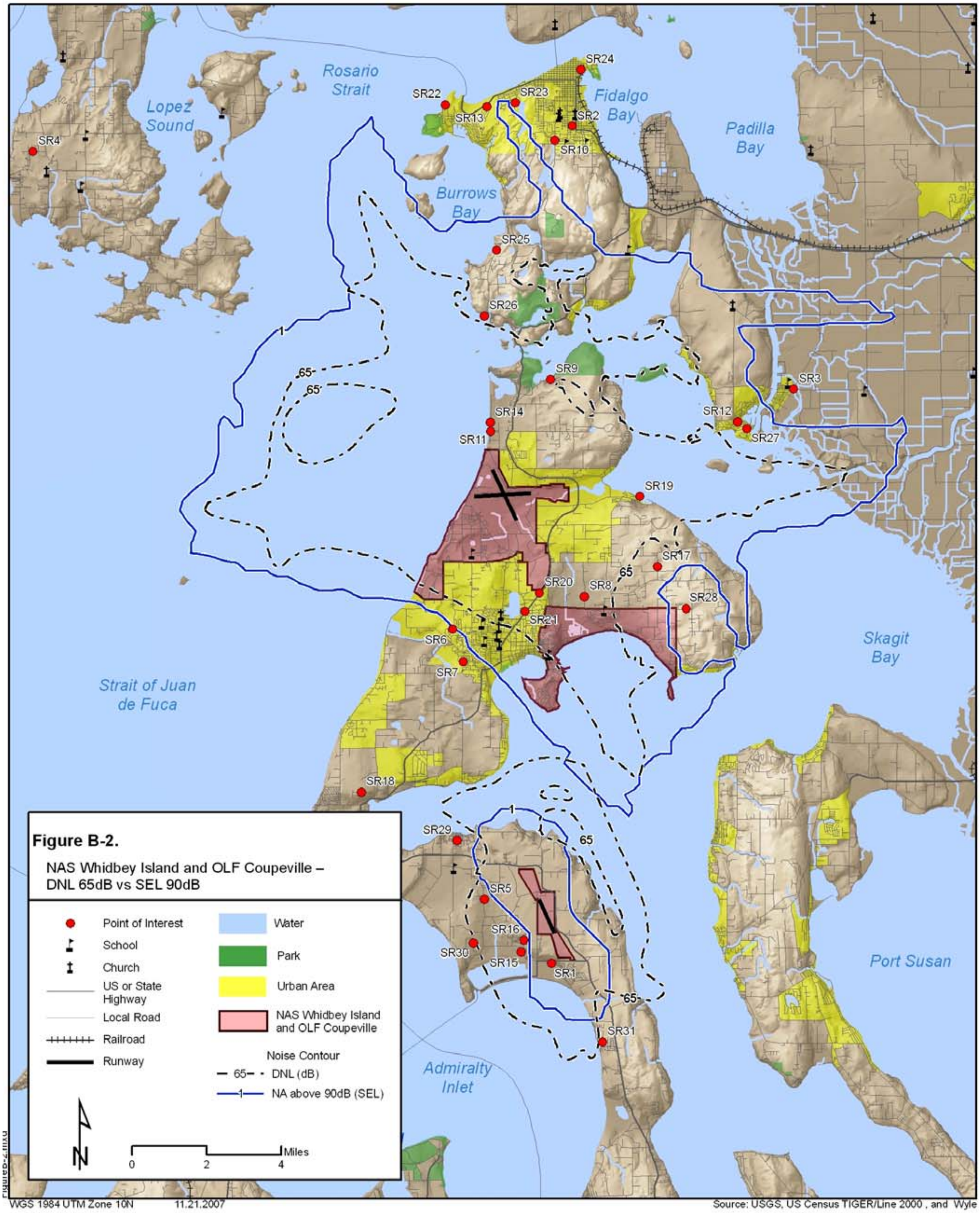


Figure B-2.

NAS Whidbey Island and OLF Coupeville – DNL 65dB vs SEL 90dB

WGS 1984 UTM Zone 10N 11.21.2007

Source: USGS, US Census TIGER/Line 2000 , and Wyle

Table B-2. Number-of-events Above (NA) for NAS Whidbey Island and OLF Coupeville

POI ID	DNL	Number of Events (NA)	
		L_{max} = or > 75 dB	SEL = or > 90 dB
SR1 - Noise Complaint	73.9	12.9	1.1
SR2 - Noise Complaint	59.4	1.0	0.5
SR3 - Noise Complaint	57.0	1.0	0.7
SR4 - Noise Complaint	31.3	0.0	0.0
SR5 - Noise Complaint	67.7	12.1	0.8
SR6 - Noise Complaint	57.8	12.0	0.3
SR7 - Noise Complaint	54.2	1.4	0.0
SR8 - Noise Complaint	71.2	37.9	4.1
SR9 - Noise Complaint	66.2	24.6	3.3
SR10 - Noise Complaint	59.3	1.6	0.5
SR11 - Noise Complaint	76.3	66.5	7.1
SR12 - Noise Complaint	60.0	6.5	1.4
SR13 - Noise Complaint	58.1	1.8	0.7
SR14 - Noise Complaint	75.2	64.8	5.6
SR15 - Noise Complaint	66.7	12.2	0.9
SR16 - Noise Complaint	67.3	12.9	0.9
SR17 - Noise Complaint	61.7	15.4	1.9
SR18 - Noise Complaint	55.3	2.3	0.3
SR19 - Noise Complaint	74.2	42.5	4.6
SR20 - Noise Complaint	77.1	51.3	4.6
SR21 - Noise Complaint	70.4	42.3	3.4
SR22 - Area of concern	57.7	1.8	0.7
SR23 - Area of concern	58.7	1.5	0.5
SR24 - Area of concern	50.9	0.3	0.3
SR25 - Area of concern	60.0	1.8	1.0
SR26 - Area of concern	62.5	21.1	2.8
SR27 - Area of concern	59.2	6.6	1.5
SR28 - Area of concern	62.4	4.8	0.9
SR29 - Area of concern	59.5	6.0	0.4
SR30 - Area of concern	63.3	6.5	0.6
SR31 - Area of concern	61.6	12.1	0.4

* L_{max} is calculated for daytime flight operations and static operations

** SEL is calculated for nighttime flight operations only.

B.3 Naval Air Station North Island and Outlying Field Imperial Beach

Naval Air Station (NAS) North Island is located in the southwestern area of the state of California, near the Mexican border and is bordered by San Diego Bay and the Pacific Ocean on the west side and the city of Coronado on the east side. NAS North Island is centered around two runways: 18/36 and 11/29. In addition, the airfield has 13 helicopter pads of which four are most used. The helicopter pads are used by resident squadrons for operations at NAS North Island (ATC, 2006b).

Outlying Landing Field (OLF) Imperial Beach is known as "The Helicopter Capitol of the World," and is situated on 1,204 acres lying approximately 14 miles south of San Diego and within the city limits of Imperial Beach. OLF Imperial Beach, as the outlying training field for helicopters, is used by the helicopter squadrons from NAS North Island and the mission at the present time is to provide a training site for helicopter traffic, both VFR and IFR, from NAS North Island. As a result the helicopter squadrons at NAS North Island conduct the large majority of their training operations at OLF Imperial Beach. OLF Imperial Beach consists of two east-west runways: 08/26 and 09/27. In addition, there are five helicopter pads located south of the runways and. (NAS North Island, 2006a) (WR 06-11)

Table B-3 shows the CY2005 condition for NAS North Island as defined by airfield operations obtained from Air Traffic Activity Reports (ATAR) and ATC logs, and modified by ATC personnel to reflect CY2005 fleet mix and number of operations. Table B-4 shows the CY2005 condition for OLF Imperial Beach.

Based on the CY2005 ATAR data, Navy/Marine H-60 operations at OLF Imperial Beach totaled 223,729. Touch and go training accounted for 86 percent of operations. On average, there is less than one nighttime operation per 24-hour day.

The CNEL contours and the daytime NA 75 L_{max} daytime contours for the selected thresholds are shown in Figure B-3 together with the complaint locations. Most of the schools and other areas of concern are located outside the DNL 65 dB contour. The NA contours clearly show the multiple flight tracks of the H-60's traveling from North Island to Imperial Beach. Because the majority of operations are conducted in the daytime hours, the CNEL contour is aligned with the highest density daytime tracks.

The CNEL contours and the nighttime NA 90 SEL contours for 1 operation are shown in Figure B-4. Since there are relatively few nighttime operations, the CNEL contours are not aligned with the tracks, demonstrating that the CNEL is determined largely by daytime operations. Note also that the NA contour in Figure B-4 is very narrow, and does not extend continuously to OLF Imperial Beach, implying a lower power setting as the H-60 approaches the OLF.

A tabulation of the number of events exceeding various noise levels is shown in Table B-5. The yellow shaded POI are all located outside the DNL 65 dB contours. POI inside the NA 75 dB L_{max} contours with 5 or more events per day and/or the 80 or 85 dB SEL contours with 3 or more events per night (rounded up to the next whole number of events), are shaded in blue. Very little noise complaint data was available for this case study, so only 4 of the POI were selected based on noise complaint data. Two of those points exceed the selected daytime NA 75 dB L_{max} threshold, but none of these or any others in the study average more than one event per night above 90 dB SEL. Grid point SR4 has 3.5 events above 85 dB SEL and 4.2 above 80 dB SEL. This level of night operations at or above 80 dB SEL may explain some of noise complaints around this installation when we consider that this case study also includes a much higher number of helicopter operations than the others in this Guide.

Because so little noise complaint data was available, additional POI at schools or in residential areas near the CNEL 65 dB contours were also selected for analysis. Our analysis revealed that a little more than half of these points experience noise exposure at or above the selected threshold levels for this case study. Eight of the 20 points did not average day or night noise exposure above the selected thresholds.

Table B-3. Modeled Flight Operations for NAS North Island for CY 2005

Aircraft Type	Operation Type	CY05 Operations			
		0700-1900	1900-2200	2200-0700	TOTAL
C550	Departure	1,431	27	0	1,458
	Arrival	1,420	38	0	1,458
	Closed Pattern[1]	162	0	0	162
C210	Departure	372	10	0	382
	Arrival	378	4	0	382
	Closed Pattern[1]	118	3	0	121
P-3	Departure	928	36	19	983
	Arrival	928	37	18	983
	Closed Pattern[1]	33	13	39	85
LEAR 24/35/36	Departure	1,707	0	0	1,707
	Arrival	1,707	0	0	1,707
	Closed Pattern[1]	2,008	0	0	2,008
C-172	Departure	3,665	32	0	3,697
	Arrival	3,681	16	0	3,697
	Closed Pattern[1]	68	54	0	122
C-2 & E-2	Departure	1,110	70	5	1,185
	Arrival	1,127	55	4	1,186
	Closed Pattern[1]	665	54	0	719
C-40	Departure	1,503	38	23	1,564
	Arrival	1,459	60	45	1,564
	Closed Pattern[1]	277	43	36	356
C-12 (C-12/C-26)	Departure	961	45	12	1,018
	Arrival	977	30	10	1,017
	Closed Pattern[1]	368	16	1	385
H-53/H-3 [3]	Departure	163	35	0	198
	Arrival	163	35	0	198
	Closed Pattern[1]	4	3	0	7
H-60	Departure	22,925	3,032	358	26,315
	Arrival	22,067	3,637	611	26,315
	Closed Pattern[1]	7,494	687	84	8,265
EA-6B	Departure	1,331	9	4	1,344
	Arrival	1,325	18	1	1,344
	Closed Pattern[1]	13	0	12	25
AV-8B [2]	Departure	42	9	0	51
	Arrival	42	9	0	51
	Closed Pattern[1]	0	6	0	6
F/A-18C/D &E/F	Departure	656	27	11	694
	Arrival	666	19	8	693
	Closed Pattern[1]	122	16	9	147
C-17 & C-5	Departure	198	11	3	212
	Arrival	198	11	3	212
	Closed Pattern[1]	50	6	0	56
C-130H	Departure	567	22	0	589
	Arrival	567	22	0	589
	Closed Pattern[1]	39	13	0	52
TOTAL		**85,685**	**8,308**	**1,316**	**95,309**

Source: ATC, 2006b

Notes:

1 Counted as 2 operations

2 H-53/H-3 operations were modeled as H-60 (0.4 percent of CY2005 operations)

Table B-4. Modeled Flight Operations for OLF Imperial Beach for CY2005

Aircraft Type	Operation Type	CY05 Operations			
		0700-1900	1900-2200	2200-0700	TOTAL
H-60	Departure	11,313	4,525	323	16,161
	Arrival	11,314	4,525	323	16,162
	Closed Pattern[1]	133,984	53,594	3,828	191,406
TOTAL		**156,611**	**62,644**	**4,474**	**223,729**

Source: ATC, 2006b

Note:

(1) Touch and Go counted as two operations

Table B-5. Number-of-events Above (NA) for NAS North Island and OLF Imperial Beach

POI ID	CNEL dB	L_{max} = or > 75 dB	SEL = or > 80 dB	SEL = or > 85 dB	SEL = or > 90 dB
SR1 - Noise Complaint	63.7	12.5	1.2	0.1	0.1
SR2 - Noise Complaint	54.5	3.1	0.1	0.1	0.0
SR3 - Noise Complaint	50.8	2.9	0.5	0.0	0.0
SR4 - Noise Complaint	55.9	29.1	4.2	3.5	0.0
SR5 - Area of Concern	54.8	6.1	0.1	0.1	0.1
SR6 - Area of Concern	54.7	6.0	0.1	0.1	0.1
SR7 - Area of Concern	50.3	4.1	0.1	0.1	0.0
SR8 - Area of Concern	67.0	13.5	1.2	0.2	0.1
SR9 - Area of Concern	62.6	16.2	0.3	0.1	0.1
SR10 - Area of Concern	62.3	11.3	0.2	0.1	0.1
SR11 - School	49.7	4.2	0.1	0.1	0.0
SR12 - School	55.5	5.8	0.1	0.1	0.1
SR13 - School	57.9	5.7	0.1	0.0	0.0
SR14 - School	51.0	0.6	0.0	0.0	0.0
SR15 - Area of Concern	46.6	0.6	0.0	0.0	0.0
SR16 - Area of Concern	51.2	0.0	0.0	0.0	0.0
SR17 - Area of Concern	50.0	0.0	3.4	0.0	0.0
SR18 - Area of Concern	48.5	0.0	0.5	0.0	0.0
SR19 - Area of Concern	58.6	0.0	37.9	0.0	0.0
SR20 - Area of Concern	61.0	112.7	37.1	33.1	0.5

* L_{max} is calculated for daytime flight operations and static operations

** SEL is calculated for nighttime flight operations.

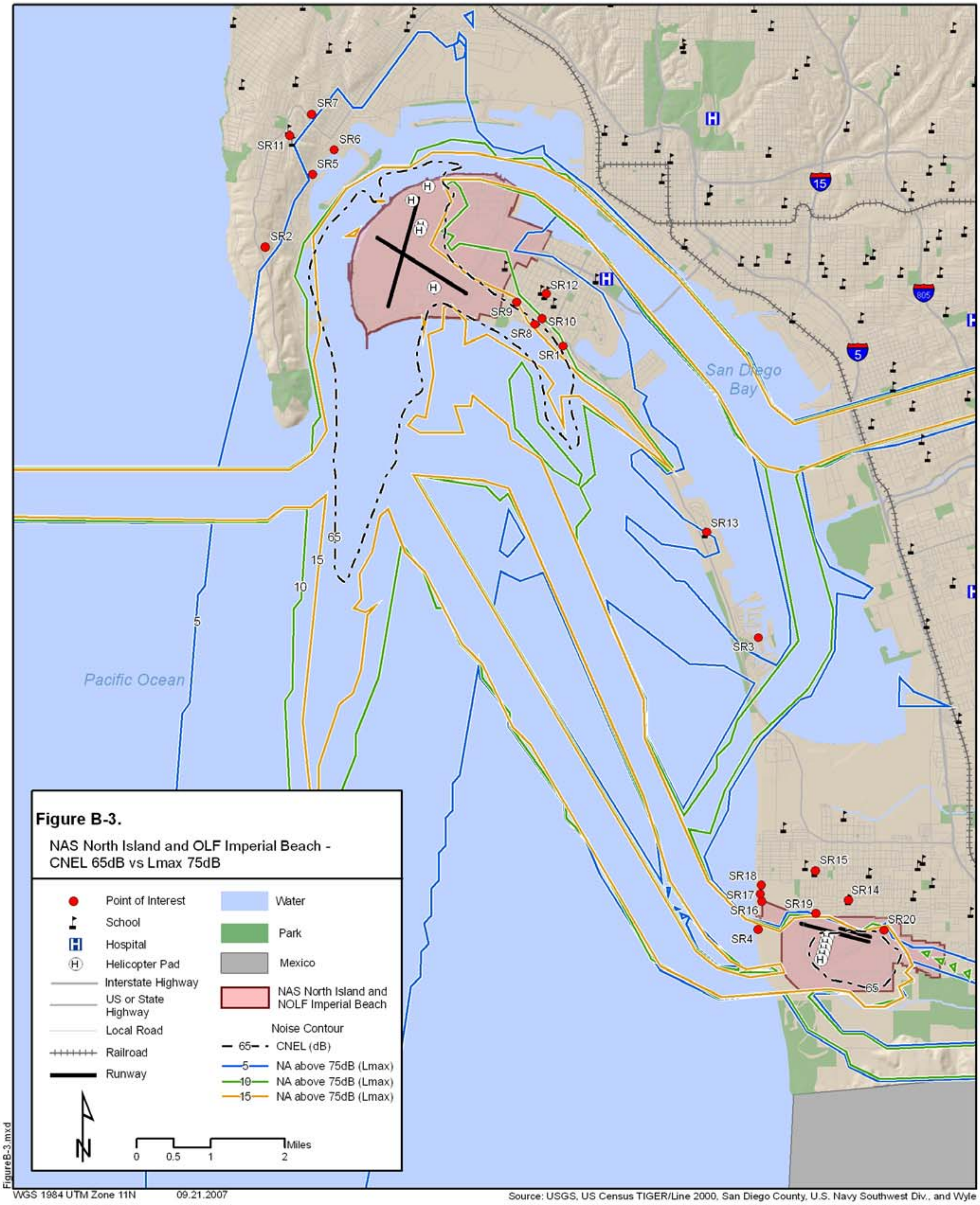


Figure B-3.

NAS North Island and OLF Imperial Beach - CNEL 65dB vs Lmax 75dB

FigureB-3.mxd

WGS 1984 UTM Zone 11N 09.21.2007

Source: USGS, US Census TIGER/Line 2000, San Diego County, U.S. Navy Southwest Div., and Wyle

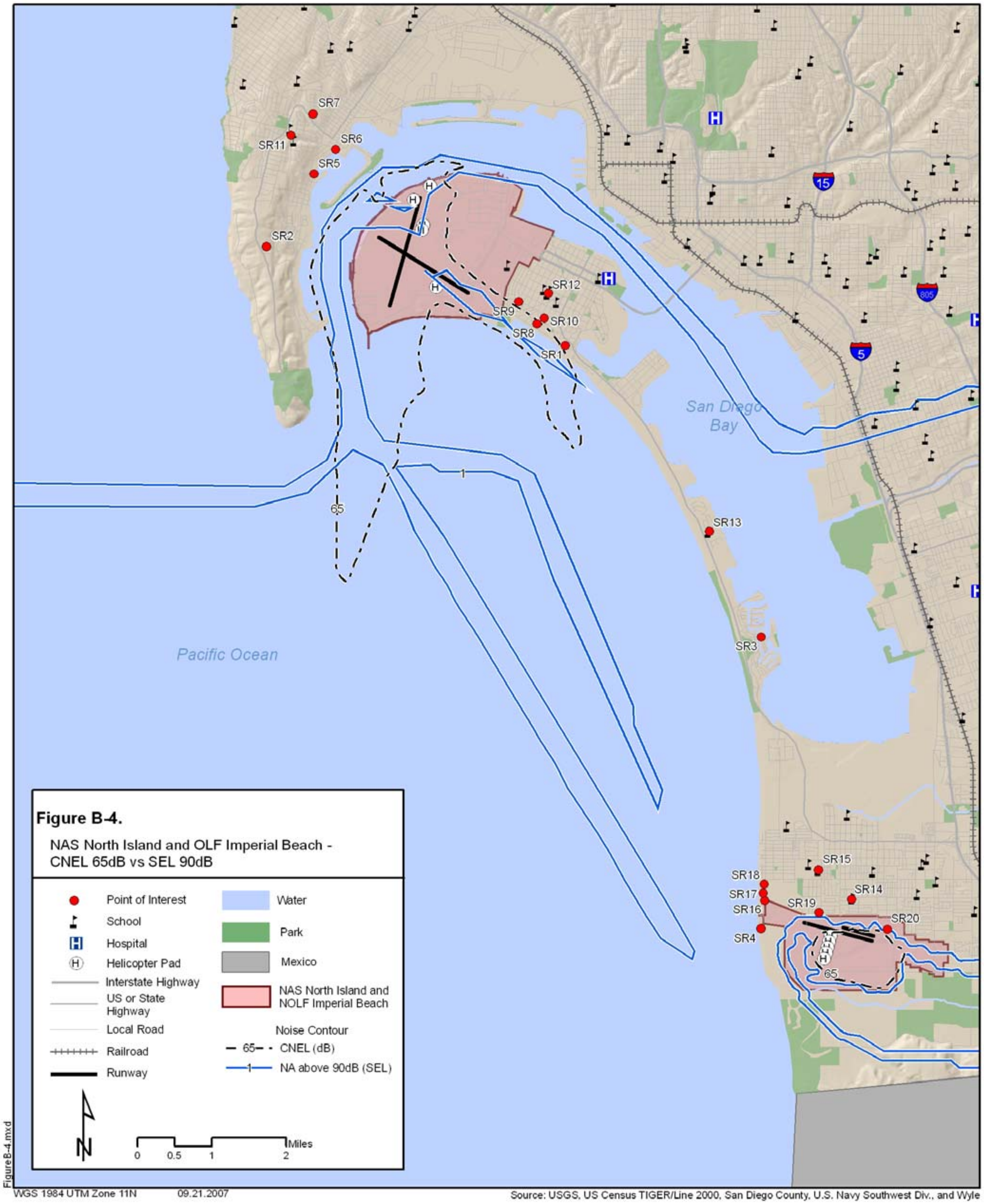


Figure B-4.

NAS North Island and OLF Imperial Beach - CNEL 65dB vs SEL 90dB

WGS 1984 UTM Zone 11N 09.21.2007

Source: USGS, US Census TIGER/Line 2000, San Diego County, U.S. Navy Southwest Div., and Wyle

B.4 Marine Corps Base Cherry Point

Marine Corps Base (MCB) Cherry Point (Cunningham Field) is located in eastern North Carolina, adjacent to the Town of Havelock. Other neighboring towns/cities include Newport, several miles to the south; Neuse Forest, along the Air Station boundary to the northwest; and Arapahoe and Minnesott Beach, northeast of the Neuse River. The Croatan National Forest represents a major neighboring land use. MCB Cherry Point has a land area of about 11,210 acres within the boundary. It also has four runways, Runway 14R/32L, Runway 14L/32R, Runway 05L/23R, and Runway 05R/23L.

The annual operations at MCB Cherry Point for CY2007 are presented in Table B-6, showing a total of 62,418. Overall, the AV-8 aircraft (both the fleet squadron and Fleet Replacement Squadron (FRS)) make up 77% of the operations, with the EA-6B accounting for 12% of operations, and transient aircraft at the base contributing approximately 11% of the total. Closed pattern operations account for 62% of all the operations at Cherry Point. Daytime operations account for approximately 97% of the total. Only 3% of operations are conducted during the nighttime hours, and 53% of these are closed pattern.

The DNL contours and the daytime NA 75 L_{max} daytime contours for the selected thresholds are shown in Figure B-5 together with the complaint locations. The NA contours clearly show the multiple AV-8flight tracks. Because the majority of operations are conducted in the daytime hours, the DNL contour is aligned with the highest density daytime tracks. The figures show that many of the complaint locations are located a considerable distance outside the DNL 65 dB contour.

The DNL contours and the nighttime NA 90 SEL contours for 1 operation are shown in Figure B-6. Note that the nighttime NA contour follows the tracks very closely, and clearly shows the presence of the AV-8 closed pattern operations to the south of the airfield.

A tabulation of the number of events exceeding various noie levels is shown in Table B-7. The yellow shaded POI are all outside the DNL 65 dB contours. Those grid points that are inside the NA 75 dB L_{max} contours with 5 or more events per day, and the 80 or 85 dB SEL contours with 3 or more events per night (rounded up to the next whole number of events), are shaded in blue. 85 dB SEL was selected as the nighttime threshold because on average, none of the grid points outside DNL 65 dB experience 1 or more events per night. Thirteen of the noise complaint POI have an aircraft noise DNL less than 55 dB and one of those points has an aircraft DNL of only 29.9. Only one POI below DNL 55 dB (widely recognized as the threshold of moderate noise exposure) averages more than 5 daytime events above the selected 75 dB L_{max} threshold, and none above the 85 dB SEL threshold. This analysis indicates that very few noise complaints originating outside the DNL 65 dB contour are related to a high number of events at or above intrusive single event noise levels.

Table B-6. Modeled Flight Operations for MCB Cherry Point for CY 2007

Aircraft Type	Operation Type	CY07 Operations		
		0700-2200	2200-0700	TOTAL
AV-8 Fleet	Departure	4,927	30	4,957
	Arrival	4,925	147	5,072
	Closed Pattern[1]	14,498	436	14,934
AV-8 FRS	Departure	2,879	8	2,887
	Arrival	2,803	66	2,869
	Closed Pattern[1]	16,799	427	17,226
EA-6B	Departure	1,198	0	1,198
	Arrival	1,499	371	1,870
	Closed Pattern[1]	4,431	118	4,549
Transient Jet	Departure	1,337	38	1,375
	Arrival	1,374	0	1,374
	Closed Pattern[1]	1,741	0	1,741
Transient Heavy	Departure	83	61	144
	Arrival	138	6	144
	Closed Pattern[1]	225	11	236
Transient Large	Departure	408	144	552
	Arrival	543	9	552
	Closed Pattern[1]	725	13	738
TOTAL		**60,533**	**1,885**	**62,418**

Source: HQMC Aviation Planning, 2007

Notes:

1 Counted as 2 operations

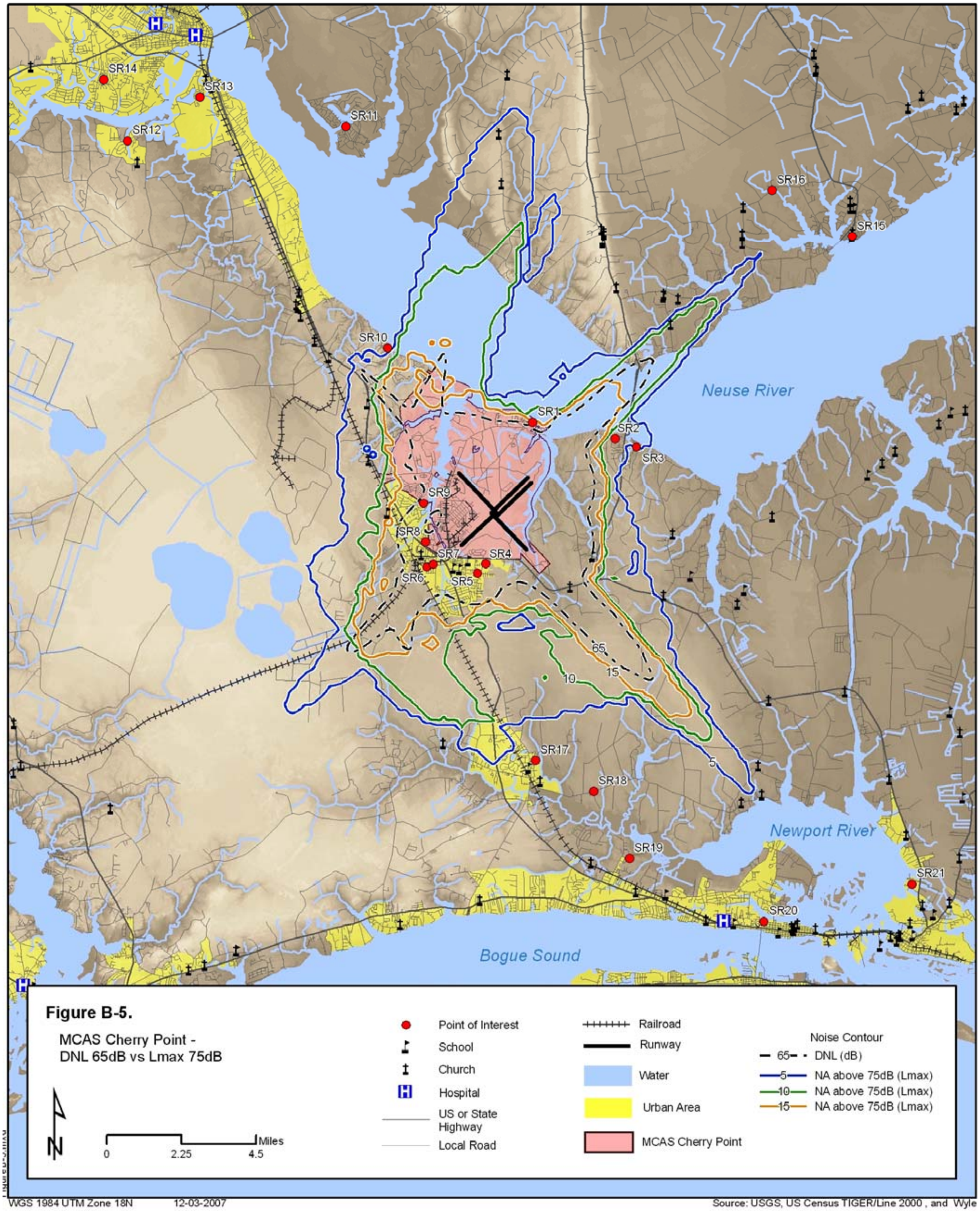


Figure B-5.

MCAS Cherry Point - DNL 65dB vs Lmax 75dB

WGS 1984 UTM Zone 18N 12-03-2007

Source: USGS, US Census TIGER/Line 2000 , and Wyle

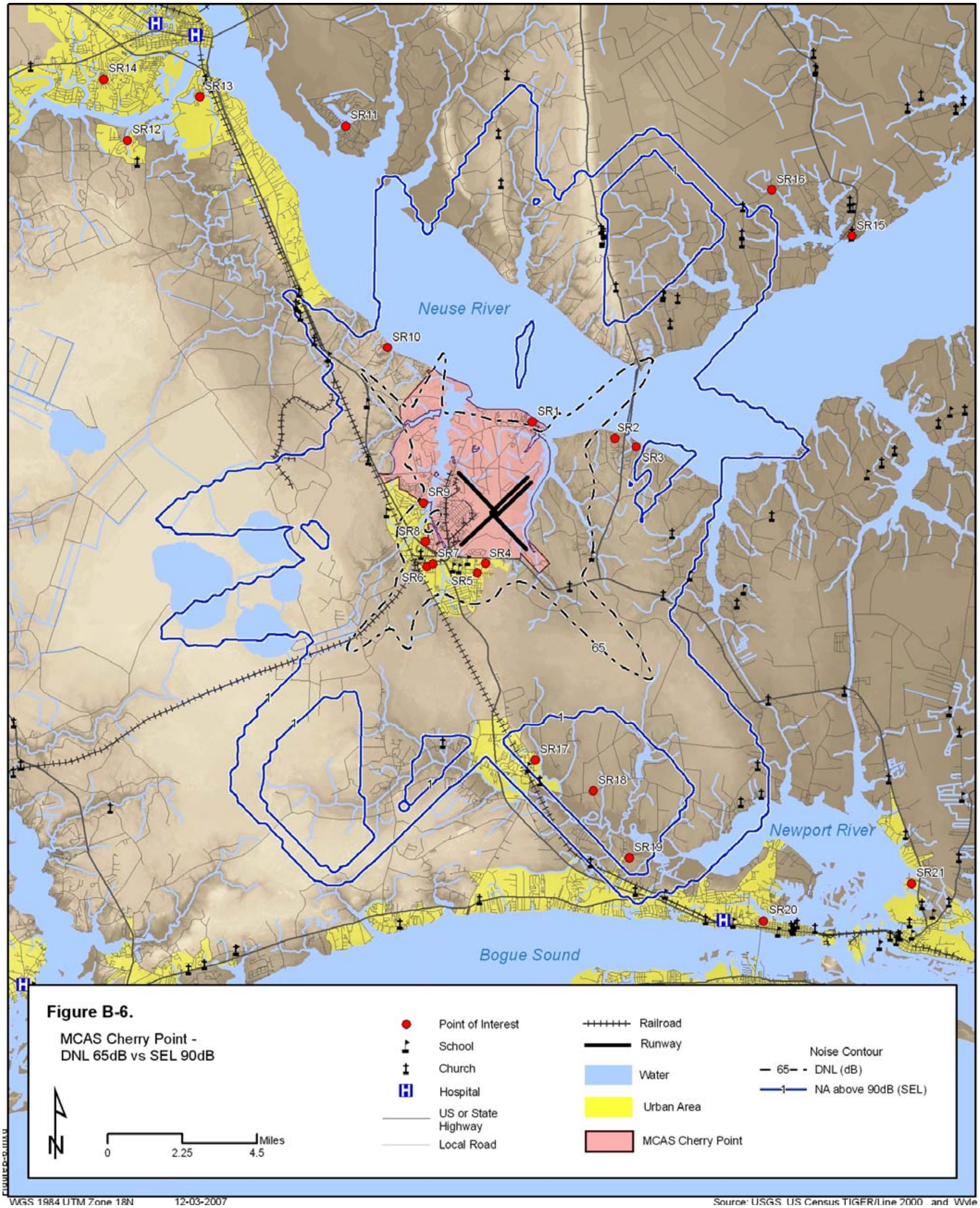


Figure B-6.

MCAS Cherry Point -
DNL 65dB vs SEL 90dB

WGS 1984 UTM Zone 18N 12-03-2007

Source: USGS, US Census TIGER/Line 2000 , and Wyle

Table B-7. Number-of-events Above (NA) for Marine Corps Base Cherry Point

POI ID	DNL dB	Number of Events (NA)		
		L_{max} = or > 75 dB	SEL = or > 85 dB	SEL = or > 90 dB
SR1 - Noise Complaint	62.1	13.7	1.6	0.6
SR2 - Noise Complaint	58.0	5.6	0.5	0.4
SR3 - Noise Complaint	52.5	6.0	0.5	0.3
SR4 - Noise Complaint	76.2	39.2	2.0	1.3
SR5 - Noise Complaint	70.3	34.8	1.8	1.1
SR6 - Noise Complaint	74.7	31.8	1.1	0.9
SR7 - Noise Complaint	76.9	33.1	1.4	0.9
SR8 - Noise Complaint	67.3	29.9	1.3	0.8
SR9 - Noise Complaint	66.1	27.6	1.5	0.6
SR10 - Noise Complaint	53.6	3.8	0.2	0.1
SR11 - Noise Complaint	37.5	0.2	0.0	0.0
SR12 - Noise Complaint	39.1	0.3	0.0	0.0
SR13 - Noise Complaint	29.9	0.0	0.0	0.0
SR14 - Noise Complaint	36.3	0.2	0.0	0.0
SR15 - Noise Complaint	39.7	0.0	0.0	0.0
SR16 - Noise Complaint	42.8	0.4	0.0	0.0
SR17 - Noise Complaint	49.5	3.0	0.0	0.0
SR18 - Noise Complaint	45.0	0.8	0.0	0.0
SR19 - Noise Complaint	49.5	2.9	0.0	0.0
SR20 - Noise Complaint	33.7	0.0	0.0	0.0
SR21 - Noise Complaint	38.1	0.0	0.0	0.0

* L_{max} is calculated for
daytime flight operations
and static operations

** SEL is calculated for nighttime flight operations.

B.5 Conclusions

These case studies show noise exposure in terms of the average number of times per day or night that aircraft noise may be intrusive at the selected threshold level over an entire study area with contours overlaid on a background map, and in more detail in tabular form for selected geographic points of interest in the study area.

By communicating noise exposure in this manner beyond the DNL 65 dB contours, base officials can increase their credibility and improve community relations. This information is also useful in handling noise complaints, since the personnel processing complaints will know approximately how many times per day and at what noise level the complainer experiences exposure above the selected day and night threshold levels.

Performing this degree of supplemental analysis prior to fleet mix or operational changes at an airfield enables officials to pinpoint noise sensitive areas that will experience a change and thus, better anticipate and manage public response when the change is implemented.

APPENDIX C

Civilian Airport Examples of Supplemental Analysis

Appendix C –
Civilian Airport Examples of Supplemental Analysis

C-1. Supplemental Information on The Noise Data for the Eastern WV Regional Airport / Shepherd Field – Martinsburg, WV

Eastern WV Regional Airport/Shepherd Field is a joint use airport located in Martinsburg, WV. In 2001, the West Virginia Air National Guard Bureau (ANGB) proposed conversion of their C-130H aircraft to the C-5A aircraft. When the conversion is implemented, the 2000 baseline annual number of C-130H operations of 6,897 would be replaces by a total of 564 C-5A operations per year. The C-5A is substantially louder than the C-130H to the extent that even though the total annual number of C-5A operations will be 12 times less than the C-130H number of operations, the forecast DNL contours are substantially larger than the baseline contours, to the extent that the projected DNL 70 dB contour will approximate the baseline DNL 65 dB contour.

In response, the local Board of Supervisors proposed to preclude new development within the future DNL 70 dB contour. If imposed, this restriction would have stopped a previously approved new subdivision valued at $15 million. The affected developer sought additional supplemental analysis to present to the Board of Supervisors to assure that they were making their decision based on the best available information.

To supplement the DNL analysis of the projected change in the noise environment between the baseline and the proposed action, a seven grid point analysis was performed using the Number-of-events Above (NA) metric. Figure 1 below shows the seven grid points, with points 1, 3, 4, 6, and 7 on the projected DNL 70 contour line; point 2 on the runway centerline extended halfway between points 1 and 5; and point 5 where the DNL 75 dB contour intersects the runway centerline extended. Figure 2 shows the relation of the selected grid points to the baseline DNL contours (note that points 3, 4, 6 and 7 fall on the baseline DNL 65 dB contour).

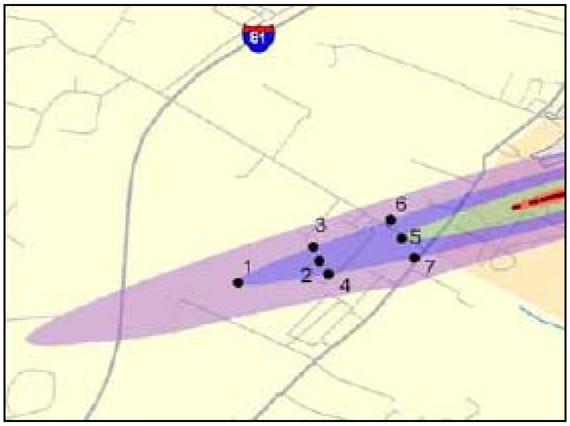


Figure 1

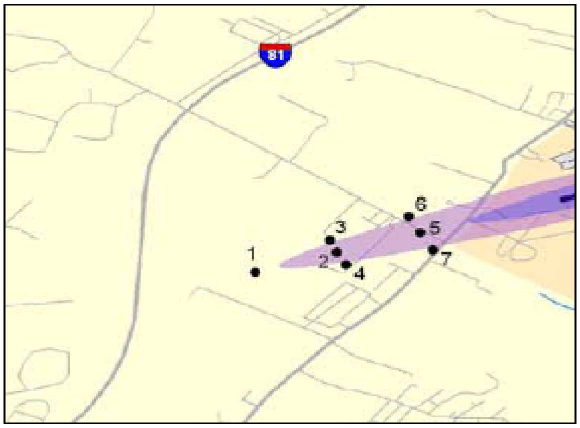


Figure 2

Table 1 below lists the coordinates and DNL values of the seven locations for both the baseline and proposed action conditions, and shows that the DNL is projected to increase from 5 to 7 dB at each grid point from the baseline to the proposed action.

Table 1. DNL at the Seven Supplemental Analysis Grid Points

Supplemental Analysis Point	Longitude (W)	Latitude (N)	BASELINE FY00 DNL (dB)	PROPOSED ACTION DNL (dB)
#1	78.01880	39.39248	65	70
#2	78.01252	39.39420	66	72
#3	78.01302	39.39531	65	70
#4	78.01180	39.39315	64	70
#5	78.00610	39.39595	68	75
#6	78.00698	39.39741	64	70
#7	78.00513	39.39443	64	70

Table 2 below compares the baseline and proposed action modeled number of aircraft events at or above the indicated Sound Exposure Level (SEL) for the average annual day and the percentage contribution of that number of events at that SEL to the DNL for that location.

Table 2. Number-of-Events Above SEL and Contribution to the DNL

Supplemental Analysis Point	SEL (dB)	Baseline FY00		Proposed Action	
		# aircraft events above	Contribution to DNL	# aircraft events above	Contribution to DNL
#1	110	0	3%	1	84%
	105	2	42%	3	94%
	100	4	52%	5	98%
	95	27	87%	8	99%
	90	42	100%	10	100%
	85	43	100%	11	100%
#2	110	1	16%	1	85%
	105	3	48%	4	97%
	100	4	52%	5	98%
	95	42	100%	10	100%
	90	42	100%	10	100%
	85	43	100%	11	100%
#3	110	0	3%	1	83%
	105	2	42%	3	95%
	100	4	52%	5	98%
	95	31	89%	9	99%
	90	42	100%	10	100%
	85	43	100%	11	100%
#4	110	0	3%	1	83%
	105	2	42%	3	95%
	100	4	52%	5	98%
	95	31	89%	9	99%
	90	42	100%	10	100%
	85	43	100%	11	100%
#5	110	2	37%	3	96%
	105	3	45%	4	98%
	100	9	57%	5	99%
	95	42	94%	10	100%
	90	43	94%	11	100%
	85	43	94%	11	100%
#6	110	0	3%	1	82%
	105	2	43%	3	95%
	100	4	53%	5	98%
	95	31	88%	9	99%
	90	42	100%	10	100%
	85	43	100%	11	100%
#7	110	0	2%	1	84%
	105	2	44%	3	96%
	100	4	54%	5	98%
	95	31	88%	9	99%
	90	42	100%	10	100%
	85	43	100%	11	100%

When comparing the proposed action to the baseline data presented in Table 2, it is apparent that while there are a few more events at or above SEL 100 dB threshold, there are considerably less events in the 85-100 dB range. 98 percent of the DNL will be generated by these few events at or above 100 dB for the proposed action, while only 54-52 percent of the baseline case DNL is caused by the events at or above 100 dB. While the future DNL noise contours will be substantially larger, it will be driven by an average of only 5 events per day at or above SEL 100 dB at each of the sites analyzed. Using SEL 95 as a threshold, a reduction on average of between 19 and 32 events per day will result from implementation of the proposed action.

Most people regard all events at SEL 95 dB or higher to be intrusive, and many might perceive the trade off of 19 -32 fewer events per day at this level for an increase of 5 per day at SEL 100 dB or greater to be an improvement in their noise environment. At least that is the conclusion reached by the Martinsville Board of Supervisors, who revised their overlay zoning proposal, based on this supplemental analysis, to allow the previously approved subdivision in the future DNL 70 dB contour to proceed, and to only preclude new development within the projected DNL 75 dB contour.

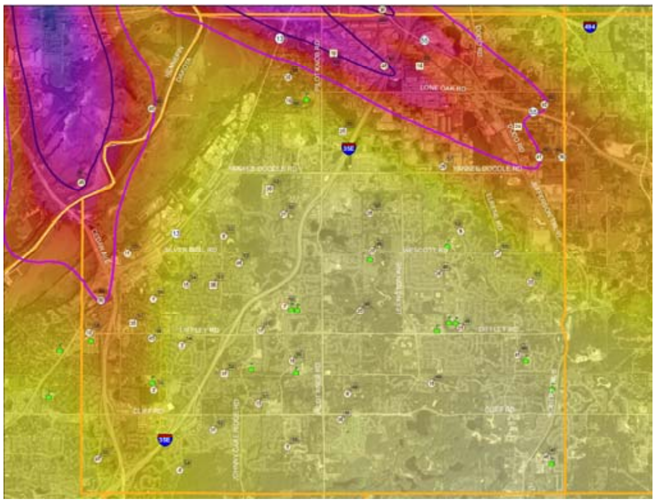
C- 2. Noise Study for the City of Eagan, MN

The new north-south runway at Minneapolis-St. Paul International Airport (MSP), Runway 17/35, opened in October, 2005. Runway 17/35 is predicted to eventually handle 37% of all departures and 16.5% of all arrivals at MSP. All departing operations on Runway 17/35 are to the south, and all arrival operations are to the north. Since the City of Eagan is the jurisdiction directly south of MSP it is directly under the new runway flight corridor. Now that the new corridor is in use, the west side of Eagan is experiencing a noticeable increase in environmental noise.

Several months before the new runway opened, the City of Eagan commissioned a study of existing and future noise levels. The goal was to analyze the future noise impact of Runway 17/35 on the City of Eagan, using the Integrated Noise Model (INM) input data from the MSP Part 150 noise study. Fifty noise modeling "grid points" were identified by City officials. A detailed analysis of noise exposure at these locations was conducted using the Day-Night Average Sound Level (DNL) metric, supplemented by metrics that focus on the noise impact of individual aircraft overflight events. To help the City of Eagan and the community better understand the expected future noise environment, in advance of the runway opening, the number and duration of aircraft operations that exceed a range of selected sound level thresholds at the fifty grid points was modeled.

The INM input data used in the recent MSP Part 150 Study to produce their 2007 DNL average annual day noise contours was used for this study. Both the existing and future noise environments were thoroughly analyzed and quantified, including a comprehensive database of noise levels measured at specific locations before the opening of Runway 17/35. This information, along with the predicted aircraft noise levels modeled at these and a number of additional locations, enabled the City of Eagan to provide citizens with detailed noise exposure information in advance of the runway opening.

Never before has a community compiled a detailed database that not only provides the projected average DNL at many specific points throughout the community, but also a breakdown of that average noise exposure into the Number-of-Events Above and the Time Above components across the full range of thresholds that comprise the average aviation noise exposure. The study enabled a citizen to look at the data for the grid point nearest to their home and find out how many times they can expect to hear airplanes each day and how loud those operations are predicted to be on the average annual day. The report was careful to point out that actual daily exposure may vary considerably from the average annual day so that citizens understand that on some days they will hear more than the average number of events and on other days they will hear less.



The residents of the City of Eagan directly under the new runway flight pattern were alerted to expect an abrupt change from no aircraft overflights, in the range of tens to hundreds per day depending on how close to the airport they reside. While no amount of data can totally prepare every citizen for such an abrupt change in the noise environment, the citizens of Eagan were far better informed in advance of this runway opening than were citizens impacted by previous runway openings at any U.S. airport. When the City of Eagan officials made this information available to the public in a series of workshops, they found that citizens consistently went to the information station that showed the NA grid point results. Ms. Dianne Miller, Assistant to the City Administrator, conducted the workshops and reported:

> *“Clearly, we heard repeatedly at our nine neighborhood open houses that DNL is not helpful in determining what impact residents can expect. Rather, we were continually told, “I don’t want to know to know the average amount of noise, I simply want to know how many planes will be over my house each day.” In large part, it was because of comments such as this that the City undertook the noise study.*

To present the results of the noise study, the City used three presentation boards—number of events above (NA), time above (TA), and a color coded DNL map. While I personally liked the color variations of the DNL map (shown below), interestingly, of the approximate 100 residents in attendance, not a single person went to the DNL map first. Rather, I would venture to say that 90% of the attendees were first drawn to the NA board. By overlaying the grid point analysis onto a City street map, residents could find their home on the map, and then look to the nearest grid point to see the number of planes per day predicted over a given decibel level (e.g. number of events per day over 65 decibels). City staff and Commissioners were very clear in explaining to residents that the NA grid was an estimate, based on a model that uses the term “Average annual day”. In short, I told residents that they could not sit at their window and expect to only count the number of events predicted by the study. In large part, residents understood that the study is based on models, and we clearly will be in a “wait and see” mode. I found that people appreciated the efforts of the City in embarking on the study, and they appreciated walking away with a number that was meaningful to them. Similarly, TA seemed to ease people a bit when they saw the actual amount of time per day they could expect events over a given threshold (e.g. twelve minutes per day with events over 65 decibels).”

C-3. Noise Study for St. Petersburg / Clearwater International Airport

In response to community concerns about aircraft noise impacts, the St. Petersburg-Clearwater International Airport (PIE) is conducting a multi-phased Noise Study that would serve to support ongoing work of the PIE Noise Abatement Task Force. The scope of the Study includes identification of any significant changes in noise exposure that may result from any recommended modifications to arrival and departure flight procedures from the separate airspace study. The Task Force expressed a critical concern in understanding the overall noise environment, so a primary goal of the Study is to identify and fully disclose the current and future aircraft-generated noise levels in the vicinity of the airport.

To fully achieve this goal, the Study includes presentation of results using supplemental noise metrics along with the traditional Day/Night Average Sound Level (DNL) metric annual average day noise contours. In addition to updating the DNL noise exposure contours for PIE, the following project tasks were performed in Phase I and will be used in the Phase II analysis of feasible noise abatement measures, which will be completed in 2007:

- Expand the noise modeling study area to include all affected neighborhoods in Pinellas County;
- Conduct detailed noise analysis at grid points throughout the study area;
- Improve the description of the noise environment using single-event metrics to "break down" the average DNL metric into its component parts; and
- Improve communication of noise results through maps showing noise exposure beyond the standard 65 dB DNL contour.

Improve communication of noise results through maps showing noise exposure beyond the standard 65 dB DNL contour.

A detailed analysis of noise exposure was conducted throughout the entire study area using DNL and two supplemental metrics -- Time Above (TA) and Number-of-events Above (NA). These metrics were used to break DNL down into its component parts and provide a more detailed analysis of noise exposure. The study area and grid points were selected by the PIE Noise Abatement office based on the following criteria: multiple noise complaints, locations near existing DNL contours, and locations near flight tracks. The grid point analysis included locations throughout the entire study area, most of which is located outside of the 65 dB and 60 dB DNL contours. The thirty-six specific grid points were selected throughout the study area for detailed analysis.

In addition to DNL, the TA and NA at each grid point was computed for sound level thresholds from 55 - 90 dB in 5 dB increments. These thresholds were selected to begin at a relatively low sound level and increase until the TA and NA was equal to zero at most sites. In addition to tables in the project reports showing TA and NA results at each grid point, contours were plotted on an aerial photo with gradual color shading to show TA and NA noise exposure throughout the entire study area as shown in Figures 1 and 2 below. These metrics were used to show the benefits of a noise abatement alternative for night air carrier arrivals from the north. The noise shift at key grid points and threshold levels are shown in Figure 3.

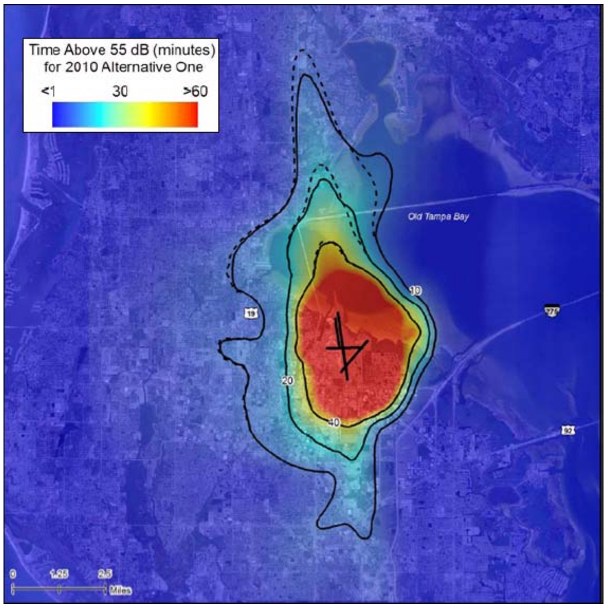


Figure 1. TA Contours

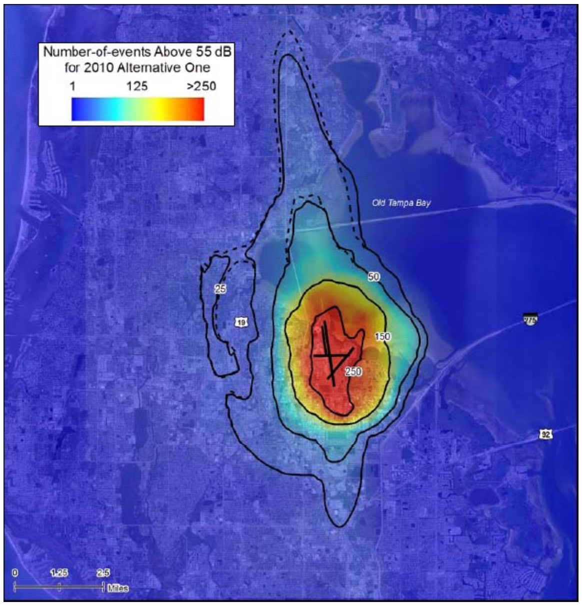
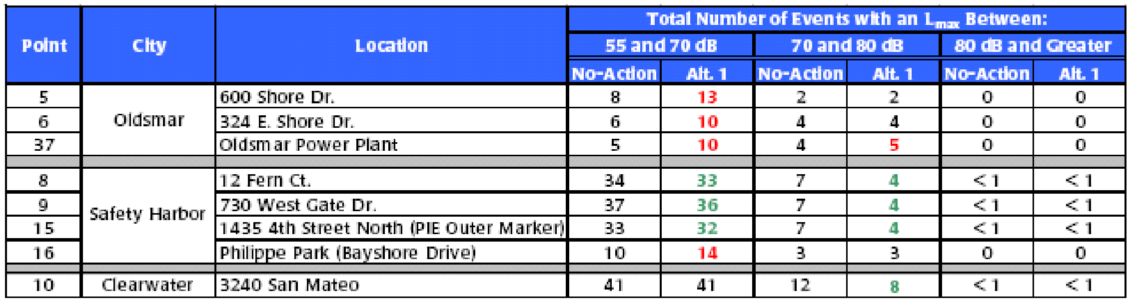


Figure 2. NA Contours



Point	City	Location	Total Number of Events with an L_{max} Between:					
			55 and 70 dB		70 and 80 dB		80 dB and Greater	
			No-Action	Alt. 1	No-Action	Alt. 1	No-Action	Alt. 1
5	Oldsmar	600 Shore Dr.	8	13	2	2	0	0
6		324 E. Shore Dr.	6	10	4	4	0	0
37		Oldsmar Power Plant	5	10	4	5	0	0
8	Safety Harbor	12 Fern Ct.	34	33	7	4	< 1	< 1
9		730 West Gate Dr.	37	36	7	4	< 1	< 1
15		1435 4th Street North (PIE Outer Marker)	33	32	7	4	< 1	< 1
16		Philippe Park (Bayshore Drive)	10	14	3	3	0	0
10	Clearwater	3240 San Mateo	41	41	12	8	< 1	< 1

Figure 3. Comparison of Number-of-Events at Several Ranges of L_{max}

When the noise modeling results were presented to the Task Force, they specifically commented that the TA and NA metric results clarified their understanding of the DNL metric and that they were appreciative of the lengths to which the airport had gone to candidly present a full disclosure of the airport's noise impacts on the community and facilitate their understanding. By doing so, Airport officials significantly increased their credibility in the eyes of the community.

C-4. New Runway EIS at Washington Dulles International Airport

The Federal Aviation Administration completed an Environmental Impact Statement (EIS) in 2004 to identify the potential environmental effects associated with the construction and operation of two new runways at Washington Dulles International Airport (IAD). FAA Orders 1050.1E and 5050.4A establish the Threshold of Significance for noise impacts to be a DNL increase of 1.5 dB or greater at any noise-sensitive areas within the DNL 65 dB contour. Further analysis is prescribed if an increase in the DNL of 1.5 dB will occur at any noise-sensitive area within the DNL 65 dB contour.

The EIS noise analysis determined that off-airport aviation-related noise impacts are not anticipated with any of the alternatives. While the DNL 65 dB contour encompasses several hundred areas off airport property, no residences and no noise-sensitive receptors would exceed the DNL 1.5 dB Threshold of Significance within the DNL 65 dB contour under any of the alternatives considered. Though not required by FAA Order 1050.1E, for the purposes of fully disclosing potential effects of the Build Alternatives, additional DNL contours were generated to identify noise-sensitive areas that would be exposed to increases of 3.0 dB or greater between the DNL 60 and 65 dB contours, and 5.0 dB or greater between the DNL 45 and 60 dB contours. This analysis revealed that increases of DNL 3 dB or greater between the DNL 60 and 65 dB contours and increases of 5 DNL or greater between the DNL 45 and 60 dB contours would occur for the build alternatives. While these projected increases would not exceed FAA's Threshold of Significance for noise impacts, both FAA and the Metropolitan Washington Airports Authority acknowledged that people may be adversely affected by these increases in aircraft noise levels associated with several build alternatives. To address these concerns, supplemental metric noise analysis was performed.

The Federal Interagency Committee on Noise issued a report in 1992 that identified sleep disturbance and speech interference as two areas where it is appropriate to consider analysis using supplemental metrics. Such analysis was undertaken in this EIS to determine whether or not these phenomena might occur and, if so, how frequently such interference/disturbance could potentially occur on an average daily/nightly basis. The supplemental metrics employed were Maximum Sound Level (L_{max}), Time Above (TA), and Number-of-events Above (NA) in order to provide information about the number, level, and duration of the aircraft noise events that comprise the average daily noise exposure expressed by the DNL metric. The frequency of occurrence was described by plotting NA contours showing the number of events projected to occur on the average annual day at or above L_{max} 70 dB. Contours were plotted for 15, 30, 60 and 120 events per day for each alternative. The EIS stated that there are no established criteria for noise exposure measured by the L_{max}, TA, or NA metrics. The EIS further explained that the supplemental metrics were used to help communicate noise exposure in terms that help the public better understand the DNL metric, specifically pointing out that DNL is the only metric used to determine if a proposed action will have a significant noise impact.

The L_{max} analysis identified the loudest maximum instantaneous sound level modeled for each noise-sensitive receptor point modeled in the EIS. This analysis indicated there will be a slight increase relative to the No-Action Alternative in the predicted L_{max} at most receptor sites under either of the build alternatives, with a maximum increase of 8.1 dB at one point under one of the build alternatives.

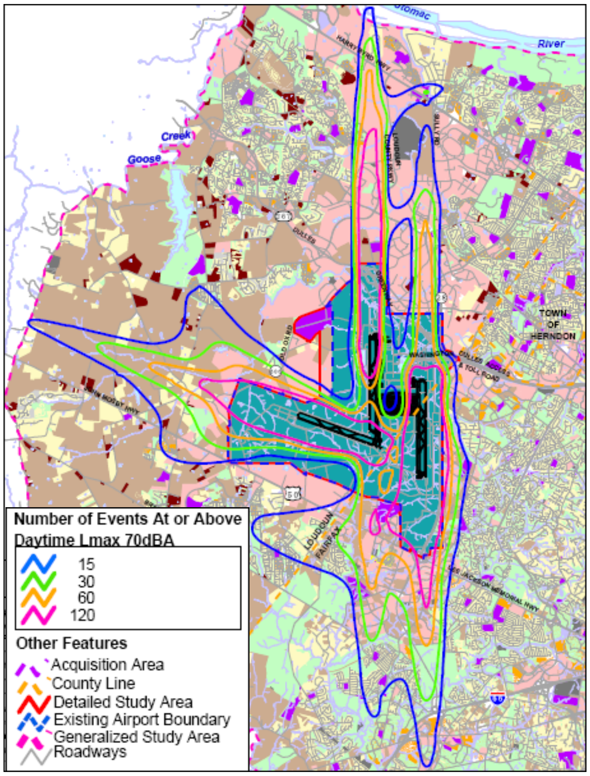
The TA metric was used to compare changes in the time above the selected threshold value of 70 dB at each of the 45 noise-sensitive receptor points. This analysis showed that relative to the No-Action Alternative the TA 70 dB would decrease at about half of the points and increase at the other half of the points with implementation of either build alternative. Considering both build alternatives, the projected changes in TA 70 dB ranged from a maximum increase of 2.0 minutes to a maximum decrease of 2.4 minutes. The average change at all 45 points for the build alternatives was 0.3 minutes and 0.4 minutes respectively, compared to the No-Action.

Alternative. The EIS concluded that the TA 70 dB analysis helped confirm there is no significant increase in noise exposure among any of the modeled build alternatives relative to the No-Action Alternative.

The NA metric was used to compare daytime changes in the number of events at or above the selected threshold value of L_{max} 70 dB at each of the 45 noise-sensitive receptor points. The analysis showed the NA70 would remain the same relative to the No-Action Alternative at 18 of the points if either build alternative is implemented, and that the increase and decrease at the remaining points would split evenly. It further showed that several sites would experience increases or decreases of up to 60 events per day at or above L_{max} 70 dB.

The NA metric was also used to compare nighttime changes in the number of events at or above the selected threshold value of SEL 90 dB at the noise-sensitive receptor points.

The EIS points out that the SEL metric relates best to sleep disturbance research results, and that an SEL of 90 dBA correlates to an indoor maximum percent awakening of 10 percent or less. The EIS states that night operations will not be affected by the build alternatives and the analysis confirmed that neither of the build alternatives would result in an increase in potential incidents for sleep disturbance when compared to the No-Action Alternative.



Example of Daytime NA L_{max} Contour

Response to the supplemental noise analysis results provided at the public workshops was all positive, even from individuals who expressed opposition to the new runways. Many specifically stated that the supplemental analysis enabled them to understand the DNL metric and to clearly understand the changes in noise exposure that will result from the new runways. Unlike virtually every other new runway project proposed at major airports in recent years, no legal challenges were made to slow or stop the project.

C-5. Nighttime Noise Criteria and Land-Use Guidelines for the City of High Point, NC

The goal of the current Federal Aviation Administration (FAA) noise compatibility guidelines is to provide guidance that encourages appropriate land uses around all U.S. airports. The FAA guidelines specify that DNL is the noise metric of choice in defining land-use compatibility. Based on this guidance, most of the Federal Aviation Regulation Part 150 Noise Compatibility Studies, Environmental Assessments and Environmental Impact Statements that have been conducted at U.S. airports are based upon the DNL 65 dB contour to identify the boundary between compatible or noncompatible noise exposure levels for noise-sensitive land uses. In essence, most of these studies have deferred to the DNL 65 dB threshold as a rigid standard or a de-facto “line in the sand”; and the general consensus has been that noise-sensitive land use without restriction should be allowed for areas that are exposed to noise levels below DNL 65 dB.

The Piedmont Triad International Airport (PTIA) is scheduled to become a new, full-service air cargo hub for FedEx in the near future. The City of High Point (City) is concerned that with the increase in nighttime operations that defining land-use compatibility by the projected DNL 65 dB contour will not be sufficient to protect the community from the increase in nighttime noise exposure. The new cargo operations forecast indicates that there will be a substantial increase in the number of nighttime operations, and that the operations are expected to occur within a short time period during the night. Since DNL is a 24-hour average noise metric (with a 10-dB weighting factor added to each operation between 10 PM and 7 AM), the City is concerned that when nighttime noise levels peak, the potential for increased sleep disturbance might not be accurately portrayed by the DNL noise metric alone. The City conducted a study to carefully and fully consider these issues by analyzing the projected noise impacts with the appropriate supplemental noise metrics, and to adopt noise overlay zones that will provide sufficient protection, balanced with development goals, in the affected areas. The study focused on the following questions:

- Is DNL the appropriate metric for all land-use guidelines?
- What additional metrics are more appropriate for the specific circumstances?
- What are the criteria for delineating land-use zones?
- What are the appropriate control measures for each of these zones?

The City did not accept FAA’s DNL 65 dB guideline as sufficient to fully portray the nighttime noise environment in every situation, even with the 10 dB weighting factor for nighttime operations. They chose instead to quantify their nighttime noise exposure using the NA noise metric in order to quantify noise levels from the high frequency of individual aircraft over-flights projected to occur within a 3 hour time window each night. The NA metric was selected because the number, intensity and duration of individual noise events that occur during a sleep period are directly related to sleep disturbance research results. By combining the noise level and number of events, noise contours were produced based on the threshold single event noise levels and number of events associated with various levels of sleep disturbance identified in the sleep disturbance research literature.

As a result, three geographic areas where identified where different zoning guidelines could be applied to provide future protection against sleep disturbance. These zones were based on NA contours derived from varying degrees of sleep disturbance. The three noise overlay zones proposed for adoption were:

- Overlay Zone 3 - based on the NA 80dB, 5 events per night contour, within which disclosure of the nighttime noise exposure level was recommended when a new residence is constructed or an existing residence is sold.

- Overlay Zone 2 - based on the NA 85 dB, 2 events per night contour, within which grant of avigation easements, a requirement for sufficient sound insulation to attain a noise level reduction of at least 25 dB in residential structures and noise disclosure were recommended.

- Overlay Zone 1 - based on the NA 90dB, 1 event contour within which prohibition of new residential development and of noise disclosure was recommended.

- A special Overlay Zone 1A within Zone 1 was also recommended to allow further residential development with certain restrictions in a current residential area that is not suited for any other type of development.

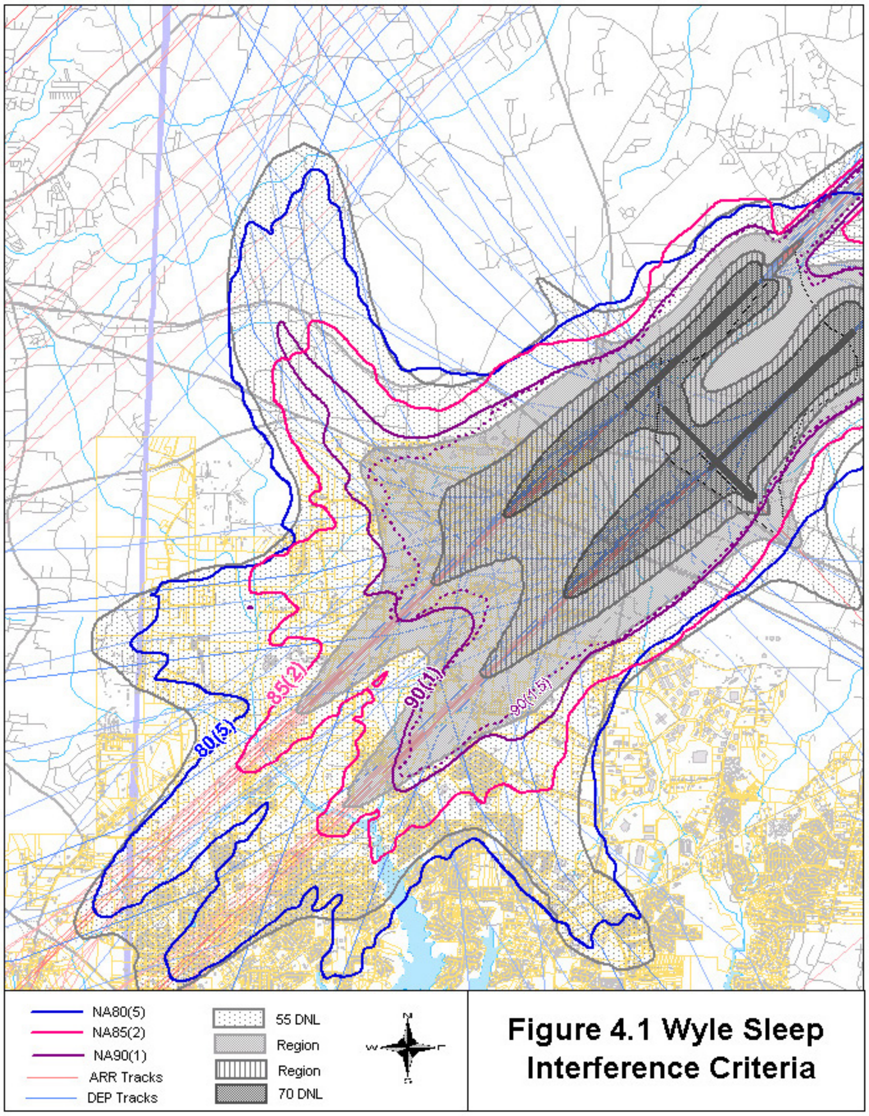


Figure 4.1 Wyle Sleep Interference Criteria

Zones 1, 1A and 2 were adopted shortly after the study was completed and Zone 3 was deferred for later consideration pending the completion of a Part 150 Study by PITA.

C-6. Oakland Airport Decision

The City of Oakland, CA prepared the required Environmental Impact Report (EIR) to analyze the consequences of their proposed Airport Development Plan for the Metropolitan Oakland International Airport. It's adequacy in defining nighttime noise impacts solely with the DNL noise metric was challenged in court by a citizens group and in it's decision, the California appeals court system set a precedent (at least in California) that DNL 65 dB is not a sufficient criteria to use in Environmental Impact Reports for this purpose and that single event noise levels must also be considered.

The appeal reviewed the decision of the Board of Port Commissioners for the Port of Oakland (the Port Commissioners) for the City of Oakland to certify the environmental impact report (EIR) analyzing the environmental consequences of the proposed ADP. The ADP is a multi-faceted, long-range expansion proposal for the Airport that will provide increased capacity for both air cargo and passenger operations.

The trial court held that the EIR prepared for the ADP violated the California Environmental Quality Act (CEQA) by failing to analyze a reasonable range of alternatives, and by failing to evaluate the cumulative impacts of the ADP in combination with other reasonably foreseeable projects; ordering the Port Commissioners to set aside approval and certification of the EIR until a supplement to the EIR was prepared and circulated that complied with the requirements of CEQA. The court concluded that the EIR specifically failed to analyze adequately the noise impacts from planned additional nighttime flights.

Accordingly, a supplement to the EIR was prepared that assessed single event noise associated with nighttime (10:00 p.m. to 7:00 a.m.) aircraft operations. The Supplemental EIR (SEIR) states that specifically, this analysis was prepared as required by the Revised Judgment to:

- Evaluate potential nighttime noise effects by comparing nighttime aircraft activity under normal operating conditions both with and without the ADP in 2010;
- Estimate the increase in the average number of nighttime flights at two or more locations in the cities of Alameda, Berkeley, and San Leandro that could result from the ADP in 2010; and
- Calculate the probability of awakening due to single event noise from a representative sampling of aircraft operations as a result of implementing the ADP. The analysis uses the sleep disturbance dose-response relationship recommended by the 1997 Federal Interagency Committee on Aviation Noise (FICAN) for interior sound exposure levels and percent awakening.

Paraphrasing the SEIR:

In addition to providing the supplemental information required by the Revised Judgment, the SEIR analyzed whether the ADP would result in a substantial increase in sleep disturbance compared to conditions existing in 2000 and to conditions that would exist in 2010 without the ADP. In performing this analysis, the SEIR recognized that sleep can be affected by both the loudness of a single event and by the frequency of single events during the course of the night. Because no one numeric threshold accurately accounts for both the loudness of an individual event and the frequency of individual events in terms of the calculation of sleep disturbance, the SEIR qualitatively considered the numeric data regarding both factors.

The SEIR also recognized that individuals' experiences differ, and that a range of effects can occur. Quality of life effects can and do occur below the level that is deemed substantial for purposes of impact evaluation under CEQA. Thus, the SEIR presents as much information regarding the nighttime environment and potential effects on sleep as is feasible, so that, whether or not an impact is deemed significant, readers and decision-makers can gain a better understanding of the nighttime environment and the ADP's potential effects on sleep.

The SEIR presented existing nighttime arrivals and departures in 2000, and the increase in nighttime arrivals and departures with and without the ADP in 2010. Because arrivals and departures affect different geographic areas, arrivals and departures are presented separately. Also, South Field operations affect different geographic areas than North Field operations; therefore, the information in the SEIR is also broken down by South Field and North Field. In addition, each type of aircraft has its own noise effects, and people may perceive nighttime noise differently during different periods of the night. Accordingly, the information regarding nighttime operations is further broken down by whether the aircraft is a passenger, cargo, or general aviation aircraft; the type of aircraft (e.g., B-727, B-737, A-300, twin-engine turboprop, etc.); and the period of night in which the arrival or departure is expected to occur. The SEIR attempted to enable the reader to ascertain what could occur near a particular residential location. Based upon forecasts, the Port predicted that, compared to conditions existing in 2000, the ADP would generate 28 additional arrivals and 28 additional departures on South Field, and 13 additional arrivals and 15 additional departures on North Field, during the nighttime hours from 10 p.m. to 7 a.m.

To evaluate the noise levels of representative types of aircraft, the SEIR provided noise contours, or "footprints," for various types of aircraft departing and arriving from South and North Fields in order to demonstrate the sound level associated with each type of aircraft in particular geographic areas, and found that, in general, aircraft noise footprints are getting smaller due to the replacement of older, louder aircraft with newer, quieter aircraft.

To provide further information regarding nighttime aircraft noise from the Airport, the SEIR quantified the number of aircraft events that are predicted to result in exterior single event noise at or above 90, 85, and 80 decibels (dB) sound exposure level (SEL) in a particular residential area on an average night. The SEIR provided single event noise contour maps depicting those geographic areas that would be exposed to single event noise at or above 90, 85, and 80 dB SEL, and the specified number of events.

The analysis showed that the majority of nighttime flights will not result in exterior noise levels at or above the lowest noise level reported (80 dB SEL). Out of 246 nighttime arrivals and departures projected for the ADP in 2010, only about 65 nighttime aircraft arrivals and departures would result in single event noise at or above 80 dB SEL at a residential location. When compared to 2000 existing conditions and to the No Project in 2010, it showed there will be no substantial ADP-related increase in the number of events at or above 85 or 90 dB SEL. In fact, in several locations, a decrease is predicted in the number of nightly aircraft events at or above these noise levels with the ADP in 2010, as compared to the other alternatives. Compared to existing conditions and future conditions in 2010, an increase in the number of events at or above the less intrusive noise level of 80 dB SEL is expected to occur at some locations near the Airport; however, this increase is not expected to substantially increase sleep disturbance.

As required by the Revised Judgment, this SEIR correlated nighttime single event noise levels with the potential for sleep disturbance. Using the methodology published by the FICAN, the SEIR identified the maximum percentage of a population that could be awakened by a single aircraft event at or above specific noise levels. Since the FICAN methodology is based on *interior* noise levels, this SEIR converted exterior noise levels from aircraft events to interior noise levels by taking into account the noise level reduction expected at particular residences based on building construction, whether sound insulation has been provided, and whether windows are opened or closed.

After considering the maximum percent awakening from individual aircraft events and the expected changes in the number of events at each noise level in each geographic area potentially affected by Oakland operations, the SEIR concluded that the ADP would not result in a substantial increase in sleep disturbance.

The SEL metric is the single event noise descriptor used in the SEIR analysis. SEL accounts for both the loudness of an event and its duration, and has been accepted by FICAN and other researchers as being appropriate for the assessment of the potential for sleep disturbance. The SEL value is *higher* than the maximum noise level (L_{max}) from a single event. The loudest noise level heard from an aircraft arrival or departure is about 10 dB *lower* than the SEL value.

The SEIR further stated: "The studies conducted at other airports have also revealed that the Number Above methodology provides meaningful information to the public regarding the expected frequency of noise events at or above specific noise levels and the geographic areas exposed to specific noise levels," and that: "This approach is consistent with the approach used routinely in the evaluation of noise effects."

The SEIR used a subjective sliding-scale approach to assess whether the increase in sleep disturbance would be deemed substantial. An increase (or decrease) in the number of aircraft events at or above 90 dB SEL was weighted more heavily than an increase (or decrease) in the number of aircraft events at or above 80 dB SEL, because events at or above 90 dB SEL have a comparatively higher probability of disturbing sleep. Even though events less than 90 dB SEL have a lower probability of sleep disturbance, they were considered, reported, and analyzed in the SEIR to provide full disclosure to the public and decision-makers.

C-7. San Diego Airport Site Selection Program

California law required the San Diego County Regional Airport Authority (SDCRAA) to adopt a comprehensive plan on the development of the SCRAA's international airport, including a review of alternate sites. Aircraft noise analyses were performed for all potential airport sites, including Marine Corps Base (MCB) Camp Pendleton ("Pendleton"), Marine Corps Air Station (MCAS) Miramar ("Miramar"), Naval Air Station (NAS) North Island ("North Island"), two remote locations (named "Campo" and "Desert") and San Diego International Airport (SAN).

For each airport site scenario involving the military airfields, it was proposed that civilian air traffic would be integrated with current military air traffic. The Campo or Desert sites would be new airports with primarily civilian air traffic. For all alternate sites, SAN would be replaced, except for North Island in which SAN would continue to operate in its current configuration and layout. The six-site analysis resulted in the SDCRAA choosing the MCAS Miramar site for the voters, via a local ballot proposition, to decide whether the SDCRAA will pursue the site for a commercial airport.

In addition to developing the Community Noise Equivalent Level (CNEL) contours, the following supplemental analyses were performed:

- Gradual color shaded CNEL contour maps
- CNEL contributor analysis
- Sound Exposure Level (SEL) contours
- Instantaneous Maximum Sound Level (L_{max}) contours
- Noise simulation videos
- Flight frequency maps
- Time Above an L_{max} Threshold (TA) contours
- Number of Events At or Above an L_{max} Threshold (NA- L_{max}) contours
- Noise simulation videos

Typical noise maps contain DNL or CNEL contour lines at 5 dB intervals with minimal or non-existent information between the contour lines. The gradual color shaded CNEL maps provided visualization of the continuous change in aircraft noise exposure from CNELs from 60 dB to 85 dB. The CNEL contributor analysis resulted in a list of the top 4 contributors to the CNEL at18 receptor sites in the vicinity of MCAS Miramar for existing and proposed scenarios.

SEL contours, L_{max} contours and three-dimensional (3D) noise simulation videos provided decision-makers a fair site-independent comparison of the relative noisiness of applicable aircraft on a single-event basis. SEL and L_{max} contours were developed for several civilian and military aircraft types.

Noise simulation videos are 3D animations (i.e., movies) of typical departure and arrival operations of accurately showing the propagation of aircraft sound levels along the ground over time. The Noise Model Simulation (NMSim) was used to generate videos of the noise simulation videos for the Campo and Desert sites. NMSim is aircraft type-specific in terms of spectral signature and sound magnitude, and includes the effect of topography and terrain on sound propagation with state-of-the-art algorithms. NMSim also includes the effects of changes in engine power, airspeed and altitude. Its resultant videos uniquely depict how instantaneous sound output and exposure changes throughout each individual event, thus increasing the credibility of the entire site analysis and demonstrating the aforementioned effects.

Flight frequency maps, using gradual color shading and density, enabled visualization of the numbers of departure and arrival events along each modeled flight corridor for the Campo and Desert sites.

For TA and NA contours, an L_{max} threshold of 60 dB, associated with speech interference, was chosen, and the period of interest was a full 24-hour day of annual average daily flight operations. NA 60 dB contours were plotted for the existing and proposed MCAS Miramar site aircraft flight operations And TA 60 dB contours were plotted for the proposed MCAS Miramar civilian traffic only. In tandem, the NA and TA contours effectively related the potential frequency and duration of speech interference for the average annual day operations for areas in the vicinity of the airport site.

C-8. GTAA: Land-Use Planning Guidelines for New Non-Urban Airports

The Greater Toronto Airports Authority (GTAA) performed a study to develop land-use planning guidelines specifically for new airports in non-urban locations in Canada. The goal was to define a noise level threshold for an Airport Operating Area (AOA) boundary, within which no noise-sensitive land uses could be developed. The noise threshold also achieved an appropriate balance between the competing requirements of development interests and community noise protection. Noise-sensitive uses include schools, day-care centers, nursing homes, residences, hospitals, and other similar uses where airport noise may significantly disrupt human activities (such as conversation, teaching, and sleep).

The study produced a comprehensive overview of current aircraft noise and land-use compatibility guidance from the responsible Canadian Federal and Provincial agencies, and included an overview of the scientific and historical basis for aircraft noise land-use guidelines.

The study focused primarily on research results of noise effects on annoyance, speech interference, and sleep disturbance. Additional noise factors examined included: habituation to noise; the differences between a non-urban and an urban environment; community attitudes toward the noise source; prior experience with the noise source; the purpose of the flight operations; and unique opportunities available during airport planning.

The existing Canadian land-use guidelines are defined in terms of the Canadian Noise Exposure Forecast (NEF) metric. The NEF is an energy-average noise metric similar to DNL. However, speech interference and sleep disturbance research results are presented in terms of single-event noise levels and the frequency of events. Therefore, the Number-of-events Above (NA) supplemental metric was used to define noise level criteria for speech interference and sleep disturbance. Separate criteria were defined for:

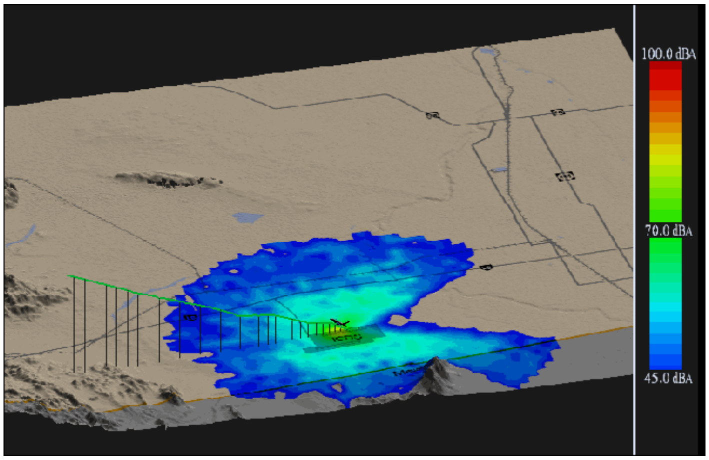
- Residential speech interference
- Classroom speech interference
- Residential sleep disturbance

To relate the study results to the existing Canadian guidelines and correlate the NA criteria with NEF levels, the Integrated Noise Model was used to model typical small, medium and large airport cases. Each airport case consisted of typical operations, which were normalized by condensing them to a single runway with a straight out departure track and straight-in arrival track with all departures and arrivals modeled in a single direction. This approach was used to isolate any variables related to airport size, number of operations and differences in fleet mix. The large airport case results are illustrated in the graphic below.

The study conclusions and recommendations were derived mainly from objective research of sleep disturbance and speech interference, rather than subjective surveys of annoyance. The speech interference and sleep disturbance research results showed the effects of single event noise, whereas the annoyance studies relied on energy-average metrics such as DNL and NEF.

The selected speech interference criteria for schools and residences were based on one event per hour at two different SEL thresholds (linked to word intelligibility in classrooms and sentence intelligibility inside a residence). The criteria were then adjusted to a full 15-hour daytime period (7:00 am – 10:00 pm). As shown in the figure, the contour showing the speech interference criterion for schools is the NA90(15) and the contour showing the speech interference criterion for residences is the NA85(15), computed from the daytime operations. The two speech interference criteria correlated with NEF levels of 25 to 33. The sleep disturbance criterion selected was 1 event at or above 90 dB SEL during night hours (10:00 pm - 7:00 am) and is delineated by the NA90(1) contour, computed from the nighttime operations. The sleep disturbance criterion correlated with NEF levels of 27 to 30.

In order to define a land-use guideline, the single event metric results were correlated with energy-average metrics to produce a single NEF criterion above which no noise-sensitive development should occur around a new non-urban airport. A single criterion was deemed more practical than varying criteria addressing each of the effects of noise separately. The selected single criterion was NEF 25, which was shown to approximate each of the speech interference and sleep disturbance criteria. Ultimately, Transport Canada adopted the recommended NEF 25 criterion nation-wide applicable to all new airports in non-urban settings.



C-9. Vancouver International Airport Vicinity Residential Land Use Planning Practices

Because airports both attract growth and must try to limit the development of land uses nearby that are considered incompatible with noise from aviation activity, planning for land uses around airports has been and continues to be one of the more challenging aspects of transportation policy-making. The purpose of this study was for the City of Richmond, BC to develop appropriate guidelines to use in evaluating various proposals for use and re-use of land in areas exposed to overflight noise from the Vancouver International Airport. It was recognized that there currently exists significant incompatible land use in the City of Richmond, so the primary goal was to prevent the development of new incompatible land uses, rather than to remediate the existing problem uses.

Adverse impacts from noise are analyzed using a wide body of scientific research, with particular attention to annoyance, speech interference and sleep disturbance (the three most well documented adverse impacts for residences exposed to airport noise). The analysis in this study combined a re-evaluation of the Transport Canada NEF-based guidance (associated primarily with annoyance) with a careful consideration of the need to protect residents from speech interference and sleep disturbance, which are better represented by the number of intrusive events during the daytime or nighttime, respectively.

Annoyance is the primary response factor upon which most nations have based their airport land use criteria. The most widely accepted threshold level to define noise-sensitive land uses as “not compatible” in Canada is $NEF_{(CDN)}$ 30 (comparable to DNL 65 dB in the U.S.). This was the existing recommended criterion for annoyance from noise for new residential and live-work dwellings in the City of Richmond at the time of the study.

To analyze the daytime NA, aircraft activity at Vancouver International Airport was assessed for the period between 7 AM and 10 PM. Setting the noise threshold at L_{max} 75 dB and looking for the area exposed to 15 noise events per day at or above this threshold produces the metric L_{max} NA75(15). This represents the area where homes are exposed to 15 events per day or an average of one event per hour at L_{max} 75 dB or higher. The L_{max} NA75(15) noise contour defines the area within which new residential construction should not be permitted in order to maintain adequate sentence intelligibility with the windows open.

Combining both the sentence and word intelligibility requirements, and considering the fact that most Richmond residents keep their windows open, these guidelines recommend preventing new construction of residential and live-work units within the L_{max} NA75(15) area. This will protect speech intelligibility inside the home and begin to manage the number of very loud aircraft overflights that interfere with the use of outdoor living areas. Given the high current and projected operation levels, and keeping in mind that social speech intelligibility disruption occurs at L_{max} 60 dB, there will be a substantial number of overflights that exceed this level. However, outdoor speech interference is given a lower priority for the purposes of providing flexibility in land use planning.

At an outdoor SEL of 95 dB, approximately 10 percent of the population may be awakened by an overflight. At an outdoor SEL of 90 dB, 2 to 3 percent of the population may be awakened by a nighttime noise event depending on whether the windows are closed or open. The NA metric, which was used with L_{max} values for speech interference, can also be used with SEL values. SEL NA contours were produced for the nighttime hours from 10 PM to 7 AM to show one event per night at the selected threshold levels.

To provide adequate protection from aircraft overflight noise at night, it was recommended that new residential and live-work homes be restricted to the area outside the SEL NA90(1) contour. For work-live areas where there is a lesser expectation of quiet, and where air conditioning is expected so that windows may remain closed year-round, SEL NA95(1) was used.

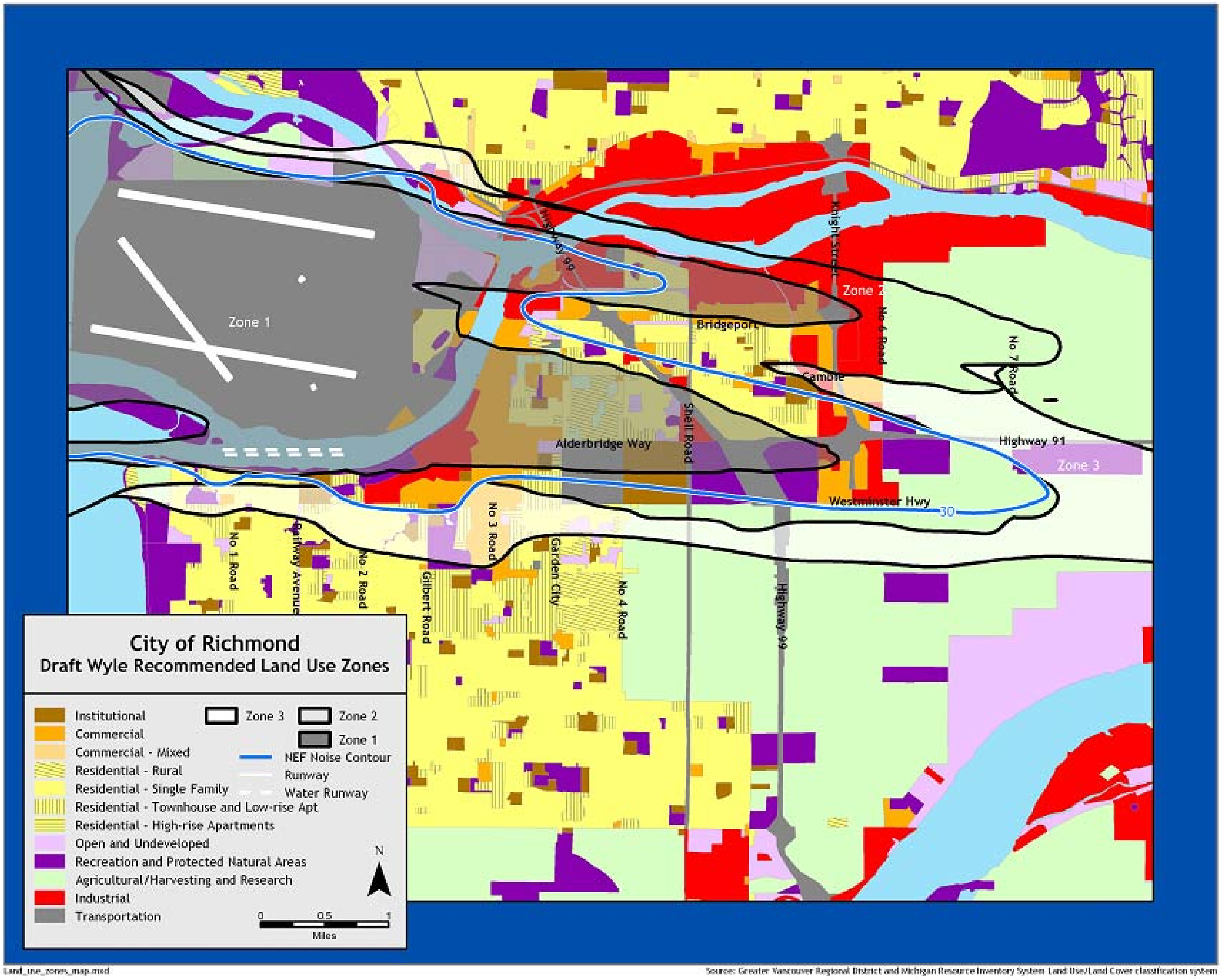
The recommendations were framed in terms of three new land use zones that reflect NEF contours for 2011 together with the single-event noise analyses noted above. The proposed planning zones were:

Zone 1 – No new residential development of any type permitted. This line combines the NEF 35, the “Fifteen events during the day with a sound level at or above 80 dB,” and I the “One event at night with sound energy greater than 95 dB” contours, merged into one boundary.

Zone 2 – No new residential or live-work development permitted. Work-live development is permitted provided adequate protection from aircraft noise is ensured through appropriate sound insulation materials and methods. This line combines the NEF 30, the “Fifteen events during the day above 75 dB,” and the “One event at night above 90 dB” contours, merged into one boundary.

Zone 3 – All types of residential development are permitted but sound insulation materials and methods are required. This line combines the NEF 25 and the “Fifteen events during the day above 75 dB” contours, merged into one boundary.

There are no restrictions recommended outside Zone 3. The graphic below show the recommended planning zones compared to the NEF 30 contour.



Land_use_zones_map.mxd

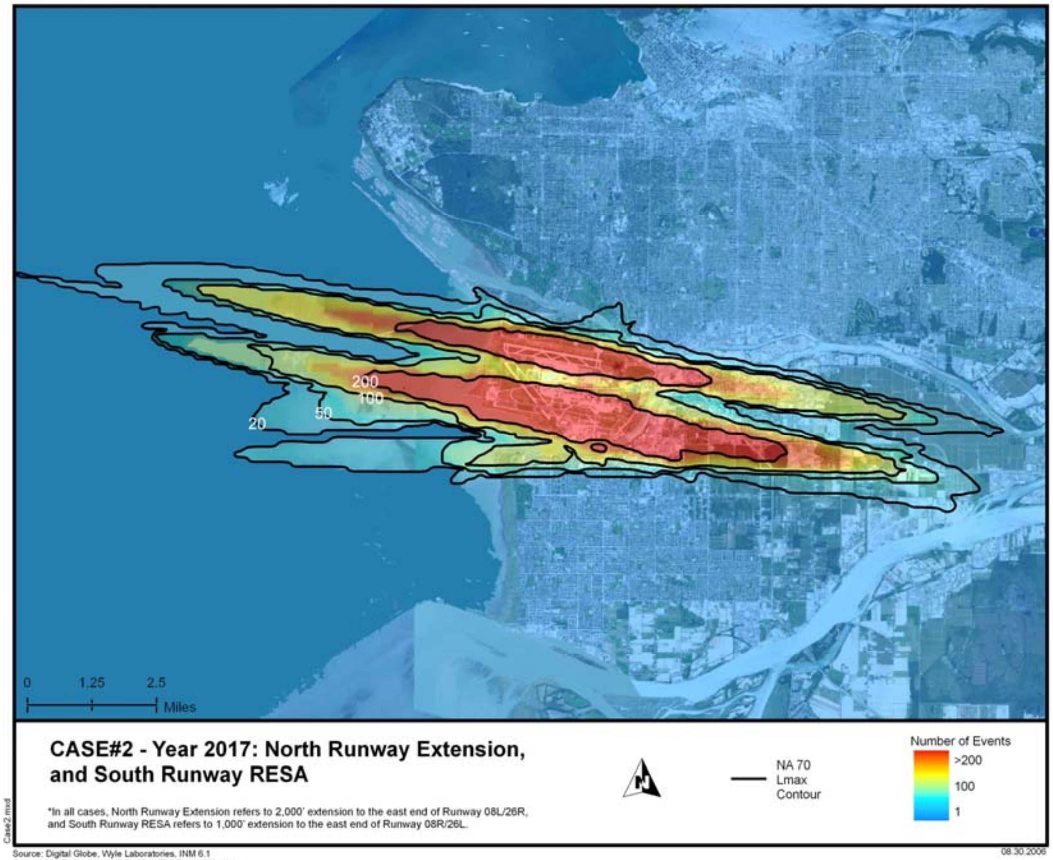
Source: Greater Vancouver Regional District and Michigan Resource Inventory System Land Use/Land Cover classification system

C-10. Alternative Analysis for the Vancouver International Airport Master Plan

Vancouver International Airport (YVR) in Vancouver, BC is in the process of updating its master plan, and is evaluating a number of alternatives. YVR officials concluded that comparing the noise exposure associated with the alternatives with Noise Exposure Forecast (NEF) contours might not yield the best comparison from a noise perspective. Therefore, supplemental noise analysis was conducted using the Number-of-events Above (NA) metric to supplement the NEF comparison of the alternatives.

A total of eight scenarios, representing various airport configuration and airport development alternatives, were modeled; and NA noise exposure contours were produced for each of those scenarios. Advanced GIS techniques were then employed to present the NA analysis and results in a graphic form that facilitates clear and easy comparison of the feasibility of the development alternatives and communicates a better understand of their potential impacts (example below). The NA threshold level chosen for the analysis and alternative comparison was 70 dB. The resulting NA contours were plotted on an aerial photograph with contour lines showing 20, 50 100, and 200 events for each of the airport alternatives modeled, with gradual color shading to show the range of events from 0 to 200+ per day. A separate graphic was produced for each alternative.

The NA 70 dB levels at the noise sensitive areas around the airport can be easily compared and will be given full consideration along with other decision factors in the process of selecting the preferred expansion alternative for the YVR Master Plan Update.



CASE#2 - Year 2017: North Runway Extension, and South Runway RESA

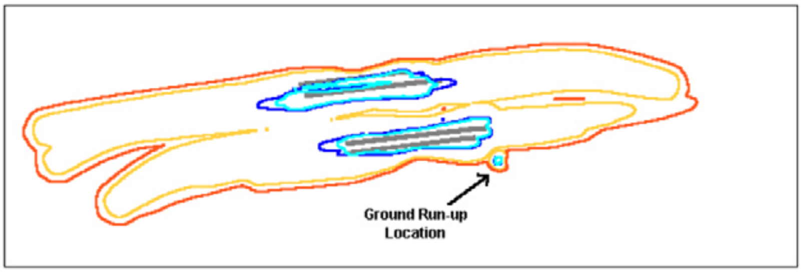
*In all cases, North Runway Extension refers to 2,000' extension to the east end of Runway 08L/26R, and South Runway RESA refers to 1,000' extension to the east end of Runway 08R/26L.

Source: Digital Globe, Wyle Laboratories, INM 6.1
Geographic Reference: WGS 1984 UTM Zone 10N, meters

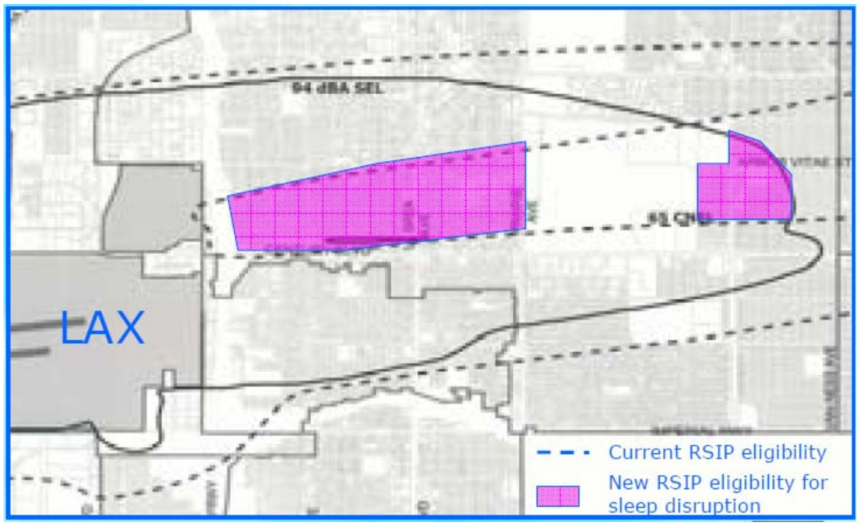
C-11. Nighttime Noise Analysis for Los Angeles International Airport

Los Angeles International Airport (LAX) receives a large number of noise complaints whenever large jet aircraft depart to the East during the nighttime hours. While the vast majority of night flights depart to the West, these East departures are of sufficient concern that LAX has undertaken a FAR Part 161 study to explore the possibility of precluding them altogether, except under certain wind conditions. Cognizant of the "Berkeley Jets" decision by California Superior Court on Oakland's EIR for nighttime cargo development, LAX officials decided to include supplemental analysis in their Master Plan Update specifically to address sleep disturbance. The "Berkeley Jets" decision required a more comprehensive look at single event noise levels, particularly at the numbers and levels of flights during the night hours, and left to the sponsor the responsibility to establish thresholds of significance to define impacts.

Based on thorough historical sleep disturbance studies performed world wide, adjusted for local conditions, LAX officials selected SEL 94 dB as a viable noise level above which a determined number of operations might cause sleep disturbance. The NA metric was selected to perform this analysis because the number, intensity and duration of individual noise events that occur during a sleep period are directly related to sleep disturbance research results. Since a single operation to the East at night generates a large number of noise complaints over a wide area, the SEL 94 dB contour was modeled to cover the entire area subject to 1 event at this level every 10 days.



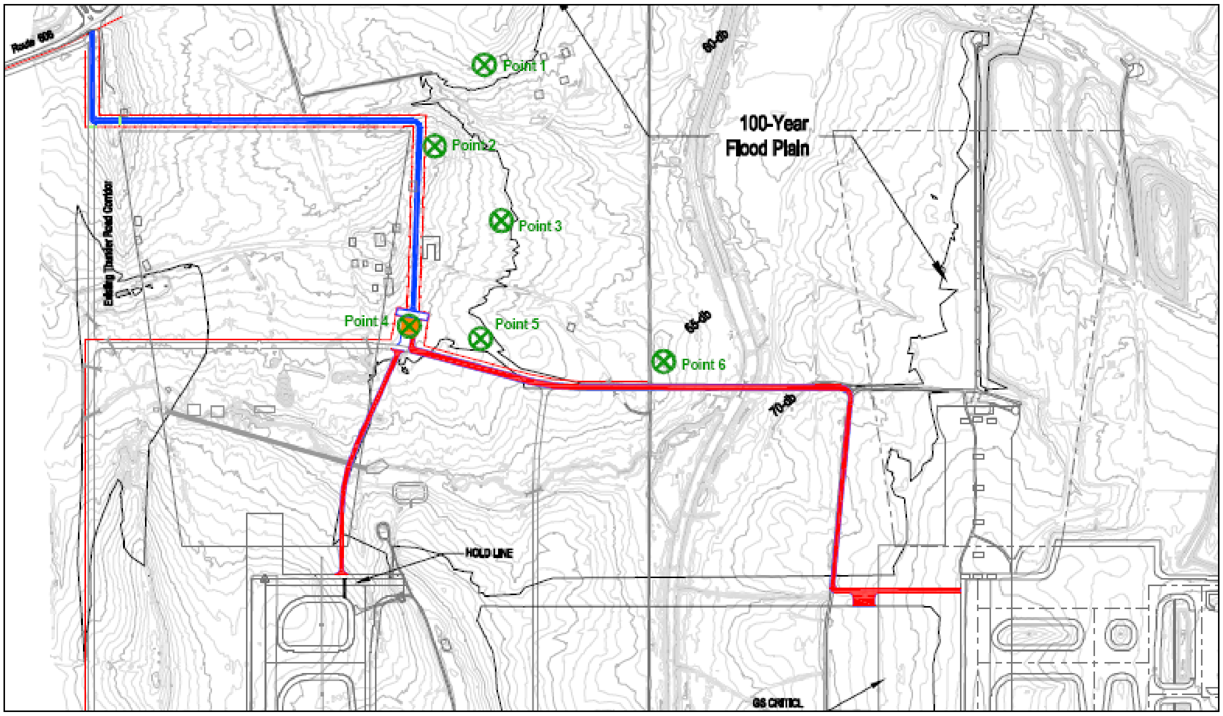
Potentially, the residential areas that are within this SEL 94 dB contour, but outside of the DNL 65 dB contour, will become eligible for sound insulation. The graphic below, from the LAX Master Plan documentation, shows this potential noise mitigation area. No final decision to include these areas in the LAX noise mitigation program has been made.



C-12. Noise Analysis for Public Safety Facility at Washington Dulles Airport

Washington Dulles International Airport performed a noise analysis to determine the best location for a new Airport Rescue and Fire Fighting Facility (ARFF). The ARFF will include housing for the staff with sleeping quarters that will be used throughout the daytime and nighttime. A noise analysis was conducted to determine the outdoor noise exposure at six potential sites, and to determine the noise level reduction (NLR) required to minimize the potential for sleep disturbance within the facility. The figure below presents the potential sites which are between the centerlines of the existing runway on the right and the future runway on the left.

Integrated Noise Model (INM) data for the preferred runway alternative from the new runway EIS forecast year 2025 was used to conduct a grid point analysis for the six potential locations. The INM was used to compute the Day-Night Average Sound Level (DNL) and the Time Above (TA). In addition, the Number-of-Events Above (NA) was computed. The TA and NA were calculated for a range of threshold levels from 60 dB and up in 5 dB increments to an upper threshold level at which the TA and NA were equal to zero. Because the ARFF sleeping quarters will be used throughout the day and night, all metrics were calculated over the full 24-hour day.



It has been well established in the scientific community that SEL predicts sleep disturbance much more reliably than the maximum sound level. While there is no widely accepted sleep disturbance criterion, the NA metric is well suited to define a sleep disturbance criterion that will minimize sleep disturbance. The NA90(1) defines locations at which one event above SEL 90 dB (outdoors) will occur during an average night or other sleep period. The indoor SEL would be approximately 20 to 25 dB lower with doors and windows closed (depending on the NLR of the building).

Only one proposed location (point 6) had a DNL of 65 dB. All other points had a DNL less than 65 dB. Under FAA land use compatibility guidelines, 65 dB DNL is compatible with residential development and therefore was assumed to be suitable for the proposed ARFF. The TA and NA metrics provided more details about the noise exposure at each point. In an 8-hour sleeping period, the NA SEL 90 dB ranged among the grid points from 3.7 to 15 events (assuming an even distribution of events throughout the day). If the ARFF sleeping area is designed with a Noise Level Reduction (NLR) of 25 dB, the indoor exposure to those events would be SEL 65 dB. If designed to achieve an NLR of 30 to 35, the SEL of these events in the sleeping area would be 55 to 60 dB, which is sufficient to preclude anything but minor sleep disturbance.

Of the six grid points analyzed, points 1 and 3 had the lowest DNL and the fewest number of events above the sleep disturbance criterion. Since factors other than noise may be considered, all locations except point 6 were deemed suitable locations for the ARFF. To assure minimum sleep disturbance from aircraft noise, a design NLR of 30 to 35 dB for the sleeping area was recommended regardless of the location ultimately selected.

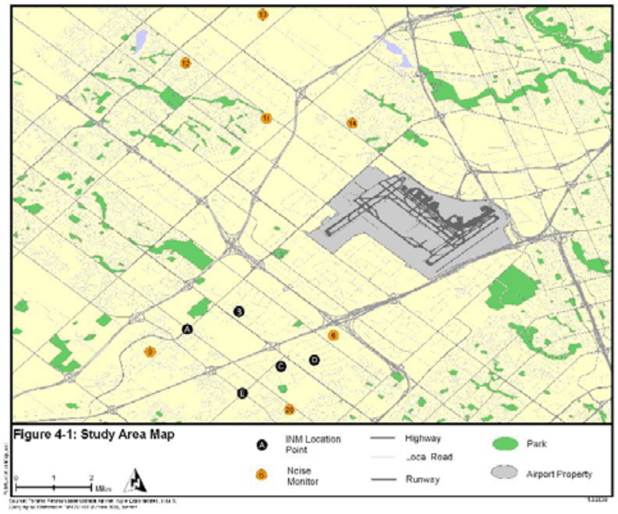
C-13. Noise Analysis of Potential Day Care and School Sites, Greater Toronto Airports Authority

The Greater Toronto Airports Authority (GTAA) performed a study to assess the compatibility of potential day care centers and schools at specified locations between the Toronto-Pearson International Airport (YYZ) Noise Exposure Forecast (NEF) 30 and 35 contours. The scope of the study was to investigate current weekday noise exposure at specific locations representing potential school and day care sites and to review existing noise research in order to develop a reference body of knowledge to assist GTAA in answering four key policy questions:

(1) Should day cares be treated differently from schools in terms of permitted or prohibited land uses within the 30-35 NEF contours?

(2) As employment uses are permitted in the immediate vicinity of the airport, should day care centers be differentiated from private schools; and thus, permitted as accessory uses to employment uses?

(3) What are the arguments for and against prohibiting day cares and schools (as a principal and/or accessory use) in the 30-35 NEF contour as supported by the existing evidence (in terms of both indoor and outdoor environments?



(4) If there is an argument for permitting day cares and/or schools (as a principal and/or accessory use) within the 30-35 NEF contour, what mitigation measures and conditions should be imposed on their development (insulation, warnings, limitations on outdoor use, provision of alternative outdoor facilities, etc.)?

The study investigated weekday aircraft noise exposure for five specific locations within the Pearson Airport Operating Area (AOA).

The locations were specified by the GTAA as sites where day care centers might be located within office buildings or other employment areas to the southwest of YYZ. Airport operations and radar data for 2005 was filtered to include only weekday arrivals and departures between 7:30 am and 5:30 pm (corresponding with school hours). One of the unique features of this study was inclusion of only those operations that affect the study locations, which occurs in two flow configurations. To determine the potential worst-case noise exposure scenarios at these locations, peak traffic levels in the northeast and southwest directions were modeled and compared to the annual average traffic levels for these two flow configurations. The noise model results for the potential sites were presented using the equivalent sound level (L_{eq}), maximum A-weighted sound level (L_{max}), and the Number-of-Events Above (NA) metrics, since the NEF exposure levels were irrelevant to the analysis. Historic community-noise measurement data was also used to supplement the modeling results.

A literature search was conducted to determine if any studies show a causal relationship between aircraft noise exposure and developmental problems in day care- and/or school-aged children. Factors such as cognition, stress, and reading comprehension were considered. The most up-to-date and relevant research studies were reviewed and referenced, but were inconclusive with respect to proving a causal relationship. There are not enough studies available to confirm or deny a relationship, and the few existing studies do not prove a definitive relationship. Speech interference was thus determined to be the most pertinent criteria upon which GTAA can base policy decisions.

In contrast with cognition, stress, and reading comprehension, the effects of noise on speech interference can be more easily quantified. There are widely accepted speech interference criteria, where a percentage of words or sentences become unintelligible. Speech interference criteria are most stringent for sensitive areas such as classrooms. The criteria used in this study were an indoor L_{eq} of 35 dB, an indoor L_{max} of 50 dB, and an indoor Number-of-Events Above threshold of NA50(10). NA50(10) corresponds to 10 events per day exceeding an indoor L_{max} of 50 dB. Assumptions were made as to how much outdoor-to-indoor noise level reduction is typically provided by a building, given both "windows closed" and "windows open" scenarios. Using these assumptions, the indoor noise exposure level at each of the five sites was modeled. The results are presented in the table below.

The study determined that, while an argument could be made to allow schools and day care centers based on L_{eq} values alone, the results of the NA analysis should be carefully considered. The noise analysis determined that more than 10 noise events would likely interrupt normal speech in a classroom at three of the five sites, assuming that the windows were closed during a 10-hour day care/school day. The NA50(10) threshold was exceeded at all five modeled locations with a "windows open" assumption. By performing this in-depth analysis of noise exposure using supplemental noise metrics rather NEF alone, GTAA was able to make more technically-defensible policy decisions regarding whether or not to allow schools and day care centers to be located between the YYZ NEF 30 to 35 noise contours.

Location Point	**Annual Average Scenario** *654 Total Operations*[2]				**Northeast Peak Traffic Scenario**[1] *722 Total Operations*[2]				**Southwest Peak Traffic Scenario**[1] *730 Total Operations*[2]			
	Indoor L_{eq} (dB) *Windows Closed**	**Indoor L_{eq} (dB)** *Windows Open***	**Indoor NA50 L_{max}** *Windows Closed**	**Indoor NA50 L_{max}** *Windows Open***	**Indoor L_{eq} (dB)** *Windows Closed**	**Indoor L_{eq} (dB)** *Windows Open***	**Indoor NA50 L_{max}** *Windows Closed**	**Indoor NA50 L_{max}** *Windows Open***	**Indoor L_{eq} (dB)** *Windows Closed**	**Indoor L_{eq} (dB)** *Windows Open***	**Indoor NA50 L_{max}** *Windows Closed**	**Indoor NA50 L_{max}** *Windows Open***
A	30.0	40.0	19	101	33.1	43.1	56	157	30.6	40.6	17	108
B	27.6	37.6	6	75	25.4	35.4	0	89	30.3	40.3	14	106
C	29.1	39.1	18	120	30.2	40.2	36	149	28.2	38.2	8	140
D	29.4	39.4	9	107	28.1	38.1	3	85	29.4	39.4	9	145
E	26.8	36.8	5	94	28.0	38.0	5	127	26.7	36.7	3	91

Notes: [1] Operations are based on one specific day, and reflect the specific runway use and fleet mix from that day

[2] Number of operations during school hours only (7:30 am to 5:30 pm)

* Assuming a room NLR of 25 dB

** Assuming a room NLR of 15 dB

C-14.Boston Logan Airport Noise Study Massachusetts Port Authority (Massport), Boston, MA, Federal Aviation Administration (FAA)

The history and background information that follows is sourced directly from the project website, http://bostonoverflightnoisestudy.com/BONS/history/index_2.asp

History

In 1995, Massport initiated a study, called the Airside Improvements Planning Project, to consider ways to reduce airfield delays and congestion. This study built on earlier studies completed by the Federal Aviation Administration (FAA) , which identified a number of options to improve airside congestion and delay at the airport. Massport then decided to pursue certain recommendations of these studies and on August 22, 1995, the U.S. Environmental Protection Agency (EPA) published the FAA's Notice of Intent (NOI) to prepare an Environmental Impact Statement (EIS). FAA and Massport then began preparation of a combined EIS/Environmental Impact Report (EIR) to meet federal and state requirements, respectively.

A Draft EIS/EIR was filed for review in February 1999 and on May 7, 1999, it was concluded that the Draft EIR should proceed to a Final EIR. In January 2000, the FAA decided to prepare a Supplemental Draft EIS (SDEIS). Two years later, on June 28, 2002, FAA published a Notice of Availability (NOA) of the Final EIS. The Record of Decision (ROD) was signed in August of 2002.

The ROD approved the following actions:

- A reduction in minima on Runways 22L, 27, 33L, and 15R;
- Construction of a new 5,000 foot unidirectional, wind speed restricted Runway 14/32, to be used only to/from the southeast;
- An extension to Taxiway D;
- A realignment of Taxiway N; and
- A reworking of the taxiways in the southwest corner of the Airport.

The approval of the ROD was conditional pending implementation of a number of mitigation measures including a joint effort with the FAA, Massport, and the Logan Airport Community Advisory Committee (CAC) to develop a scope that would enhance existing and/or develop new noise abatement measures applicable to aircraft overflights.

This study, officially called the Boston Logan Airport Noise Study will be completed in three phases. Phase 1 will define and, to the extent feasible, implement potential noise abatement alternatives that do not require a detailed environmental assessment. Phase 2 will address additional noise abatement alternatives that will require detailed analysis to meet FAA environmental requirements. Phase 3 will assess modifications to the Preferential Runway Assignment System and provide for appropriate environmental documentation that may be necessary for implementation of recommended actions of Phase 2. Phase 1 began in late 2004 and was completed in late 2006. Phase 2 began coincident with the completion of Phase 1 and is expected to take another two years.

Supplemental Noise Analysis

The Boston Study is the first FAA-sponsored study to rely on supplemental analysis as a major decision-making tool. Most of the flight track changes for the first phase are 15-20 miles from Logan and result in minor changes in Day-Night Average Sound Level (DNL) – well beyond DNL 65 dB – where decision-making on what alternatives to carry forward can only be reached through the use of supplemental analysis tools. The intention is to extract out the component parts of DNL into values that document the proposed changes and allow FAA, MASSPORT, and the CAC to use in their decision-making process.

In all, 18 measures were evaluated in Phase 1. Phase 2 is expected to evaluated 14 measures that are expected to have significant environmental impacts.

Note that the Phase 1 alternatives are the so-called “low-hanging fruit.” These are alternatives developed during the study that were expected to be Categorically-Excluded (Cat-Exed) under the National Environmental Policy Act (NEPA). Consequently, where the environmental analysis showed that the DNL increases did not trip the “levels of significance” under FAA Orders 1050.1E and 5050.4B, the supplemental analysis results developed for the project were used as the main decision-making tools. Essentially, for those alternatives that did not have significant environmental impacts under NEPA, the community relied on the supplemental tools and metrics to make their decision on what measures that they considered beneficial to the surrounding communities.

Grid Point Analysis and Extended Study Area

As stated above, most of the 18 Phase 1 measures were comprised of air traffic changes anywhere from 10-20 form the airport, with all but one alternative having no effect on sound levels of DNL65 or above. To assist the project stakeholders in the process, 130 community locations were evaluated throughout an extended study area (approximately an area of 30nm by 30 nm). Multiple supplemental noise metrics computed to document before and after conditions. Examples included – Number-of-Events Above (NA) various Sound Level Thresholds (NA50-55, NA55-60,…NA80+) and Time Above (TA) Specified Sound Level Thresholds (TA50, TA55, TA60, TA65) over the course of an annual average day. An example of a typical analysis table is shown below. For those measures were nighttime flights were of concern, Nighttime NA values above 70 dB SEL were computed to allow some assessment of the potential for sleep disturbance. Similarly, NA values above 60 dB SEL per average day were presented – this threshold was chosen as a representative threshold to predict outdoor effects on speech.

Location	Condition	Average Annual Day (24 Hours)	Number of Events Above (NA) Specified Sound Levels									Time Above (TA) Specified Sound Levels			
			Average Annual Day (24 Hours)							Total NA 60+ SEL (ops)	Nighttime (10:00 pm - 7:00 am)	Average Annual Day (24 hours)			
		DNL	NA 50-55$_{SEL}$ (ops)	NA 55-60$_{SEL}$ (ops)	NA 60-65$_{SEL}$ (ops)	NA 65-70$_{SEL}$ (ops)	NA 70-75$_{SEL}$ (ops)	NA 75-80$_{SEL}$ (ops)	NA 80+$_{SEL}$ (ops)		NA 70 $_{SEL}$ (ops)	TA 50 (min)	TA 55 (min)	TA 60 (min)	TA 65 (min)
PT001	Existing Condition	53.7	8	3	1	1	<1	<1	0	**6**	<1	<1	<1	0	0
	Alternative 1	53.7	8	3	1	1	<1	<1	0	**6**	<1	<1	<1	0	0
	Change	*0.0*	*<1*	*0*	*<1*	*<1*	*<1*	*0*	*0*	***<1***	*0*	*0*	*0*	*0*	*0*
PT002	Existing Condition	47.2	21	10	6	2	<1	<1	0	**19**	<1	2	<1	<1	0
	Alternative 1	47.2	22	11	6	2	<1	<1	0	**21**	<1	2	<1	<1	0
	Change	*0.0*	*1*	*1*	*<1*	*<1*	*0*	*0*	*0*	***2***	*0*	*0*	*0*	*0*	*0*
PT003	Existing Condition	45.8	15	7	3	1	<1	<1	0	**11**	<1	1	<1	<1	0
	Alternative 1	45.8	16	7	3	1	<1	<1	0	**12**	<1	1	<1	<1	0
	Change	*0.0*	*1*	*<1*	*<1*	*0*	*0*	*0*	*0*	***<1***	*0*	*0*	*0*	*0*	*0*
PT004	Existing Condition	49.4	9	2	2	<1	<1	<1	0	**6**	<1	<1	<1	<1	0
	Alternative 1	49.4	9	2	2	<1	<1	<1	0	**6**	<1	<1	<1	0	0
	Change	*0.0*	*<1*	*0*	*0*	*0*	*0*	*0*	*0*	***0***	*0*	*<1*	*0*	*<1*	*0*

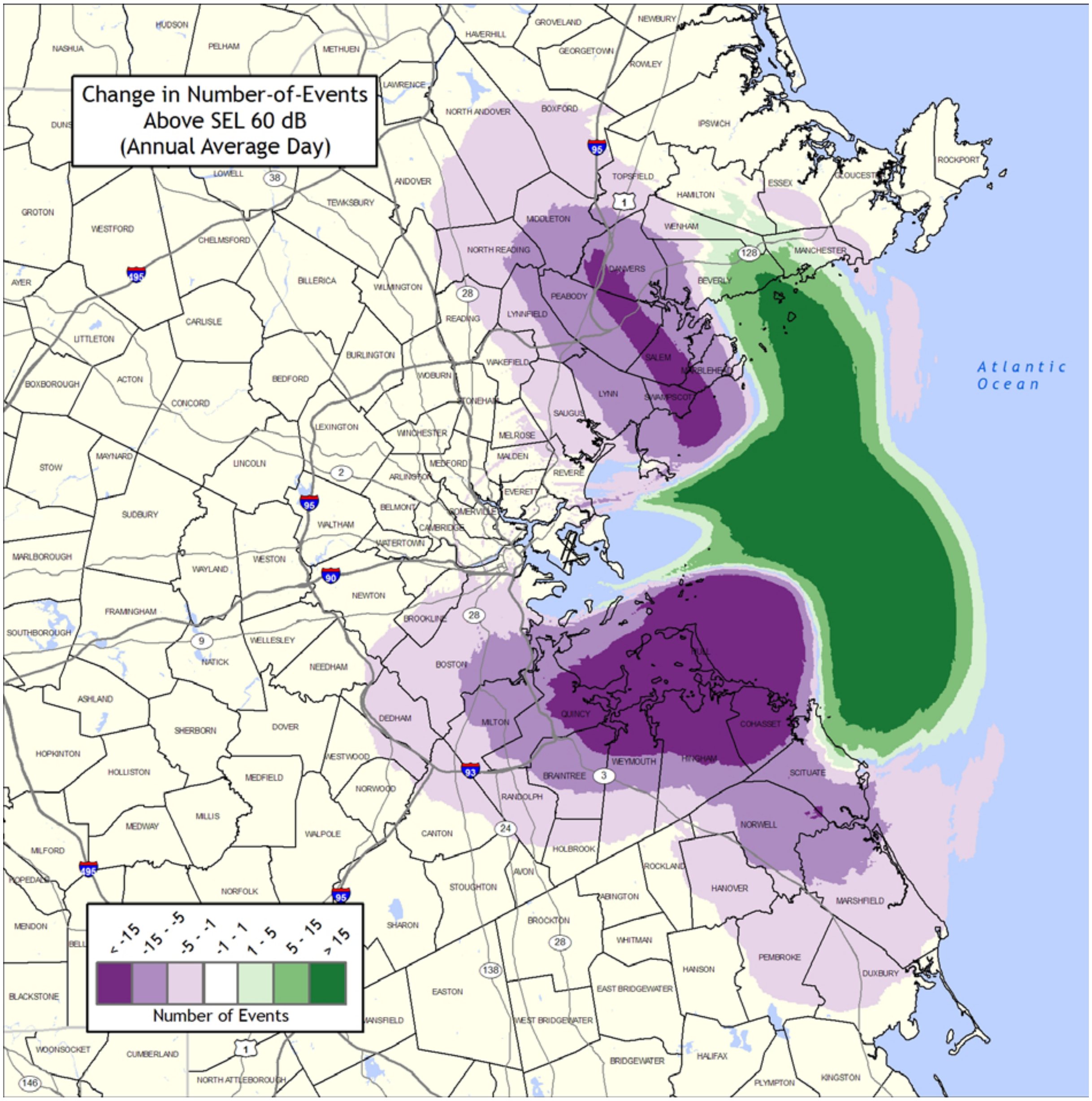
An Example of NA and TA Analysis – the component parts of DNL

NA Change Maps

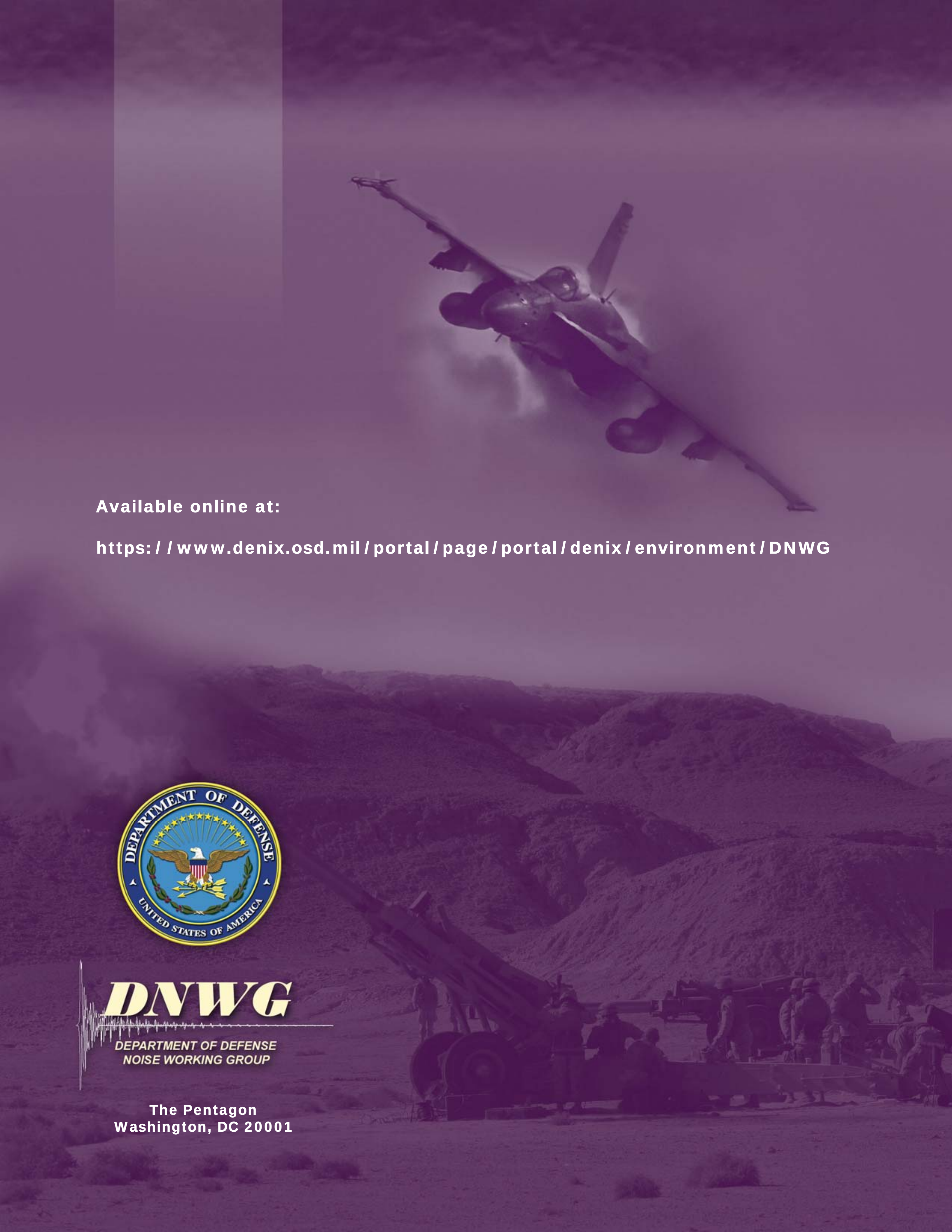
One of the most effective tools developed for the Boston project was the NA change map. For each of the 14 measures evaluated, a map was developed that allowed the project stakeholders to quickly see the changes in number of aircraft events above 60 dB SEL.

Shoreline Crossing Evaluation

An additional supplemental analysis tool that was used is a prediction of the change in aircraft altitude that was expected for several alternatives. The simple concept for these alternatives was to move the departing aircraft further out over the Atlantic Ocean before turning them back toward land, thereby providing some relief to the community. The project extracted out both the actual altitude of aircraft from radar and the INM-modeled altitudes (6000-7000 ft, 7,000-8,000 ft, etc.) of aircraft as they cross various gates along the shoreline north and south of Logan. This tool proved to be a highly effective surrogate analysis tool that provided results that could not be shown with a noise metric.



An Example of an NA Change Map



Available online at:

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DEPARTMENT OF DEFENSE
NOISE WORKING GROUP

The Pentagon
Washington, DC 20001